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FOREWORD

The volumes of these PROCEEDINGS are a record of the presentations and dicussions that occurred at the 2nd Regional (Eastern Asia, Oceania, Australasia) meeting og the Crocodile Specialist Group in Darwin, Northern Territory, Australia on 12 - 19 March 1993. The manuscripts are unreviewed and unedited. The CSG PROCEEDINGS, by definition, are records of what occurred at the meeting. They are not tomes filled with articles that were critiqued, edited, revised, and polished subsequent to the meeting. Apart from preparing a table of contents, compiling the articles alphabetically by author, the papers are published just the way they were submitted. For this reason, they appear in a variety of formats and typefaces. Compiled by the Conservation Commission of the Northern Territory, Australia.

The opinions expressed herein are those of the individual authors and are not the opinions of IUCN - the World Conservation Union, or its Species Survivial Commission.

IUCN - The World Conservation Union was founded in 1948, and has its headquarters in Gland, Switzerland; it is an independent international body whose membership comprises states (irrespective of their political and social systems), government departments, and private institutions, as well as international organizations. It represents those who are concerned about man's modification of the natural environment through the rapidity of urban and industrial development and the excessive exploitation of the earth's natural resources, upon which rest the foundations of his survival. IUCN's main purpose is to promote or support action which will ensure the perpetuation of wild nature and natural resources on a world-wide basis, not only for their intrinsic cultural or scientific values but also for the long-term economic and social welfare of mankind.

This objective can be achieved through active conservation programs for the wise use of natural resources in areas where the flora and fauna are of particular importance and where the landscape is especially beautiful or striking, or of historical, cultural, or scientific significance. IUCN believes that its aims can be achieved most effectively by international effort in cooperation with other international agencies, such as UNESCO, FAO, and UNEP, and international organizations, such as World Wide Fund for Nature (WWF).

The mission of IUCN's Species Survival Commission (SSC) is to prevent the extinction of species, subspecies, and discrete populations of fauna and flora, thereby maintaining the genetic diversity of the living resources of the planet. To carry out its mission, the SSC relies on a network of over 2,500 volunteer professionals working through more than 90 Specialist Groups and a large number of affiliate organizations, regional representatives, and consultants, scattered through nearly every country of the world.

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A UNITED EFFORT

The inability of farmers, tanners, manufacturers and retailers to get together was constraining any serious united effort in Australian, and at an international level. Some countries have got together and implemented refined marketing programs.

ECONOMISTS AND MARKETING EXPERTS

The industry should Solicit interest in their problem, from marketing specialists and arrange their attendance at the next CSG meeting, where they could perhaps participate in another workshop.

FARMED SOURCES

It was mentioned that the public was more likely to buy products from "farmed" sources, even though from a conservation viewpoint this should not be a central platform of conservation value.

THE LINK WITH INDIGENOUS PEOPLE

The prospect of linking the retail marketing to the welfare of the people doing the hunting - e.g. hunters in Irian Jaya - was considered favourably.

CONCLUSION

The status of marketing needs to be examined at two levels or resolution, and although "conservation value" may be an appropriate strategy at both levels, professional marketing expertise will be needed before anything can be decided definitely.

In the interim, people in the industry with direct contact with the public should test some of the ideas, to determine whether any obvious positive response occurs.

It is clearly up to the industry to pursue these matters, notwithstanding their indirect relevance to crocodilian conservation and management.

CROCODILE SPECIALISTS GROUP CONFERENCE

8.30am, Monday, March 15, 1993

PROFESSOR HARRY MESSEL (CHAIRMAN OF THE CROCODILE SPECIALIST GROUP);
MR JACQUES BERNEY (DEPUTY SECRETARY GENERAL, C.I.T.E.S. SECRETARIAT);
MEMBERS OF THE CROCODILE SPECIALIST GROUP;
LADIES AND GENTLEMEN.

GOOD MORNING, AND WELCOME TO DARWIN. IT IS A GREAT HONOUR TO BE HERE TODAY TO OPEN THE FIRST CONFERENCE OF THE CROCODILE SPECIALISTS GROUP TO BE HELD IN THE NORTHERN TERRITORY AND TO BE ADDRESSING A GATHERING OF THE WORLD'S FOREMOST CROCODILE EXPERTS.

IT IS IN SOME WAYS A DAUNTING EXPERIENCE, BECAUSE I KNOW THAT WHATEVER I SAY THIS MORNING ABOUT CROCODILES AND THE NORTHERN TERRITORY'S ROLE IN THEIR CONSERVATION AND MANAGEMENT, THERE WILL BE MANY PARTICIPANTS HERE WHO KNOW A GREAT DEAL MORE THAN I DO ABOUT THE SUBJECT.

SO I'LL KEEP MY COMMENTS RELATIVELY BRIEF AND LET YOU GET ON WITH THE BUSINESS OF THE CONFERENCE.

IN THE NORTHERN TERRITORY WE PRIDE OURSELVES ON THE RESPONSIBLE WAY WE HAVE DEVELOPED OUR CROCODILE

MANAGEMENT STRATEGIES, COMBINING SUSTAINABLE USE WITH EFFECTIVE CONSERVATION MEASURES.

THE GOVERNMENT RECOGNISED MANY YEARS AGO THE NEED FOR PROTECTION OF THESE ANIMALS. WE INTRODUCED PROTECTION FOR THE FRESHWATER CROCODILE, CROCODYLUS JOHNSTONI, ALMOST 30 YEARS AGO IN 1964, AND PROTECTION FOR THE ESTUARINE CROCODILE, C. POROSUS, IN 1971. THIS WAS SUPPORTED BY A COMMONWEALTH BAN IN 1972 ON THE EXPORT OF CROCODILIAN PRODUCTS.

HOWEVER, THE NORTHERN TERRITORY GOVERNMENT ALSO RECOGNISED THE ECONOMIC POTENTIAL OF A CROCODILE INDUSTRY BASED ON SUSTAINABLE USE OF THE WILD POPULATION. IN DEVELOPING THIS POTENTIAL, WE REALISED THAT IT HAD TO BE BASED ON SOUND RESEARCH AND CONSERVATION PRINCIPLES.

CONSEQUENTLY, WE DIRECTED CONSIDERABLE RESOURCES INTO RESEARCH PROGRAMS CONDUCTED BY SUCH EXPERTS AS PROFESSOR HARRY MESSEL AND DR GRAHAME WEBB. ONLY WHEN WE WERE ASSURED THAT A CROCODILE INDUSTRY COULD BE ESTABLISHED WITHOUT A DAMAGING IMPACT ON THE WILD POPULATION DID WE PROCEED WITH INDUSTRY DEVELOPMENT PLANS.

OF COURSE THAT RESEARCH EFFORT CONTINUES, AND IT WILL REMAIN THE BASIS OF OUR CROCODILE MANAGEMENT

PROGRAMS. GOVERNMENT EXPENDITURE ON CROCODILE CONSERVATION AND MANAGEMENT OVER THE PAST 15 YEARS IS ESTIMATED AT $10 MILLION, AND THE CONSERVATION COMMISSION'S EXPENDITURE IN THIS AREA IS CURRENTLY RUNNING AT ABOUT ONE MILLION A YEAR. THESE ARE CONSIDERABLE SUMS OF MONEY WHEN CONSIDERED IN THE CONTEXT OF THE NORTHERN TERRITORY'S RELATIVELY SMALL ECONOMY.

I DON'T WANT TO DWELL ON INDUSTRY MATTERS BECAUSE I KNOW THAT IS NOT THE FOCUS OF THIS GROUP'S ATTENTION. NEVERTHELESS, THE DEVELOPMENT OF THE INDUSTRY HAS IN ITSELF PROVIDED ADDITIONAL STIMULUS FOR CONSERVATION MEASURES, SO I WILL MAKE A FEW POINTS CONCERNING THE WAY IN WHICH THE DEVELOPMENT OF THE INDUSTRY HAS IMPACTED ON CROCODILE CONSERVATION IN THE TERRITORY.

MOST TERRITORY GOVERNMENT EFFORTS IN THIS AREA HAVE BEEN DIRECTED AT ESTABLISHING A SOUND CONSERVATION STRATEGY FOR THE MANAGEMENT OF WILD CROCODILES. IN FACT, WE HAVE ACHIEVED STRONG PUBLIC SUPPORT FOR OUR CROCODILE PROGRAMS AS A RESULT OF OUR EMPHASIS ON CONSERVING THE WILD CROCODILE POPULATION THROUGH THE ESTABLISHMENT OF THE ECONOMIC VALUE OF THE RESOURCE AND THE CONTROLLED DEVELOPMENT AND REGULATION OF CROCODILE FARMING.

WE HAVE BEEN SO SUCCESSFUL IN THIS THAT THE DEVELOPMENT OF OUR CROCODILE FARMING INDUSTRY HAS COINCIDED WITH A STEADY INCREASE IN THE WILD POPULATIONS OF BOTH C.POROSUS AND C. JOHNSTONI.

ANOTHER ASPECT OF THE CROCODILE INDUSTRY THAT IS VERY IMPORTANT TO US IN THE NORTHERN TERRITORY IS THE ANIMAL'S VALUE AS A TOURIST ATTRACTION. I REFER PARTICULARLY TO THE ATTRACTION OF CROCODILES IN THEIR NATURAL WILD HABITAT, ALTHOUGH CROCODILE VIEWING ON FARMS IS ALSO POPULAR.

THE CROCODILE IS A POTENT SYMBOL OF TERRITORY TOURISM WHICH IS RECOGNISED INTERNATIONALLY, AND THIS IS FURTHER INCENTIVE FOR THE MAINTENANCE OF A HEALTHY WILD POPULATION AND FOR THE CONSERVATION OF NATURAL CROCODILE HABITATS.

LAST YEAR, FOLLOWING EXTENSIVE RESEARCH AND INDUSTRY CONSULTATION, THE GOVERNMENT ISSUED A DETAILED STRATEGY FOR THE DEVELOPMENT OF THE NORTHERN TERRITORY CROCODILE INDUSTRY.

SINCE, AT LEAST IN THE SHORT TERM, THE MAJOR LIMITATION ON THE ESTABLISHMENT OF NEW CROCODILE FARMS AND THE GROWTH OF EXISTING ONES IN THE TERRITORY IS THE SIZE OF THE WILD HARVEST WHICH INVOLVES COLLECTING EGGS AND SUB-ADULTS, THE FIRST

OBJECTIVE IDENTIFIED BY THE STRATEGY IS THE SUSTAINABLE USE OF THE WILD CROCODILE RESOURCE.

TO ENSURE ADHERENCE TO THIS OBJECTIVE, THE NORTHERN TERRITORY CONSERVATION COMMISSION ENSURES THAT THE PROGRAM CONTINUES TO CONFORM WITH TERRITORY, COMMONWEALTH AND INTERNATIONAL LEGISLATION AND AGREEMENTS.

THE CONSERVATION COMMISSION ALSO MAINTAINS A MONITORING PROGRAM TO PROVIDE SUFFICIENT DATA TO ACCURATELY EVALUATE THE STATUS OF THE WILD POPULATION.

THERE ARE A NUMBER OF OTHER NORTHERN TERRITORY GOVERNMENT INITIATIVES IN RECENT YEARS THAT HAVE IMPROVED CROCODILE CONSERVATION. THESE INCLUDE:

. MELACCA SWAMP, WHICH YOU WILL HAVE THE OPPORTUNITY TO VISIT ON SATURDAY WITH THE FIELD TRIP TO VIEW CROCODILE NESTING. THIS AREA WAS ACQUIRED BY THE GOVERNMENT SPECIFICALLY FOR CROCODILE BREEDING AND CONSERVATION PURPOSES.

. THE NORTHERN TERRITORY PASTORAL LANDS ACT, WHICH PROVIDES A MECHANISM TO ASSIST IN SOUND PASTORAL MANAGEMENT THROUGHOUT THE TERRITORY, INCLUDING THE PROTECTION OF CROCODILE HABITATS IN WETLANDS AND ALONG RIVER BANKS.

. THERE IS A CONTINUING PUBLIC EDUCATION PROGRAM TO FOSTER POSITIVE PUBLIC ATTITUDES TOWARDS THE CONSERVATION OF CROCODILES.

. AND, FOLLOWING THE COMPLETION OF OUR TERRITORY CROCODILE INDUSTRY STRATEGY, WE ARE LOOKING AT A NATIONAL APPROACH. WE HOPE TO OBTAIN THE SUPPORT OF THE GOVERNMENTS OF QUEENSLAND AND WESTERN AUSTRALIA, AND OF THE COMMONWEALTH'S AUSTRALIAN NATIONAL PARKS AND WILDLIFE SERVICE, FOR A NATIONAL CROCODILE MANAGEMENT STRATEGY.

THE NORTHERN TERRITORY GOVERNMENT HAS ALREADY DEMONSTRATED THAT IT IS KEEN TO FORGE STRONGER LINKS WITH COUNTRIES PARTICULARLY IN SOUTH-EAST ASIA, TO EXCHANGE INFORMATION AND TO COLLABORATE ON CROCODILE CONSERVATION ISSUES TO OUR MUTUAL BENEFIT.

THE GOVERNMENT'S SUPPORT FOR THIS CONFERENCE IS A FURTHER DEMONSTRATION OF OUR COMMITMENT TO THE AIMS OF CROCODILE CONSERVATION AND TO OUR DESIRE TO DEVELOP OUR PROGRAMS IN CONCERT WITH INTERNATIONAL AIMS AND CONSIDERATIONS.

OUR NEXT MAJOR OBJECTIVE IN THE DEVELOPMENT OF OUR POLICY OF SUSTAINABLE USE OF THE CROCODILE RESOURCE

IS TO GAIN UNQUALIFIED LISTING OF THE AUSTRALIAN POPULATION OF C. POROSUS ON C.I.T.E.S. APPENDIX 2.

WE INTEND FOR THIS TO BE ACHIEVED THROUGH RIGOROUS EVALUATION OF INFORMATION COLLECTED ABOUT WILD HARVESTS AND RESEARCH INTO OUR CROCODILE MANAGEMENT AND CONSERVATION PRACTICES. USING THIS INFORMATION, THE CONSERVATION COMMISSION WILL PREPARE A SUBMISSION FOR THE C.I.T.E.S. SECRETARIAT BY DECEMBER 1993, IN CONJUNCTION WITH THE AUSTRALIAN NATIONAL PARKS AND WILDLIFE SERVICE, FOR CONSIDERATION BY THE CONFERENCE OF PARTIES IN 1994.

I TRUST THAT, FOLLOWING YOUR VISIT TO DARWIN AND THE FIRSTHAND INFORMATION YOU WILL GAIN REGARDING OUR CROCODILE MANAGEMENT PRACTICES, YOU WILL SUPPORT OUR APPLICATION.

REMOVAL OF THE QUALIFICATION WILL ALLOW US TO EXPAND THE OPPORTUNITIES FOR SUSTAINABLE COMMERCIAL USE OF THE CROCODILE RESOURCE AND WILL INCREASE CONSIDERABLY THE VALUE OF CROCODILES TO THE LAND OWNERS AND TO THE PEOPLE OF THE NORTHERN TERRITORY.

I THINK THAT IS ENOUGH FROM ME. I'M SURE YOU ARE ALL ANXIOUS TO GET ON WITH THE REAL WORK OF THE CONFERENCE.

ON BEHALF OF THE NORTHERN TERRITORY GOVERNMENT, LET ME ONCE AGAIN WELCOME YOU - PARTICULARLY THOSE OF YOU WHO HAVE TRAVELLED FROM OVERSEAS - TO OUR CITY OF DARWIN. I WISH YOU THE VERY BEST IN YOUR DELIBERATIONS THROUGHOUT THIS CONFERENCE AND I TRUST THAT YOU WILL RETURN HOME WITH THE FEELING THAT YOU HAVE ACHIEVED A GREAT DEAL, THAT YOU ARE BETTER INFORMED ABOUT THE STATE OF CROCODILE MANAGEMENT WORLDWIDE, AND WITH FOND MEMORIES OF THE NORTHERN TERRITORY AND ITS PEOPLE.

THANK YOU.

CONSERVATION, MANAGEMENT AND FARMING OF CROCODILES IN UNION OF MYANMAR.

U B. K. Aung Moe
Manager
M.F.E
March 3,1993.

Mr. Web, distinguished guests and participants,

First of all, please allow me to express my sincere thanks and appreciation to the vice-Chairman, Eastern Asia, Oceania Australasia for informing our minister, Brigadier-General Maung Maung, Minister for Live Stock, Breeding and Fisheries, and the Government of Myanmar who selected me to represent Myanmar in this meeting of the IUCN CSG meeting being held in Darwin, Australia and giving me the opportunity to make a brief presentation on "Conservation, Management and Farming of Crocodiles in the Union of Myanmar".

Introduction.

Myanmar is the largest country on the main land Southeast Asia with a total land area of 676,577 sq.KM sharing total International borders of 5,858 KM with Bangladesh and India on the Northwest, China on the Northwest and Laos and Thailand on the Southeast. It has a total coastline of 2,832 KM. It stretches 2,090 KM from north to south and 925 KM from east to west at its widest points.

Myanmar could be taken as a forest clad mountaineous country. Three parallel chains of mountains ranges run from north to south. The Western Yoma or Rakhine Yoma, the Bago Yoma and the Shan Platau. They begin from the eastern extremity of the Himalaya Mountain range. These mountain chains divide the country into three river systems, the Ayeyarwaddy, the Sittaung and the Thanlwin, of which the Ayeyarwaddy, the most important river, about 2,170 KM. As it enters the sea, the Ayeyarwaddy forms a vast delta of 240 KM x 210 KM.

As it is mainly in the tropical region, Myanmar has a tropical monsoon climate with three seasons: the Hot Season from mid. February to mid. May, the Rainy Season from mid. May to mid. October and the Cool Season from mid. October to mid. February. Annual rainfalls vary from 500 CM in the coastal regions to 75 CM and less in the Central Dry Zone. Mean Temperature ranges from 32 degree centigrade in the coastal and delta areas and 21 degree centigrade in the northern low lands.

Myanmar's population is estimated at 40.03 million in 1989 / 90 an increase of 1.88% over the previous year.

The Agricultural sector dominates the Myanma economy, accounting for about 40.6% of the total GDP in 1989/90. The total area of 67.6 million hectare, the area under cultivation is 8.0 million hectare. Forest covers about 57% of the total land area.

Species.

As per available records the three species known are:-1) *Crocodylus porosus*; 2) *Crocodylus palustris*; 3) *Gavialis gangeticus* in Myanmar, but at present only *C. porosus* can be found mostly in delta areas.

Status.

There is no record available whether any survey was made for the existence of *C. palustris* and *G. gangeticus* in Myanmar. Whereas, as per survey made by Graeme Caughley (Senior Principal Research Scientist, CSIRO Division of Wild Life Research, Canberra, Australia), Consultant to the FAO of the United Nations in March, 1980. *C. porosus* was found in delta area, but according to him the population of crocodile is still declining due to the destruction of habitat, disturbances by people and some illegal hunting which is still being unchecked.

Legislation.

Though the Union of Myanmar is not a member of CITES, they are considering to apply for the membership in this world body. However, the present government, the State Law and Order Restoration Council has formed a Union of Myanmar National Commission for environmental affairs to preserve the natural resources and accordingly passed a law known as Myanmar Marine Fisheries Law 9/90 on 25th April, 1990 which prohibits a person to search for or collect any marine products without a licence, and so far no licence has been granted to anybody by the authority concerned. The Myanma Fisheries Enterprise under the Ministry of Livestock Breeding and Fisheries is the only authorized body to function for such affairs.

Farming.

In the year 1978, a Crocodile farm was established at the outskirt of Yangon (Rangoon) known as Thaketa which is only a State-run farm by the Myanma Fisheries Enterprise under the Ministry of Livestock Breeding and Fisheries. At the beginning, this farm was mainly dependant on supply of young crocodiles (*C. porosus*) from Ayeyarwaddy delta. At present in a pond of 450 ft x 350 ft there 46 male and 69 female for breeding purposes. In the year 1982 from 13 nests out of 510 eggs 49 hatchlings were obtained, whereas, this year from 26 nests out of 1076 eggs 213 hatchlings could be obtained. As per the latest calculation including above mentioned breeders the total number of Crocodiles of all sizes are 640.

Rearing ponds are made of concrete. Main diets of crocodiles are Marine Fishes and prawns for hatchlings. There is no private farmings established so far.

Regulation of Trade.

From 1983 to 1989, a total number of 1830 alive crocodiles were exported at the cost of US$ 1,62,689 to Thailand and Singapore by this Enterprise.

Imports & Manufacturing.

So far there is no imports or manufacturing of skin products here in Myanmar.

Research:

A survey was made by Mr. Graeme Caughley in March, '80 to estimate the numbers and trend of crocodiles (*C. porosus*) in the delta area. At that time estimated populations were 2,750 + or - 1,270.
In June, 1985 a preliminary appraisal note and comments of the programme management control unit on the Draft Project document for BUR/81/002: Crocodile Research & Management was prepared by Mr. Bolton, F.A.O. Consultant under TCP/BUR/0107 (1) in collaboration with Staff of the People's Pearl & Fisheries Corporation and F.A.O. Representatives Office in Myanmar. But due to some unavoidable circumstances the project could not be materialised.

Protected Areas:-

No protected areas has been signified by the Authorities concerned so far.

Discussion:-

The present Crocodile Farm at Yangon is a govern-owned Commercial Enterprise with self-sufficient electric and water supply. The aim is to preserve the Myanmar crocodile and to rear crocodiles captured as wild hatchlings and farm hatchlings to the size where they will yield a skin of marketable size.Although the Farm has been running for only some years there is a future prospect to provide Myanmar with much Foreign Exchange. The numerous difficulties associated with the stocking and running of a farm of this size have been overcome by hardwork, skill and dedication.

For future prospect, the Draft Project Proposal made by Mr.Bolton is still under consideration by the present authorities concerned.

FN:BKAM.WP(4.3.93)

Conservation, Management and Farming of Crocodiles in Cambodia

By

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LEGISLATION

Crocodiles conservation and farming are under authorisation of Fishery Department, Ministry of Agriculture.

In the Fishery Law:-

1) Hunting of wild crocodile is prohibited.

2) Farm who has crocodile in captivity more than 5 heads must register their farm and crocodiles to the local Fishery officer or Fishery Department in Phnom Penh.

3) Export fee for small live crocodile is 5.00 U.S. Dollars per head.

It is noted that Cambodia is not a member of CITES, so any international trade of wildlife including crocodile could not be regulated and controlled by Cambodian law.

ABSTRACT

Cambodia is known to be one of the last source of many tropical endangered wildlife. Crocodilians, *Crocodylus siamensis* and *Crocodylus porosus* are also among those species. Wild genetic stock should be protected and conservation through sustainable utilisation should be emphasised. More researches such as scientific survey must be conducted in order to support information for management of wild and captive crocodiles. These will become true if assistance are provided from friends around the world.

♣

INTRODUCTION

Cambodia is located in the south-western part of the Indochinese peninsula and occupies an area of 181,035 square kilometres.

Cambodia situates among three countries, Laos in the north, Thailand in the west, Vietnam in the east and Gulf of Siam in the south. In 1991, Cambodia had a population of 8.59 million. This number is expected to climb to 10 million by 1995 (FAO source).

Cambodia has a tropical climate with two distinct seasons, wet and dry. The raining southwest monsoon season last from May through October; the dry northeast monsoon seasons lasts from November through April. The temperature ranges from 20°C to 36°C and high humidity throughout the year.

CROCODILIANS IN CAMBODIA

Two crocodilian species are known to be endemic in Cambodia:

1) Siamese freshwater crocodile, *Crocodylus siamensis*, Schneider 1801. Local name is KRA PEU TUK SAP.

2) Saltwater crocodile, *Crocodylus porosus*, Schneider 1801. Local name is KRA PEU TUK PRAY.

STATUS OF CROCODILIANS IN CAMBODIA

No information survey of wild crocodile have been done in Cambodia, during more than two decades of civil-war. However, referring to the latest annual report on "Crocodile in Cambodia" (1992) by the fishery department and a short visit conducted by a group of Thai scientists, we can summarise as follows:

C. siamensis has distribution range in wetlands around Tonle Sap which surrounded by the provinces of Siem Reap, Kompong Chnang, Battambang, Pursat and Kompong Thom. Sray snam and Stung Treng were also reported to have crocodile hunting activities in the past. Estimated number of wild crocodilians is about 10,000.

C. porosus were reported to be in the estuarine of Mondul Seyma river which opens into Gulf of Siam at Koh Kong province. Very few information on this species. Most cambodian said that *C. porosus* might be extinct in the wild.

♣

FARMING

Crocodile farming in Cambodia has been started since 1945. All of these farms raised only *C. siamensis* because *C. porosus* were not available. The crocodile farming technique is quite far behind standard level. They still use conventional methods of farming; raising, incubation, etc. There are 491 crocodile farms distributed in many provinces as summarised in Figure 1.

These farms can be classified into three classes according to size and management:

CLASS 1 – small size, 2-20 heads, raised in pond or wooden cage.

CLASS 2 – medium size, 20-70 heads, raised in social pond.

CLASS 3 – large size, over 100 heads, raised in many social ponds.

Most of the breeders came from the wild by catching adult crocodiles. Hatchlings and eggs were also collected and raised to be breeders. Crocodile farms have to breed and raise their own hatchlings. Population of captive crocodiles in Cambodia was around 6,100 heads in 1992 and number of hatchlings was around 5,200 heads in 1992 as shown in figure 2 and 3 respectively.

♣

REGULATION OF TRADE

This is controlled by Fishery department, Ministry of Agriculture as described in legislation section. The problems of interborder trade or smuggling of live crocodiles is very hard to control because of a very long border (803km) between Thailand and Cambodia. Even though the Thai border is closed according to the United Nation resolution, smuggling is still occurring but in a low number.

IMPORTS & MANUFACTURING

No import and export of any crocodile products in Cambodia. They exported only hatchlings and a very few skins. Neither factory nor tannery for crocodile product has been established.

RESEARCH

During the massacre, nearly all the scientists and researchers were killed. Many educational institutes were ruined. No scientific research ever done in any kind of subjects including crocodiles.

Since 1988, Cambodia got some assistance in crocodile farming technique from Cuba but no research ever conducted.

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PROTECTED AREAS

In Cambodia, undisturbed natural areas is about 218,600 ha. which composed of swampy and Mangrove forest. These areas are crocodiles habitat.

Before civil-war (1970), Cambodia had established their national parks and protection reserves as follows:

1.	PREAR VIHAR province, protection reserve	1,467,000 ha
2.	RATANAKIRI province, protection reserve	1,97,480 ha
3.	KRACHEH province, Phnom Prick reserve	195,120 ha
4.	KAMPONG THOM province, Beoung Pe reserve	n/a
5.	SIEM RIEP province, Angkor Wat National Park	10,700 ha
6.	PURSAT province, Phnom Krawain reserve (Cardomon Mtns)	280,640 ha
7.	KOMPONG SPEU province, National Park	81,760 ha

SANCTUARIES

*8.	11 sites of fishery reserve in the G.L. of Tonli Sap	4,000 ha established since 1988, 8 sites with 3,000 ha.

Regarding to the C. conservation I myself have very strong confidence to bring local people to participate into the conservation project and promote them how to use their own wild C. with a sustainable use.

** Belief of the indigenous people.

"THE END"

* *Crocodile Habitats*

♣

DISCUSSION

More information on wild and captive crocodilians need to be collected from both government and private sector in Cambodia that will be very useful to set up management plan for crocodilian. Then conservation organisation could assist Cambodia in order to protect wild genetic stock of *C. siamensis* which believed to be the last and purest stock in the world. Sustainable utilisation of crocodile must be more concerned than before.

Crocodile farming technology should be transferred from other countries which already done to increase production in their farm. Further more, Cambodia should be a member of CITES, then in international trade of crocodile from captive breeding operations will be accepted. This will serve and support crocodile farming business in this country. Control smuggling crocodile across border should become more easy.

We do hope that Cambodia will be one of the best place in the future world of crocodile conservation and farming.

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STATUS AND CONSERVATION OF CROCODILES IN VIETNAM

Ho Thu Cuc
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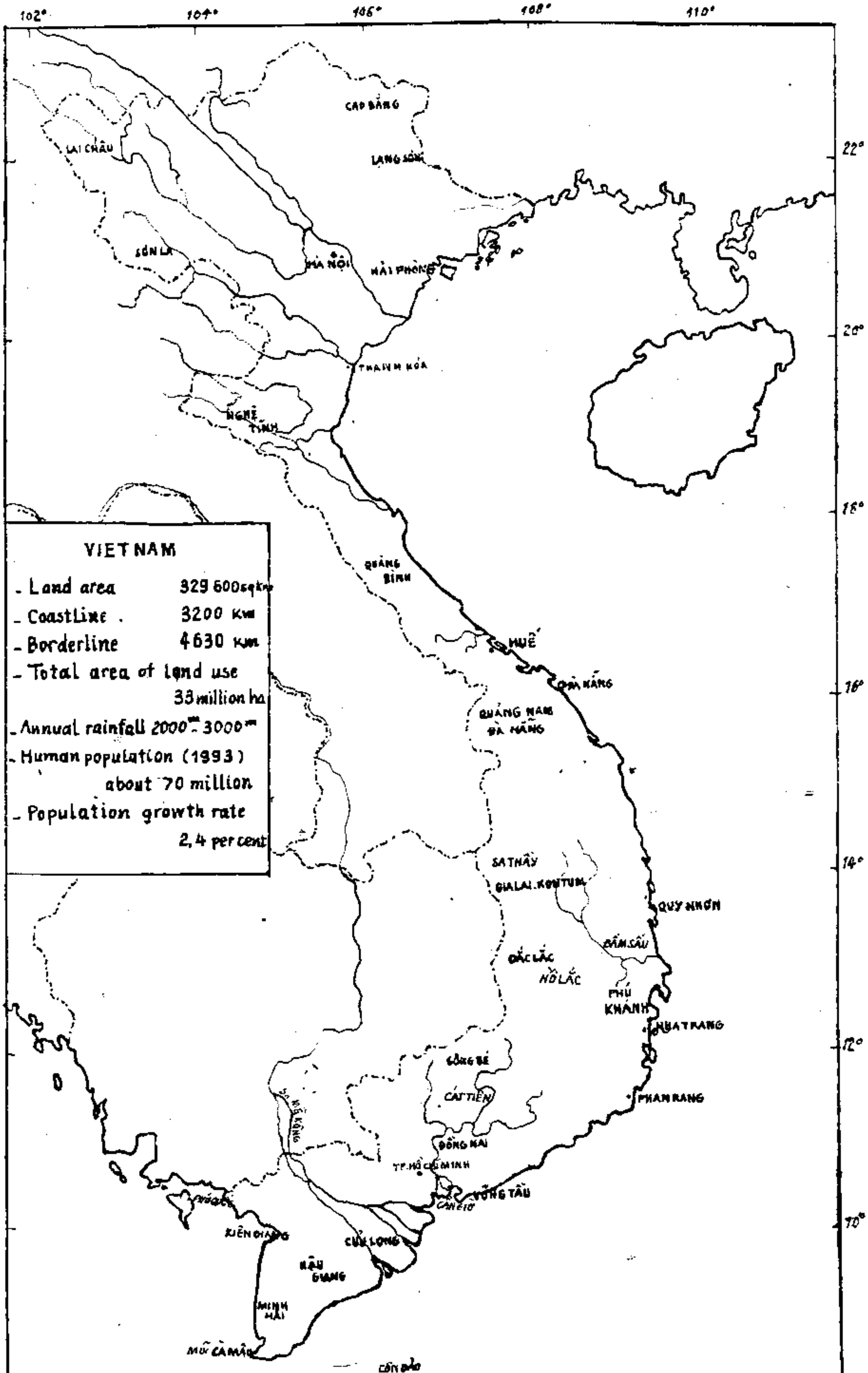
I. NATURAL AND SOCIAL CONDITIONS OF VIETNAM

Vietnam situates along the southeast margin of the Indochinese Peninsula. It stretches from latitude 8°N to 24°N. Total coastline is about 3200 km and total land area is 329 600sq.km. The main mountain range - Truong Son range - forms the natural boundary with China, Lao and Cambodia. The mainland borderline is 4 630km (1430km with China, 2 067km with Lao and 1 100km with Cambodia).

The country is S-shaped, broader in the Northern and southern parts, where it is swelled by the Red river and Mekong Delta and very narrow in the middle, where in the Binh Tri Thien province it is only 50 km wide at the narrowest point. So, the country has its length much longer than its width. A broad,shallow continental shelf follows the shape of the land, wide in the north and south and narrow in the middle.

Three-quarter of the country consists of mountains and hills. The highest peak - Fanshipan - reaches 3 144m in Northwestern Vietnam, where they form an extension of great Himalayan Range. The land suitable for agriculture reclamation covers about 100 000sq.km. It is situated mostly in the large fertile plains of Nambo and Bacbo,which include the Mekong and Red river deltas, respectively. Total area of all current patterns of land use is 33 million ha. Of it 6.9 million ha for agriculture, 11.8 million ha for forestry, 1.4 million ha for towns and other special use and 12.9 million ha of very poor or unproductive land.

Vietnam shows a variety in climate condition on account of its wide range in latitude and altitute. Although, the entire country lies in the intertropical zone, climate varies


VIETNAM
- Land area 329 600 sqkm
- Coastline 3200 km
- Borderline 4630 km
- Total area of land use 33 million ha
- Annual rainfall 2000 - 3000 mm
- Human population (1993) about 70 million
- Population growth rate 2,4 per cent
102°
104°
106°
108°
110°
22°
20°
18°
16°
14°
12°
10°
CAO BẰNG
LẠNG SƠN
LAI CHÂU
SƠN LA
HÀ NỘI
HẢI PHÒNG
THANH HÓA
NGHỆ TĨNH
QUẢNG BÌNH
HUẾ
ĐÀ NẴNG
QUẢNG NAM ĐÀ NẴNG
SA THẦY
GIALAI. KONTUM
QUY NHƠN
ĐẦM SÂU
ĐẮC LẮC
HỒ LẮC
PHÚ KHÁNH
NHA TRANG
SÔNG BÉ
CÁT TIÊN
PHAN RANG
ĐỒNG NAI
TP. HỒ CHÍ MINH
VŨNG TÀU
KIÊN GIANG
CỬU LONG
HẬU GIANG
MINH HẢI
MŨI CÀ MAU
CÔN ĐẢO

from humid tropical condition in the southern lowlands to bracing temperate condition in the northern hills. Mean annual sea level temperatures correspondingly decline from 27°C in the South to 21°C in the extreme North. The mean annual rainfall is 2 000mm, but this increases in the narrow central mountainous region to 3 000mm, sufficiently heavy to support tropical rain forests. There are three monsoon seasons,namely the northeast winter monsoon, and the southeast and western summer monsoons. Destructive typhoons sometimes develop over the East sea during hot weather.

The river network of Vietnam is mazy and varied. The North alone has 1 083 rivers and water ways of all sizes. In Nambo, there is a big river every 10 km along the road, and a river estuary every 20km along coast.

The very rich lake, swamp system in conjunction with 3 200km of coastline and islands provides Vietnam with large wetland area as favourite habitats for water fauna, including crocodiles.

Vietnam is the most densely populated country in Southeast Asia with about 70 million residents in 1993 and a mean annual growth rate of 2.4 per cent. This gives a mean density of about 200 persons per square kilometer,the highest density for any agricultural country in the world.

The high population growth rate, together with severe destruction during the recent war has brought great negative affects to the habitats of wildlife, including crocodile: forest loss for agriculture land use and new villages, towns, forest logging and fires etc...

II. STATUS OF CROCODILES IN THE WILD

There are 2 species of crocodiles in Vietnam:

- Siamese crocodile or freshwater crocodile (Crocodylus siamensis).
- Saltwater crocodile (Crocodilus porosus).

Both species has distribution range only in south Vietnam, southern of Tay Nguyen plateau. The siamese crocodile is freshwater one. They inhabit big rivers, lakes, swamps in Tay Nguyen Plateau and Cuu Long delta, such as Sathay river (Kon Tum province), Ba river (Gia lai province) Lac lake, Krongpach Thuong lake, Easup river, Krongana river (Dac Lac province), Dam Sau Tay Son (Khanh Hoa province), Bau Sau in Nam Bai Cat Tien Reserve (Song Be province), Dong Nai river (Dong Nai province), and Cuu Long river.

Saltwater crocodile (Crocodilus porosus) inhabits mangrove swamps, river estuary in Vung Tau, Can Gia, west to Kien Giang Bay, Phu Quoc Island and Con Dao Island.

In the past, freshwater crocodile was relatively abundant in Vietnam. Pham Mong Giao, 1981 informed of 200 crocodiles in 80-hectared Bau Sau Tay Son (Phu Khanh province). Local people oftenly caught the crocodiles in Lac lake (Dac Lac province) for meat, and collected crocodile eggs in Bau Sau of Nam Bai Cat Tien Reserve for food. It was informed that the crocodiles were captured in large number in Krongpach lake and Easup river.

The forest logging and conversion of hundreds hectares of riverain, lakes, swamps into agriculture land have seriously decreased the habitats of wildlife, in general, and crocodiles, in particular. Meanwhile, agressive hunt has also seriously decimated the number of crocodiles in the wild. The crocodiles were captured by diffrent ways, such as shooting by guns, traping, explossive mines. The using mines for captuie of crocodiles is very dangerous due to mines can kill not only adult but also young crocodiles and severely destroy their habitats.

In spite of small number of crocodiles remained in the wild the crocodiles in Vietnam are still intensively hunted for meat, eggs, and for skin. Morever, illegal animal trade also becomes more intensive during recent years. The crocodiles (adult and young) are captured and skins are collected for illegal export to China, Thailand and other countries. In Vietnam, a crocodile is sold for about $100 - $2000 depending on their status.

III. CONSERVATION

The conservation of crocodiles in Vietnam is a problem of government interest. The government has adopted several policy/measures for habitat protection, stop of hunt and animal trade of endangered species, including crocodiles.

Both species of crocodile in Vietnam are enlisted in the "Red Data Book of Vietnam" in highest category - "E", "Endangered" for urgent conservation measures.

A network of 87 national parks and nature reserves has been gazetted by Vietnam's Government in 1986 for nature conservation. Of them 3 reserves is inhabited by crocodile populations:

- Nam Bai Cat Tien National Park (36 000 ha) in Dong Nai province. Coordinates:11°25N, 107°26'E. The park has a swampy area, where the crocodiles concentrate in high density, so that it is named "Bau Sau"-"Crocodile swamp".

- Suoi Trai Nature Reserse (80 ha) in Tay Son district, Phu Khanh province. Coordinates: 13°20N, 106°45E. There is so named "Dam Sau"-"Crocodile Lake"- with high density of crocodile in the Reserve.

- Lac Lake (540 ha) in Dac Lac province. Coordinate: 15°25N, 108°11E.

Due to many reasons the management of these reseves is not strict enough and crocodiles are still poached occasionally.

There are several crocodile farms in Vietnam (The Vietnam-Cuba Friendship Crocodile farm, Thanh Loi Crocodile farm, Ankhanh Crocodile farm, Hanoi Zoo, Saigon Zoo, Centre for Forestry Science Application, etc..), but mostly for economical purposes and zoos, not for conservation, properly. Before 1960, Hanoi Zoo kept some individuals of crocodile provided by China, which lived for 10 years in the Zoo.

In October 1985, a group of 100 crocodiles (Crocodylus rhombifer) was imported from Cuba. These crocodiles have been distributed to several provinces for captive breeding: 5 in Hanoi Zoo,10 in Saigon Zoo, others in Danang, Nha Trang and Minh Hai. Of them, at present only 27 individuals still survive (Hanoi Zoo: 1, Saigon Zoo: 4, Vietnam-Cuba Friendship Crocodile Farm : 10 and Centre for Forestry Science Application: 12). Others died or have been sold to private farms. Some farms (Hanoi Zoo, Saigon Zoo, etc...) have been successful in breeding crocodiles. Saigon Zoo, for example got the first result of crocodile breeding in captivity in July 1989, and present percentage of hatching is

80-90%. Especially, the Zoo has been successful in hybridization of 2 species, C. siamensis (female) and C. porosus (male). Their hybrid has given 20 eggs, 17 of which hatched successfully. But, in general, crocodile farming in Vietnam is not developed and the achieved results are very limited. The main reasons are shortage of knowlegde on techniques of husbandary and limitation of fund.

IV. CONCLUSION AND PROPOSALS

In Vietnam, both species of crocodile survive in very small number and face with threats of extinction in near future. Several conservation measures have been conducted but not effectively enough. As the result, crocodile habitats are being destroyed and disturbed, hunting pressure is still considerable.

Meanwhile, very little is known about the natural history of the crocodiles and study on crocodiles in Vietnam is very unsufficient.

All these make the conservation of crocodiles in Vietnam a very urgent and difficult problem. In order to ensure survival of the last remained populations of crocodiles in Vietnam, restore them in future an action plan for conservation of crocodiles in Vietnam should be developed and implemented as soon as possible. The following activities should be included in the action plan:

- To strengthen the effectiveness of extant policy and measures of crocodile conservation, aware people of the government policy and regulations for crocodile conservation and interest of crocodile conservation by radio broadcasting and TV programmes, video, posters etc...

- To conduct fieldsurveys to determine exact status and distribution of crocodiles in the wild to elaborate relevant recommemdations for their management and conservation.

- To carry out crocodile farming project for conservation (not for economical) purposes, to ensure their survival, increase their number, and study their biology and ecology.

- To train Vietnamese officers on techniques of crocodile management and breeding.

- The conservation of crocodiles requests large manpower, experience and budget, so that the international cooperation for crocodile conservation in Vietnam is utmost important. We should be most grateful for any international support and collaboration on the programme.

CROCODILE CONSERVATION:

THE BENEFITS OF FARMING AND RANCHING

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Abstract

Crocodiles are a commercially valuable wild animal and of high conservation interest. Being both inherently dangerous to man and requiring conservation poses unique problems to management authorities.

This paper outlines the history of crocodile conservation and management, particularly in respect to the Northern Territory, and explains the contribution crocodile farming and ranching has and could continue to make to conservation of Australian crocodiles.

The interdependence of crocodile farming, wildlife conservation, and land management is discussed and the pressures likely to come onto the relationship in the future.

It is concluded that crocodile farming has made a significant contribution to crocodile conservation. The continued economic justification for active crocodile conservation programs however is dependent upon fostering the existing farming industry, ensuring that it never becomes completely divorced from its foundations in utilisation of wild crocodiles, and promoting the less tangible "crocodile economics" such as tourism.

INTRODUCTION

Two crocodilian species are indigenous to Australia, both confined to the tropics but with an extensive distribution. The endemic Australian Freshwater crocodile *Crocodylus johnstoni* is a medium sized animal restricted primarily to freshwater habitats, has a timid nature, does not attack people, cattle or horses and is not perceived as a danger to people or pastoralists.

Its wild population is difficult to survey because of the nature of its habitat but is estimated to be 30,000 - 60,000 in the Northern Territory with significant populations in Queensland and Western Australia. Lake Argyle in Western Australia alone contains over 25,000. Freshwater crocodiles. (G.Webb 1989)

Because of its slow growth rate, smaller size and lower skin value due to the presence of osteoderms (bony plates in the scales of the belly skin), *C. johnstoni* is commercially less valuable than the classic crocodilians and is currently not economic to grow on farms purely for its skin value.

The more well known species is the large and more aggressive Indo-Pacific or Saltwater crocodile, *Crocodylus porous*. The saltwater crocodile is the largest of the living crocodilians with a distribution ranging from India to the Solomon Islands. The coastal wetlands of the Northern Territory represent the key habitat for the species in northern Australian and along with Papua New Guinea and Indonesia (Irian Jaya) contain the majority of the population with a secure conservation status.

The saltie has a fierce disposition and reputation as a man-eater. It has a number of other features which make them difficult to farm - it is very territorial and prone to fighting when penned in high densities; it is difficult and expensive to collect their eggs; they nest in isolation over a prolonged period; have a high egg mortality in the wild; and hatchlings are difficult to get feeding with food preferences that vary between clutches. Not what you would consider to be the ideal farm animal.

However, *C. porosus* has the most commercially valuable hide of any crocodilian. It is used to make high quality fashion goods for the European and Japanese markets.

CROCODILE MANAGEMENT

Hunting

Both the Freshwater and Saltwater crocodile were hunted commercially in northern Australia before protection in about 1964 for *C. johnstoni* and 1971 for *C. porosus*. (Each of the States protected the species at different times.) At the time of protection both species had become rare due almost entirely to hunting in the Northern Territory and Western Australia, and to hunting and habitat modification and human population pressures in North Queensland.

Protection and the implementation of survey and management programs between 1975 - 1987 produced dramatic improvements in the conservation status of both species in the Northern Territory. Protection in Western Australia and Queensland but the absence of any active follow up conservation management program resulted in less spectacular but nevertheless positive improvements in the conservation status of both species.

It was evident to the Northern Territory in the late 1970's that protection of crocodiles alone was not going to secure the long-term conservation of the species, particularly the dangerous saltwater crocodile. While crocodile populations were low following protection, people were happy to conserve crocodiles as intrusion of the species into human activities was low.

However, it was foreseen that once saltwater crocodile populations increased significantly large and potentially dangerous crocodiles began moving into marginal habitat previously thought safe for swimming and other water based recreation and there was to be more frequent contact between people and crocodiles, particularly in recreational and pastoral activities, human tolerance and acceptance of crocodile conservation would wane.

The Northern Territory embarked upon a program which would hopefully provide additional public and political support for crocodile conservation once these dangerous animals began appearing in Northern Australians' every day lives.

This program simply was to not only espouse the conservation value but provide an economic value on crocodile populations to as many people of the Northern Territory as possible. It is a program aimed at placing an economic value on wild crocodile, using crocodile farms as a nucleus and designed ultimately to make crocodiles an economic asset for the people of the Northern Territory generally, and to the owners of land in particular.

Management Programs

Following the easing of National and International controls over the trade in Australian crocodile skins in 1986 (a story in itself) a conservation program was prepared for the Northern Territory based on extensive research and surveys conducted over the previous ten years which determined an allowable harvest of the various size classes of each species. Permits were issued initially for three farms in the Northern Territory based solely on the wild harvest. Today there are six farms in the Northern Territory, four totally dependent and two substantially dependent upon a wild harvest for their viability.

Figure 1: Estimated Captive Population of *C.porosus* and *C. johnstoni* on Australian Crocodile Farms - December 1993

	No Farms	*C.porosus*	*C. johnstoni*
Northern Territory	6	20,000	15,000
Queensland	6	18,200	2,000
Western Australia	3	2,000	2,500

All crocodile farms in the Northern Territory are actually ranches, using wild stock. The six farms in Queensland and three in Western Australia are essentially closed cycle systems, not being able to use wild-harvested stock. However, with the recent approval by the Commonwealth of the Western Australia crocodile management program farms in that state will become ranches.

Crocodile farming and ranching is now a small but high profile industry which contributes to the Northern Territory economy in particular directly through the sale of world class skins to the export market and meat and other products to the domestic market. The value of the crocodile industry based on farm gate values has grown to an estimated $2.75 million per annum. Tourism associated with crocodile farms is worth an estimated additional $2.5 million per annum. (Onions, 1991).

While the direct economic benefits of crocodile farms are calculable, the indirect benefits of crocodile conservation are less quantifiable but nevertheless significant. The presence of crocodiles in wetlands of the Top End is very much part of the "northern adventure" and a major marketing tool bringing in millions of dollars for the local tourist industry.

The crocodile has been raised to the status of an icon in northern Australia. The ease with which visitors can view crocodiles in the wild, particularly in the Northern Territory, is of enormous tourist value. There are several multi-million dollar tourist operations which can attribute their viability to the crocodile, and numerous smaller operations which specialise in boat tours highlighting crocodile viewing. Although there is deepening concern in northern Australia over the increasing saltwater crocodile populations (currently increasing at 4-5% per annum) this has been tempered by the value of the species to the tourism-based economy.

The conservation and economic status of both species has now been established and it is time to re-enforce and maximise both. Saltwater crocodile populations are currently estimated at 65,000 in the Northern Territory up from ±10,000 in 1970 and well towards the historical estimate of around 100,000. Our knowledge of crocodile populations and conservative harvesting in the past ten years should now allow us to capitalise on more intensive harvests aimed ultimately at population control. More intensive harvests means more animals available to existing or new farms and a greater financial return to the owners of land from which crocodiles are removed.

Past management has concentrated on establishing a viable ranching industry from which benefits would ultimately flow to the landowners who after all were being asked to continue conserving crocodiles in the face of increasing stock losses and increasing dangers to pastoral activities. At present 20-50% of the cost to a farm of a saltwater crocodile hatchling obtained from the wild is payment to the landowner.

Expansion of the harvest away from solely egg/hatchling collection to other size classes in the future, and expansion of current harvests into new areas, will provide increased benefits to landowners, particularly aboriginal.

Being the largest single owner of prime crocodile habitat in Northern Australia, Aboriginal communities stand to derive economic benefit from, and are in a position to contribute to, crocodile conservation. However, because farms require significant inputs of capital and food, neither of which are generally available in remote communities, the potential for communities to develop full scale commercial farms must be treated with caution.

Two crocodile farms in Queensland and one in the Northern Territory are currently owned by Aboriginal people and employ Aboriginal staff. For a variety of reasons including the availability of food, technical skills, services and because of the logistic problems caused by remoteness, conventional crocodile farming may have limited application in Aboriginal lands generally. However there are various avenues through which Aboriginal people can gain financially from the sustainable use of crocodiles (Webb 1992) such as egg collection, harvesting on behalf of farms and tourism. Such enterprises are consistent with the concept of Aboriginal people seeking financial independence but maintaining links with the land and its wildlife. As managers of habitat they have the ability to control supply to farms and to command fair prices.

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The Future?

The marriage between crocodile conservation and crocodile farming and ranching is dependent upon many factors which will require judicious management.

If wild crocodiles are to be worth money to the landowner there must be a market. For there to be a market there needs to be viable farms to raise, grow, and process animals to the standard demanded by the skin and meat trade. In the end the value of the product to the consumer must be maintained and improved.

Farming and ranching is a key component of the conservation strategy for crocodiles. Without the financial incentive for primary producers to be involved there will be no economic return to landowners, there will be no financial incentive to manage land which optimises a return from crocodiles, there will be no financial return to the economy. The benefits to people of having to 'live' with a dangerous animal will be far less tangible, and political and community pressures for 'culling' will become difficult to resist.

The continuing increase in numbers of crocodiles and the range of sites they occupy risks alienating a public that is, in general, sympathetic to crocodile conservation and remarkably tolerant of the constraints placed on access to waterways.

In order to deal with growing public concern and associated pressures for more active management it is desirable that a greater range of management options be incorporated in new programs to enhance the compensating public benefit from the presence of crocodiles, including a greater return to landholders from harvest programs.

Crocodile farming and ranching, the major payer to landowners for stock, is integral to the continued conservation of crocodilians.

However, the long term economic viability of crocodile farms must surely lie in intensive raising and captive breeding, as has been the case for nearly every other production animal, rather than in the harvesting of wild stock. Emphasis on captive breeding will be counter productive to the sustainable utilisation of wild crocodiles.

With the development of a production farm crocodile there will be no need for farms to pay landowners for stock; landowners will as a consequence have a much reduced incentive to protect habitat supporting wild populations because of reduced returns.

The challenge for wildlife managing authorities is to provide for a healthy viable crocodile farming industry but at the same time ensure the industry does not forget its roots in access to the wild resource and somehow continues to pay a dividend to that resource.

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CAPTIVE BREEDING OF ALLIGATORS AND OTHER CROCODILIANS

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ABSTRACT. Although "ranching" of crocodilians has become the preferred method of sustained utilization, in some cases there is a role for closed system farming programs. Some 25,000 crocodilian skins were produced in 1990 by captive breeding; however, many attempts at captive breeding meet with limited success. This paper examines the history of early crocodilian farm programs and outlines the present status of crocodilian breeding programs. Current areas of active research and problems requiring further study to improve and better understand the complex physiological science of captive crocodilian breeding are also discussed.

Introduction

Although the first alligator farm in the United States was established in 1891 in Jacksonville, Florida (Joanen and McNease 1982), it was not until 1964 that extensive research was initiated in Louisiana by the Department of Wildlife and Fisheries on the ecology, reproductive biology, and captive propagation of *Alligator mississippiensis*. This program included the design of an experimental alligator farm at Rockefeller Wildlife Refuge that led to the development of methods for artificial incubation of alligator eggs, heated controlled chambers for the culture of juvenile alligators, and breeding pens for adult alligators (Joanen and McNease 1971, 1974, 1975, 1976, 1979, 1987).

A wealth of data was obtained over the next thirty years at Rockefeller, supporting the concept of alligator culture as a viable conservation strategy and a sound economic venture. Today there are over 100 established alligator farms/ranches in Louisiana housing well over 250,000 alligators, and the feasibility of raising crocodilians in captivity for commercial and conservation purposes is well documented (Joanen and McNease 1990, 1991, Webb et al. 1987, Hutton and Webb 1992).

Similar early work by researchers examined captive breeding in other crocodilians (Blake 1970, Blake and Loveridge 1975, Downes 1973, Pooley 1971, 1973, Yangprapakorn et al. 1971), and with the data accrued at Rockefeller launched crocodilian farming, ranching, conservation, and management programs worldwide [Webb et al. (eds.) 1987]. There are presently at least 597 commercial farms and another 75 experimental or non-commercial crocodilian facilities in some 47 countries worldwide (Luxmoore 1992). These farms/ranches maintain an average of 1,700 crocodilians each, for a total stock of over 1.1 million.

The purpose of this paper is to examine the captive breeding aspect of crocodilian farming. The early developmental history will be reviewed, followed by current status of captive breeding of the most important commercial species. Lastly, areas of active research and problems requiring further detailed study will be examined.

Farming, Ranching, and Conservation

Recent studies have demonstrated that crocodilian ranching (rather than closed system farming) is the preferred form of sustained utilization (Hutton and Webb 1992). Ranching is generally more economically advantageous than closed breeding systems, which can be costly and labor-intensive to initiate, and frequently meet with limited success for the first several years. Ranching also wisely uses crocodilian eggs/hatchlings which otherwise would be lost to a very high natural mortality. Ranching programs often require release of some percentage of larger juvenile "head-start" crocodilians back to the habitat from which the eggs/hatchlings were obtained, usually at a size large enough to limit natural mortality. Closed system farming has adult breeders and obtain all stock in hatchlings from captive laid eggs. Many of the Louisiana "farms" combine ranching with closed system farming, though the majority rely strictly on ranching. However, not all crocodilian species exist in large enough numbers to support as extensive a ranching program as is present in Louisiana.

Captive breeding is useful; however, in several situations. In some species, wild populations may not be large enough to support a ranching program, and wild egg collection may be prohibited or severely limited. In some instances, where wild populations are very low, captive breeding might be considered as a method to obtain juveniles for restocking to replenish the wild population. In some locations, habitat for crocodilians has been depleted by human factors and captive breeding may again provide juveniles for reintroduction in similar suitable habitats. Caution must be taken; however, not to regard captive breeding as a panacea for the conservation of wild crocodilian species and their habitat (Hutton and Webb 1992).

In 1990, about 15% of skins produced worldwide were from captive breeding, however approximately 25% of animals currently maintained on farms are derived from captive breeding, and should contribute more to the skin industry over the next few years (Luxmoore 1992). Although most classic skins (Alligator, C. niloticus, C. novaeguineae) are produced by ranching rather than captive breeding, a significant portion of the Crocodylus porosus skins are produced through captive breeding; and some rare species (C. rhombifer and C. siamensis) are almost exclusively produced through captive breeding (Luxmoore 1992).

Rockefeller Refuge's first experimental alligator farm

A thorough review of some fifteen years of research on captive propagation of the American alligator done at the Rockefeller Refuge was recently published (Joanen and McNease 1987). It should be stressed that a strong interest in the breeding physiology of wild alligators led to the study of alligators in captivity in order to closely observe alligator courtship, breeding, nesting, life history, etc. which would be more difficult to document in the field. The discovery that alligators would breed in captivity later led to research as to the economic feasibility of commercial raising of alligators. In the early years of our program, stringent legislation and concern over the "threatened" classification of alligators prohibited the collection of wild eggs/hatchlings for ranching except for very limited experimental collections on state-owned lands on which no wild harvest occurred. Thus captive breeding (rather than ranching) was the only source of stock for alligator farming trials initially available. A brief summary of the captive breeding aspect of this research is presented below.

The first studies (1964-1971) involved the housing requirements of wild adult alligators brought into captivity for breeding purposes. However, excessive fighting and territoriality in communal pens was detrimental and led to deaths of several alligators (Joanen and McNease 1971). Data from these studies indicated that wild caught animals maintained in single pairs had less territoriality and nested with some degree of success. The clutch size and hatch rates from 5 pairs of alligators in 1/4 acre pens were comparable to the wild, but 2 females nested only once in the five year study and one did not nest until the third year.

It was felt that a higher level of productivity would be needed for a commercial farm operation, as separate pens for each pair of wild caught alligators was cost-prohibitive. This led to the raising of alligators entirely in captivity to be used as breeders. Alligators were reared from hatching until 4'-5' long (approximately 3 years), then were stocked into breeder pens. These animals were more docile and had less social competition between dominant animals.

The results of telemetry studies with wild adults (Joanen and McNease 1970, 1972) were used to identify basic habitat needs when constructing pens to house adult alligators. These studies indicated that deep open water areas (such as bayous, canals, large lakes) were needed for courtship and copulation; and small potholes and ponds in heavily vegetated areas were needed for use as nesting sites. These habitat types were later incorporated into pen designs (Joanen and McNease 1987). Reproduction of a large group of alligators cultured since 1972 has now been achieved, and their reproductive histories have been carefully documented.

Important aims of the early studies were to investigate the maximum stocking densities which pen-reared alligators could tolerate in captivity, given the provision of suitable habitat requirements for each sex. Various stocking densities, male:female ratios, and land:water ratio/pen design, and diets were studied.

Pen design refinements developed over the years were incorporated into the construction of four breeding pens in 1975; all were about 0.8 ha (2 acres). The pen design, dimensions, fencing, vegetation, maintenance and husbandry have been described in detail (Joanen and McNease 1987).

The method of feeding has been described previously (Joanen and McNease 1971, McNease and Joanen 1987). Several feeding sites were established in each pen to help disperse the alligators, usually situated near a basking area or a path adjacent to the water's edge. Feeding began in March or April of each year and terminated in September or October; alligators are not fed during late fall and winter, when ambient temperatures are too low. A feeding rate of 6% body weight per week was adhered to during the spring and summer, when most food was consumed.

Two diets were initially tested on the penned breeders; whole fish (Micropogon undulatus) and nutria (Myocastor coypus) carcasses. Also, two pens were heavily stocked, and two pens were stocked at a low density. One high and one low density pen were fed fish, and the other two pens nutria. A vitamin premix was added to the diet of all alligators at a maximum rate of 1% by weight. The specifications of the premix (manufactured by Dawe Laboratories Ltd., Chicago Heights, Illinois 60411, USA) have been published previously (Joanen and McNease 1987).

Early results - captive breeding on Rockefeller Refuge's experimental alligator farm program (1972-1984).

Age at first nesting for captive alligators, housed and reared in controlled environmental chambers for the first three years of life, then placed in outside pens, was five years 10 months. Age of sexual maturity reported for Louisiana alligators held in semi-natural outside pens was nine years and 10 months (McIlhenny 1935, Joanen and McNease 1975).

Nesting rates for captive alligators fed nutria (Pen 6; low density) were consistently higher than for those fed fish (Pen 5; low density). During a four year period, when the alligators were seven to 10 years of age, an average of 62.8% of nutria fed animals nested annually, whereas the equivalent rate for those fed fish was 26.8%. The low nesting rate in Pen 5 (fish) increased abruptly to 56% when the diet was switched to nutria in the spring of 1982 and this change was maintained the following year (57%)(Joanen and McNease 1987).

Independent of diet, nests from first time nesters had an average clutch size of 25 eggs. Joanen (1969) reported an average clutch size of 38.8 eggs for wild nests in southwestern Louisiana, and penned alligators approached this level in their third or fourth year of reproduction (Figure 1).

Alligators fed a nutria diet consistently had higher fertility rates than those fed fish but both groups had lower fertility and hatch rates than recorded for the wild populations. Initially the hatching rate of eggs from captive alligators fed nutria remained slightly above the value determined for wild eggs left in the field to incubate, but was well below the 91% achieved with eggs collected from the wild and incubated in controlled incubator chambers. Eggs from captive alligators fed fish demonstrated very low hatching rates, averaging 27.4% over five years. This problem will be discussed in detail later in this paper in the diet/nutrition section. When the captive breeders were about 10 years of age (1983) reproductive success was quite good, with some pens having some 80-85% nesting rates (Figure 2), 85% fertility (Figure 3), and 60-65% hatch rates (Figure 4).

Higher stocking densities on both diets led to higher plasma corticosterone (stress hormone) levels in captive adult alligators; and correlated with lower nesting success than in alligators maintained at low stocking densities (Elsey, et al. 1990)

Recent results - captive breeding on Rockefeller Refuge's experimental alligator farming pens (1985-1992)

More recently, as the alligators in our captive breeding stock have aged, reproductive success has declined dramatically. Although clutch sizes in captive animals have remained fairly high (30-45) (Figure 1), the nesting rates (Figure 2), egg fertility (Figure 3) and hatch rates (Figure 4) have all dropped dramatically. From 1987 to 1988, hatch rates dropped from 34.3% to 6.8% in Pen 5, from 32.6 to 25.8% in Pen 6, and from 25.8% to 9.8% in Pen 8. Hatch rates ranged from 45.3-48.9% for these pens in 1986 and from 38.3%-65.3% in 1985. In 1989, no eggs hatched from those nests produced in Pens 5 and 7, and only 13.5% hatched in Pen 6. The great majority of eggs incubated that appeared fertile died in weeks 1-3 of incubation. Numerous eggs were also misshapen, poorly calcified/soft-shelled, crushed, or infertile. Since 1983, all pen alligators were fed a nutria diet with supplement vitamins and since 1990, a mixture of half nutria and half commercial dry pelletized rations was fed to breeder alligators.

An extensive set of research projects was then initiated to attempt to solve the problem of poor egg hatchability; as we are encouraged by the fact that good nesting attempts are made in all pens and clutch sizes remain normal. Also, the nesting rates (percent females in a pen that construct a nest) may be skewed to the low side in recent years in pens 5-7, as the "proven nesters" have frequently been caught and relocated to new pens to evaluate different stocking densities, male:female ratios, and pen designs.

Louisiana' statewide farm breeding results, 1992

There are currently 122 licensed farms/ranches in Louisiana with a total inventory of approximately 288,000 alligators. Thirty-three farms have captive breeding stock; although only 19 farms have alligators old/large enough to be considered capable of breeding (Table 1).

In 1992, some 418 nests were constructed, and 4,389 hatchlings were produced (10.5 per nest). This is a downward trend from 1990, wherein 7,607 hatchlings were derived from 482 nests (15.8 per nest). The average nesting rate was 30.9%, with a 42.4% hatch rate. Only 3.2 hatchlings were produced per adult female alligator maintained (breeders plus non-breeders).

It remains unclear if breeding results on Louisiana farms will improve over the next few years. Certainly more hatchlings will be produced as the immature brood stock becomes sexually mature; however, there appears to be a decline in reproductive effort over time as mature breeders age.

Captive breeding in other southeastern states

Florida. In 1991, some 58 licensed alligator farms in Florida produced 21,645 hatchlings (4.29 per adult female), slightly increased from 4.15 hatchlings per adult female in 1990 (D. David, pers. comm.). From 1984-1990, the average hatch rate on all Florida farm eggs was 35% (Cardeilhac 1990). Cardeilhac (1988) suggested that farmers must maintain an annual hatch rate of 7 hatchlings/female to be successful.

Georgia. Although only a few alligator farms exist in Georgia, captive breeding has been undertaken on the majority of these farms. Four operations produced 341 hatchlings in 1989, and 661 hatchlings were produced from 5 of the 6 licensed farms in 1990 (Luxmoore 1992).

Texas. Some 42 alligator farms are operating in Texas, but most are new and have very limited stock/commercial activities at present (Luxmoore 1992, B. Brownlee, pers. comm.). The majority are obtaining stock by ranching; but four farms had captive in 1992; 992 eggs were collected from 28 nests, and 452 hatchlings produced (B. Brownlee, pers. comm.).

Mississippi. Five alligator farms are presently licensed in Mississippi, of which two have recently constructed breeder pens. At this time the brood stock are all immature (J. Lipe, pers. comm.).

Captive Breeding - other crocodilians worldwide

Despite extensive research, captive breeding of crocodilians still is poorly understood; and most importantly significant differences between species can make comparisons of breeding/culture regimes difficult (Hutton and Webb 1992). These species-specific traits have been discussed previously (Webb 1990, Hutton and Webb 1992) and will be briefly reviewed below.

The social behavior of crocodilian species varies greatly, and has important implications for management of breeding herds (Lang 1987, Hutton and Webb 1992). It is paramount to realize that solitary nesters (*A. mississippiensis*, *C. porosus*) frequently breed poorly in captivity; whereas communal cavity/hole nesters (*C. niloticus*) in general are more successful with captive reproduction.

Most crocodilian brood stock perform better if raised entirely in captivity rather than being captured from the wild as adults for brood stock (Joanen and McNease 1971, 1987, Hutton and Webb 1992). In the Nile crocodile; however, this is less of a problem (Hutton and Webb 1992). Captive reared stock have been found to better tolerate variable pen designs/housing conditions than their wild counterparts brought into captivity for breeding purposes, and will breed at an earlier age than wild crocodilians of the same species (Joanen and McNease 1987, Hutton and Webb 1992) brought into captivity. It would be of interest to document the reproductive success and age of first nesting of sub-adults (4'-5') caught from the wild, then maintained in captivity.

Some of the many variables that make comparisons between brood stock productivity difficult are: species differences, age, early history, housing conditions, land/water ratios, diet, sex ratios, husbandry practices, stocking rates/density (Joanen and McNease 1987, Hutton and Webb 1992). All these compounding variables can make comparisons relating to one factor unclear. An excellent review of the husbandry and management of captive breeding herds of some of the most commercially important species was recently published (Hutton and Webb 1992) and is highlighted below.

Nile Crocodile (*Crocodylus nilotus*). Nile crocodiles are communal nesters which can nest as early as 6 years if entirely captive raised. Generally females should be housed with larger, older males. Suitable raised banks should be available for these hole nesters. Most farms employ one of two breeding systems, either a few females in a small enclosure with one male, or up to 300 females with as many as 60 males in a large (several hectare) pen. Nile crocodiles breed very well in captivity, with a high percentage of females producing eggs for as long as 20 years

(Hutton and Webb 1992). Marias and Smith (1992) report 42% and 77% nesting rates on two large breeding units in 1989-90; with clutch sizes of 43 and 52 with 70-85% hatchability. These were large breeding pools containing 130 and 132 females, again a situation that is possible due to the communal nesting habits of Nile crocodiles. However, not all communal nesters breed this well in captivity; a recent study found 35% infertile eggs laid by captive C. johnstoni as compared to a 3-6% infertile rate for wild eggs collected the same year (Webb 1990).

Estuarine Crocodile (Crocodylus porosus). These solitary mound nesters may reach sexual maturity in 8 years. Crocodile farms have maintained C. porosus in large communal pens (multiple males and females); or in small enclosures of 1-5 females with 1 male. As has been seen in alligators, with time and increasing age of adults, nesting rates in communal pens generally decreases to 20-30%, with poor egg quality (some 30% viable, Webb 1990, Hutton and Webb 1992). Even more so than in alligators, females and males both fight amongst themselves, leading to adult mortality (Webb 1990). Variable results are obtained with small breeding groups (1 male:2 females, 1 male:3 females, etc.); and single pairs of 1 male and 1 female apparently nest more successfully (Webb 1990).

Common caiman (Caiman crocodilus). Captive raised female caiman can become sexually mature at age 2.8 years, and are less territorial than alligators and saltwater crocodiles, and therefore can breed well in captivity (Hutton and Webb 1992). A sex ratio of 2 females:1 male has been recommended, and suggested enclosure designs previously described (Hutton and Webb 1992).

New Guinea Crocodile (Crocoylus novaeguineae). The majority of the C. novaeguineae skins produced are obtained from ranching and wild harvest; although limited captive breeding is underway in Singapore and other areas (Hollands 1987, Luxmoore 1992).

With this background on captive breeding of crocodiles, we now will address some new areas of current research presently underway at Rockefeller Refuge. The areas we are attempting to address are how to improve the nesting/reproductive success of captive crocodilians, increase hatchability of crocodilian eggs, and minimize the high rates of early embryonic death we frequently incur.

Social interactions/"stress".

As mentioned, agonistic/aggressive behavior and disputes over territory, nesting space, and dominance hierarchies can hinder successful reproduction, especially in alligators and C. porosus. We have seen that acute restraint stress will raise plasma stress hormone (corticosterone) levels in adult alligators, and concomitantly depress the plasma sex steroids, estradiol and testosterone (Lance and Elsey 1986, Elsey et al. 1991). Other stressors that have been shown to adversely affect the normal physiology of juvenile alligators are crowding (Elsey et al. 1990) and exposure to salt water (Lauren 1985). Overcrowding could lead to stress-related disease, and heavy leech infection was shown to be correlated with a sixfold increase in eosinophilia in wild alligators (Glassman et al. 1979). Crowding stress also may affect the immune system of the alligator. Juvenile alligators acutely stressed (restraint) had significant increases in leukocyte counts, with an increase in the percent heterophils and a decrease in the percent lymphocytes by 24 hours (Elsey unpublished). Similarly, stressors could adversely affect the immune system functioning and lead to disease and reproductive failure in captive adult crocodilians.

Overcrowding/stress.

Early research conducted at Rockefeller showed that alligators maintained at high stocking density had elevated plasma corticosterone levels, and those with lower stocking density had lower stress hormone levels, and correlated with better reproductive rates (Elsey et al. 1990). This may have been due to a stress induced suppression of sex steroids by the elevated plasma corticosterone levels, as our acute stress experiments suggested.

Thus, we constructed a large breeding pen in 1989, 16-acre in size, stocked with 16 females and 5 males. This pen was much larger than our other pens of 2 acre size, and was an attempt to minimize any territorial disputes/fighting over nesting space or "crowding stress". Unfortunately, an unusually hard winter freeze in December 1989 killed 1 male and 6 females in this pen. Four females nested in 1990, 6 in 1991, and 5 in 1992. Fertility was 60.8% in 1991 and 42.1% hatched that year. Data are not available for the fate of eggs produced in 1990 and 1992 as they were shipped elsewhere for laboratory evaluation. The nesting rates are not dramatically improved from our other pens, despite the extra space provided per female.

Recently, in C. porosus, Webb (1990, Hutton and Webb 1992) has noted larger clutch sizes and higher egg viability in "unitized" pens. These consist of a small pen with 20-30 m^2 water and housing a single pair of crocodiles (1 male, 1 female). Encouraged by the work done on C. porosus, we constructed six "single pair" pens in June/July 1990 and stocked these with alligators transferred from our other breeding pens. Nesting rates have improved in that four of the six females nested in 1991 however, fertility was only 35.1% and hatchability 8.7% in 1991. All six nested in 1992; but eggs in 1992 were sacrificed for biochemical analysis (lipids, fatty acids) thus were not incubated. Three nests in 1992 had normal appearing eggs, 2 had 16-21 soft-shelled, non calcified /oviductal material type eggs, and one nest contained only scanty oviductal material. Research is currently underway to try to understand why the fertility of our captive breeder's eggs has declined recently, and why the hatchability of these eggs once produced, is so low.

Age

Advancing age could explain some of the reproductive failure seen in our breeder herds. Similarly, Cardeilhac (1990) reported that 50% of 18 breeders necropsied at 26 years of age had oviducts blocked by egg or follicle retention from not being reabsorbed in prior years. It is unknown how long crocodilians continue to nest in wild populations.

Hormonal Therapy

A study done in 1970 at Rockefeller Refuge on the effectiveness of injecting human chorionic gonadotrophin (HCG) on female alligators met with limited success. Six adult female alligators were caught from the wild, 3 were given 800 IU/lb. of HCG and 3 were give 50 IU/lb., and they were then placed in captivity. Only one female given the higher dose nested (Joanen and McNease, unpublished progress report). Attempts at artificial insemination were unsuccessful in 1970 and 1971 (Joanen and McNease unpublished repts, 1971 and 1972). Likewise, Cardeilhac et al. (1981, 1982) demonstrated that female alligators are unusually resistant to attempts to induce ovulation by hormone injections (HCG, progesterone, luteinizing hormone releasing hormone) and insemination.

Oxytocin was used to induce oviposition in captive _Caiman crocodilus yacare_ at the New York Zoological Park (Brazaitis 1984). Several doses of one IU/100 g body weight was administered intramuscularly, and over several days 20 eggs were expelled. Three eggs were crushed/damaged and thus not incubated, and 7 were infertile. Three embryos died before 30 days of incubation, 5 died late in incubation, and 2 viable male hatchlings were obtained (Brazaitis 1984). Oxytocin has also been shown to induce oviposition in a dystocic saltwater crocodile at a single lower dose of approximately 1 IU/kg IM. (Carmel 1991). Twelve of 27 eggs obtained hatched successfully.

Male alligators have been shown to respond to mammalian FSH and GnRH with increased testosterone secretion (Lance and Vliet

1987, Lance et al. 1985). Also yohimbine, an alpha-2-adrenergic blocker given to captive male Nile crocodiles increased the frequency of the headslap display (a behavior seen in reproductive activity) but did not increase copulation frequency. However, the females in the male treated groups had higher egg fertility (34.1 and 39.0% treated as compared to 30.5% in the control group), thus there may have been more successful (though no increase in frequency) copulations (Morpurgo et al. 1992). However, in general most researchers feel crocodilian reproductive failure is due to a female physiology problem rather than male sterility/abnormality, although little is known about the quality of semen or spermatozoa viability in crocodilians (Lance 1987). The reproductive endocrinology of crocodilians has been reviewed in detail (Lance 1987, 1989), and extensive blood serology work has delineated the normal annual reproductive hormone cycles in alligators (Lance 1987, 1989). Some data is also available on the reproductive hormones of wild *C. niloticus* (Kofron 1990).

Diet/Nutrition/Supplements.

Diet plays an important role in the general health, and therefore contributes to the reproductive capability of crocodilians. Our early results in captive breeding groups clearly showed alligators fed a red meat (nutria) diet had higher nesting, fertility, and hatch rates than those fed fish (Joanen and McNease 1987). Some researchers have advocated a varied diet rather than a mono-diet consisting of a single food source. However, in *C. porosus*, single pairs fed only chicken produced very well, whereas multiple groups on a mono-diet of chicken did poorly; and single pairs fed fish did well (Webb 1990). In those cases, the pen design effect appears to override the dietary influence on reproductive performance.

We have also been concerned that our breeding herd, and other crocodilians maintained in captivity may not be breeding well due to overfeeding, lack of exercise, and resultant obesity. This could lead to poor muscular condition and contribute to reptilian dystocias (Grain and Evans 1984).

Previously, we fed our captive breeders 6% body weight per week during the feeding season of spring/summer (Joanen and McNease 1987) and have decreased this in recent years. Any benefits from this may be offset by the advancing age of our breeders.

Formulated crocodilian feeds have recently been reviewed; (Staton and Vernon 1991) this paper again emphasized the need for further study of the nutritional/feeding requirements of breeding crocodilians, although a wealth of data has been published on feeding regimes for juvenile crocodilians.

We have advocated adding a vitamin premix at a rate of 1% by weight to the diet of all alligators (Joanen and McNease 1987). To determine if deficiencies of vitamins/trace elements essential for reproduction were present in the captive alligators fed fish or nutria, an extensive blood chemistry analysis was done at Rockefeller in 1980-1982 (Lance et al. 1983). Fish fed alligators had higher plasma selenium and lower vitamin E levels than the nutria fed or wild females; (despite the addition of a vitamin E containing premix to each type diet) which could have caused the reproductive failure. As mentioned, when the fish fed alligators were changed to a nutria diet in 1983, their nesting success increased (Joanen and McNease 1987). However, the fish itself may not necessarily have been the problem, as fresh fish has been shown to be a good source of long chain (C20 and C22) fatty acids needed for embryo survival. However, frozen fish may not have been protected against oxidation of the long chain PUFAs, as described further below. Thiaminase activity has been measured in many species of common food fish (Cooper and Jackson 1981), and thiamin is a necessary part of our vitamin premix.

Hunt (1980) reported that two pairs of C. moreleti at the Atlanta Zoo failed to produce viable eggs until a diet of marine fish was stopped; also crocodilians at the St. Louis Zoo fed mackerel developed severe vitamin E deficiency, with six dying from steatitis (Wallach and Hessle 1968). Some of these conditions may be lessened by feeding fresh fish, rather than frozen, and definitely not rancid fish which may have undergone oxidation (Noble et al 1993, M. Staton pers. comm).

Singh and Sagar (1991) showed an improvement in clutch size (from 26-27 to 31.7) and hatchability (from 44-49% to 62.9%) in captive C. palustris given supplemental vitamin E orally, 400 mg daily for 10 consecutive days 3 months prior to nesting. Their study involved 2 males maintained with 4 females.

Due to the very poor hatchability of the eggs produced by our captive alligator breeders in recent years, we have sent most eggs available to laboratories for biochemical analysis to test for deficiencies/abnormalities that may be present in the yolk/developing embryo. Noble et al (1993, in press) found extensive differences in the lipid and fatty acid composition of the yolks from eggs of captive vs. wild alligators. The yolks for the captive eggs contained considerably lower levels of C20 and C22 polyunsaturated fatty acids (PUFA) and higher levels of C18 PUFAs than the wild. The C20 and C22 PUFAs play an important role in the embryonic development, particularly of the nervous system (Noble et al 1993, Neuringer et al. 1988). These yolk fatty acid compositional differences may be associated with the low hatchability and increased early embryonic deaths we have seen in the eggs produced by our captive breeders (Noble et al. 1993). Similarly, Staton (unpubl. data) found significant differences in the fatty acid composition of eggs and hatchlings from wild vs. captive alligator breeding populations. The essential fatty acid monitoring in juvenile alligators was recently evaluated in detail (Staton et al. 1990).

Preliminary results from Noble's study also indicate captive bred alligators may have a marked reduction in selenium levels compared to the wild alligator eggs; and emphasize the need to supplement diets with Vitamin E plus selenium to protect against oxidation of the long chain polyunsaturated fatty acids. <u>Fresh</u> fish is high in long chain PUFAs and adequately protected from oxidation. Captive alligators fed nutria or commercial mixes (low in long chain PUFAs) or frozen dead fish/fish products (in which inadequate protection against oxidation is present) may have poor breeding performance due to these dietary influences on yolk constituents/embryo hatchability (Noble et al. 1993, M. Staton pers. comm.). Studies are underway at Rockefeller to supplement several groups of our pen breeders with Vitamin E, selenium, and long chain PUFAs in a "sausage" mixed with nutria, and compare these to control groups not given supplementation.

Dr. Paul Cardeilhac (1991) examined the effects of total fat intake, vitamins, antibiotics, highly unsaturated fat intake, and protein intake on alligator breeding performance at several large alligator farms in Florida. Again, multiple pens, stocking densities, age of breeders, and diets made evaluating the effects of these varied nutrients on embryo survival difficult, however antibiotic and vitamin therapy strongly correlated with production of fertile eggs. Antibiotics administered were virginiamycin and oxytetracycline; and multiple vitamins and elements (including selenium and vitamin E) were added (Cardeilhac et al. 1991). We have initiated studies in 1991 at Rockefeller adding a powdered supplement containing these mixtures, however thus far little improvement has been noted. Cardeilhac (1990) also recommends that the diet of captive breeder alligators should be at least 15% polyunsaturated fat.

Eggshell quality.

Early studies on alligator eggshells by Shirley (1982) indicate diets also affect eggshell thickness. Alligators fed fish produced a thicker shell than either those fed nutria or those in the wild; this in turn could be implicated in the high percentage of early embryonic deaths that occurred in eggs from alligators fed fish.

We have frequently noted an obvious tactile difference in alligator eggs produced in captivity vs. those from wild alligators. Captive eggs are frequently rough, with extraneous calcareous deposits or are soft-shelled and misshapen. The wild eggs are usually of a smoother even texture. To determine if the low hatchability of alligator eggs from captive breeders might be due to differences in the morphology of the eggshells, we compared the morphology of eggshells of wild alligators to those of captive alligators using electron microscopy. Our results indicated the number of open pores of eggshells was lowest in eggs of captive alligators with early embryonic death. The number of pores was intermediate in eggs with early embryonic death from wild alligators, and the number of pores was highest in eggs with full-term embryos from wild or captive alligators. It was suggested that decreased porosity of eggshells may be associated with early embryonic death, is more prevalent in captive animals, and may, therefore be related to poor hatch rate among pen-reared alligators (Wink et al. 1990). Other crocodilian species however, normally have very rough, sculptured surfaces and the role of eggshell porosity in determining embryonic hatchability is still unclear (G. Webb, pers. comm.). Clearly; however, we have seen a marked worsening of eggshell quality with advancing age of our captive breeders.

Multiple Clutches.

The question has been posed as to whether crocodilians could produce more than one clutch of eggs per year (Lance 1987). Whitaker and Whitaker (1984) reported that captive C. palustris commonly produces 2 clutches annually. Most mature females lay two clutches of 25-40 eggs per clutch, about 40 days apart; but this phenomenum has not been documented in wild populations. Blake and Loveridge (1987) report on a possible case of double nesting in C. niloticus at St. Lucia in 1984, but believe their observations may have been indicative of "staged" or staggered nesting, where in all eggs in a single clutch are not laid at the same time (Blake and Loveridge 1987).

In alligators, Lance (1989) has suggested that annual reproduction represents a considerable investment on the part of the female alligator: the mobilization of yolk proteins for a clutch of 30-40 eggs, weighing 50-70 g each. Eggshell formation in alligators also regimes the mobilization of calcium from structural bone (Wink and Elsey, 1986, Wink et al. 1987) to produce 30-40 egg shells, each containing 3.0-5.0 g of calcium (K. Packard, personal communication). The expenditure of energy during nest building and nest guarding also further drain the female alligator, and thus nesting twice in a year seems unlikely (Lance 1989). Lance (1989) also suggested that crocodilians likely have a refractory period after ovulation which would prohibit double nesting; and attempts to induce double nesting might cause premature senescence due to depletion of ovarian oocytes. Also, wild alligators have a relatively short nesting period, with a narrow time frame of warm weather for ovulation, courtship, breeding, nest construction, and incubation. A refractory/recovery period would place the time of incubation/hatching of a second nesting event well into the cool fall/winters experienced in the range of the alligator. Thus, attempts to induce second clutches in captive breeders would likely be unsuccessful.

DNA Fingerprinting.

One final area of new research we are undertaking is that of keeping genetic records, or a "stud book" of captive breeders in our experimental pens. Questions we hope to answer concern multiple parentage (?does more than one male service a female, or are all hatchlings in a clutch sired by the same bull?), and identify the males and females in communal pens which are contributing to the nesting efforts. Whether "pair bonds" exist is another question DNA studies can answer; and answers to these questions may further help our understanding of wild and captive crocodilian breeding biology.

Conclusion

Although all crocodilian species have bred in captivity (Hutton and Webb 1992), success has been limited and most biologists and wildlife managers agree that ranching programs (which wisely use the segment of crocodilian populations otherwise lost to natural mortality) are the preferred utilization method and source of stock for crocodilian farms. The tremendous expense of captive breeding pens (land, construction, feeds, maintenance, labor) is cost-prohibitive for many species, particularly where only 5-10 hatchlings may be produced per adult female maintained annually. Present soft markets dictate captive breeding not economically feasible for most species, although the more valued C. porosus skins may still be profitable enough to warrant captive breeding attempts.

However, the physiological problems of captive breeding in crocodilians are very interesting, and deserve further study. Much more research is needed in many areas to improve captive breeder performance on crocodilian farms. The many factors that could adversely influence nesting in captivity such as age, stocking density, pen designs, stress, disease, obesity, inadequate nutrition, inadequate vitamins, minerals, trace elements, adverse social interactions and economic factors could be further researched to refine recommendations to commercial farmers/conservationists in attempts to improve captive breeding results.

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FIGURE 2. Nesting rates of captive alligators, Rockefeller Refuge.

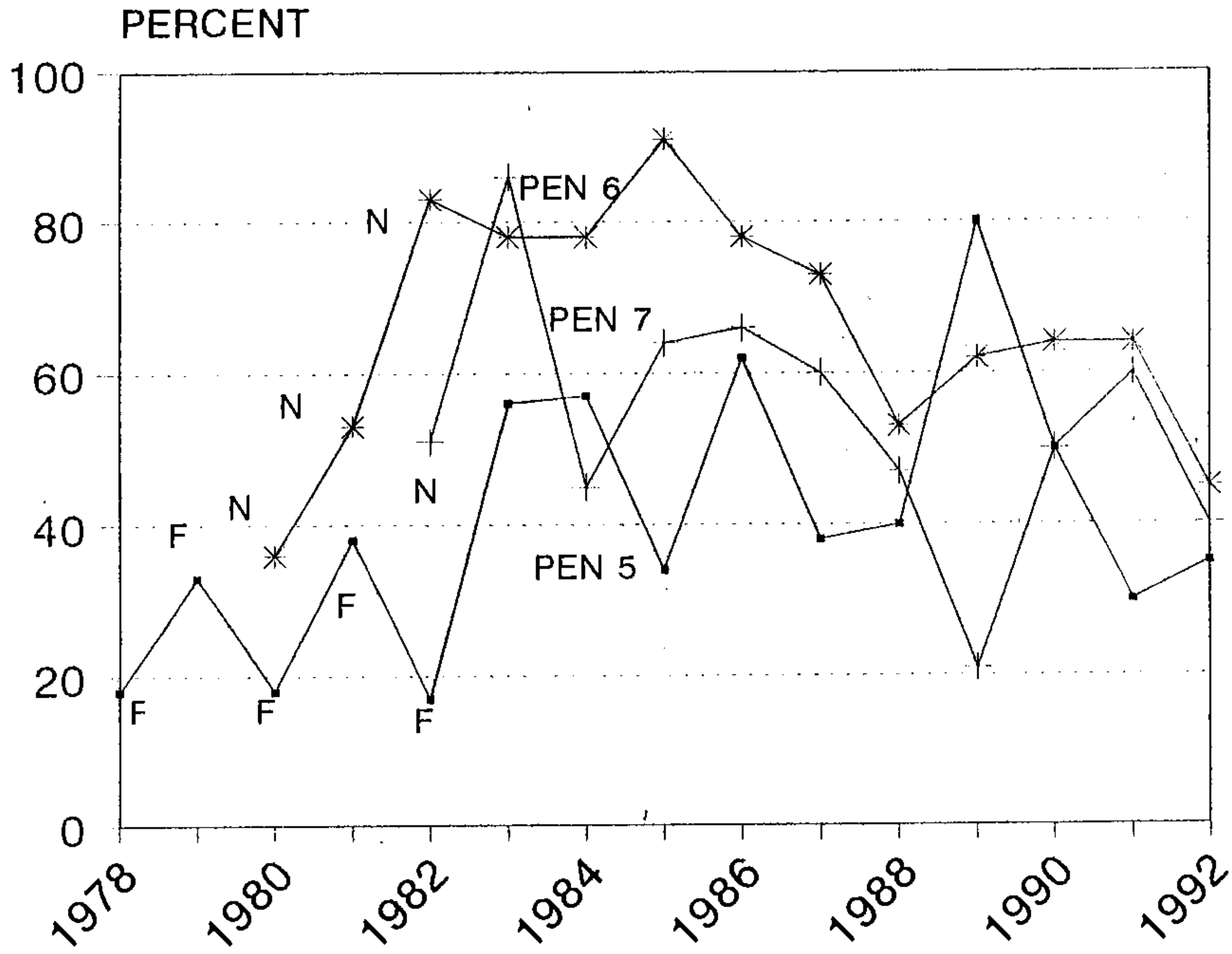


FIGURE 1. Clutch size of captive alligators, Rockefeller Refuge.

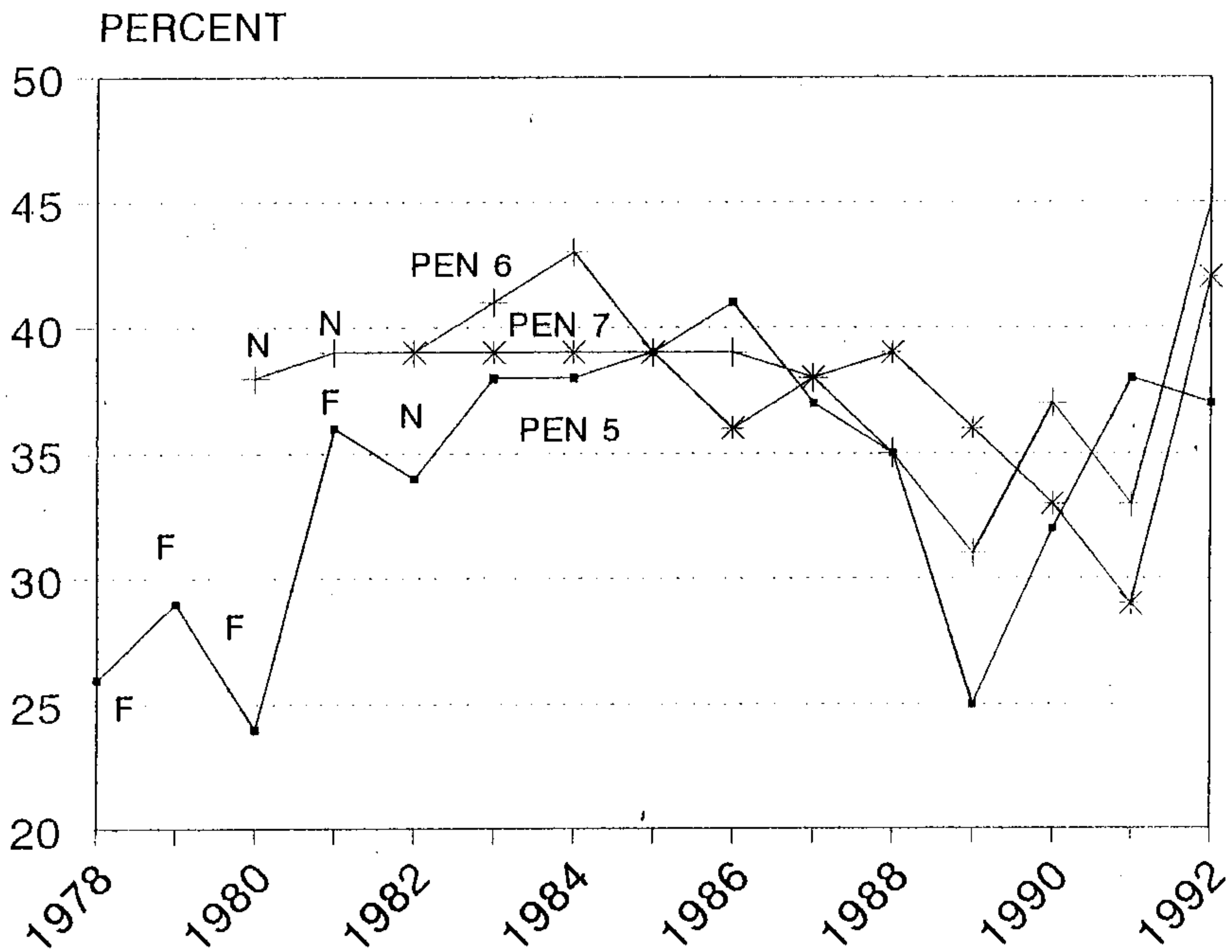


FIGURE 4. Hatching rates of captive alligators, Rockefeller Refuge.

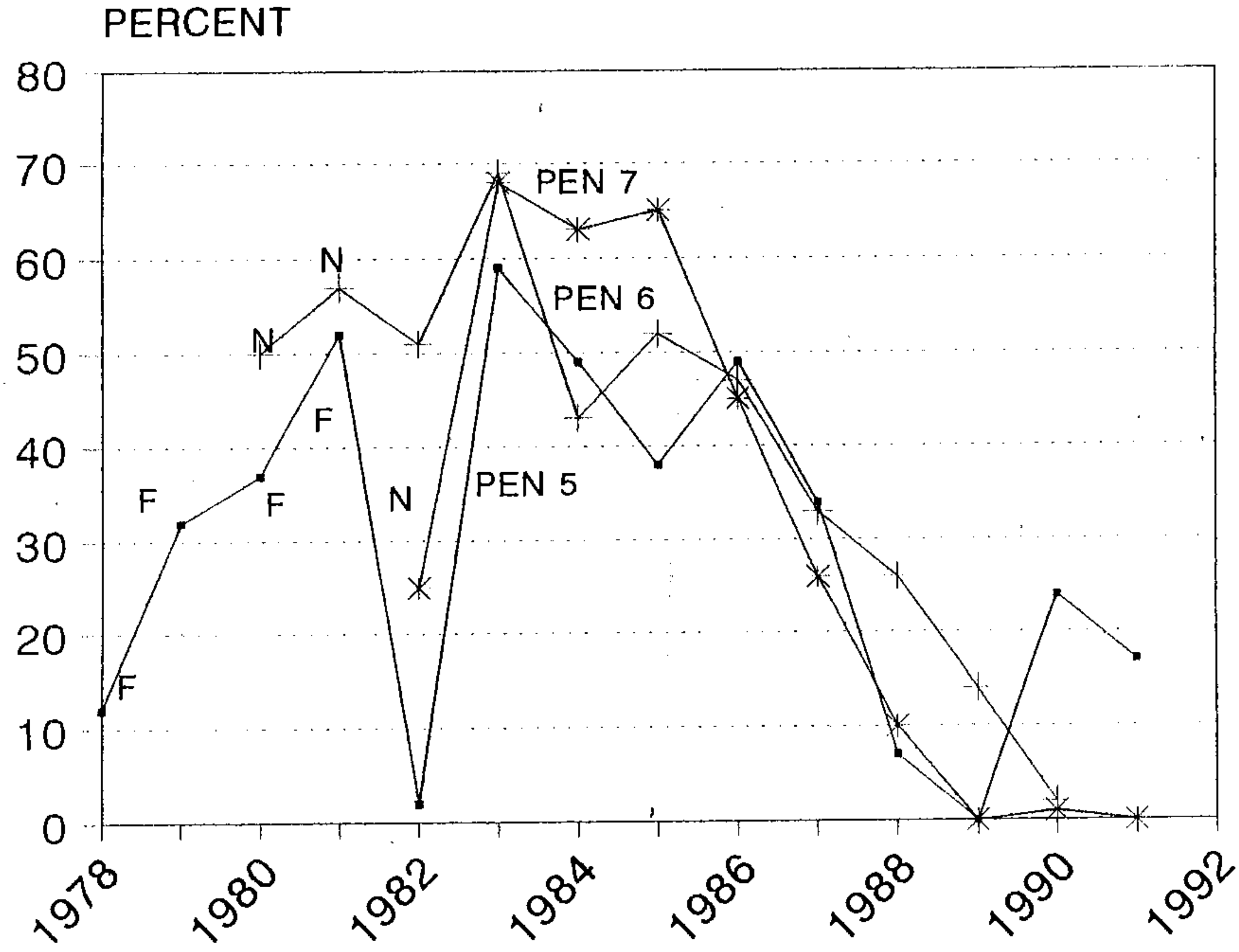
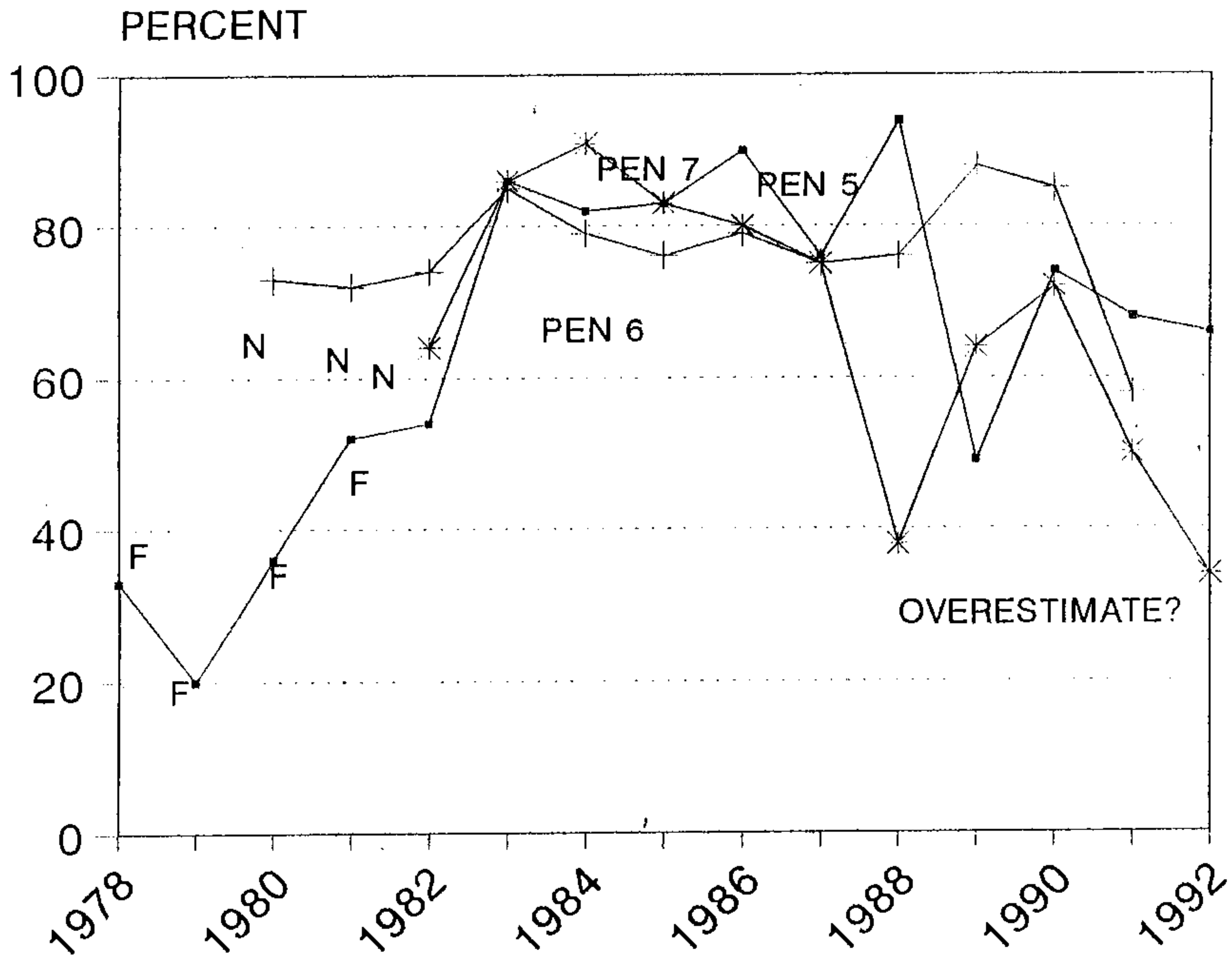


FIGURE 3. Fertility rates of captive alligators, Rockefeller Refuge.



LOUISIANA'S ALLIGATOR FARM CAPTIVE BREEDING RESULTS, 1992

FARM	# MATURE FEMALES	# NESTS	% NESTING	# EGGS	HATCHLINGS PRODUCED	% HATCH	HATCHLINGS PER FEMALE
A	227	39	17.2%	1560	1385	88.8%	6.1
B	213	85	39.9%	1003	355	35.4%	1.7
C	165	50	30.3%	2437	150	6.2%	0.9
D	157	45	28.7%	1000	501	50.1%	3.2
E	108	60	55.6%	1939	660	34.0%	6.1
F	83	30	36.1%	492	280	56.9%	3.4
G	72	4	5.6%	90	66	73.3%	0.9
H	66	23	34.8%	203	84	41.4%	1.3
I	45	8	17.8%	0	0	0	0.0
J	40	4	10.0%	130	85	65.4%	2.1
K	34	0	0.0%	0	0	0	0.0
L	28	12	42.9%	234	54	23.1%	1.9
M	27	13	48.1%	319	150	47.0%	5.6
N	25	15	60.0%	25	11	44.0%	0.4
O	25	12	48.0%	432	312	72.2%	12.5
P	15	7	46.7%	180	82	45.6%	5.5
Q	11	8	72.7%	275	180	65.4%	16.4
R	9	2	22.2%	all infert.	0	0	0.0
S	1	1	100.0%	34	34	100.0%	34.0
19	1351	418	Avg. 30.9%	10,353	4389	Avg. 42.4%	Avg. 3.2

Conservation, Management and Farming of Crocodiles in China

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INTRODUCTION

China locates at the eastern part of Asia, the west bank of Pacific Ocean, and conjuncted with other 12 countries. China has very long history, and the earliest words emerged about 4000 years ago. China divides into 31 provinces now.

The population of China is about 1,150,000,000, and the size is about 9,600,000 square km (about 125 persons/square km). The distribution of the population is unbalanced. Most of the people lived in the eastern part of China, for example the population Anhui province is about 52,170,000 with size of 130,000 square km (401 persons/square km), the population of Jiangsu province is 62,690,000 with size of 100,000 square km (627 persons/square km), and the population of Zhejiang province is 40,700,000 with size of 100,000 square km (407 persons/square km).

The relief of China is high in the west and low in the east forming three steps from east to west. The mountain region is about 2/3 of total size and forest 12%, cultivated land 10%, grassland 36%. The dominant form of land use is agriculture. The main crops is rice, wheat and maize. About 70% of the total population is peasant.

The main rivers are Yankee river, Yellow river, Heilongjiang, pearl river, Liaohe, Haihe, Huaihe, Qiantangjiang, and Lancangjiang which flow into Pacific ocean, Nujiang, Yarlungzangbo Jiang which flow into Indian Ocean, Ertix river which flows into Arctic Ocean.

China has various types of wetland. From 1986, the government has paid much attention to protect the wetland. About 40 reserves concerning wetland have been established including Poyang lake in Jiangxi province, Nansihu lake in Shandong Province, Zhalong in Heilongjiang Province, etc.. The total size reaches about 190,000 square km.

China has various of climatic patterns. The dominant is a typical monsoon climate. The winter monsoon comes from the middle and high latitude zone of Asian inland. There are several cold air flow emerging in China leading a sharp declining of temperature every year, so the most part of China is cold and dry in winter. China is the coldest country comparing with others in the same latitude, for example, the south bank area of Yangtze river is lower about 8 c in January. The summer monsoon includes SE summer monsoon and SW summer monsoon. The SE summer monsoon comes from Pacific Ocean which affects the east part of China. The SW summer monsoon comes from Indian Ocean and South China Sea which affects SW part of China and the south coastal region. The SE part of China is the time-longest region controlled by the summer monsoon and with much precipitation. It is one of the most rainfall area in the world. The rainy season of most parts of China is related with the forward and backward of the monsoon.

The spring is the rainy season in the middle and lower reaches of Yangtze River. Rainfall in March increases sharply, and keeps high until July, then the rainfall declines. After the dry summer and

autumn, the rainfall
increases slightly in November, and the winter has many cloudy days but no much rain. The yearly average precipitation is about 1200-1400mm, the average precipation of January is 30-50mm, and the one of July is 150- 200mm. The yearly average temperature is 14-16 c, the average temperature in Jan. is 1.9 c, and the one in July is 28.2 c.

SPECIES

There are three living crocodiles distributed in China ever since. Chinese Alligator (Alligator sinensis) lives in middle and lower reaches of Yangtze river now, but the saltwater crocodile (Crocodile porosus) and Tomistoma (Tomistoma schelgelii) has not trace after 1922.

Saltwater Crocodile— According to the description in the ancient book, the crocodile distributed in the reaches of pearl river has a body length of 3-30m and the capacity of eating human and deer. Many scientist (Zhang,1979, Wen et al. 1981) identified it as saltwater crocodile. Mull(1922) reported two skeleton and a skull of saltwater crocodile from Hongkong and Lantoudao at the mouth of Pearl river. The fact that saltwater crocodile once lived in China has been accepted by over the world.

Tomistoma-- In 1963, one skull was found from a tomb of about 1800 years ago, located in Shunde of Guangdong Province. In 1973, a mandible was found from a tomb of about 1000 years ago at the same place. Both of them were identified as Tomistoma by Zhao in 1986. He also believed that the crocodiles distributed in the reaches of Pearl river is Tomistoma schlegelii and Saltwater crocodiles distributed only in south coastal region possibly.

STATUS

SaltWater Crocodile (Crocodile porosus) and Tomistoma (Tomistoma schlegilii)

The status of these two species only can be traced by the records in ancient books, and it is very difficult to distinguish these two from each other.

There are many descriptions about the crocodile in Chinese ancient books. The earliest is in Han Dynasty (206 BC-220 AD). In Tang Dynasty (618-907 AD) and Song Dynasty (960- 1279 AD), much more records was found from the ancient books. According to the records, the distribution area can be divided into 5 (Map 1): 1. the mouth of Minjiang; 2. the lower reaches of Hanjiang; 3. the month region of Pearl river and lower reaches of Dongjiang; 4. the Lianjiang and Nanluijiang reaches and upper reaches of Xijiang in Guangxi province; 5. Hainan Island and Penhu Islands.

Map 1. Distribution of Saltwater Crocodile
and Tomistoma in History

In area 2, much more details was found. According to the records, thousands of crocodiles lived there and killed local people and their domestic animals in Tang Dynasty. After Song Dynasty, no much records was about crocodiles. In area 4, until the end of 19 century, there are some records still being found (Wen et al. 1980). After Song Dynasty, the population of the crocodile decreased sharply. The latest record about saltwater crocodile is the skeleton found at Hongkong by Mull in 1922 which was kept in Berlin Zoological Museum.

Some people believe that some of saltwater crocodile still lives in south of China, possibly Hainan Island and the bound of Vietnam-China, however, in my opinion, nothing lives in China now.

2 reasons have been considered about the extinct of the crocodile in China:

First, the increase of population. Much land was cultivated for crop growing, and habitat of the crocodile was destroyed. About 600 years ago, a war between Song and Jin broke out and then a war between Song and Mongolia. Many people lived in north and centre of China moved to the south, the population at that time increased sharply.

Second, the climatic change. After 1050, esp. after 1450, the temperature became lower. In 1110-1111, 1506-1507, 1655-1656, 1892-1893, extreme cold weather affected the living of the crocodile (Zhang 1979, Wen et al. 1980).

Chinese Alligator (Alligator sinensis)

Today's distribution area of Chinese alligator is limited in the middle and lower reaches of Yangtze river, but in ancient period the alligator had a much large distribution area. According to the ancient records, before the end of Ming Dynasty (1368-1644) the alligator had a very large population. Only in population of the alligator decreased sharply.

1. Prehistorical ages

From the middle of Pleistocene at least, Chinese alligator already distributed at Yanzhou, Taian (Shandong province), Yuyao (Zhejiang province), Maqiao (Shanhai), Hexian (Anhui province) (map 2). The climatic change and increase of human activity possibly the reasons of the contract of distribution (Cao, 1984).

Map 2. Distribution of Chinese Alligator
at Prehistoric Age

2. Before this century

The earliest verbal record of the alligator is about 3000 years ago. From Tang Dynasty to Qing Dynasty (1616-1911), there are many book had the record about Chinese alligator. Its distribution area is much larger than today (map 3).

Map 3. Distribution of Chinese Alligator before This Century

Several conclusions can be obtained from the records:

1) A large population lived in the meddle and lower reaches of Yangtze river and Hannjiang .

2) Before about 300 BC, people used the skin of alligator making musical instruments. From Zhou Dynasty (about 1100 BC-256 BC) to the end of Ming Dynasty (1368-1644), people had the custom of regarding the alligator meat as delicacy. After that time, there was no records about people eating alligator meat.

3) Because of burrowing behaviour, the alligator always destroyed the dam for preventing flood and the irrigating tunnel. It is this behaviour leading the hunting on a large scale. In 1380, a thoroughly killing made the population lived in the Yangtze river near Nanjing almost disappeared.

4) In 1119, an alligator was found in Kaifen of Henan province, far north of its natural distribution. It is estimated that some trade of alligator existed at that time (Zhang 1979, Wen et al. 1981, Chen et al 1985).

The reasons for the declining was possibly the climate change and human activity.

3. In this century

A lot of scientific report about its distribution and wild population status were published in this period.

In 1934, Hsiao reported his collection from Wuhu, south of Anhui Province. He visited Qingshuihe in January and got 28 alligators around Qinshuihe Town. From his description, it sound the population was very large in the area.

In 1951, 1954, 1956, Chu conducted a detail survey about alligator's distribution, life history, habitat and tunnel structure. The distribution area shrieked to:

From Pengze (Jiangxi province) to Anqing (Anhui province), along the Yangtze river, the alligator only distributed in south beach, no any on the small islands in the river. A lot of Alligators lived in the lower reaches of Xuanhe and Qingyijiang rivers of south Anhui province. The alligator also distributed in the rivers, ponds of Jingxian, Nanling, Xuancheng, Ninggou, Fanchang, Wuhu of Anhui province, Dangtu, Langxi, Gaochun of Jiangsu Province (map 4) (Zhu, 1957). In Zhejiang Province, a unclear population lived in Changxing and Anji Counties.

Map 4. Distribution of Chinese Alligator in This Century
------ distribution of 1956 _._._. distribution of 1978
1 ARCCAR 2 ZYAF

From 50's to early 70's, It is a disaster time for wildlife in China. For the need of economic development, forest was cut, wetland was converted in crop field. In the end of 70's, Chinese Government began to pay some attention to wildlife conservation. A lot of research work were conducted about the alligator. In Jiangsu and Jiangxi Provinces, the population was possibly disappeared at that time. No alligator from wild was reported after 70's. In Zhejiang Province, only a very small population was survived. Chinese Government focused their conservation enforcement on Anhui population.

Anhui Province

During 1976-1978, Chen and his colleagues conducted a survey about its distribution and ecology in south of Anhui Province. The alligator sporadically distributed in the reaches of Qingyijiang, Shuiyangjiang and Zhanghe rivers and some ponds, reservoirs of Xuancheng, Nanling, Jingxian, Langxi, Guangde (Chen et al 1985) (map 4). It remains to today.

The population of part along the Yangtze River almost disappeared. The type location of Chinese Alligator -- Qingshuihe, in 1934, Hsiao once found a large population, had nothing at that time. In Xihe Village, Chu found 17 individuals in 1954, but almost nothing in 1976. Chen selected 29 subcounties as samples in which the alligator was common in the early 50's. In 1976, only 4 subcounties still were easy to spot a alligator. 9 subcounties the population were disappeared. Others were much less than 50's.

In 1980, a reserve was established in Anhui. In 1981, a United States-China joint survey in Anhui province was conducted about ecology and conservation of the alligator. Myrna Watanable estimated about 300-500 individuals possibly lived in Anhui Province. (Chen et al 1985, Chen 1986).

After that, the reserve management authority had a census survey in the reserve every two years.

In 1983, the reserve concluded the total population is about 500 individuals after a comprehensive investigation.

In 1985, another investigation found a total population of about 530 individuals in the reserve.

In 1987, a 557 individuals was found in the reserve.

In 1990, the latest survey showed the population in the reserve increased to about 735 individuals.

Out of the reserve, it is estimated that about 100 alligator lives in the around areas (Webb and Vernon 1992).
However, the data is very doubtful.

Zhejiang Province

Huang (1985) reported about 25 alligator lived in Anji county based on the survey of 1982. In the recent contact with the local government, only 2 times spotted alligator from wild during 1991 and 1992. It is possible that a small population still lives there. In Changxing county, the most recent record of field capture was in 1979. After that, no trace was found from wild. The population may disappear from that region (Webb and Vernon 1992).

The reasons for declining before the end of 70's were considered as:

1. Habitat destruction
This the most important factor. The alligator lived in one of the most human dense area. Two large scale movement of converting the desert river beach into rice field in 1904. 1931 and the movement of constructing irrigation system in 1956 destroyed a lot of its habitat.

2. Human killing and nests destroy
During construction rice field and other work, local people always killed the alligator and destroy its nest when ever it was found.

3. Wide use of chemical fertiliser and insecticide
In 1958, for the purpose of preventing the people from infecting schistosomiasis, a snail eradication campaign carried out. The wide use of insecticide not only killed the food animals of alligator but also killed the alligator.

4. Pollution of the rivers and ponds.

There is another population with more than 4000 individuals living in farms or zoos.

LEGISLATION

Chinese Alligator was listed in Appendix I of CITES. From 1972, the Chinese Government identified it as a first class animal under protection. China Wildlife Conservation Law, enacted in March 1 of 1989, listed it as category I of State Special Protected Animals. Some orders or regulations about protecting the alligator enacted by the local governments.

FARMING

There are two alligator farms in China. One is Anhui Chinese Alligator Research Centre (ARCCAR), and the other is Zhejiang Yenjiabian Alligator Farm (ZYAF). Both of them specifically aimed at preventing the alligator extinct from wild and a imitation of natural habitat was adopted.

1. ARCCAR

ARCCAR established in 1979 by joint fund from The Ministry of Forestry and Anhui provincial Government. Its size is 1 square km and locates at south of Anhui Province in the Anhui Reserve.

Facility— ARCCAR consists of 3 quasi-natural breeding ponds, 10 aged-separated rearing pens and 6000 square meters open water surface to provide food for Chinese Alligator, like fish, snails, etc. Besides there are an environmental controlled incubation chamber and hatching breeding chamber with a annual handing capacity of 100,000 eggs and 3,000 hatchings respectively. ARCCAR has a staff of 40 including 5 researchers. The environment of breeding pond is carefully managed to imitate the natural habitat: aquatic invertebrate organism, fishes and molluscs lived in the ponds, tall and dense grass, bamboo and bushes shade the ground. There are some other buildings for administration and accommodation (The People's Republic of China 1992).

The original stock— From 1979 to 1982, total 212 individuals rescued from some disrupted habitats or purchased from the local villagers which formed the original stock. A few escaped back to the wild during a flood and some others died. Now there are about 170 still living with a sex ratio of 6 female to 1 male (The People's Republic of China).

Captive Breeding— After several years research work, ARCCAR got a successful captive reproduction in 1982. After that, ARCCAR maintained the success annually. Table 1 shows the annul production of the original stock.

Table 1. Records of A. sinensis egg production, fertility and hatchling rates at ARCCAR

Year	Nests	Eggs rate	Fertility rate	Hatchling
1982	10	224	—	65.6
1983	12	264	88.9	58.7
1984	20	501	90.4	83.7
1985	30	809	90.5	90.3
1986	29	801	90.4	82.0
1987	37	1045	84.0	92.4
1988	42	1219	91.9	95.0
1989	34	955	92.1	94.0
1990	34	942	95.4	85.3
1991	35	901	80.0	90.2
1992	?	1140	?	?

In 1988, the alligators hatched in 1982 reached maturity and laid 25 eggs which produced 22 hatchings. A annual production of F2 showed in Table 2. Up to the end of 1991, a total of 378 F2 individuals lived in ARCCAR.

Table 2. Annual production of F2 eggs in ARCCAR (Follow Webb and Vernon, 1992)

Year	Nests	Eggs	Hatchings
1988	1	25	22
1989	5	143	120
1990	4	109	
1991	9	217	
1992	?	260	
Total		754	

From 1982 to now, ARCCAR obtained a high survival rate of the juveniles. The total stock has reached 4197 in the beginning of 1992. The survivors to 1992 showed in Table 3. In 1989 and 1990, because of financial difficulty, ARCCAR only had a limited development (Webb and Vernon 1992, The People's Republic of China 1992).

Table 3. Annual hatchings and survival to 1992 in ARCCAR

Year	Hatchings	Survival to 1992
1982	147	66
1983	237	77
1984	476	117
1985	667	300
1986	694	576
1987	744	649
1988	989	910
1989	510	450
1990	675	462
1991	901	590
total	6040	4197

Restocking work-- ARCCAR had a restocking work plan at early years, but due to the rejection of local people and high compensation, the plan hadn't been carried out. In 1991, a flood destroying the fence of ARCCAR, about 30 alligator (3 or 4 years old) escaped to wild. It resulted a accidental restocking work.

2. ZYAF

ZYAF established in 1979. Its size is 0.67 hectare and locates in Changxing Village. It is running and funding by the local people, and most of the fund came from the donation of local people and visitors.

The original stock is 11 individuals from wild, some from the around area, some possibly other area. 8 died in 1982. 3 (2 female, 1 male) lives now.

The facility includes a building for accommodation and hibernation, 2 breeding ponds and several raising ponds. In 1984, ZYAF succeeded in captive breeding.

Table 4 shows the annual hatchings. At the end of 1992, ZYAF has obtained a stock of 143 individuals, including 3 adults (2 female, 1 male) and 140 juveniles.

Table 4. The annual production of ZYAF

Year	Nests	Eggs	Hatchings	survivor to 1993
1984	1	22	10	6
1985	1	24	18	12
1986	1	25	22	20
1987	1	25	14	13
1988	1	18	15	9
1989	1	21	3	1
1990	1	26	26	23
1991	2	47	39	34
1992	1	23	23	22
Totals	10	231	170	140

Before 1990, only 1 female laid eggs each year. In 1990, another female recovered from hurt and began laying eggs. The hatchings of 1984 was nearly maturity, and are expected to breed soon.

3.Zoo

In China, Shanghai Zoo, Ningpo Zoo, and Beijing Zoo have large stock of Chinese Alligator, about 200, 20, 30, respectively. Shanghai Zoo and Ningpo Zoo obtained alligator hatchings in captivity, esp. the Shanghai Zoo with new hatchings every year after 1979.

TRADE

The trade only limited to living species in China.

ZYAF sold 10 individuals to Qiandaohu National Forest Park at Zhejiang province in 1991, 7 to Hangzhou Aquarium and 3 to Yuhang park in 1992.

ARCCAR sold 200 individuals to Guangzhou English Special Animal Experimental Farm in 1992.

No commercial import and export were existed.

IMPORT & MANUFACTURING

No manufacture product about Chinese alligator up to now.

The Anhui Provincial Bureau of Forestry conducted a research about the possible utilisation of alligator including tanning of skins, Chinese medicine use, and chemical industry use.

RESEARCH

1. Outline of Research Work Taken in China

Historical Study of Crocodiles— geographic and historical origins of Genus Alligator in the geologic period (Cao 1984, Xu and Huang 1984), geographical change and population variation of Saltwater crocodile and Chinese alligator in the period of 7000 years ago to present (Wen et al. 1980, and Zhang 1978, 1979), the effect of climatic change, human activity and geographical factors on the variation of crocodile and alligator (Zhang 1978,1979, Wen et al. 1980, 1981, Xu and Huang 1984, Cao 1984).

Morphology and Anatomy— Chen et al. (1985, p.19-185) had a thorough description of external and internal body structure of Chinese Alligator. Age variation of the skull Chinese Alligator (Cong et al. 1984), ultrastructure of the eggshell of Chinese Alligator (Zhao and Huang 1986), structure and function of Chinese alligator's lingual glands (Chen et al. 1989), morphology of blood cell of Chinese alligator (Wang R. 1991).

Ecology and Status— Burrowing behaviour and tunnel structure (Zhu 1954,1957, Chen and Li 1979, Chen et al. 1985), reproductive behaviour in wild (Zhu 1957, Chen and Li 1979, Qian and Zhou 1982 Chen 1983, Chen et al. 1985, Huang et al. 1986), reproductive behaviour in zoo (Gu and Zhang 1983), habitat investigation using remote sensing image (Huang et al. 1985), status in wild (Zhu 1957, Li and Chen 1981, Chen et al. 1985, Chen 1986, 1990).

Captive Breeding— Effect of temperature and humidity on hatching rate of Chinese Alligator (Lian and Pan 1990), Hatching and growing of young Chinese Alligator (Xie et al. 1984, Chen and Wang 1984, Zhang and Pan 1986, Wang and Li 1990, Zhang and Zhao 1990, Wang and Pan 1990, Zhang et al.1992), food of young Chinese Alligator (Gu et al. 1987), diseases of young Chinese Alligator (Hong et al. 1986, Zhang and Wang 1986), hibernation of young Chinese alligator (Zhang and Wang 1987, Zhang et al. 1990), development (Zhang and Ding 1990, Zhang 1991).

Others—Hormones (Shi et al. 1986, Wang R. 1990), and chromosome of Chinese alligator (Shi et al. 1984), chemical element and function of eggshell of Chinese alligator (Wang and Qin 1983, Gu et al. 1987, Chen and Liang 1990), electrocardiogram research (Rang et al. 1988, Wang R. et al. 1990), metabolism (Chen 1985).

2. Research Work undertaken
A research work about the utilisation of Chinese Alligator was conducted by Anhui Provincial Bureau of Forestry.

3. In 1981, a joint research between American Academy of Sciences, Chinese Academy of Sciences and Anhui Normal University conducted. A lot of data about Chinese alligator's ecology, status were obtained.

PROTECTED AREA

There are two protected areas existed in China now: Anhui National Chinese Alligator Reserve in Anhui province and Changxing Yinjiabian Chinese Alligator Protected Area in Zhejiang province.

1. Anhui National Chinese Alligator Reserve (ANCAR)

The reserve first established in 1980 as a provincial lever reserve and funded by Anhui provincial government. In 1986, the reserve promoted to a national lever and supported by central government and provincial government together.

ANCAR locates in south of Anhui province and its size is 907 square km. Different with some other reserves, a lot of villages locates in it. In the reserve, the human population density is about 300 persons/square km, and the dominant land use is rice growing. Only some rivers, ponds and reservoirs leaves to the alligator. ARCCAR locates in the reserve.

The management of the reserve is by ARCCAR under the direction of the Anhui Provincial Bureau of Forestry . Because of the Alligator's sporadic and widespread distribution, a protecting strategy of "Comprehensive management in whole reserve with smalls area special protected" was adapted. 5 satellite stations and 16 special protected areas were set up. In the protected areas, extensive protecting effects were carried out for keeping the ecosystem and habitat. Tree and grass cutting and landscape destroying were prohibited. Out of protected areas, the land can be multiply used by local people. Each station has 1 or 2 full-time worker responding for the daily conservation work and in charge of a group of protected areas. Each area has 1-3 part-time worker who are responding for preventing people from destroying habitat and collecting eggs, census of the population and other conservation works. The data collected by the workers will send to ARCCAR.

Due to the hard work of the staff, ANCAR has gotten a lot of achievement. The total population of alligator has increased from 500 in 1983 to 735 in 1990.

In the near future, ANCAR proposed to increase the size of
protected area and improve the habitat such as bamboo and grass planting. A restocking work will be done while the adoptive habitat are enlarged.

ANCAR has conducted some education work also. Notices for warning and teaching are posted every year. At the present time, no report of killing by local people was found. Because the reserve locates in a high human dense region, some compensation action has been carried out.

2. Changxing Yinjiabian Chinese Alligator Protection Area (CYCAPA)

CYCAPA was established in 1982 ,locates in Yinjiabian Village of Zhejiang province and its size is 122 hectare. It is funding and running by local people.

ZYAF locates in CYCAPA and co-ordinates its work. Because no wild alligator was pointed in wild after 1982, the main purpose of CYCAPA is to restore the habitat and restocking captive alligator to wild. The ZYAF has succeeded in captive breeding now, so a release work is expected soon.

DISCUSSION

After nearly 20 years struggle, China have obtained a lot of accomplishment in protecting the Chinese Alligator. In wild, the destroy of habitat is under controlling, the population is steady and a little increasing now, the idea of alligator-protecting has been established in the local people.

In captivity, the facilities has been set up in ARCCAR and ZYAF, the work experiences has been accelerate, incubation rate reached 95% and the first year survival rate reached 96% in ARCCAR (The People's Republic of China).

But still a lot of problems existed. In wild, the destruction of habitat was stoped, but no much improvement. From the census data, the population increasing slightly, but it is rare to spot a juvenile from wild. Because the alligator sporadically distributed in ponds, rivers, the possible connect is doubtful. In a long term, the population fragmentation will be a great threats. For the reason of limited habitat, the restocking work belated.

About research work, international cooperation is absolutely deficient. We need experienced people from overseas to work with Chinese scientist and bring their technique and equipment. We need to training our people in the country like Australia and United States.

The most important problems, in my opinion, the conflict between human and alligator for land use still exist. In a
dense human population region, it is the crucial point to let the local people lives harmony with the alligator. The future detail ecological work will showed the degree of harm of the alligator and a education work will convinced the local people it is possible to lives with alligator at the same land.

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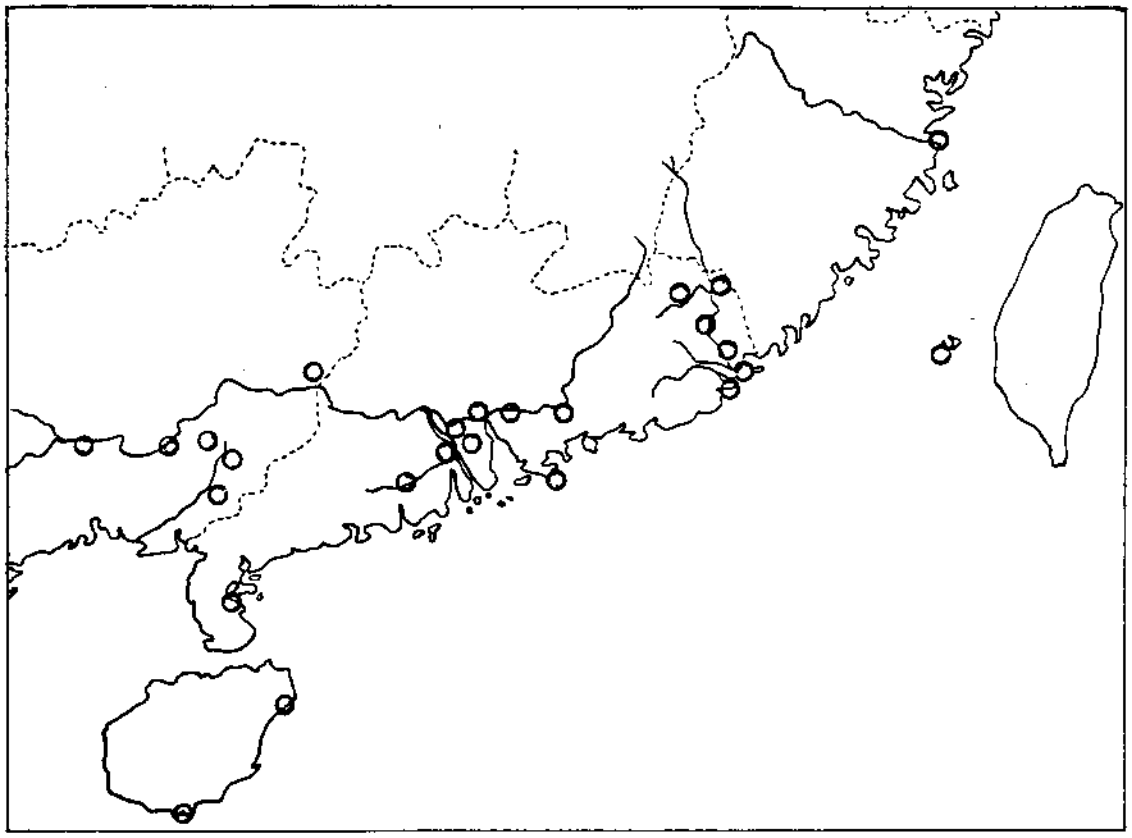
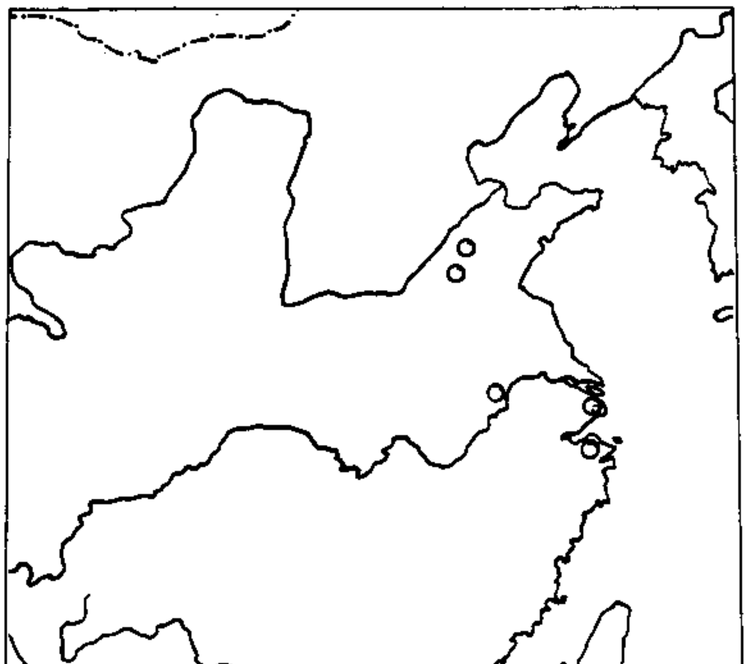
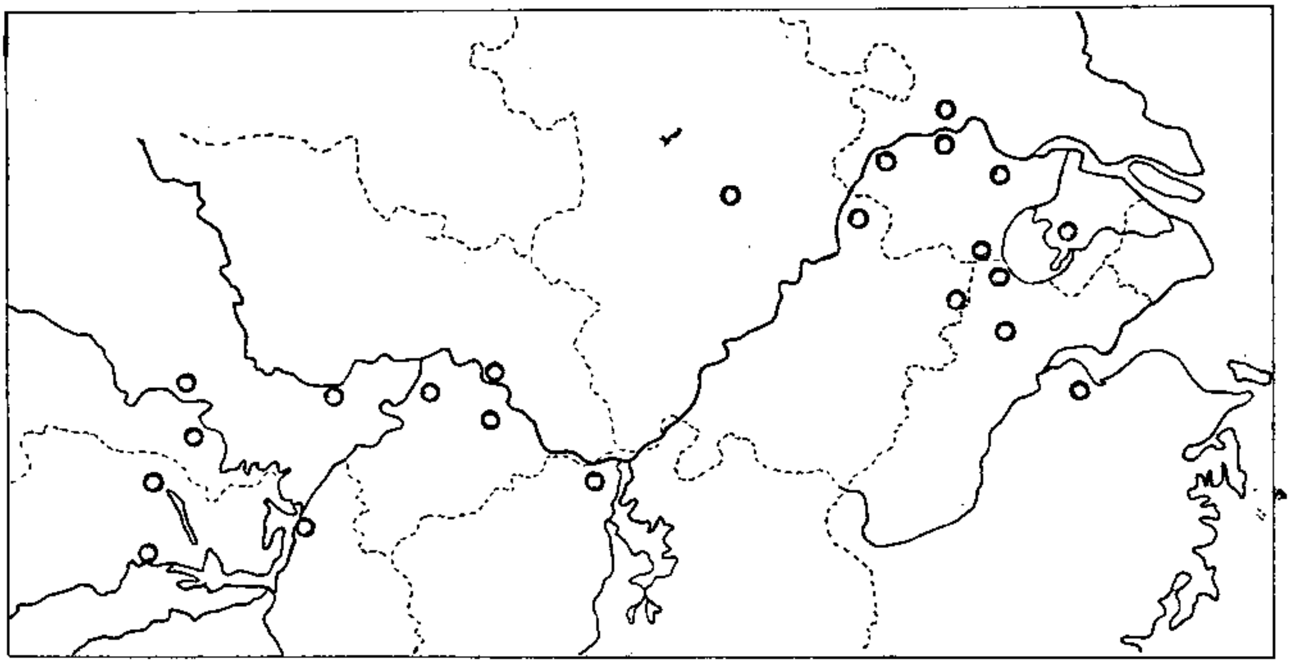


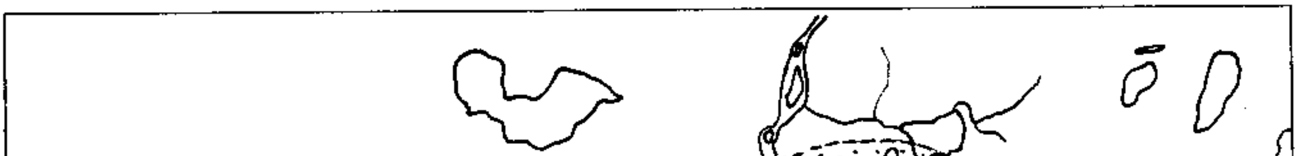
Map 1. Distribution of Saltwater Crocodile in China
(Wen et al. 1980)



Map 2. Prehistorical Distribution of
Chinese Alligator



Map 3. Distribution of Chinese Alligator Before the Beginning of 20th Century (Wen et al. 1981)



Map 4. Distribution of Chinese Alligator

distribution in 50's   O distribution present

CONSERVATION, MANAGEMENT AND FARMING OF CROCODILES IN PAPUA NEW GUINEA

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ABSTRACT

PNG's two species of crocodiles, *Crocodylus n. novaeguineae* and *C. porosus* are widely distributed on the lowlands of the mainland and the high islands. The former is restricted to the mainland and has two distinct wild populations which occur north and south of the central cordillera. Uncontrolled early exploitation resulted in declines of wild populations especially for *C. porosus* which led to development of legislations and included the Crocodile Trade (Protection) Act, Chapter 213, and further supported by the International Trade (Fauna and Flora) Act, Chapter 391. Legal protection of wild populations is ensured and the major conservation area is the Tonda WMA in Western Province. The national crocodile management program has dual goals of conservation on sustained-yield management basis and improving the welfare of the rural people. Main components of the program include wild harvests and ranched skins for commercial trade, annual monitoring surveys inconjunction with rural extension services and enforcement. Recent developments include implementation of the downstream-processing policy by the Government with a tannery in operation in Port Moresby. The program is achieving its goals however there are major problems to be addressed. These include inadequate funding for monitoring surveys, more meaningful participation by landowners towards conservation-oriented projects, and effective enforcement. The commercial trade including ranching and farming activities are virtually held by the private sector with the Department of Environment and Conservation as the coordinating agency. PNG to-date has not being subjected to international trade restrictions under CITES. Various national and donor supported projects are in place which will enable DEC to improve and develop its capability under its current reorganization for a more effective national crocodile management program based on sustainable utilization of the crocodile resources into the next century.

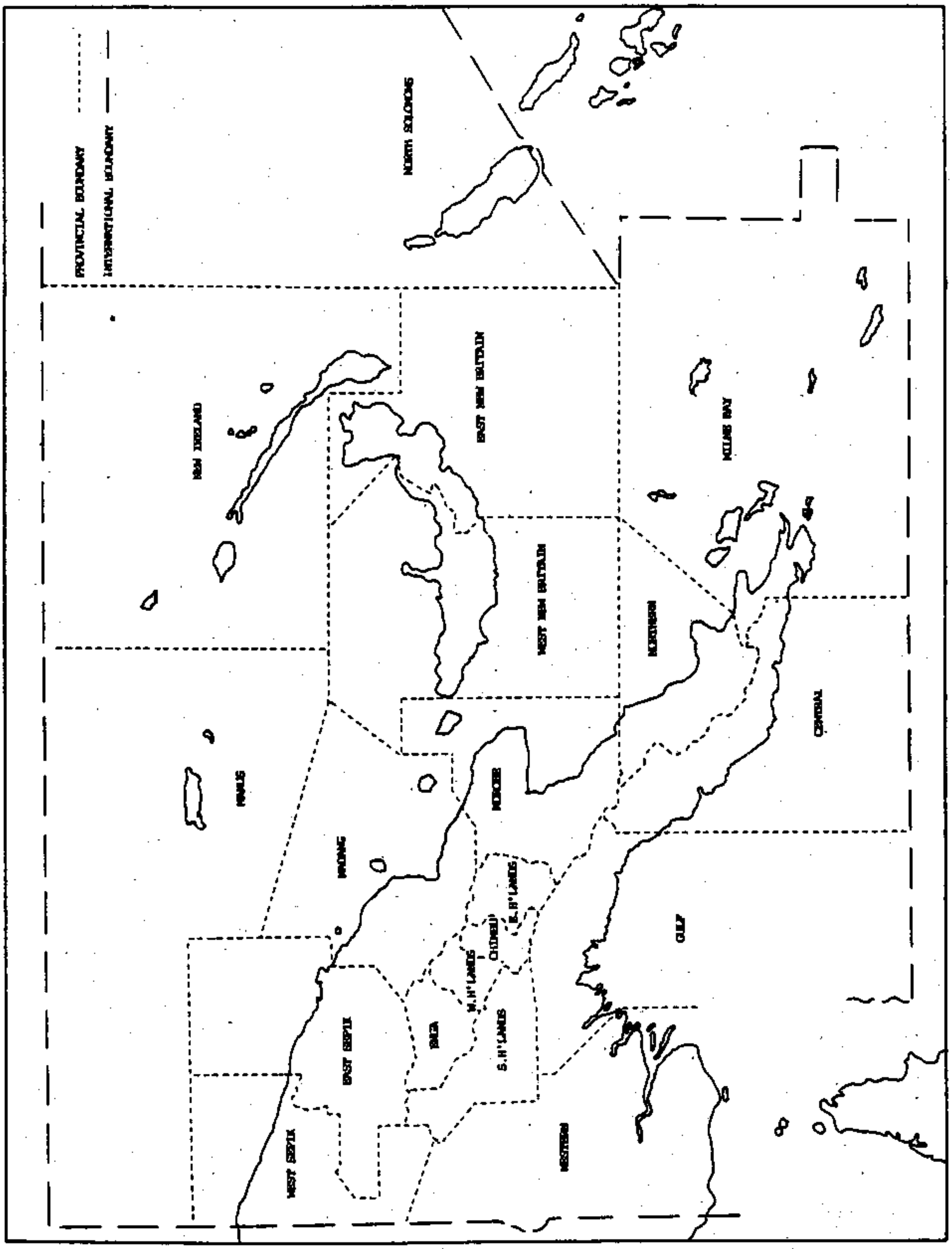


Fig 1: Map of Papua New Guinea showing international and provincial boundaries. (Leach and Osborne, 1985).

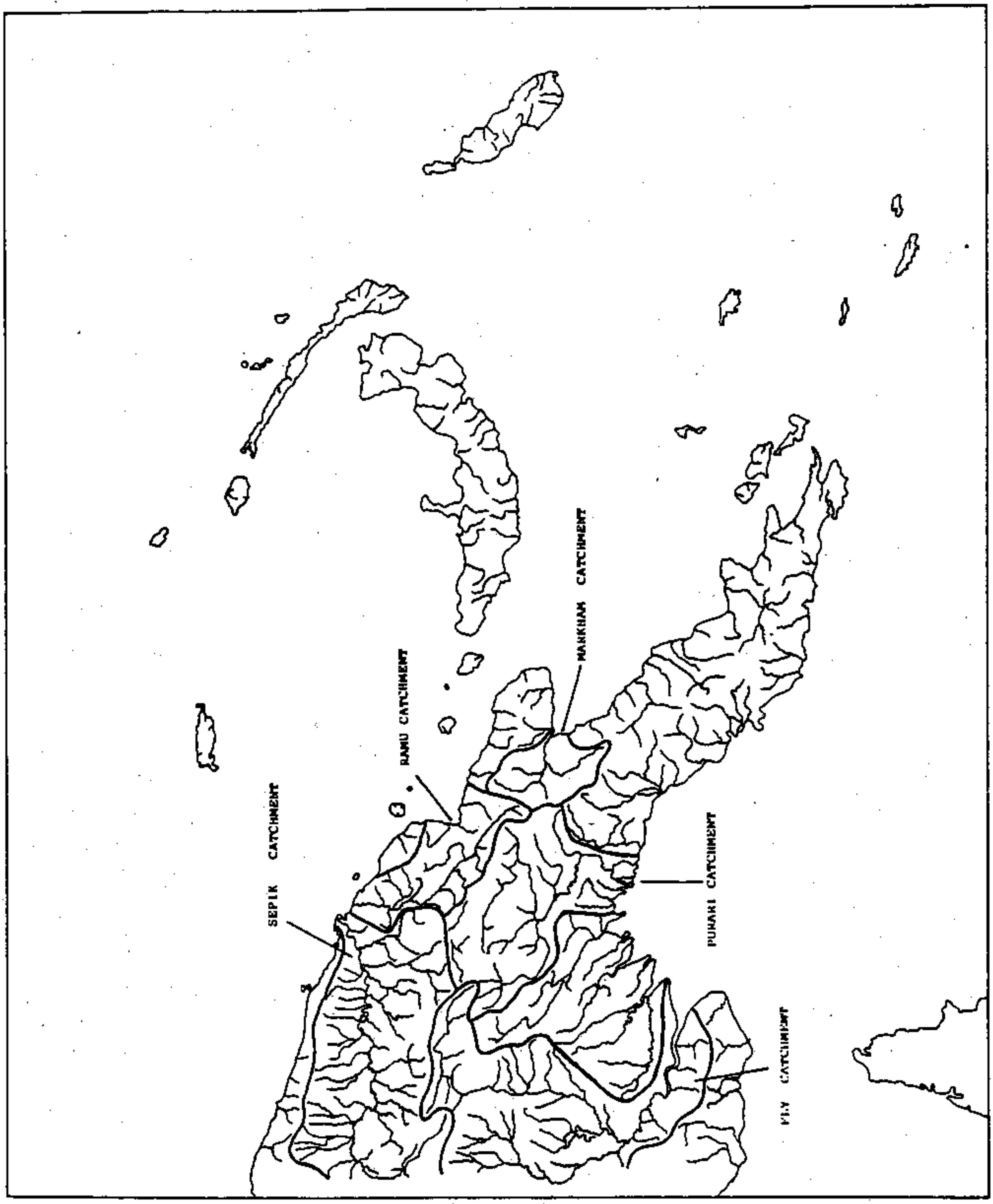


Fig 2: Map of the major river catchments of Papua New Guinea. (Leach and Osborne, 1985).

Figure 3. The major rivers, lakes, mountains and wetland areas in Papua New Guinea. Major wetland sites: (1) Abia (2) Empress Augusta Bay (3) Toriu (4) Namo (5) Rakua (6) Mullins Harbour (7) Kemp Welch and Mori (8) Vanapa (9) LakeKamu (10) Kikori (11) Fly River (12) Vanimo (13) Arnold River (14) Sepik River (15) Ramu River (16) Markham River (17) Mambare (18) Musa (19) Kelaua (20) Malai. (Osborne 1992).

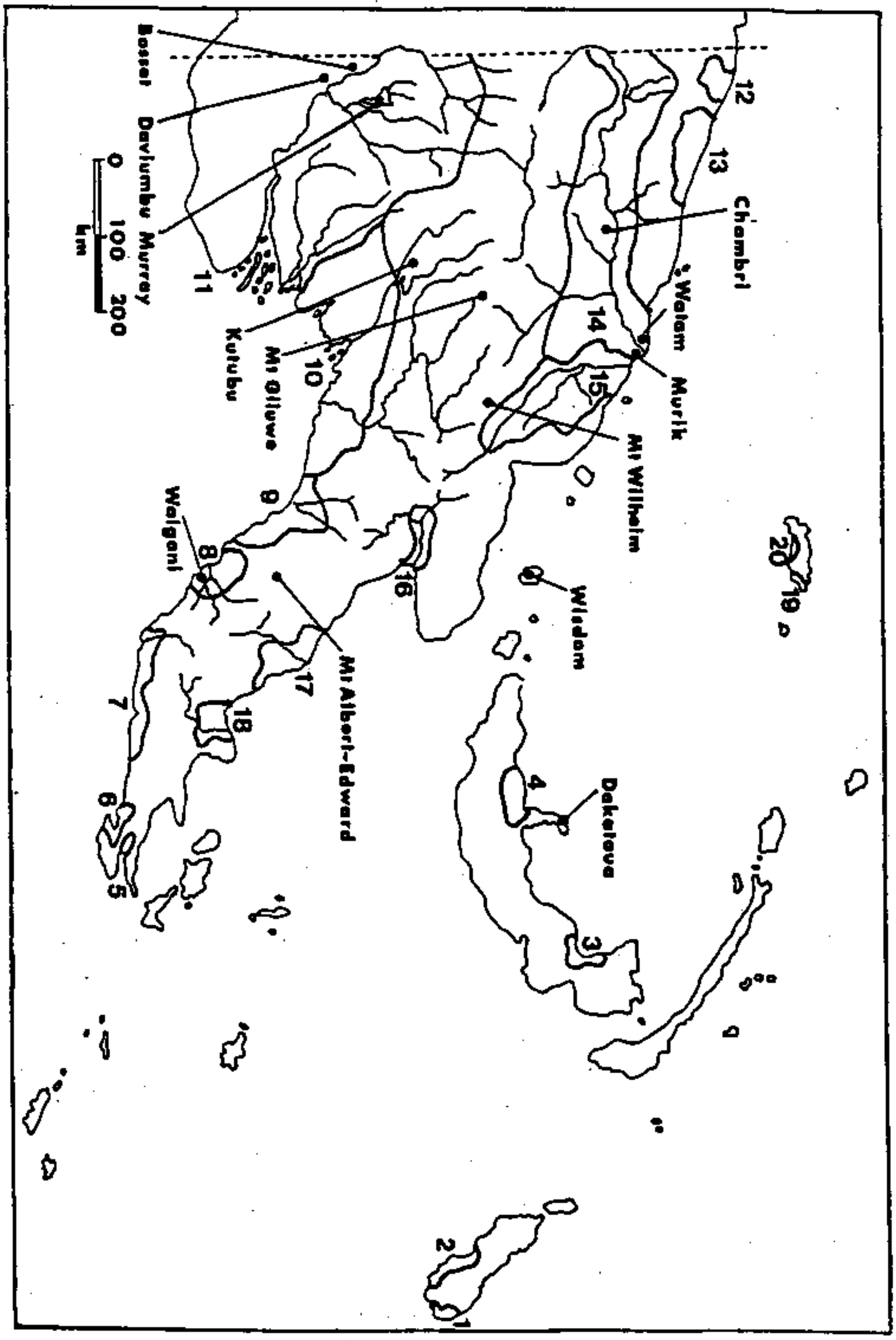


Fig 4: Distribution of crocodiles in Papua New Guinea.
(Hollands 1985)

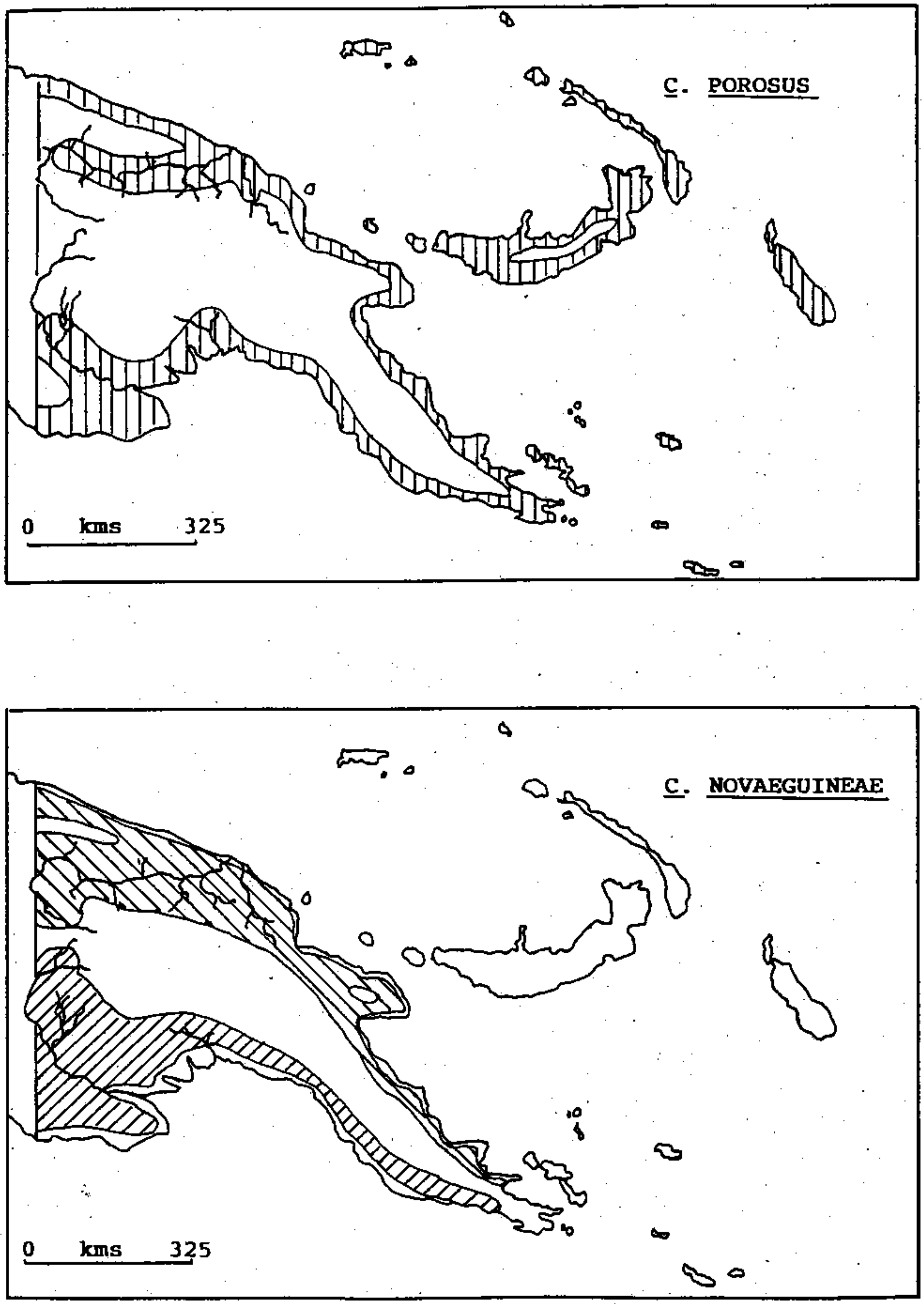
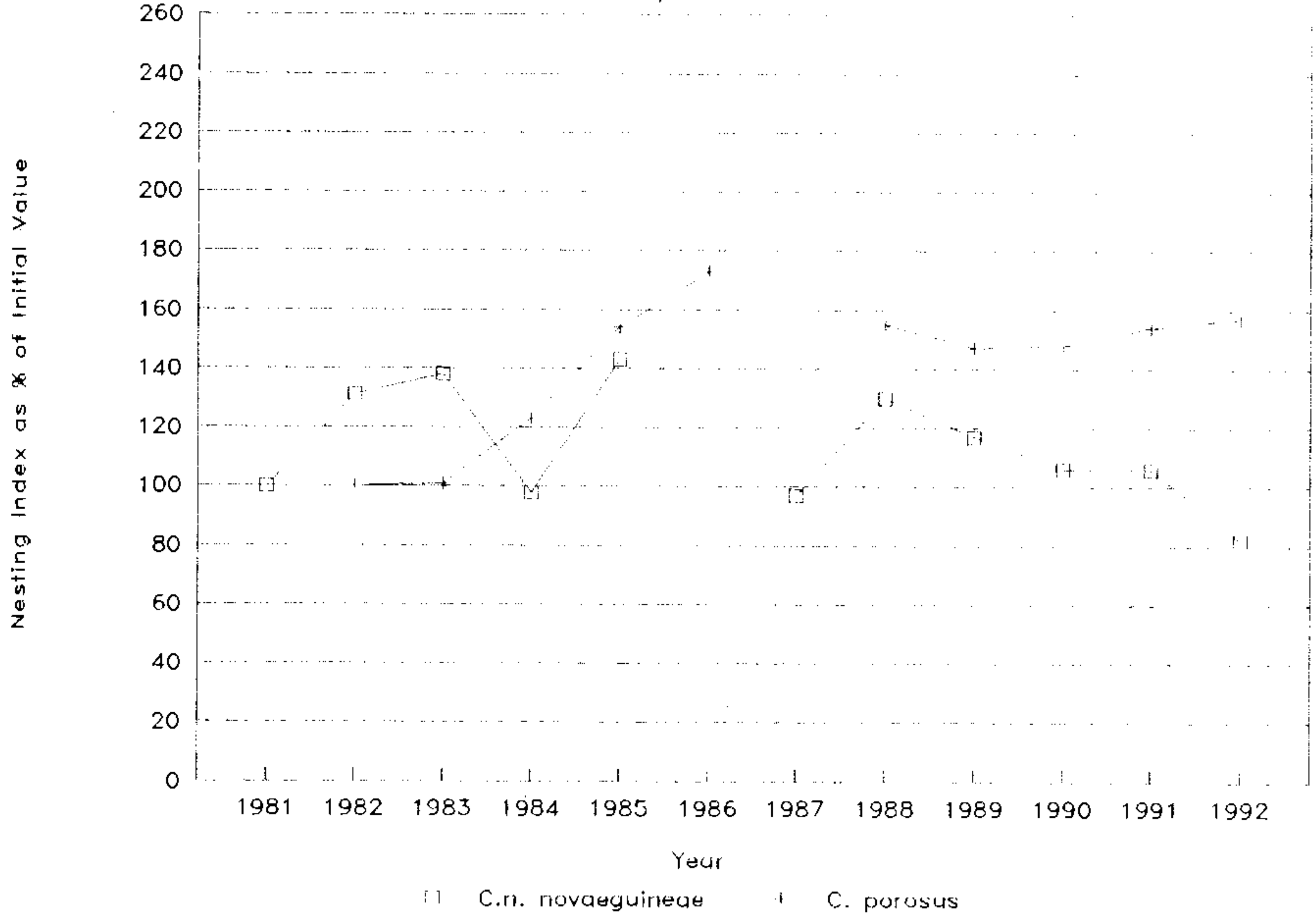


FIGURE 5: Nesting Index of Crocodiles

In The Middle Sepik, PNG 1981 – 1992



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Sincere Greetings to you all (Grahame, Brett and yourself) from the Land of the Unexpected, PNG!

Could you please urgently forward a hard-copy of my country paper submitted? Need it here for actioning by the department. Do not worry about the maps etc, only the text.

Best of regards.

JOHN-MARK GENOLAGANI
National Crocodile Management Unit, DEC

Many thanks for hospitality etc at Darwin. I will drop a line to you all soon.

JAN PETERS
could we send him up a copy of the PNG paper ...
G

Monitoring the International Crocodilian Trade: Useful Tool or Useless Bureaucracy?

Ginette Hemley
Director, TRAFFIC USA and
Vice Chairman for Trade Monitoring,
Crocodile Specialist Group

presented by

Debbie Callister
Director, TRAFFIC Oceania

Crocodilians represent a group of species for which conservation programs based on sustainable utilization principles are relatively well advanced. The high commercial value of crocodilian products inextricably links these programs to the global market, and CITES has recognized this by progressively allowing for a growing number of products derived from crocodilian species to be traded internationally. Such regulatory changes, which have generally been viewed as positive for crocodilian conservation, are closely tied to and in many ways dependent upon a key activity: trade monitoring.

Today, with CITES the principle international structure for both controlling trade in crocodilian products and ensuring the survival of exploited crocodilian species, the ultimate success of many crocodilian utilization programs depends to a large extent upon the efficacy of trade monitoring systems. To date, crocodilian trade monitoring programs, while imperfect, are probably among the best in place for any wildlife commodity in global trade -- largely the result of extensive CITES deliberation, and regular review of trade and management programs by the CITES parties and associated experts. At the same time, these systems themselves need continual monitoring and refinement to ensure that the costs of their implementation do not outweigh the conservation benefits they intend to provide.

Trade Monitoring: Sources of Information, Meaning and Use

Trade monitoring can mean many things. In the CITES sense, it generally refers to tracking the movement of shipments of species and derivative products across international borders. The Convention does not define "trade;" it does however require that member nations keep records of the numbers of specimens of CITES-listed species imported into or exported from their national boundaries (Article VIII of the Convention). Such information is required to be filed with the CITES Secretariat on an annual basis -- these comprise the so-called "annual reports" of CITES parties. Because most reports are not filed until at least ten months after the year the actual trade took place, such data are of limited value for detecting immediate trade problems, but can be useful for assessing long-term trade trends.

Nationally or locally, trade monitoring can mean tracking the movement of goods entering commerce at any level. It is often associated with legal taxation requirements, such as Customs duties. Most governments keep national trade statistics for dutiable goods; in general, imports are more broadly subjected to excise taxes or duties than exports, and are thus more accurately tracked and reported. More often than not, such statistics are very general for wildlife commodities, i.e. are not recorded to the species level, and are thus of limited value for wildlife management and conservation purposes. They can, however, provide a useful gauge for general categories of trade.

The reliability of wildlife trade data vary considerably with types and sources. The CITES Secretariat has regularly reviewed the annual reports submitted by Parties, revealing that many reports are incomplete or submitted late, and that a few parties (e.g. Israel) fail to submit annual reports altogether (see Doc. 8.17 from the Eighth Meeting of the Conference of the Parties to CITES). These reviews have also shown significant discrepancies between the reports of importing and exporting countries for certain species, suggesting that the data reported represent a bare minimum of trade. As a whole, annual reports appear to be improving, and in spite of their shortcomings, they do provide a growing body of information on the state of international trade in many species. For certain crocodilian species, such as American alligator (Alligator mississippiensis) and Nile crocodile (Crocodylus niloticus), CITES data are relatively reliable. For other species such as caiman (Caiman crocodilus), where the illegal trade dwarfs the legal trade, annual reports are of minimal value. (See Luxmoore, 1992, for the most recent comprehensive review of crocodilian trade statistics.)

As was shown by the Ivory Trade Review Group in the late 1980s, trade monitoring systems are only as good as the pieces making them up, and the compliance of trading countries. An extensive review of the ivory trade published in 1989 showed that, in spite of major investment by some CITES nations into making the CITES ivory trade quota system work, the failure of other nations to comply completely undercut the entire effort -- to the point that, by the late 1980s, more than three-quarters of the ivory entering international commerce was traded outside the CITES system (Anon., 1989). This problem, which was a major factor in the widespread decline of the African elephant (Loxodonta africana) during the 1980s, resulted in a complete ban on the ivory trade through a CITES Appendix I listing of the species in 1989. Trade statistics from sources other than CITES helped document the magnitude of the illegal trade and provided the basis for the dramatic, if controversial, action that led to shutting down the trade. Any future trade of ivory that may be sanctioned by CITES will depend to a large extent on development of a comprehensive trade control and monitoring system that all but assures only legal ivory enters global trade, a significant challenge for the near term.

In general, trade statistics can have direct relevance to the conservation and management of species exploited for commerce when they are: detailed enough to have relevance to individual species (e.g. are reported to the species level); reported uniformly and consistently among trading countries or entities; and are generated in a timely fashion sufficient to allow for practical integration with field management and conservation data. In addition, in order to measure the utility of trade monitoring systems there should be a means of verifying the accuracy of statistics and what they encompass; i.e. it should be possible to physical inspect the record-keeping system and actual goods traded from time to time. The CITES reporting systems in a growing number of party nations meet many of these conditions, although the late delivery of reports under the current system limits their utility for direct field application, an issue presently under discussion by the Crocodile Specialist Group.

The Role of TRAFFIC

The TRAFFIC Network was established in 1976 with the express task of monitoring trade in connection with CITES. A non-governmental program jointly sponsored by WWF and IUCN, TRAFFIC today is comprised of 17 offices worldwide, with a coordinating office, TRAFFIC International, in the United Kingdom. Over the years TRAFFIC's role has become multi-fold: to monitor and investigate wildlife trade, including illegal commerce; to analyze and try to strengthen the policies and laws governing the wildlife trade and the conservation programs of affected species; and to increase public and industry awareness of the effects of trade -- both positive and negative -- on exploited species. TRAFFIC works in close cooperation with the CITES Secretariat and the Management Authorities of CITES member nations. TRAFFIC also serves as an objective source of information on wildlife trade and related issues for government officials, the scientific community, and the general public.

TRAFFIC's work revolves to a large extent around data collection and analysis. The TRAFFIC Network regularly produces reports on wildlife trade and exploitation -- several hundred such reports have been published since the Network's founding -- to assist CITES parties and the CITES Secretariat in their implementation of the Convention, and to help national and local wildlife officials in their efforts to manage exploited species on a legal, sustainable basis. Official government trade and CITES statistics provide a mainstay for TRAFFIC's analyses.

The Network also relies on a wide range of sources, often confidential, for information on illegal trade. In such cases, TRAFFIC's primary role is to facilitate the enforcement efforts of national and international government agencies by providing information that might not otherwise be available to them, to assist in interdicting illegal shipments.

In sum, TRAFFIC's trade monitoring contributes to the conservation of exploited species through both biological and legal channels. On the biological front, trade data can provide an important measure of exploitation levels of a given species or population, which can be useful for ensuring that harvest is maintained at sustainable levels. In some cases, where little is known about the actual status of a species or population, trade data can provide important if very general baseline status information. When combined with detailed information on the composition of a population -- including age structure and size data, for example -- trade monitoring can provide a constructive tool for assessing the effects of exploitation on the population. Ideally, such monitoring should be carried out continuously over a period of years or seasons and be fully integrated with studies on the general biology, and population structure and dynamics of the exploited species.

On the legal side, trade monitoring can provide critical intelligence on illicit commerce and trade law compliance problems. TRAFFIC's work in this area is largely unpredictable and often depends on anecdotal information and unsolicited field reports. While CITES and its member nations, with the help of the Secretariat, have made significant progress in arresting illegal wildlife trade, it is estimated that at least $2-3 billion worth of illegal wildlife goods continues to enter commerce each year.[1] Through its regional outposts and growing network of field contacts, TRAFFIC has helped uncover a number of significant illegal trade cases in recent years, several relating to crocodilians (see below). TRAFFIC strongly supports the contention that curbing illegal trade is vital to the overall success of CITES and conservation programs aimed at ensuring long-term survival of species through sustainable utilization.

<u>What Has Trade Monitoring Accomplished?</u>

As noted earlier, in the big picture of international wildlife commerce, the crocodilian trade has been relatively well monitored. This has proven a major benefit for crocodilian conservation programs and the crocodilian industry overall. In spite of what may be perceived as an increasingly complex regulatory environment, CITES has moved in step with the many

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[1] Estimates calculated by TRAFFIC USA put the total global wildlife commerce, excluding fisheries and timber products, at a minimum US$5-8 billion per year. This figure is extrapolated from official trade statistics and might be considered comparable to a minimum wholesale value.

advances in crocodilian conservation and management over the last 15 years, and the parties have allowed for the progressive downlisting of crocodilian species, including the American alligator, Nile crocodile, and saltwater crocodile (Crocodylus porosus). The success of ranching as a conservation tool for crocodilians has been recognized and advanced by CITES, with technical support from the Crocodile Specialist Group and growing cooperation from the industry. But such recognition has, as mentioned, only come on the condition that trade must continue to be carefully checked and reported (see Jelden, 1990, for a review of CITES regulatory history for crocodilians). Compliance with such trade monitoring and reporting requirements continues to vary, but generally is improving.

The application of harvest or export quotas to crocodilians entering legal trade, either through agreement by the CITES Conference of the Parties (e.g. Nile and saltwater crocodile) or through unilateral measures imposed by individual countries (e.g. caiman), has provided a practical means of international oversight of the trade. Such quotas, which have been adopted by most crocodilian exporting countries, have helped link trade monitoring activities directly to harvest and management programs.

CITES' most recent effort at strengthening crocodilian trade controls came in March 1992 at the Eighth Meeting of the Conference of the Parties in Kyoto, when a resolution calling for a universal tagging system for crocodilian skins was adopted (Res. Conf. 8.14). Designed to help verify the source and legality of skins in global commerce, this system has yet to be fully implemented and it remains to be seen how the costs of implementation compare with the conservation benefits the system aims to provide -- a point worth considering given that annual world trade in crocodilian skins has run between 500,000 to over one million skins per year during the last decade (both legal and illegal trade combined; Luxmoore, 1992). However, in the face of continuing largescale illicit trade of such species as Caiman crocodilus, the universal tagging system is generally regarded as a much-needed step in the battle to shut down the black market.

It is fair to say that trade monitoring -- reviewing CITES data submissions and identifying areas of illicit commerce and non-compliance -- has helped provide the basis for growth of an industry tied increasingly to managed, legal harvest programs. Efforts undertaken through the International Alligator and Crocodile Trade Study (IACTS) suggest that trade monitoring and compliance reviews, combined with political pressure, have helped divert illegal trade to legal sources (Ashley, D., pers. comm.). While some hold to the argument that growth in the legal trade will only stimulate illegal trade, a growing body of evidence derived from crocodilian trade monitoring suggests otherwise. However, it may be premature to draw conclusions, because the current crocodilian market situation is affected by a host of complex and interrelated political, economic, and conservation factors.

Current "Hot Spots"

In spite of the relative success of crocodilian conservation and management initiatives around the globe, all is not well in the croc trade world. Largescale illegal trade continues in some areas, while important crocodilian producing countries still to lack the commitment to and infrastructure for ensuring that crocodilian utilization is well-managed and sustainable. And, laws governing the crocodilian trade in some importing as well as exporting countries continue to run counter to CITES, potentially detracting from the development of new conservation opportunities for exploited species.

The caiman problem. There is little question that widespread illegal trade of *Caiman crocodilus* continues to plague the crocodilian industry and undercut efforts to manage this species, by far the most heavily trade crocodilian, on a sustainable basis. It has been estimated that three-quarters of the trade in caiman skins is illegal and takes place outside of the CITES control structure, with total trade ranging from one-half to over one million skins per year (Pani, pers. comm.; Villalba-Macias, pers. comm.; Menghi, pers. comm.; Luxmoore, 1992). Current legal sources of skins are limited, with Venezuela, Guyana, Nicaragua, and Colombia the only countries presently allowing exports. Much of the illegal trade apparently originates in the Pantanal region of Brazil, with Paraguay having served in the past as a major exit point for the South American continent (Luxmoore, 1992). Most recently, the Netherlands Antilles have served as key conduits for largescale illegal trafficking of caiman (see below).

In 1988, TRAFFIC was instrumental in uncovering a ruse used to smuggle thousands of caiman skins into Japan through Thailand on the basis of stolen, forged or otherwise illegal documents. A routine inspection of Japanese Customs data showed a sudden and inexplicable twenty-fold increase in crocodilian skin imports from Thailand, hitherto an insignificant source of crocodilian skins for the Japanese market. Further analysis revealed that more than 48 metric tons of crocodilian skin, representing at least 120,000 animals, had entered Japan between January and July 1988 from Thailand. It appeared that the skins had been part of a larger illegal consignment secretly loaded onto Asia-bound ships off the cost of Uruguay in late 1987. Subsequent investigation traced the consignment, or parts of it, through at least seven countries -- Brazil, Paraguay, Uruguay, Korea, Taiwan, Singapore, and Thailand -- before it reached Japan. Thailand had served the major "laundering" point, where CITES re-export documents, some stolen and others legally issued but based on false information, had been obtained to cover the illegal imports to Japan (Anon., 1988).

The investigation help trigger a major review of both Thai and Japanese CITES control systems, both of which have improved significantly in the subsequent years. Thailand was the focus of a CITES Standing Committee trade moratorium recommendation in 1991, after additional investigation revealed major inadequacies in the country's legislation and trade controls. Political changes and legislative reforms prompted CITES to withdraw the trade ban recommendation in 1992.

Japan, a key consumer market for crocodilian products, particularly for classic skins, has since strengthened its import control measures for caiman, adopting a system of prior confirmation of permits issued by countries of origin to verify legality before imports are allowed (Tokunaga, pers. comm.).

TRAFFIC and CITES trade monitoring efforts continue to highlight the subversive nature of the caiman trade. In late 1992, after receiving a tip from a wildlife officer in Aruba, Customs authorities in Montevideo, Uruguay seized a major shipment of over 85,000 caiman skins, the largest such confiscation ever made in that country. The skins, valued at over US$1 million, apparently originated in Colombia and possibly Venezuela, and were shipped through Aruba and Curaçcao before heading for their final destination -- Singapore -- via Montevideo. The bales of skins bore the number of a permit issued by Colombia's CITES Management Authority for some 15,000 skins, although no permit accompanied the shipment. It appears that the additional 70,000 skins may have been added to the shipment during the stopover in Aruba. The skins are presently in the hands of government authorities in Montevideo (Villalba-Macias, pers. comm.; Menghi, pers. comm.).

This major seizure points to a number of significant problems. There is clearly still an active consumer market for illegal caiman skins. Until consumer countries make a stronger commitment to flushing out the illegal commerce, trade control efforts will continue to be frustrated in producer countries. Recent CITES discussions have focused on the importance of conducting crocodilian skin inventories in major consumer countries in an effort to clarify trade control needs. It is critical that countries such as Singapore, which have maintained CITES reservations on crocodilian species and thus may harbor large numbers of unrecorded skin stocks within their borders, undertake inventories of all crocodilian hides intended for trade on the global market. Italy -- a major importer of caiman skins -- has recently embarked on such an initiative (see below; Pani, pers. comm.).

The Montevideo caiman seizure also underscores a major loophole in the trade control system: countries and territories which remain outside of CITES' reach because of their non-party status, or because legislation has not yet been applied. Such is the case with Aruba and Curaçao (the Netherlands Antilles), which, although territories of the Netherlands (a CITES party since 1984) do not yet have legislation controlling CITES trade. In such cases, wildlife and customs authorities have no legal basis for investigating potential CITES violations and making seizures. It is imperative that the Netherlands, as the country responsible for CITES application in its territories, take immediate steps to remedy the problem. Similarly, countries such as South Korea and Taiwan, increasingly important crocodilian skin consumers, remain non-parties to CITES, providing important gaps in the trade control structure (the latter is not eligible to join under current rules).

As suggested above, the caiman trade has operated on a black market basis for years, in spite of national laws in many countries of origin that attempt to restrict it. It may very well be that the laws themselves, and inconsistencies in such laws among neighboring countries, have provided more of an obstacle than a benefit to caiman conservation efforts in South America. Revenues earned from caiman exports remain largely in the hands of black market traders, providing virtually no benefit for local communities and national governments. It is clear that the caiman resource has withstood heavy exploitation for decades; this exploitation should be brought above board, officially measured and reviewed, and guided by practical management and trade control procedures. Only then will conservationists be able to gauge the impact of trade and truly assess sustainable use, conservation, and local community needs.

Indonesia. Indonesia's crocodile trade has been the subject of extensive CITES review and debate for almost a decade. As one of the most important crocodilian producers, the country's *Crocodylus porosus* population was among the first to be approved for a temporary downlisting from Appendix I to Appendix II under special CITES criteria tied to export quotas (Res. Conf. 5.21). In the seven years since that "temporary" downlisting, the CITES parties have agreed to keep Indonesia's *porosus* population on Appendix II, pending a more detailed assessment of the population's status and development of a permanent infrastructure for crocodilian monitoring and trade control. Such infrastructure, unfortunately, is not yet in place. Concerns have been raised by CITES parties and the CSG alike, and although illegal trade is not occurring on the scale it was five years ago (one estimate put illegal *porosus* exports at close to 20,000 skins per year in the late 1980s; Hemley, 1990), this is more likely a factor of market depression than adequate trade control devices.

A Crocodile Specialist Group/CITES mission to Indonesia in November 1992 outlined a series of measures it felt was needed by Indonesia in order for the country to gain the support of the CITES parties for an unrestricted Appendix II listing of C. porosus. Much of that review centered on population and trade monitoring, reporting, and enforcement measures (Messel et al, 1992). It remains to be seen how Indonesia will implement these recommendations before the next CITES meeting takes place in late 1994 when a full official review is expected.

Italy. The crocodilian industry was dramatically shaken up in 1992 when the CITES Standing Committee urged all parties to embargo trade in CITES-listed species with Italy, the result of in-depth review by the CITES Secretariat and TRAFFIC of Italy's extensive CITES implementation problems. Although adoption of this recommendation was inconsistent among the parties, it had the effect of spurring the Italian government into action after a decade of near dormancy on CITES enforcement. A CITES member since 1979, Italy had for 12 years completely lacked a legal structure to properly implement the Convention; this problem had allowed for a virtually unimpeded flow of both legal and illegal wildlife goods into and out of the country.

The CITES Standing Committee outlined several basic conditions that Italy would have to meet in order for the ban to be rescinded, notably providing the legal authority for penalties to be assessed for CITES violations, and establishing proper customs and document control and inspection procedures with official oversight by wildlife officers. Italy had begun the process of adopting new legislation in late 1991, but significant progress was not made until mid-1992. With substantial guidance from TRAFFIC's Italian office and the CITES Secretariat, a new law decree finally passed the Chamber of Deputies and Parliament in early March 1993 which incorporates comprehensive provisions for CITES implementation. As part of the new legislation, Italy is undertaking a full inventory of whole crocodilian skins held in private stock, and has agreed to abide by the new CITES universal tagging requirement for crocodilian skins (Pani, pers. comm.).

The United States. The United States, the world's largest wildlife consuming country, maintains -- like many countries -- national legislation which goes beyond CITES in restricting the trade in a number of species, including several crocodilians. In 1990, partly in recognition of progress made in the conservation of several croc species, and partly because of statutory requirements to review and adjust as appropriate the legal status of certain species under the Endangered Species Act (ESA), the US Fish and Wildlife Service has begun a process of reclassifying certain populations of the Nile crocodile, the Australian population of the saltwater crocodile, and yacare caiman (Caiman crocodilus yacare). Because of the extensive informational and internal and public review requirements of the ESA, the process of reclassification is lengthy. Final changes, which would allow the import to the US of products of these species under certain conditions, are expected in 1993. However, it is likely that the US government will also impose new specific requirements -- in line with CITES concerns -- to allow for careful oversight of and action against illegal trade and traffickers. Problem countries such as Singapore and Italy will no doubt be subject to particular scrutiny when the new regulations are adopted.

Looking Ahead

There appears to be ample evidence that international trade monitoring efforts -- however incomplete or inconsistent they may be -- have provided an important tool for the development of a crocodilian industry increasingly relying on products from legal, managed sources. It is equally clear that illegal trade, particularly of caiman, continues at a significant level. The industry carries the greatest responsibility in combatting this problem, and the trade will continue to be tarnished by those traders who persist in moving illegal products.

Overall, the crocodilian trade demonstrates an evolving success story for conservation. Continuing progress will depend not only on strengthened CITES enforcement, but on adapting and refining the rules to meet the unique conservation and management needs of countries of origin. It is increasingly clear that, while international standards are critical, conservation needs and infrastructure differ significantly from country to country. The Crocodile Specialist Group has begun to address this problem through a review of the CITES listing criteria for crocodilians, with an eye towards a new trade control and management structure that better links trade monitoring to in-situ management of exploited species. Flexibility is needed to accommodate different crocodilian utilization practices, while providing strict international oversight to ensure that conservation benefits outweigh conservation costs. Trade monitoring, no doubt, will be a fundamental part of any new system.

In addition, the trade monitoring systems themselves must continue to be monitored to ensure that they are achieving what they have been established to do. This includes the new universal tagging system for crocodilian hides, slated to be fully operational in 1993. It is hoped that this new system will make a significant dent in the illegal trade, but it may be costly to implement.

Once the illegal trade is under better control, industry can begin to focus more effort on crocodilian market futures analysis and trade projections, to help safeguard much-needed investments in crocodilian conservation and utilization programs. Such long-term planning will potentially be an important aid to both conservation and industry, and will help stem the negative impacts of market downturns as well as safeguard the survival of exploited species. Provided trade control checks and population monitoring systems continue to improve, industry and conservation should be able to work effectively together through CITES to achieve their common goals.

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INTERNATIONAL DIRECTIONS IN THE SUSTAINABLE USE OF WILDLIFE

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The previous two speakers have made a good job of explaining what we mean by the sustainable use of wildlife, how it relates to people and conservation and specifically to the conservation of crocodiles.

I am anxious not to repeat what has already been said, but in my discussion of the direction that sustainable use is heading there may be some overlap and for this I apologise in advance.

Much of what I have to say has its roots in a recent workshop which the Africa Resources Trust held in London to examine a number of problems associated with the sustainable use of wildlife. This workshop concluded that there is a great deal of investment in sustainable use programmes at all levels and from a number of directions. It also concluded that many of the problems we are presently encountering have arisen because we have neglected public relations and have been politically naive.

As a result, in this brief paper I will not be concentrating on what is happening on the ground, but on some of the supporting activities that are taking place and on four principal directions or trends that I believe are important.

First of all, it is important to point out that sustainable use is not new. It is obvious that wild species have been used sustainably ever since man appeared on the earth. However, much of this use has been sustainable by accident - for much of our history resources were so big relative to the human populations they had to support that they were used within their capacity for renewal. Although this is still commonly the case today, increasingly a combination of population and technology have increased the pressure on wildlife so that its use is not sustainable and populations are in decline.

Because unplanned use is increasingly unsustainable, there is an ever increasing emphasis on management. **THIS IS THE FIRST OF THE TRENDS THAT I WANT TO HIGHLIGHT.** Today we tend to use the term sustainable use to describe the deliberate planned use of resources within their capacity for renewal. Given the conservation status of many species, it is hard to argue with this trend which is reflected in all our activities and is inevitable. The whole CITES structure is built around one fundamental requirement - that trade in a species is not detrimental to the survival of the species. Why else would there be such emphasis on surveys?

Arising from the requirement that use be planned is **THE SECOND IMPORTANT TREND** - the search for an academic and ethical framework for sustainable use, including simple criteria to define when use is and is not sustainable. Again, it hard to disagree with this in principle.

Unfortunately, while I have indicated that each of these developments is inevitable, and deserving of support, they introduce the **THIRD INTERNATIONAL TREND** to our discussion. This trend is dangerous at best, and utterly unacceptable at worst. I refer to the current attempt by western-based groups to influence the sustainable use debate and to demand more and more restrictions on the use of wild species, even when use can be demonstrated to be sustainable in the strictest biological sense. Increasingly, these western-based groups see use as bad or wrong unless it gives <u>benefits</u> to a) the species, or b) habitats, or c) underprivileged people, or a combination of these and in addition is also <u>humane</u>. This system of qualification is, for example, increasingly important within CITES which in addition to requiring that trade is non-detrimental (i.e. sustainable) increasingly requires that it give conservation benefits (eg. Resolution Conf. 3.15). It is important to note that the adoption of these qualifications would make most marine fishing activities unacceptable - which is clearly ludicrous.

At this point I want to consider who makes up these western groups which are having such an influence? Who is driving this process?

There are many well meaning people in the west who have genuine and deeply held concerns about conservation and who believe that this is best achieved through a codified regime of restriction and prohibition - what we loosely term, although it is poor use of the English language, protectionism or preservationism. It is my experience that these people rarely stick to their rigid ideas once they are exposed to the reality of conservation in the developing world and to a clear explanation of sustainable use. Because they can be educated, I like to refer to this group as honest, but misguided. There are many such people in positions of influence around the world and they will continue to make negative inputs into the sustainable use debate until we reach and educate them with our message.

For the time being the "honest, misguided" element will find a natural ally in a second major group which I call the "dogmatic opposition".

This group comprises the animal welfare and animal rights groups, some of which appear to be more interested in fund raising than conservation. Indeed, although most of these groups pose as conservationists, many of them are not interested in the conservation of species and ecosystems at all. The role model for these groups is the elephant researcher from east Africa who said that she would rather see elephants go extinct than see them conserved through sustainable use!

It is possible that many in this audience have not yet been exposed to the animal welfare groups. Crocodiles have lots of sharp teeth and they eat people so it is not easy to get public sympathy for them, and almost impossible to use them for fund raising. As a result they have largely been ignored by animal welfare and we have been able to get on with some very successful conservation and management programmes without having to battle every step of the way. Not everyone has been so fortunate. Animal welfare has derailed entire conservation programmes (such as the eradication of exotic fauna on Round Island, Mauritius) and even entire rural economies (such as that of the Pribilof Islanders, destroyed by a ban on seal products).

Animal welfare groups are well funded and highly organised. In order more effectively to influence CITES in 1994 they recently collaborated to form the Species Survival Network in direct opposition to the IUCN's Species Survival Commission. These groups have been and are very cunning and should never be underestimated. Their smartest move so far has been to hijack the middle ground in the conservation debate. After years of completely unopposed manipulation, almost entirely through a gullible media, there is utter confusion between animal welfare and conservation and as a result the average man in the street believes that sustainable use and the killing of animals is immoral and incompatible with conservation. In reality, the pragmatic attainment of conservation goals may well require the killing of thousands and even millions of animals. For example, if all the cane toads, feral cats and foxes could be exterminated many of Australia's conservation problems would be solved.

All this sounds a bit depressing for sustainable use. But fortunately we haveso far only been looking at sustainable use as a conservation tool. One of the inherent features of sustainable use is that it gives benefits to the user as well as the resource. As a result sustainable use is extremely attractive to development groups who, of course, have a very different perspective to conservation and animal rights groups. Development agencies are not interested in sustainable use as a conservation tool, but refer to the use of wild species in sustainable development. To these groups wildlife use is a development tool which is environmentally friendly.

So far, there has been an artificial demarcation between "environment" and "development" and sustainable use has been almost exclusively debated within the environmental community. In fact the fundamental conditions for sustainable use are to be found in the realms of political economy and in a social, cultural, institutional and economic matrix. Accordingly, new inputs from development agencies are to be encouraged not only to widen understanding and to promote the successful implementation of sustainable use programmes, but also to counteract the existing tendency of "conservation" agencies to marginalise the role of people. **THE INCREASING INVOLVEMENT OF DEVELOPMENT AND AID AGENCIES IN SUSTAINABLE USE IS THE THIRD IMPORTANT TREND WHICH I WANT TO BRING TO YOUR ATTENTION.**

THIS BRINGS ME DIRECTLY TO THE LAST OF THE IMPORTANT INTERNATIONAL TRENDS WE ARE WITNESSING - there is a rapidly growing coalition of conservation and development agencies which is determined to support sustainable use and which is preparing both to counter the animal welfare movement and to educate the honest, misguided element.

This coalition will be working in the short term on issues such as CITES, but has the long term objective of dividing the current opposition so that the public can clearly distinguish between conservation and animal welfare extremists. I am not going to dwell on this at length since we are only just beginning to identify our allies and mobilise our resources. However, I expect that many of the people in this room will eventually contribute to this coalition in some way, however minor.

Finally, I am going to show you two transparencies. One illustrates a "conservation" group raising funds around a life-size elephant sculpture with the aim of preventing the reopening of a legal ivory trade. The second shows the trophy room of an American big game hunter who pays huge sums of money to shoot elephants in Africa for sport. When the public can sensibly distinguish which of the two contributes most to conservation in Africa then our coalition will have been successful and sustainable use will be secure.

THE PRINCIPLES OF FARMING CROCODILES

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This subject was recently addressed by the authors, as an introductory chapter to the "Directory of Crocodilian Farming Operations" Second Edition (Edited by R.A. Luxmoore. IUCN Publ.: Gland Switzerland). The full text is reprinted here.

CONTENTS

ORIGINAL PREFACE

The Steering Committee and members of the IUCN/SSC Crocodile Specialist Group (CSG) receive an inordinate number of inquiries about crocodile utilization and farming each year. Although we attempt to answer all letters, many are of a general nature - "I am starting a crocodile farm. Please send me all the relevant literature, management details and farm plans." They have often been written by people who have never set eyes on a live crocodilian, nor heard of CITES. Yet they are clearly from people interested in the "business" of crocodiles, and there are many examples where such cursory interest has ultimately led to significant conservation gains. The late Graham Goudie's exploits in Papua New Guinea are a good example.

A comprehensive crocodilian farming handbook is one approach that the CSG Steering Committee considered. However, the task of compilation would be daunting and the final price would restrict its utility for general inquiries. This booklet, then, is our solution to the problem. It provides a comprehensive, but brief and easily readable background for prospective crocodilian farmers - and it is not expensive. We feel it answers most of the commonly asked questions. It is directed at a general audience rather than at established crocodilian farmers, although we hope that they might find it interesting and perhaps learn a thing or two in its reading.

From the outset, it must be recognized that research on intensive production of crocodilians has been "patchy". Egg management, for example, has a strong research background and advice can be given with confidence. Captive breeding and the immediate post-hatching treatment of hatchlings are less well understood, and may be subject to significant differences between species. Much more research is needed before crocodilian farming will become a highly efficient system of animal production *per se*. Nevertheless, some farms which follow a few simple guidelines are model business operations which generate significant profits.

Finally, in compiling this booklet, we have kept jargon and scientific terminology to a minimum, and have not cluttered the text with references. Given that some terms are still likely to be new and unfamiliar to the general reader, a glossary has been included.

CONTRIBUTORS & ACKNOWLEDGEMENTS

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The final version owes much to these people, although any remaining "howlers" in the final text are entirely the responsibility of the editors. Particular thanks are due to the people who went to great lengths to produce manuscripts, many of which were outstanding, but which were eventually deemed to be largely outside the scope of this work. Some of these contributions have been included in a greatly reduced and rewritten form, others have subsequently been published elsewhere.

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1. REGULATIONS

The term *crocodilians* is used to refer to the 23 different species of crocodile-like animals around the world: alligators and caimans (8 species), true crocodiles (13 species) and gharials and false gharials (2 species). Within most countries, crocodilians cannot just be kept and traded like domestic animals and pets. They are "wildlife", and there will usually be laws restricting what private individuals can do with them. For example, wild crocodiles may be totally protected, or they may be managed through a system requiring licences and permits for catching, keeping, selling, trading, killing, etc. As these laws vary from country to country, and enforcement of them ranges from strict to lax, we make no attempt to summarize them here. However, they are of critical importance to anyone considering crocodilian farming.

At the international level, trade in crocodilians and products derived from them is controlled through CITES - The Convention on International Trade in Endangered Species of Wild Fauna and Flora. The mechanisms by which CITES exerts control are more complex with crocodilians than with any other group of living organisms. There are two basic levels of control. Most crocodilian species are listed on *Appendix I* of CITES, for which no commercial trade between nations is allowed, unless the animals being traded have been bred in captivity. The remainder are on *Appendix II*, for which trade is permitted if export permits are issued by the relevant authority. Since the inception of CITES in 1975, all species of crocodilians have been listed on Appendices I or II.

Since 1975, a number of local populations have been transferred from Appendix I to Appendix II, for a variety of reasons, and using a variety of mechanisms. Consequently, there are now at least five different levels of control accorded to crocodilians under CITES:

1.1. Appendix I

Appendix I contains "all species threatened with extinction which are or may be affected by trade. Trade in specimens of these species ... must only be authorized in exceptional circumstances" (CITES, Article II, para. 1). The export of wild animals to be used as breeding stock for establishing farms or zoos is not permitted, unless the aim is to instigate a breeding program intended to ensure the survival of the species. Hunting trophies intended for personal use (not resale) may be exported, although some nations (e.g., the USA) prohibit their importation unless a specific exemption is provided in their domestic import regulations.

1.2. Appendix I (Bred in captivity for commercial purposes)

Appendix I animals may be controlled as though they were Appendix II animals if they are "bred in captivity for commercial purposes". This has been defined as: "born or otherwise produced in a controlled environment, ... of parents that mated ... in a controlled environment". For crocodilians, this means that the offspring must hatch from eggs laid in a farm, and that the breeding stock must be "established in a manner not detrimental to the survival of the species in the wild" and must be "maintained without augmentation from the wild, except for the occasional addition of animals ... from wild populations to prevent deleterious inbreeding". It must also be managed in a manner designed to maintain it indefinitely, and that "has been demonstrated to be capable of reliably producing second-generation offspring." This does not mean that the farm cannot trade until it has achieved second-generation breeding, but rather that it must be using suitable and reliable husbandry techniques. Farms must also be registered with the CITES Secretariat (via the local Management Authority) and approval may be withdrawn if they fail to comply with the required conditions.

1.3. Appendix II (transferred from Appendix I for ranching)

Under CITES Resolution Conf. 3.15, Appendix I animals "which are deemed by the Parties to be no longer endangered and to benefit by ranching" may be transferred to Appendix II, if strict management criteria are adhered to. Ranching is defined as "the rearing in a controlled environment of specimens taken from the wild". The operation must be "primarily beneficial to the conservation of the local population (i.e. where applicable contribute to its increase in the wild)". In order for a country to transfer a population from Appendix I to Appendix II for ranching, it should have carried out research on the wild population and be able to ensure "that the taking from the wild shall have no significant detrimental impact on wild populations". With crocodilians, harvests of eggs and hatchlings (for ranching) appears to have a minimal impact on the wild populations relative to harvests of adults.

1.4. Appendix II (an interim transfer from Appendix I on the basis of a quota)

CITES Resolution Conf. 5.21, now replaced by 7.14, was adopted as an interim measure in 1985 to allow limited quotas of skins of Appendix I animals to be exported, pending transfer of the population to Appendix II by other means (e.g. for ranching). Quotas are set by international agreement and must be based on surveys predicting the likely impact of the harvest. Quotas may be set separately for the export of wild-caught and ranch-reared animals or their skins. The system is intended to operate for a maximum of four years, after which a country is expected to have accumulated sufficient information to show either that the population has recovered and merits retention on Appendix II, or that a ranching scheme can operate.

1.5. Appendix II

Populations on Appendix II, or which have been transferred back to Appendix II after having recovered, may be traded internationally provided that the Management Authority issues an export permit. This, in turn, may only be done when scientific advice indicates that the trade "will not be detrimental to the survival" of the species.

In order to export skins under any of the systems described under sections 1.2-1.4 above, the skins must be marked with a tag bearing a unique number. In practice, several countries also tag skins from Appendix II animals (1.5 above), and there are now few crocodile skins in legal international trade that are not tagged. A proposal that all crocodilian skins in international trade be tagged is currently under review by CITES.

2. BASIC REQUIREMENTS

Crocodile farming is a relatively new industry, subject to the whims of fashion in distant markets - markets which are typically beyond the farmer's influence. The industry is commonly based on wild crocodile populations which may be equally beyond the farmer's control. Any new crocodilian farming venture needs to appraise carefully all of the components and variables that may influence biological and commercial success. As a guide, the farmer should make sure his plan addresses each of the issues in the diagram. These are fundamental requirements and a pathway through them must be found! Crocodile farming requires a significant investment in facilities and stock. The "quality" of the skin of the target species, is clearly very important. Everything else being equal, species with "classic" skins [small scales with few boney plates (osteoderms) in the belly scales] are likely to be more economical to farm than "non-classics" (e.g. caimans), as the value of the skin is appreciably higher.

3. ACQUISITION OF STOCK

The three principal resources for successful crocodilian farming are stock, food and money. In some countries, especially developing countries, wild crocodilian eggs may be readily available at low cost, but there is no inexpensive food to feed growing crocodiles and often little money to develop facilities. In other countries, particularly developed countries, funds may be available for development and waste animal protein may be available for food - but there may be no wild crocodile resources upon which to base a sustainable utilization program. In all countries obtaining land suitable for crocodilian farming, especially in and about residential areas, may be difficult due to cost and/or zoning restrictions.

Because the majority of wild crocodilians occur in developing countries, the CSG encourages their sustainable use for skin and meat production. Using wildlife in this way is a legitimate conservation tool, as long as the use is sustainable and it creates commercial or other incentives to conserve both the crocodilians and the wetland habitats they occupy. The CSG has expressed concern about the introduction of exotic crocodilians into countries for commercial purposes farming operations and " ... recommends that crocodile species should not be used for commercial farming operations outside their historical range where those operations are located within the range of other native species of crocodilians."

This section describes the main ways in which farms can obtain their commercial stock legitimately, and describes systems of production and management which ensure that conservation benefits result.

3.1. Captive Breeding

The captive breeding of endangered species, for reintroduction to the wild, is a specialist area of conservation that uses farming technology, but has different goals - it is not treated in depth here.

Crocodilian species vary greatly in their social behaviour. Some are communal nesters in the wild, and these usually breed well in captivity - even if collected as adults from the wild and placed in captivity. The Nile crocodile is a good example. Others, such as the Estuarine crocodile and American alligator are solitary nesters in the wild, and they often show strong territoriality in captivity, even amongst females. They commonly perform poorly in captivity. However, all species of crocodilians have bred in captivity, and can perhaps be induced to do so on a commercial scale.

Captive breeding is essential if there are no wild crocodilians of commercial value, or if the wild resources are being utilized to their maximum extent. However, from a conservation viewpoint, ranching (see Section 3.2) is a preferred form of utilization where it is possible. Captive breeding was commonly recommended on the grounds that it takes the pressure off wild populations, even in places where wild egg resources are abundant. Until recently, CITES regulations made it more attractive than ranching, even in countries with large wild crocodilian populations. We now know that this approach is wrong. Where adults are taken from the wild to stock farms for captive breeding, there may be significant negative effects on the conservation of the wild populations. This is especially so where adults are in low densities. Captive breeding operations do not create direct incentives to protect wild populations and their habitats. Once a "closed farm" is operating, the conservation benefits may be minimal or nonexistent. Ranching, on the other hand, links the commercial viability of a farming operation directly to the maintenance of wild populations, and in many farms today, captive breeding and ranching go hand in hand.

Stock for captive breeding can be obtained either from the wild as adults or juveniles, or through the growing-out of raising stock. In many countries problem or nuisance animals can be used for stock, the alternative usually being their destruction. Capture and handling techniques are well established for all commercial species. Most techniques involve some degree of danger, either to the animal or the handler, and some require the use of specialist drugs.

Wild-caught adults should be housed in pens which provide the appropriate environmental conditions for that particular species. For example, Nile crocodiles require deep and constant water levels, but appear "content" in large numbers in a small area. In contrast, adult Estuarine crocodiles need lots of space, or enclosure in pairs, and appear to do well with shallow and even fluctuating water levels. The Common caiman (Caiman crocodilus) appears to breed well in small, shallow ponds, even at high population densities.

Young animals suitable for growing out to breeding are often readily available from existing farms. Captive-reared stock are more tolerant of variable housing conditions and begin breeding at smaller sizes (and therefore sooner) than their wild counterparts. With Nile crocodiles, for example, wild females rarely reproduce at sizes less than 2.7 m total length (TL) whereas captive raised females begin to lay eggs at 2.0 m TL, or smaller. In some species (e.g. Nile crocodiles and Estuarine crocodiles) captive-raised adults do not appear to breed as well as wild animals (nesting frequency, clutch size, egg quality), although this may be due to their age and and housing conditions, and more research is needed. In contrast, captive-raised Common caimans appear to nest more frequently and with larger clutch sizes than their wild counterparts.

It is impossible to generalize on the productivity of breeding stock. With the exception of Indian Muggers (Crocodylus palustris), most species nest once per year (some Muggers nest twice). Clutch size is highly variable between species, and clutch size, fertility and hatch rates within a species are affected by age, the early history of individuals, housing conditions and perhaps food. To obtain 1000 Nile crocodile hatchlings may require only 30 female crocodiles. To obtain the same number of caiman hatchlings it would require 60 females, and for Amercian alligator hatchlings, perhaps 100 females.

All captive breeding operations involving species on Appendix I of CITES are subject to a number of CITES Resolutions, and must be registered with the CITES Secretariat (Section 1).

3.2. Ranching

Ranching is a commercially viable strategy for crocodile farming which is widely used and has well accepted conservation advantages. The collection of eggs, hatchlings or juveniles from the wild gives natural populations a conspicuous economic value. Since wild clutches are often large and have a high fertility rate, ranching based on eggs is as cost-effective, and usually more so, than captive breeding. However, the logistics associated with the collection of eggs, hatchlings and juveniles varies between species and localities.

Ranching strategies can involve a set quota of eggs or juveniles to be collected or as many as can be found. Where the extent of total recruitment collected is considered high, management programs often require farmers to return 5-17% of collected animals back to the wild, once they have reached a size at which predation is considered unlikely. Such compensation minimizes the impact of the harvest and clearly has the potential to exert a positive impact in terms of population size.

The time and duration of nesting are strongly correlated with the weather, particularly rainfall and temperature. As a general rule, nesting seasons tend to be extended in warm areas and contracted in cool areas. However, the type of nest (hole or mound) used by a particular species is involved. For example, in northern Australia, Estuarine crocodiles (mound nesters) nest during a six month period spanning the wet season, when it is warm. Australian Freshwater crocodiles (hole nesters), in the same region, nest in a three week period during the dry season - the only period of the year when conditions are warm and dry enough for eggs in the ground to incubate successfully. American alligators (mound nesters) are also restricted to a three week nesting period ("pulse" nesting) apparently for the same reasons.

Egg and hatchling collections from the wild are more efficient and economically feasible in areas where crocodilian densities are high, where their habitats are accessible logistically, where the species constructs an obvious mound nest, and where the population nests in a short pulse. (Information on eggs and incubation is in section 4.2).

In some countries, for example Papua New Guinea and Irian Jaya (Indonesia), ranching involves the collection of older juveniles from the wild - animals which have dispersed from the nest site. This has proved to be one of the only feasible strategies of ranching where crocodilians live in heavily vegetated freshwater swamps, where nests are difficult to locate. It also appears to be well suited to indigenous native hunters in remote areas, although the logistics of establishing buying networks can be formidable.

Since ranching involves the direct exploitation of wild resources, the populations concerned should be listed on Appendix II of CITES. Under special circumstances a local population may be transferred from Appendix I to Appendix II to encourage a ranching program (Section 1).

4. HUSBANDRY AND MANAGEMENT

4.1. Captive Breeding

Maintaining a captive breeding colony can be expensive, as it can involve a significant area of land and high construction costs, in addition to feed, water and continual maintenance. If animals cannot be captured from the wild, the development of a captive breeding herd may be a long-term and costly commitment, since most commercially important crocodilians take 6 years or more before they breed successfully; i.e. before they produce significant numbers of viable hatchlings. Diet plays an important role in maintaining optimum breeding in captive animals. With at least some species, animals fed a red meat diet consistently have higher nesting, fertility and hatching rates than animals fed solely a fish diet. However, in some areas fish represents the only source of protein available, and with some species adults fed primarily fish do nest successfully year after year. It should be recognized clearly that some crocodilian species do not command a high market value for their skins, and for these species, the commercial viability of captive breeding and farming in general may need to be looked at very closely indeed - it may not be warranted.

The biological and economic success of maintaining a captive crocodilian breeding group depends largely upon species, with factors such as sex ratios, land/water ratio and stocking rates varying greatly between them. Some species, like the American alligator and Common caiman nest on rising water levels, whereas species like the Nile crocodile nest on falling water levels. Crocodilians are either solitary or colonial nesters. Captive propagation within colony nesting species has been accomplished with relative ease and a high degree of success, but the solitary nesting habits of other species make captive propagation more complex. For these, space requirements with respect to both stocking rates and sex ratio are difficult to satisfy and for the most part have created major problems in establishing economically sound breeding programs. Problems associated with the commercially viable breeding of solitary nesting species are currently being investigated. Broad generalizations with respect to the technology of captive breeding are impossible.

In evaluating captive breeding success, the number of viable hatchlings produced per adult maintained in captivity is perhaps the only meaningful measure of success. The quality of eggs laid can vary tremendously, and in many captive breeding situations infertility and early embryonic deaths (prior to laying) can render 60-70% of eggs non-viable.

A brief review of successful systems for the four most commercially important species exemplify the different strategies that are employed on crocodile farms.

The Nile crocodile. The Nile crocodile is a social, communal nesting species. In modern facilities, females can be grown from hatchlings to breeding (at about 1.8-2.0 m) in 6 years, but good fertility, hatching and hatchling quality are rarely achieved before 8 years. Wild females rarely nest before they are 2.7 m, which may take up to 30 years, but such age-size relationships are strongly population specific. The reduced age at nesting in captive-raised stock appears to be a function of their early rapid growth since wild caught females of 1.8-2.0 m do not start breeding until they would normally do so in the wild, irrespective of the conditions under which they are maintained in captivity. Males will mate with females of the same age, but such unions are rarely successful. It is more usual to keep females with larger, older males.

Wild caught animals and those grown-out under farm conditions differ markedly in the extent to which they will tolerate other adults and breed successfully in different housing conditions. Wild animals "tame" down and accept human disturbance well, but do so quicker if isolated and left undisturbed. Wild caught females respond well where captive conditions simulate the wild: pools with deep and shallow areas, and reasonably stable water levels (pools should never be emptied). As a hole nester, Nile crocodiles look for nesting areas about 1 m above water levels and suitable raised banks should be provided about 2 m from the water. These should be adjacent to shade and facing west to catch the afternoon sun.

Farm reared animals have less rigourous requirements and will lay eggs in shallow, concrete rearing enclosures which are drained and cleaned regularly. However, even these animals are more productive if water depth is constant and suitable nesting areas are provided.

Two main breeding systems for Nile crocodiles have emerged on crocodile farms: a few females kept in a small enclosure with one male (most common); and, anything up to 300 females kept with multiple males (as many as 60) in ponds up to several hectares in size. It is not possible to compare stocking density and sex ratio data and relate the performance and efficiency of these two systems precisely, because data from multiple male systems are not available. However, some general observations can be made. The main advantage of large, multiple male systems is that the presence of one infertile male is unlikely to result in the loss of a whole year's production. Set against this are the often severely damaging territorial conflicts which occur between males when they are introduced to the enclosure. There is a high likelihood that only a few males are actually engaged in mating activities, the rest being maintained to no advantage. It is also difficult to follow and record the reproductive history of females in such large systems and management at the level of individual crocodiles is virtually impossible.

In small enclosures, one male may be sufficient for 20 females, but 6-10 are more usual and 8 is recommended. The females should all be of a similar size, with the male 20-40% bigger. Enclosures should be designed to give wild females 8-10 m2 water surface each, but farm-reared animals will be "happy" with half this space. A simple rectangular pool will suffice, but a moat-like configuration with an island is preferred. If the security fence is set 5-6 m back from the water so that burrowing animals cannot escape, the pools can be of simple earth construction. Concrete basins are acceptable, though expensive. The most efficient and cost-effective pens have been made by impounding small, natural drainage lines.

In small breeding groups, 90-100% of females can be expected to nest for 20 years, and possibly much more. Monitoring and individual management are easy and with good design, pools can be drained and refilled quickly should individuals need to be removed. The principal disadvantage is that a whole seasons production may be lost if a male is incompatible or otherwise non-viable. This occurs in about 10% of such groups, although the system allows rapid identification and replacement of these males.

The Estuarine crocodile. Estuarine crocodiles are solitary mound nesters, which in the wild rarely nest within sight of each other. Under captive conditions females may reach maturity (2.0-2.3 m) in 8 years, but it may take longer before larger clutches of viable eggs are produced. In addition to male territorality, females are also highly territorial and the "optimum" breeding system is a matter of conjecture and debate.

The two most common breeding systems used on crocodile farms are large communal pens, typically with multiple females and males in large ponds, and/or small breeding enclosures with 1 male and 1-5 females. In all cases it is "thought" that falling water levels prior to the nesting season restrict nesting, although definitive data are lacking. Similarly, it is "thought" that captive-raised adults are more tolerant and less territorial than their wild caught counterparts, although there are conflicting data.

The proportion of adult females that nest in large communal pens varies from year to year, and this may reflect general ambient weather conditions (the same variation occurs in the wild) as well as other factors (food, pen design, etc.). In some enclosures, with young, farm-raised adults, 90-100% of females have been reported to nest, although this is the exception rather than the rule. With time, and increasing sizes of the adults, this proportion seems to decrease significantly and in some communal pens it may reach only 20-30%. The quality of eggs laid is one of the main variables. In general, large communal pens probably give an average of 30% viable eggs, although it may be higher initially (especially with farm-raised stock) and greatly reduced with increasing adult age. Pen design, water quality, and food may be far more important than hitherto realized.

In small breeding groups, mixed results have been obtained. Once single pairs nest successfully, they appear to do so annually with large clutch sizes and high egg viability. Relatively small areas of water may be needed for each pair (20-30 m^2), and they appear to do better if shade and clean or circulated water are provided. In larger groups (1m:2f, 1m:3f ... 1m:5f), there has been much variation. Wild adults placed in such groups usually result in 1 or 2 "good" clutches, and often the females kill each other. With farm-raised stock, the situation is unclear. Pen design may be more important than is generally recognized, as some larger groups appear to settle well over time and give high numbers of hatchlings per female.

The "best" strategy depends partly on economics. Large enclosures with large numbers of males and females are generally cheaper to build and the losses due to poor egg quality over time may simply be a burden that has to be carried - if there are enough hatchlings produced, it may not matter. However, single pairs are perhaps the most reliable breeding system if pens are constructed wisely. The pens should be partly subdivided such that the male and female can separate from each other, they should be visually isolated from adjacent pens, have constant water levels and water at least 1.0-1.2 m deep. Single pairs fed fish appear to reproduce as successfully as those fed red meat or chicken.

The American alligator. The Amercian alligator is a solitary, mound nesting species. In the extreme southern and warmer portion of its range, age at sexual maturity for captive alligators reared in controlled environment chambers for the first 3 years of life, then placed in outside pens, is 5.8 years. However, good fertility, clutch size and hatcbling quality are rarely achieved before 8 years. Age at sexual maturity for wild alligators in Louisiana is 9.8 years, which is the same for captive alligators raised in semi-natural outdoor pens (without artificial heating); good fertility rates, clutch sizes and hatchling quality are not achieved in these animals until 13 years.

Environmental parameters vary considerably throughout the range of American alligators and play an important role in regulating the age of sexual maturity. In the extreme northern part of the range sexual maturity (1.8 m) takes 15 years for females and 18-19 years for males. The reduced age to maturity in captive alligators raised in controlled environment chambers reflects primarily the high and stable temperatures maintained. In the wild, the animals are exposed to temperatures with fluctuate greatly and are generally much lower.

Alligators of both sexes are territorial and usually wild females do not nest within sight of another nesting female. However, females raised totally in captivity are more tolerant of each other, can be stocked at higher densities, and are more reliable nesters (than wild-caught females brought into captivity). It is recommended that stocking densities should not exceed 2 females per acre with a sex ratio of 1m:3f. The proportion of young adult females that nest each year in large communal pens varies slightly from year to year, averaging 65-70%. The reproductive performance of wild-caught subadults raised in semi-natural breeding enclosures is now being compared with that of wild caught adults.

Diet can have a significant impact on alligator productivity. Alligators fed a diet of red meat consistently produce larger clutches and have higher nesting, fertility and hatching rates, than those fed fish. Nevertheless, production from alligators maintained in communal pens gradually declines with age, with up to a 50% decrease in nesting, fertility and hatching rates within 20 years. To enhance the productivity of middle-aged females, research is currently being directed at the source of stock (wild or captive-raised), stocking densities, stress levels, diet and pen designs, which include smaller pens containing single pairs (1m:1f).

Pen designs for single pairs should include deep open water for mating and isolation ponds for nesting, with adequate vegetation for both nesting material and cover. Preliminary results indicate higher nesting rates (compared to communal pens), but unacceptably low fertility and hatching rates.

Recent data indicate the normal diet of fresh or freshly frozen foods may be inadequate for breeders, and the development of a nutritionally complete, pelletized food for them is currently being researched.

Regardless of pen design and stocking rates, breeding pens should incorporate pumps that can supply adequate water on demand, especially during periods of prolonged drought. Breeding ponds should be at least 2 m deep, and be maintained at that level year round, and ideally increased during courtship (spring) to encourage breeding. If water is not added during droughts, an entire year's nesting effort may be lost. Rainfall and its related effects on accrued surface water influence the proportion of the total female population which nest each year: it is reduced when water levels are high or low. Perimeter fencing should be buried at least 15 cm into the ground to avoid tunnelling/burrowing and should be at least 1.8 m high, and 5-6 m from the waters' edge.

The Common caiman. Caimans appear to be one of the least territorial of crocodilians. To achieve efficient reproduction, wild-caught females should be 1.2-1.4 m, and males 1.6-1.9 m. Females should weight 4-12 kg and males not more than 24 kg. There is observable variation in the degree to which individuals adapt to their enclosed breeding pens, but the presence of some "well-adapted" animals seems to contribute to the settling down of others. Captive-raised female caiman can reach sexual maturity (1.0-1.2 m) in 2.8 years, which is appreciably shorter than any other known crocodilian species. Furthermore, captive-raised females settle and reproduce better than their wild-caught counterparts.

Caiman prefer to build their own nest, but will share their nest with other females if necessary. Each female needs 30-35 kg of dry vegetation to build a nest. From an economic standpoint, a sex ratio of 2f:1m results in the most efficient production (hatchlings produced per adult maintained). Ideally there should be 30 m^2 of pen space per adult.

Caiman breed well in captivity if provided with similar environmental conditions to those found in the wild - shade, high humidity and temperature (especially during the nesting season), irregularly shaped ponds and water depth to a maximum of 1.5 m. To simplify management, pen sizes no larger than 2500 m^2 are recommended, and these should ideally be composed of 70% land and 30% water, and contain about 80 animals.

4.2. Egg Management

Recent research has dramatically improved our knowledge of crocodilian eggs, embryos and optimal incubation environments, which has obvious application to crocodilian farming.

4.2.1 Egg Structure and Embryonic Development

The eggs of crocodilians vary in size (40-140 g), but all have a hard calcified shell attached to a fibrous eggshell membrane. Inside the eggshell membrane is the albumen (egg "white") and yolk: the yolk is itself enclosed within a very thin membrane (the vitelline membrane).

The calcified portion of the shell can appear smooth (most crocodilians) or rough (caimans), but always contains networks of fine pores passing through it. They may not be obvious to the naked eye, but the pores are vital for the transport of oxygen (in to the embryo) and carbon dioxide (out from the embryo). If an egg is placed under water, gas exchange ceases and the embryo dies. The pores are also sites through which water can be drawn into the egg, causing it to swell, or be lost from the egg through dehydration, often causing it to collapse. The incubation environment (see section 4.2.3) should be such that water losses and gains are minimal. Air spaces are not a normal feature of crocodilian eggs, and if present they indicate dehydration.

The yolk, surrounded by the vitelline membrane, is the central unit of an egg. It contains the vital embryonic material and most of the nutrients that will maintain the embryo. It starts as a small sphere in the ovary, and grows in size as food supplies are built up in it. When it is mature (large), the yolk/ova leaves the ovary and enters the oviduct (ovulation). Here it is fertilized and essentially packaged in albumen (which is the main water supply for the embryo), egg shell membrane (controls gas exchange) and the eggshell (water exchange and mechanical protection). The eggshell provides calcium and magnesium for embryonic bone development.

Clutch size and egg size vary within and between species. For example, in Australia, Estuarine crocodiles have a mean clutch size of 50 eggs, and a mean egg size of 113 g, whereas Australian freshwater crocodiles have a mean clutch size of 13 eggs with a mean egg size of 68 g. Hatchling size is related to egg size, such that the average Estuarine crocodile hatchling 64% of egg weight (72 g) and the average Australian Freshwater crocodile hatchling 62% of egg weight (42 g). Within a species, larger (older) females tend to lay larger eggs, which produce larger hatchlings.

Embryology and opaque banding of the shell. At the time of laying, the outside of the egg is covered with mucus from the oviduct. All eggs in a clutch contain embryos at about the same stage of development (about 4 mm long), which are attached to the inside of the vitelline membrane which surrounds the yolk. The ball of yolk swings (rotates) freely within the albumen if the egg is moved. At or about the time of laying, water from the albumen is drawn in by the embryo, and deposited within the yolk. Since this fluid is less dense than the surrounding yolk, it and the embryo (where the water enters) swing to the top, regardless of the orientation of the egg.

Within 24 h of laying, the albumen directly above the embryo is dehydrated and the embryo and part of the vitelline membrane becomes attached to the eggshell membrane. This dehydration affects the structure of the eggshell membrane, which in turn causes an opaque spot on the shell (at a site overlying the embryo). If eggs are rotated before the embryo adheres to the eggshell membrane, then the yolk will swing back and normal development occurs. However, after the embryo adheres (opaque spot forms), the yolk can no longer swing, and if the egg is inverted the embryo will remain at the bottom, under the yolk, and will die. Unlike most birds, crocodilians do not turn their eggs during incubation.

After the embryo is attached to the shell membrane (causing the opaque spot), albumen dehydration continues and more and more water is transported into the yolk, where it floats to the top, beneath the embryo. The dehydration is responsible for the opaque spot expanding to a band around the midpoint of the egg. It is within this band that the attached embryo grows initially. Later, the embryo develops a sac (allantois) in which it places waste products, and the outside surface of this sac becomes covered in blood vessels and extends out from what is now an opaque band, towards either end of the egg. At this time, the remainder of the egg becomes opaque. The development of the embryo and its membranes is thus mirrored, to some extent, by the pattern of opaque banding on the egg, and this can be used to distinguish eggs that cease developing.

Within the egg, the embryo also develops a yolk sac membrane (not to be confused with the vitelline membrane) which surrounds the yolk contents and transports nutrients into the embryo.

Infertile eggs do not band and rarely become infected; the yolk and albumen are both thought to contain important anti-microbial defences. When an infertile egg is opened the albumen appears uniformly translucent and the yolk is uniformly yellow. Eggs which have been fertilized, but died within the oviducts of the female, are very similar to infertile eggs: they almost never band and show minimal degradation during incubation.

Monitoring embryonic development. From a management point of view, it is important to be able to distinguish between good and bad quality eggs (a problem with adults) and and good and bad incubation (a problem with the incubation environment). It is thus important to be able to identify infertile eggs, or early embryonic deaths, before incubation starts. Some egg husbandry regimes involve the detection and removal of dead eggs during incubation, such that a complete inventory can be made of the problems - the age at which embryos died, etc.

The pattern of banding can be used as an approximate guide to embryo age. However, the rate at which the band forms can be affected by incubation temperature and humidity, and thus aberrations do occur. For example in very wet conditions the band may not complete. The band can be used to identify non-viable eggs (infertile and early embryonic deaths do not develop a band), to monitor continuing development of embryos (the band changes with time), and to isolate eggs within a clutch that have died (where the band remains constant relative to that in other eggs).

Candling can also be used to monitor embryonic development in crocodile eggs. With freshly laid eggs (before the opaque spot appears), a strong light behind the egg is sufficient to allow the extent of fluids in the yolk to be seen. If there is no fluid, the egg is infertile or an early embryonic death (i.e. died in the female's oviducts). Later, blood and blood vessels can sometimes be seen through the opaque area on the shell.

Assuming optimal incubation conditions, embryonic deaths usually show two peaks: one early and one late in incubation. Early deaths are thought to reflect a range of different problems, for example: nutritional deficiencies in the adults; stress of breeding adults; adverse incubation conditions prior to egg collection; and, mechanical damage when moving eggs. Late embryonic deaths typically occur when the embryo is maximizing growth and they appear to reflect an inability of the embryo to access the resources needed (oxygen, water and nutrients from the yolk) and assimilate them. In some cases they are embryos which have been compromised early in incubation by the factors listed above, but in other cases the reasons are unclear. Suboptimal incubation conditions (dehydration, too hot or cold, insufficient gas exchange) may not kill young embryos, whose resource needs are small, but may result in increased mortality when resource needs are greatly increased towards the end of incubation.

4.2.2. Handling and Transport.

Where possible, eggs should be collected and moved as soon as possible after laying - ideally within the first 24 h. At this time the embryo has not yet attached to the shell membrane (no opaque spot or band has formed), and thus there is no risk of orienting eggs with the embryo at the bottom. Eggs laid vertically in the nest (in which embryos sometimes develop abnormally) can be corrected (oriented horizontally); the embryo will reorient to the top. It allows total control over the complete incubation period, and if incubation conditions are stable, hatching will be synchronized. From a wildlife management point of view, early collection reduces losses to predators, desiccation, flooding, suboptimal temperatures and in crowded breeding pens, damage to the eggs by females nesting in mounds that already contain eggs.

Geographical and logistical circumstances often prevent egg collection on the day of laying. Eggs can be successfully collected and transported at any stage of development, although more care is needed at some stages. Embryos seem more sensitive to mechanical injury when approximately 8-12 days of age, although if reasonable care is taken to prevent sudden mechanical shocks, they too can be collected and transported successfully.

Regardless of embryo age, it is important to ensure that the eggs are not overheated (34°C) during collection and transportation. Temperatures around 30°C or less will not cause problems, whereas temperatures of 34°C or more are more likely to do so. It is always advisable to measure the temperature of the clutch (2-3 eggs deep) before collection, as high temperatures, on the day of laying or soon after, can be an important cause of mortality. Clearly, eggs should not be kept in dry, exposed positions where they are likely to dehydrate.

Eggs should be gently removed from the nest, preserving their orientation in the horizontal plane - a line from a pencil along the top of the egg will allow orientation to be maintained. If an opaque spot has developed, that spot should be directly above the embryo - if it is not, the egg should be oriented so that the spot is on the top. Concern has been expressed about using felt pens to write on eggs (it is felt that the solvents may affect the embryos), although many operators use them and to our knowledge there is no data indicating a link between their use and increased mortality.

Eggs can be packed in a variety of containers, but insulated ones may assist temperature control. Nesting media or vermiculite are usually packed around the eggs to prevent them rolling and to maintain temperature and humidity.

When preparing eggs for incubation, some operators neither wash nor examine the eggs closely. Others wash the eggs and remove all detritus and then write the details (clutch and egg number) on each egg. Both approaches give high success rates and are really a matter of choice.

4.2.3. Incubation

The incubation environment is extremely important. It influences the rate of embryonic development and growth, hatching time, embryonic mortality rate and sex. Furthermore, there is increasing evidence that the incubation conditions affect the later (after hatching) performance: growth rates, survival rates, and perhaps other attributes. In short, relatively minor fluctuations in the incubation environment may exert major long-lasting effects of commercial significance. The three major variables of the incubation environment are temperature, humidity and gas exchange.

Temperature. For most crocodilian species, eggs can be successfully incubated at constant temperatures between 30°C and 33°C; outside this range embryonic mortality increases markedly. Within the range, 32 ± 0.5°C is usually considered optimal for post-hatching growth, although with most species it will produce mainly males (see below). Although constant temperature incubation is usually recommended, and typically gives good results, there is room for more research. The results of fluctuating versus constant temperature need to be investigated. Furthermore, during the later stages of normal development in wild nests, temperatures commonly increase by 1-2°C due to the production of metabolic heat by the growing embryos. It is likely that such increases accelerate yolk utilization and embryonic growth, and perhaps facilitate hatching. There may well prove to be advantages in steadily increasing incubation temperatures during the last 2-3 weeks of incubation, although definitive research results are lacking. Some species, for example Australian Freshwater crocodiles, are subjected to steadily increasing incubation temperatures in the field, and higher hatch rates and hatchling quality are obtained with escalating rather than constant temperature incubation. However, this species appears to be the exception rather than the rule. Clearly, eggs incubated in nesting material within an incubator are subject to temperature increases from metabolic heat anyway (even though this may not be reflected in the temperature of the incubator air space), and increasing the incubation temperature may cause lethal limits to be reached.

All crocodilians have temperature-dependent sex determination. The basic pattern appears to be high and low temperature females (typically <31°C and >33°C), with a band of males in the middle (close to 100% at 32°C). Some species appear to lack high temperature females, or at least have the temperature inducing them 34°C or higher, which approaches lethal limits. Sex is known to be determined during the first half of embryonic development.

Total incubation time is highly correlated with incubation temperature. For example, Australian Freshwater crocodiles take 123 days to incubate at 28°C, 90 days at 30°C, 76 days at 32°C and 64 days at 34°C. This reflects the profound effects of temperature on embryonic growth rates, and these effects appear to endow the embryos with different potentials to grow after hatching. In general, the best growth rates are obtained at the temperatures which produce the highest percentage of males. From an evolutionary point of view, the mechanism appears to be one that allocates "maleness" to the embryos with the best potential of growing to a large size after hatching; i.e. small and large females may still be mated, but small males may contribute little if anything to the population.

Humidity and gases. Crocodilian eggs need to be incubated under conditions of high humidity (99+%), but should not be incubated in direct contact with water. Under low humidity conditions, dehydration occurs and will be first indicated by airspaces within the egg. They can be seen easily hy candling. Although some species can withstand significant (<20%) losses of water, it is highly likely that the embryos will be compromised. Extreme dehydration can cause grossly abnormal hatchlings, and even mild dehydration may affect the movement of minerals from the shell to the embryo, which may in turn affect hatching (it is thought that the shell may not be weakened enough). In contrast, if eggs are in direct contact with water, it will flow into the egg (especially during the second half of incubation). The egg will swell appreciably, causing longitudinal cracks in the shell, and sometimes the contents will burst through the shell membrane. Direct spray on eggs can cause beads of water over the egg, which can interfere with gas exchange through the pores.

In general, crocodilian embryos are tolerant of fairly high levels of carhon dioxide and low levels of oxygen, but they require more oxygen and increased rates of carbon dioxide loss during the last third of incubation when growth is maximized. At this time, embryos in eggs which are too wet often die or hatch prematurely (often with the yolk still external). Similarly, if incubation temperature is increased towards the end of incubation, gas exchange needs will be accelerated, and it may be necessary to pump more air into the incubator.

Incubators. An enormous variety of incubators are used successfully with crocodile eggs, and there is no single "ideal" system. In general, incubation in artificial nests is risky, because the incubation conditions cannot be easily controlled. Yet in Thailand, most eggs are incubated in nests or in holes in the ground, with the thermal environment monitored closely. In some cases the nests are constructed a specific distance above the water table, to maintain humidity.

Controlled temperature chambers are a common approach to egg incubation. These can be purchased or constructed in a variety of ways, as long as the optimum incubation environment can be maintained. Water-jacketed temperature cabinets are becoming more popular. If kept in a cool location, they only need a heating circuit to be able to maintain the desired incubation temperature. Fans and cooling circuits need to be evaluated carefully, as they may lower the humidity. Eggs are typically laid out on racks, and humidity is maintained by pumping air through a water reservoir within the incubator; i.e., temperature is maintained precisely and humidity and gas exchange are maximized.

Many farmers place eggs within some kind of moist nesting medium (sand, vegetation or vermiculite), within trays or boxes, which are then stored in large "walk-in" rooms. They may have warm water sprays on the inside to increase humidity and various mechanisms for controlling temperature. The advantage of such systems is that the eggs are buffered (in the boxes) from changes in both temperature and humidity, although rises in temperature due to metabolic heat are not controlled. A disadvantage is that eggs cannot be regularly inspected throughout incubation. Regular inspection allows the early detection, removal and examination of dead eggs, which in turn allows information on the age and perhaps cause of death to be established. Clearly, excessive or rough handling of eggs is to be avoided.

Record Keeping. Although incubation success and hatchling performance can be affected by incubation conditions, "clutch" effects (genetic effects) are very pronounced in crocodilians. By maintaining careful breeding and incubation records it may be possible to evaluate the performance of specific adults, and to determine whether they are above or below average. Good record keeping should ideally address both the male and females's reproductive success. It is widely recognized that "first" clutches (young females) contain high proportions of infertile or abnormal eggs, and that old females show a variety of anomalies. However, there is simply a paucity of information on the relationship between clutch characteristics and age for most species of crocodilians, regardless of the commercial implications of such data. Similarly, the reproductive performance of males has tended to be ignored, yet it is clearly a critical area for investigation and management. Detailed record keeping and analysis of all failed eggs are critical to an objective evaluation of reproductive success.

4.2.4. Hatching

The final stages of development involve the embryos drawing the remainder of the yolk (the residual yolk) into the body cavity. Once this is completed, embryos may begin making high pitched chirping noises from inside the egg. In the wild, these vocalizations stimulate the adult female to uncover the nest. In an incubator it is often stated that vocalizations from one nest can stimulate another to hatch prematurely, yet with at least some species this does not appear to occur.

Hatching is initiated by the fully developed embryo using its "egg tooth" (caruncle - a small calcareous outgrowth on the snout) to cut through the shell membrane and puncture ("pip") the egg-shell. This can be followed by a burst of activity in which the hatchling leaves the egg, or there can be a delay between pipping and hatching of at least a day. Unlike birds, crocodilians contain significant volumes of fluids in the egg (particularly those containing dissolved waste products), and at the time of hatching, these need to be accounted for (they shouldn't be allowed to drip all over eggs still developing).

Where eggs are incubated on racks, with even temperature, all eggs in a particular clutch can be expected to develop at the same rate. A pipped egg is usually removed and hatched by hand. Although a few individuals may pip early (when premature), once the majority of a clutch has hatched, any that have not pipped should be hatched by hand. Some individuals may have difficulty hatching and will die if not assisted (some evidence indicates such animals tend to perform poorly in any case).

Where incubated in holes in the ground, nests, or other situations where temperature gradients occur, or if eggs have been collected from the field late in development such that they have already been subject to such temperature gradients, hatching within a clutch may not be as highly synchronized (i.e. different eggs may have been developing at different rates).

During the rapid growth phase of development (last half of incubation), embryos are capable of making numerous adjustments to increase their chances of survival. For example, if resources are lacking (e.g. not enough oxygen) or are approaching critical limits (temperature too high), the embryo will start to complete its development early, and may hatch as a small animal with a large residual yolk. It has essentially "packed its bags and got out" before reaching conditions that would lead to its death." In contrast, at cooler temperatures (say 30°C), embryos may delay hatching, such that they hatch at a larger size, but with minimal amounts of residual yolk. At very low incubation temperatures (28-29°C), normal yolk utilisation is impaired, and many embryos die in the egg, still with external yolk. The residual yolk is a food supply used by the hatching during the first few weeks. Hatchlings with a large residual yolk should be kept at fairly high temperatures (34°C) to facilitate its absorption. Hatchlings with external yolk usually die.

4.3 Rearing

Whilst there is no standard way of raising crocodilians commercially, there are fundamental principles and biological details common to all species. Once new producers are aware of these principles they are advised to look at as many different farms as possible to see the range of designs that other farmers have devised around them. Limited research data suggest that features such as the size and shape of pens, and the amount and nature of light, are not inherently important to growth and survival. In contrast, hygiene or temperature control may be critically important. Much more research on the factors which influence raising success is needed, and until it is done, it is impossible to make definitive recommendations about production systems.

4.3.1. Basic Principles

Growth in terms of body mass should increase exponentially, and if it only increases linearly, it is usually a sign that something is not optimal. Food conversion rates decline as an animal grows, and thus the annual consumption of feed will increase markedly with time and increased body size. To make the most efficient use of food and restrict the number of pens required, most farmers try to grow crocodiles to skinning size in the shortest possible time, while minimising mortality. To achieve these goals, farmers have devised buildings and systems of management which meet the requirements dictated by four basic principles:

i. Good incubation and neonatal treatment.
ii. Maintenance of a high metabolic rate.
iii. Elimination of stress.
iv. Adequate nutrition.

Incubation and Neonatal Treatment. The conditions of incubation strongly influence subsequent growth and survival. Hatching and the treatment of neonatals in the first few weeks after hatching is also critical. Whether an animal will be large by 2 years of age can usually be quite accurately predicted within the first few months, and even weeks. Not enough controlled research has been done on neonatals, and tbeir treatment varies greatly between farms. However, good results are achieved where the hatchlings are always treated gently. Some farmers promote a 6-12 h rest period after hatching, at 32-34°C, either in dry or wet (shallow water) conditions, before transfer to the enclosures where they will be raised for the next few months. Others maintain them in the incubator for the first day or two. In general, hatchlings should immediately be subjected to the conditions they will experience later, and these should be unchanging.

Nile crocodiles, seem to prefer and benefit from slightly higher temperatures than older juveniles. Some farms successfully keep them at 34°C for the first 4-6 weeks, before dropping the temperature to between 30°C and 32°C. In other species (e.g. American alligators), increasing temperature immediately after hatching can lead to heat stress and disease. With Estuarine crocodiles, transferring hatchlings directly from the incubator to the raising pens at 32°C gives high survival and growth rates.

Hatchlings of American alligators seem to initiate feeding on dry rations or mixes of meat and/or fish within a few days of hatching, without any difficulty. Yet with other species, for example Nile crocodiles, hatchlings may need to be induced to live food (winged termites, tadpoles and small live fish have been used), to induce feeding. Movement of the prey seems to be the key element, and small pieces of meat and/or fish tbrown towards hatchlings will usually be snapped up. Once a few individuals are feeding keenly, the rest usually follow. Some farmers of Estuarine crocodiles and Common caimans introduce small feeding animals from the previous year ("starters") to "teach" the newborn how to feed. Animals which hatch with large reserves of yolk in a round and bulging belly are sometimes subjected to special treatment. With Nile crocodiles they appear to survive and grow better if kept in water at 34°C without feeding until they slim down, and with Common caimans they are maintained at the same temperature, oxygen and humidity environment at which the eggs were incubated. In both cases it may take over a week until they appear "normal" and are introduced into the hatchling pens.

The palatability of different foods and the way in which they affect hatchling growth appears to be variable between species and between clutches within the one species. In addition, the response to changing diets is variable. Red meat seems to be preferred, and seems to give superior growth to fish. With Nile crocodiles a change from fish to red meat is usually both easy and beneficial, whereas a change in the opposite direction can produce animals which refuse to eat and eventually die. In contrast, American alligators switch between diets with ease. In order to induce feeding some farmers keep neonatals in their clutches and offer them a variety of foods, some of which may be quite exotic and expensive, until they eat with relish. However, there may be problems when the farmer tries to change the diet to one which is commercially viable, including artificial rations, which are becoming more popular.

Maintaining a high metabolic rate. Under optimum conditions a hatchling crocodilian has a high metabolic rate, nearly half that of a man, while an adult's is less than one tenth as much. A high metabolic rate means a higb food requirement and rapid growth in terms of percent gain. The largest adult animals are incapable of rapid growth (i.e. percent increase in weight) under any circumstances, since they cannot supply much energy for the purpose. Temperature affects the metabolic rate of crocodilians and, by and large, their environment determines their temperature.

The marked improvement in the growth and survival of crocodilians held at temperatures between 30°C and 32°C over those kept only a degree or so cooler is well documented, as is the way in which temperature affects digestion, absorption and assimilation in these animals. Feeding at temperatures of 30 - 32°C produces the maximum metabolic rate in hatchlings of several species and a search for an exact optimum is unwarranted since it will vary between individuals depending on their clutch of origin and incubation temperature, amongst other things. However, the nature and degree of this variation do require investigation.

While the commercial benefits of a high metabolic rate in young crocodiles are accepted, there is some disagreement on the way that temperature should be used as a tool in production. Ecological studies of thermoregulation in crocodilians commonly refer to "preferred" temperatures and it is clear that wild animals deliberately vary their body temperature in response to their physiological state. Thus, a recently fed crocodile will try to raise its temperature to achieve its maximum metabolic rate and digestion, while a starved animal may try and lower its temperature to save energy. Sick or diseased animals may display behavioural fever. As a result of these observations, some people are of the opinion that farmed animals should be given a chance to thermoregulate within a thermal gradient. The more traditional approach is to maintain a constant ambient temperature at or near that which a healthy, recently fed animal would select.

Three pieces of information appear to support the second approach: firstly, crocodiles given a choice of temperatures do not seem to feed as frequently nor approach their maximum growth potential as closely as those held at the "optimum" for digestion; secondly, the ability to convert food into body tissue is affected by the frequency of feeding which, as noted, is highest at suitable constant temperatures; and thirdly, animals under these constant conditions are very resistant to disease, providing they are not otherwise stressed. There is, however, one problem with constant temperature culture. Although not well quantified, even temperature drops of short duration appear to have a pronounced effect on feeding and growth, which can continue even after the temperature has been rectified. To prevent fluctuations in temperature, and their adverse effects on feeding and growth, many farmers use preheated water for washing pens down and refilling them after cleaning.

It is rare to find natural climatic conditions which are ideal for the commercial rearing of crocodilians and even in the tropics farmers are usually more successful where their animals are kept in an artificial environment. Almost all farmers maintain such an environment, with high, constant temperatures, by keeping their animals in heated water. Although heating systems vary considerably, they usually involve considerable recurrent expenditure. To conserve energy, systems have been devised where animals are kept in shallow water in well insulated enclosures and such constraints have imparted a degree of similarity to farms around the world.

Eliminating stress. Every crocodilian farmer recognizes "stress". Commonly, the animals huddle in piles, are excitable and have reduced appetite. Avoiding stress is the farmer's perpetual problem. Stress, however, is often hard to explain and pin down. Obvious stimuli, such as inordinately high or fluctuating temperatures, dehydration, noise, movement and handling often result in obvious stress symptoms, such as piling. However, more subtle stresses, which often escape attention, can slow growth. It is known that inadequate individual space can be stressful, even though this is not obvious until considerable growth has been lost. Stocking densities are poorly understood. The interaction and relative importance of animal size, stocking rate, enclosure area and feeding space has received only cursory scientific investigation. Although relatively little information is available on stress in crocodilians, there is vast literature on stress in other animals, and the pathology appears to be broadly similar. Chronic stress induces changes in leucocyte counts and reduces immunity; it also results in raised levels of corticosterone (which promises, as in other animals, to be an indicator for quantifying stress).

To understand and avoid stress it helps to understand that stress may be pathological in captivity, but in nature it has a survival value. Predators feeding on hatchlings would normally do so with a flurry of activity and the piling response of young crocodilians to unusual noises and other factors probably enhances the chances of an individual avoiding being eaten. Stress is therefore something induced by perceived stimuli - something heard, seen, smelt or felt which acts as a switch. With care in raising, stress may never be switched on, but once on it cannot necessarily be switched off immediately by removing the stimulus. Thus avoidance is essential. Unfortunately, some stress is inevitable in any management system. For example, handling and grading can be very stressful, but so is the alternative situation where some individuals are allowed to dominate others in an enclosure.

A further complicating factor is possible intraspecific, geographic variation in the degree of wariness. For example Australian Freshwater crocodile hatchlings from some areas show little wariness and will readily expose themselves during daylight hours to feed, regardless of whether people are there or not. Hatchlings from other areas are extremely wary of exposing themselves in the daylight hours, or when people are present, and appear inherently more wary. [It is thought that such differences may reflect adaptations to long periods of Aboriginal hunting in some areas].

There are three principal approaches to coping with disturbance stress in commercial production. In the first, artificial screens are provided, often low over the water, to take advantage of the hatchling's natural desire to find cover, under which it feels secure. In the second, the animals are reared in the dark, isolated from many stimuli. In the third, the animals are acclimatized to disturbance through constant background music or other noise and activity. None of these options is well researched and all have been more appropriate and successful in some situations than others. It is relatively easy for farms in which the animals are held within enclosed, insulated chambers to exclude light and other external stimuli, and introduce constant noise. However, farms in the tropics, which use little energy, often find it cheaper to construct simple facilities without lids or roofs, and in these situations screens may be the only viable option.

Finally, successful farms all have a strict routine in which management activities such as feeding are consistent. In the extreme, a regime may require workers to wear the same colour overalls, enter the enclosures in the same place and clean in exactly the same way on every occasion!

Adequate nutrition. As in any intensively raised animal, nutritional deficiencies occur and can have significant effects on growth and mortality. At the extreme, animals may be under- or overfed, but more usually they are deficient in important dietary minerals and vitamins.

Information on the basic nutritional needs of crocodilians is only now being clarified, and the role of some components, for example fatty acids, is in need of further experimentation. However, the lack of definitive information on nutrition need not be a major constraint to commercial production - although it may well make it more efficient in the future. The bulk of the diet of wild crocodilians is animal protein, and providing adequate nutrition for captive animals can be a relatively simple matter of supplying fresh food, usually red meat, fish or chicken, with calcium and vitamin supplements. Growth on these diets can be equally good, and generally better than on fish which has been stored (frozen). However, there are often some individuals which refuse to eat fish and the conversion rate on a dry matter basis is lower than for red meats. Although not rigourously tested, conventional wisdom holds that fat in the diet is undesirable (it certainly has implications for cleaning and hygiene) and that carbohydrate and protein of vegetable origin is inefficiently used, unless precooked to break down cell walls. The latter assumptions are now under close scrutiny, because artificial rations with carbohydrate and vegetable protein, which are much cheaper than animal protein, are now working well with Amercian alligators, although recent trials indicate better performance with increasing quantities of animal protein (versus vegetable protein).

A typical juvenile crocodilian will consume about 15-20% of its body weight in food every week at a constant temperature of 30^{o}C-32^{o}C. However, in outdoor pens food consumption will vary greatly depending on ambient conditions and season. Overfeeding, especially with fatty foods, can result in excessive fat deposition and gout, especially if temperature is not adequately controlled. Crocodilians can go long periods without food, especially at low temperatures, but they can also turn to cannibalism if adequate food is not provided and especially if the animals are not graded on the basis of size.

The most common deficiencies are those associated with calcium, vitamin A and, in fish fed animals, vitamin E/selenium. Calcium is usually added at 1-2% by weight in a palatable form such as bone-meal. A standard vitamin supplement is widely used, but even in this, vitamin A is readily oxidized and degraded. Vitamin supplements should therefore be fresh and kept in a cool place.

Presentation is important. Hatchlings obviously cannot manipulate and swallow large particles of food, and thus they are usually fed ground, minced or chopped food. "Chunks" of food seem to be preferred, but cubing is labour intensive, and grinding/mincing is far more common. It also allows the efficient mixing of supplements.

Although nocturnal feeders in the wild, crocodilians in captivity can be trained to eat at any time. Most farmers feed at night and leave the animals in the polluted water all night; they clean the next morning. However, there appears to be interspecific differences in the degree to which they pollute the water. For example Estuarine crocodiles usually retreat into the water to feed, where ground/minced and artificial food breaks up easily and is lost. Australian Freshwater crocodiles, on the other hand, tend to consume more of their food on the land surface. With Nile crocodiles it is recommended to feed in the morning, so that the food can be left for about two hours before the enclosures are cleaned and fresh water added. Where they are housed in shallow, warm water (without land), the water is drained before feeding, although this approach is also used in some farms with land. Such a strategy maximizes the amount of food eaten (it is not lost in the water), but the food must be well spread out to avoid stressful scuffles, piling and injury. In colder climates the draining of water for a few hours can adversely affect the temperature of the pens, negatively impacting on both feeding and growth.

Feeding rate has not been well studied, but animals must be fed at regular, close intervals to maintain their maximum rate of digestion and assimilation. The duration of these intervals changes as an animal grows so that hatchlings are best fed once a day, but juveniles of 1.2 m every second day. Occasionally hatchlings are fed several times daily, and grow significantly better. However, the amount of food they eat rises out of proportion to the additional growth: under these conditions a 10% reduction in food may result in only a very small decrease in growth rate. Similarly, more regular feeding of large animals leads to an increased metabolic load such that both food conversion and growth actually decline.

4.3.2 Growth Rates, Survival and Age to Slaughter.

The economic success of a farm depends on survival rates and age at slaughter, which is a function of both growth rate and market factors. As noted above, both survival and growth rate are dependent on temperature and the way it affects the development of embryos and the metabolic rate of juveniles (and perhaps embryos). Crocodilians of all species will grow and survive well in a commercial farming situation if they are given a good start through incubation and are well fed and maintained in a stress-free environment with temperatures in the range 30°C-32°C.

Survival. Good data on survival are available from a number of crocodilian farming regions in the world. These can be analyzed to show levels of mortality amongst eggs during incubation, among hatchlings during their first year and among rearing stock: the three most natural divisions in the husbandry process.

Measures of incubation success are intimately linked to the quality of eggs, and the degree to which non-viable eggs are detected and identified. With wild collected eggs, if all dead eggs are examined to determine whether an embryo death occurred before or after collection, it is possible to assess precisely the incubation efficiency; it is possible to hatch 90-95% of viable eggs (eggs containing live embryos at the time incubation starts). It is also possible to identify clutches in which progressive mortality relates to conditions that occurred prior to collection. It must be remembered that in some areas wild eggs may also be compromised and there may be low percentages of viable eggs. With Nile crocodiles in Zimbabwe, 5-10% of eggs collected from the wild are usually discarded, and overall hatching success is in the range of 75-90% of all eggs found. With Estuarine crocodiles, 90-95% successful incubation of viable eggs may relate to 50-60% of all eggs found (there are high losses due to flooding and overheating). With Estuarine crocodiles in captivity, the overall hatch rate is markedly reduced (often to as low as 30% of all eggs) and there is often a poor hatch of apparently viable eggs (80%). In contrast, captive Common caimans have a fertility rate of about 75% and of these, an average of 92% hatch after efficient incubation.

Severely deformed embryos, together with those which hatched but died soon after are usually counted as incubation failures, although "hatched normal" and "hatched abnormal" can be used as separate criteria.

Hatchling mortality (up to one year of age) is typically maintained at 5% or less on farms which provide good control over the hatchling environment, with most species. There is typically an increase in mortality after a month or two, when runt animals succumb, then the mortality rate declines. However, many farms experience losses of between 50% and 100%, invariably due to a failing in environmental management - especially inadequate temperature control (too cool). However, even with good artificial environments severe mortality (10-25%) can occur due to stress-related disease (section 4.4). The cause of stress may be obvious (a response to disturbance or a change in routine) or subtle (such as nutritional deficiency).

Once crocodilians have reached about 0.7 m total length, which is often at 9-12 months, they are hardy and tolerate more variation in the management regime. Deaths after one year should be uncommon (0-2%) and, again, are usually stress-related.

Growth and age to slaughter. In a farming situation, growth (which is best defined as the synthesis of protein into body material) is commonly measured as total length. This is probably better than a measure of weight since animals fed high fat diets may put on weight without actually growing. Thus although weight is used to calculate food conversion, the results need to be interpreted cautiously. Growth rate is limited by the amount of energy available, which is a function of the crocodilian's metabolic rate. This in turn is determined by physical and biochemical constraints - the design of the animal - and it appears that for most crocodilians there is a maximum theoretical rate of growth of 4 mm per day. Even the most successful farmers have been unable to achieve this growth, but some get close with a very small number of fast-growing animals. With American alligators 2.5-3.0 mm per day gets animals to the 1.2 m size in a year. As a general observation, the best growth rates are often attained by farmers with a few hundred animals, rather than those trying to raise thousands.

With the larger species of crocodilians, an efficient farmer can expect to grow a significant portion (30-40%) of his animals to 0.9-1.0 m in 12 months and 1.3-1.4 m in 18 months. Some animals do much better, but the majority only reach 1.5 m in 24 months, or more. With Common caimans, similar growth rates are achieved but the economics of marketing the skins means that few if any farmers extend commercial raising longer than 18 months.

The age at which stock is slaughtered depends on a multitude of factors such as growth rate, but also market forces and the cost and availability of vital inputs. For example, a farm with access to few eggs but abundant cheap food, heating and space may opt to grow animals which are much larger than would be considered economic by a farmer who has a good supply of eggs, but limited or expensive food or space. However, in every main producing region farmers generally slaughter animals of 1.2-1.5 m or less. Beyond this size, the cost of production increases dramatically; very few farmers find it feasible to produce animals as large as 1.8-2.0 m. The main consumers of raw skin (Section 6) require some animals over 1.8 m to ensure that the full market is satisfied, but the present price structures do not provide the necessary incentives for farm production in this range. Clearly, with good stock control inefficient or non-productive breeding stock can be recognized and used to satisfy some of this demand.

Finally, when deciding upon size at slaughter, crocodilian farmers, must research any legal restrictions on size limits which may apply. Some countries have a maximum size limit on skins that can be exported, regardless of whether the skin originates from the wild or from a farm.

4.4. Disease

Crocodilians, like all animals, are subject to a variety of clinical disorders. Outbreaks of disease can cause high mortality, poor growth or a reduction in hide and meat quality, all of which can have a disastrous economic impact on a farming operation. It is a common and serious misconception that a disease problem is resolved simply by treatment with medications. Outbreaks of disease in crocodilians are almost always indicative of management errors that must be corrected if the disease is to be truly controlled. A thorough analysis of a disease problem has to look at what the disease is, when and where it originated, why it became a problem, which animals are affected, and how they were infected.

4.4.1. Disease and its Prevention.

Viruses, chlamydia (virus-like agents), bacteria, protozoa, fungi and helminth worms have all been isolated from crocodilians, and some of these infective agents are of great clinical significance in farming operations. Nutritional deficiencies, or occasionally excesses, may also cause disease.

The organ systems of the animal affected by disease may also be significant. For example, diseases affecting the skin can reduce the quality and value of the hide. Pox virus causes erosions of the skin and may additionally be associated with high hatchling mortality. A variety of bacterial and fungal organisms can also invade the skin, as can filarial nematodes which produce characteristic zigzag marking of the belly scales. Diseases of the liver and gastrointestinal system can cause massive mortality, or in less severe cases, result in poor growth rates. Generalized bacterial infection (septicaemia) by agents such as *Aeromonas*, *Salmonella* and *Edwardsiella* can also cause sudden death while pentastomes (a parasitic, worm-like arthropod) and bacteria can affect the respiratory system.

Identification of the specific disease causing agent will usually require professional assistance. Farmers should become familiar with appropriate veterinarians, pathologists or researchers, well before any crisis occurs.

Most crocodiles carry bacteria, and possibly other pathogens, which have the potential to cause disease under the right conditions. Another common source of infectious disease is via the introduction of new animals to an established farm population. Management should include facilities for quarantine and isolation of crocodilians from outside sources. Contaminated feed may also introduce disease to a farm. For example, poultry may be a source of *Salmonella*, and certain fish are intermediate hosts for nematode and pentastomid parasites. Water source and quality may also be critical, especially with hatchlings. Water taken from sources with resident wild crocodilians is considered by some to be a dangerous source of pathogens, some specific to crocodilians. Where there is any doubt about water quality, it should be purified.

Wild crocodilians appear to be hardy animals, relatively free of disease ("sick" animals are encountered rarely), which suggests that they have a particularly effective immune system (although this aspect of wild crocodilians has received little research attention - dead and diseased wild crocodilians may disappear rapidly). However when they are raised in captivity, it involves a totally unnatural environment, which in turn appears to affect both stress levels and the immune system: for example, increased population densities, altered environmental temperatures, different water and feed qualities, a variety of stress factors and general cleanliness. Deviations from the optimum environmental conditions and even deviations in cleaning routines or other management procedures, can result in stress, which generally weakens animals, causing reduced appetites and decreased resistance to disease. Evaluation and correction of improper environmental conditions is an essential component of disease control. Disease is also more likely with an unbalanced diet and/or in animals which have experienced suboptimal incubation.

Controlling the spread of infectious disease requires the identification, isolation and rapid treatment of all exposed animals. Rearing facilities with numerous small enclosures are therefore preferred over those with large pens. Disease is most prevalent amongst hatchlings and particular attention should be paid to all aspects of the management of this age group.

The warm, wet crocodilian rearing environment is ideal for the spread of pathogenic organisms. Once they are introduced, diseases may be spread if contaminated water as well as feed, equipment or footwear moves directly from one pen to another, or by the transfer of animals between enclosures. For proper disease control, facilities should be designed such that groups of animals form strictly isolated populations. Improper facilities in which water flows from pen to pen, or where personnel walk directly from pen to pen invite epidemics. Hygiene is critical. With Nile crocodiles it is recommended that pens be cleaned and rinsed after each feeding and that they be scrubbed with disinfectant at least once a week - once a day if food is particularly fatty. With American alligators and Estuarine crocodiles the water is usually changed after each feed but scrubbing with disinfectant is far less frequent. With Common caimans and most species, stringent hygiene tends to be applied to young hatchlings, but has been found to be less important once animals are established and growing.

4.4.2. Treatment

Many of the diseases of crocodilians can be treated with modern antibiotics, antifungal medications and parasiticides that are used for domestic poultry and livestock. Other diseases, especially viral diseases, cannot easily be treated and further research is needed especially in the development of vaccines. Some treatments may be administered in the water or in the feed. It is important to realize, however, that many other treatments must be administered to each animal individually, often for several days, and that the farm design must allow that this be accomplished efficiently. The specific treatments of choice will change with the development of new drugs and medications, and farm management should keep informed of current veterinarian practices. The best treatment is clearly prevention.

5. SLAUGHTER AND PROCESSING

The production of hide, meat and curios has become the central goal of crocodilian farms, even though many cater to tourism. The following section deals with the end products of commercial farming.

5.1 Humane Slaughter

There is international expectation that humane methods will always be used to slaughter crocodilians. These methods should give instant brain death, or at the very least immediate and complete unconsciousness of a crocodilian with the minimum of excitement and discomfort.

Both chemical and mechanical methods are available, but the use of lethal drugs is uncommon because they are expensive and may render the meat unfit for human consumption.

Mechanical stunning instruments, traditionally used in livestock slaughter, are not often used with crocodilians. The penetrating captive bolt and concussion mushroom are cumbersome and difficult to use without damage to the jaw skin. Of the two main mechanical methods which are used, shooting is capable of causing the minimum of disturbance and stress both to the individual and its colleagues. Usually a .22 short calibre, silenced rifle is used point-blank to destroy the brain from behind while the animal is still in its rearing enclosure. In some circumstances other crocodiles do not appear to notice that any management activity is taking place. A flat trajectory with entry at the post-occipital junction with the spinal column ensures that the skin below the jaw is not damaged and the skulls of such animals are still intact and of value as curios. In all cases the spinal cord should be severed once an animal is removed from the enclosure. The main disadvantage of this method is that some contamination of neck and jowl meat may occur due to bone splinters. It may also be of limited use in countries where firearms are prohibited.

The other mechanical method commonly used, the "nape-stab", involves the physical restraint of the crocodilian and usually its removal from the rearing enclosure. Wet, heavy material is placed over the animal's eyes and its head lowered in a downward position to extend the neck vertebrae. A sharp chisel-like implement is then quickly forced between the base of the skull and the first spinal vertebrae, severing the spinal cord. It is then essential that a rod of about 3 mm diameter (ideally stainless steel) be used to probe and totally destroy the brain (pithing), and it is an advantage to skinning (prevents local reflex actions) if the spinal column is destroyed similarly.

5.2 Skin Management

Although meat sales are increasingly important to some crocodilian farmers, the product of principal value remains the animal's hide for the exotic leather trade. Even a small skin of 17 cm belly width, destined for watch-strap manufacture, has a value higher than the hide of any traditional livestock animal. Care of the skin is therefore of paramount importance and some commonly used techniques, from skinning to transport, are described here.

Skinning. The majority of classic skins in trade present the belly whole, with high dorsal cut lines. An alternative, the horn-back, is produced by opening the skin at the belly. With both, the position and accuracy of the opening cut lines is critical. In some countries, sections of the opening cut lines are changed from time to time for law enforcement purposes.

Techniques of flaying vary from place to place and it is always best for new producers to learn the cut lines and other flaying techniques from an experienced skinner. However, there are some features of general importance. Only as many animals as the skinners can comfortably handle in three hours should ever be killed (where meat is to be produced this requirement will be even more restrictive). From killing onwards, every care must be taken to ensure that the skin is not mechanically damaged or contaminated with dirt or blood. The carcass should be bled in a cool, shaded place and washed before flaying. All flesh and fat must be removed by scraping, and sometimes with high pressure water jets, and the skin should be cured as quickly as possible.

One experienced person can flay an animal of 1.2 m in about 15 minutes, and comfortably complete 20 in a day. Thus, skinning an annual crop of 3000 skins will require roughly 150 man-days.

Curing. Until skins are chemically turned into leather they are subject to microbial deterioration. To preserve them prior to tanning, they are cured by dehydration which is best achieved through saturation with salt. Moist salt is either applied directly to the skin in a salt stack, or the skins are soaked in super-saturated brine solution.

When applied to the flesh surface of the skin, salt removes water and also dissolves and enters the tissue where it additionally retards bacterial growth. Skins kept in brine are well preserved, stay more pliable and may shrink less. However, damage occurs to all the skins if the salt is used up without the farmer noticing, and in any case they have to be drained and salted before packing and shipment. To build a salt stack, medium-grained moist salt, equivalent to about three times the weight of the skin, is rubbed into its flesh side. After about 48 h the small skins are well dehydrated and have stopped shrinking. They are then re-salted with a thin layer of fresh salt.

Tagging and grading. Soon, all crocodilian skins in trade will have to be tagged in terms of CITES regulations (see Section 1). These tags are the responsibility of the CITES Management Authority, but are commonly held and applied by farmers or farmers' associations. Tags for CITES purposes must be self locking and bear information on the country of origin, year of skinning and a unique serial number. They are usually applied to the tail and are generally left on during tanning.

Although practices are variable, and in some places governed by specific regulations, it is most convenient to tag skins before they are finally measured and graded so that measurements, grade and number can be recorded together in a packing list. However, skins are usually sold in distinct size classes and it is often necessary broadly to separate these before tagging and the final measuring exercise.

Grading standards vary, but in general classic skins have an area of prime importance known as the "pattern" and skins with a hole or serious scars or lesions in the pattern are down-graded to second quality with a 25% loss in value. More serious damage may lead to the third grade which loses a further 25% in value. In some countries skins have traditionally been measured by length, but since they are sold after tanning by belly width most farmers now prefer to sell their skins in the same way. They are measured across belly at a point approximately one third of the way down the hide between the inside edges of two prominent bony scutes.

Packing and storage. Skins must be packed in such a way that they can be stored and transported to tanneries without deterioration.

The best method of packing small, wet salted skins is to roll them tightly, starting from the head to the tail. The legs should be folded inward along the natural line of the body (there must he plenty of salt in the folded area). The tail, being outermost, protects the valuable pattern and allows the CITES tags or other identification marks to stay exposed. With large skins the side of the belly skin should also be folded in and the whole rolled skin held in place with twine or a rubber band. The rolled skins are then placed in clean, moist hessian sacks. These in turn may be stacked inside small wood or waterproofed crates.

Untanned skins should never be stored for long periods irrespective of the quality of curing. Well cured skins can he stored in the shade in salt stacks for several weeks provided they are kept moist, but chilling at 2-5^{o}C in a cold room is preferable. Sacks of rolled skins kept at these temperatures must again be kept moist to prevent dehydration.

Transportation. Given the relatively high value to weight ratio of crocodile skins, international transportation is best by air. The consignee and consignor's details are stencilled on the side of the boxes with details of the storage required. Insurance cover is essential. Full documentation, including detailed packing lists and CITES documentation should accompany each shipment.

5.3. Meat and Byproducts

The processing of crocodilian meat for human consumption almost always involves the farmer in strictly regulated abattoir management and additional responsibilities relating to packaging, labelling, shipping, and record keeping. Abattoirs must be constructed and operated according to health gnidelines laid down either within the country of production or, when export is planned, the proposed importing country. The regulations and requirements are usually particularly onerous where the meat is to be exported. Abattoir facilities are always costly to build, maintain and operate. The difficulty and expense involved in meeting the requirements of hygienic meat production, together with considerations of marketing, have prompted many producers to pool their resources into regional or group facilities to reduce costs and achieve a more dependable flow of meat products.

Approximate meat yields from a farmed crocodilian are as follows:

Live length (m)	Bone in weight (kg)	Fillet weight (kg)
0.9-1.2	0.8-3.0	0.4-1.5
1.2-1.4	2.7-6.8	1.4-3.4
1.4-1.5	4.5-11.0	2.3-5.5

Byproducts are important in some farming areas and are conveniently considered in two categories: curios/novelty items; and, ingredients for medicines and other products.

Novelty items such as heads, feet, teeth and claws and back-strips are commonly retailed as curios by farms which entertain tourists, but are usually sold in bulk by the farmer in the first place since the process of turning these items into a marketable form is involved and best handled by another party. Raw ingredients such as glands, bile and fat are used in medical research or as ingredients in other products. Those items which are to be used for medical research must usually be prepared in at least the same environment as that used for meat processing.

6. MARKETING OF PRODUCTS

Meat is the most important byproduct and can add significant value to the total return on the hide. For example, in 1991 when skin values declined, meat contributed 35-40% of the total value of small (1.2 m), farm-raised Amercian alligators. Other by-products like skulls and teeth, which provide occasional opportunities for sales, are not generally consistent income earners. There may also be opportunities for farms to sell live animals to other farms as rearing or breeding stock.

Prices vary widely on all farm products. Factors of importance are the species involved, the size and quality of hides, the proximity to developed wholesale meat markets, annual production of eggs and hatchlings from ranching or captive production and competitive demand for rearing or breeding stock. However, hy far the most important factor is the demand for skins which is fickle and poorly understood.

6.1 Skins/Leather

Although crocodilian leather has been used in various parts of the world for generations, it was during the period 1945-1960 that trade in crocodilian skins reached its peak. Over 3 million wild-taken skins were marketed each year. Then, as today, this trade was divided into two broad categories: low value, high volume caiman skins; and, high value, low volume classic skins.

South American caimans have always provided the bulk of crocodilian skins in trade. Caimans have a strongly ossified belly skin and traditionally only the soft sides, or flanks, entered trade. These have been used to produce belts, shoes and other less valuable items. During the 1950's and 1960's eight million skins of all sizes, including flanks may have been traded annually. By 1984 this had been reduced to less than one million. Today, an increasing number of caiman farms are using captive breeding and ranching to produce the skins of small caimans, destined for the less expensive more popular finished products. Some of these farms are designed to raise large numbers of animals (50,000 plus), which may well be essential for commercial viability.

Until recently, farming was generally restricted to classic species - crocodilians whose belly skins had minor or no ossification. The whole belly skin of these animals can be used to produce high quality (and value) leather goods, but even within the classics there is a hierarchy of value. Traditionally, the trade favours the Estuarine crocodile ("Singapore small-scale"), paying a 20% premium over the Nile crocodile, commonly known as "Croco Afrique", which in turn is valued 10-20% higher than the Amercian alligator and the New Guinea freshwater crocodile. Today, more than 90% of all the classic crocodilian hides produced are from Australia, Indonesia, Papua New Guinea, the United States and Zimbabwe.

It is believed that the level of trade in classics in the 1950's and 1960's may have reached 500,000 skins per annum, but later estimates suggest that this had decreased to 300,000 by the early 1970's and to 150,000 by 1984. It was still about 150,000 skins in 1989, though the composition of the trade was changing dramatically. Wild-taken skins were declining, whereas farm-raised skins were increasing by about 50,000 per annum. As wild skins have been taken out of trade due to conservation programs, farming has prospered. To some extent this has been self perpetuating since the increased legal supply has stimulated the trade and encouraged a resurgence of fashion based on crocodilian leather.

A very important factor affecting the resurgence in classic crocodilian skin production has been the number of specialist tanners, which has declined markedly since 1970. There are now only about 12 tanneries, in Europe, Japan and the USA, which can produce high quality crocodile leather. Of these, a few French and Italian tanners dominate by virtue of both capacity and quality - they handle 80% of the world's produce. Not surprisingly, tanners are in a strong position and those in Europe themselves trade in raw and finished skins. Producers of any significant size usually sell to them direct. Japanese tanners do not buy skins, but rely on Japanese trading houses to bring in business through contract tanning. Finished leather is sold to high-class manufacturers, and again these are principally European. Ultimately, the whole business depends on fashion and while the increased production of classics has stimulated the fashion industry to revive and promote crocodilian products, an oversupply of farm skins has resulted.

Farm-raised hides are generally harvested and marketed after rearing from 1-3 years, depending on the farmer's facilities, operating capital and marketing strategy (see section 4.3). Generally, skins from 1-3 years-old rearing stock from controlled environments will have belly widths between 15 and 45 cm, and they will be sold in size groups of 15-24 cm, 25-29 cm, 30-34 cm, 35-39 cm and 40 cm+. Smaller skins are generally used for small leather goods like wallets, watchbands and shoes. Mid-range sizes are primarily used for handbags and belts, while larger sizes are traditionally used for boots, briefcases and luggage. Price increases of 10 to 15% between size classes are common, and since most farm hides are small, there is generally a more substantial increase in price for skins over 40 cm.

Crocodilian hides are normally offered for sale on the basis of negotiated or bid prices either by individual farmers or through farms marketing cooperatively. A standard method of measuring and grading hides is generally used to ensure a fair market price between buyer and seller.

There is increasing support through international cooperation of producing countries, trade groups and individual companies to promote farmed crocodilian leather. Retailers and customers are informed that farmed crocodilian skins are not illegal. To complement this approach, the farming of crocodilians is strictly regulated to ensure that conservation advantages accrue.

6.2 Meat

The most developed market for meat is in the USA where alligator is usually marketed directly to restaurants or through seafood distributors. Tail and body meat, which is considered the best quality, is usually sold separately to leg meat. Meat is often cubed (tenderized) and sold frozen in 2.3 kg (5 lb) seafood cartons. Markets for ribs or ground meat also exist, but are not as well developed.

In all parts of the world, most meat ends up in restaurants often offered as an appetizer or entree either fried or sauteed, though many recipes for veal or chicken adapt well to crocodilian meat. Cookbooks and promotional brochures with recipes and tips on handling and preparing meat are commonly published as marketing and promotional tools.

7. ECONOMICS

The commercial viability of crocodilian farming depends on many factors, especially species, market trends and management. A crocodilian farm which does not include tourist facilities, will usually have a lag time of at least 3 years before income is received. If the farm is based on captive breeding, and juvenile stock have been purchased to be grown out to breeders, then this lag time will be appreciably greater. The most successful farms commercially are commonly those with a significant number of paying visitors or those which are integrated with some other income generating business.

Prospective crocodilian farmers are advised to prepare a detailed and realistic business plan for the venture, and seek professional advice at an early stage. This section examines the most important factors upon which economic success and failure are usually based.

7.1 Sources of Revenue

The purpose of a crocodilian farm is to generate sufficient income from hides and other crocodilian products, to make a profitable return on the investment. Farm income is commonly derived from a combination of live sales, skins, meat, other byproducts and tourism.

Skins are the major product (Section 6). It is usually possihle to plan stock numbers and output reasonably precisely, and with knowledge of the particular species' value, realistic projections of the major source of income are usually possible. Crocodilian meat, skulls, back straps, teeth, feet and internal organs all have a value, but it typically contributes in only a minor way to total income.

Farms generate interest in crocodilians and their conservation and, in the right location, tourism can make a very significant contribution to farm income. A word of caution - developing the farm to accommodate visitors will incur significant additional expenses and will have a cost in terms of animal stress and production. It is therefore recommended to open only part of a farm to visitors.

7.2 Key Cost Factors

Economic analyses spanning a range of circumstances identify a number of key cost factors: effects of location; capital outlay; stock supply and costs; food supply and cost; labour; and heating costs.

The importance of location cannot be over stressed. In general, the farm should be established where food supplies, power, water and other services are readily available, and crocodilians should be moved to the farm, and not vice-versa. Supplies and services may not seem important initially, but as the farm develops so do its service requirements. A remote location is to be avoided. However, crocodile farms situated too close to urban centres may face a different set of problems including security, expensive land, and problems of effluent disposal.

The capital outlay in setting up a crocodilian farm varies greatly from place to place. In some developing countries building materials and costs are low, while vehicles and freezer equipment are imported at high cost. Farms which are added to an existing infrastructure avoid the costs of land and its development. Capital expenditure is not usually the factor which determines a farm's success or failure in a developing country, though it often does in the developed world.

Amongst recurrent costs, the most significant are usually stock, food and labour, though remote farms may suffer inordinately high transport and power costs. Stock costs may be very low or very high depending on demand and on whether the farmer has to buy in a competitive situation. Generally, the cost of a hatchling is less than 30% of the value of the skin of a one-year-old. Food and management/labour tend to be more significant overheads. The most successful farms have inexpensive, even free food. On many others food is the pivotal factor in profitability. Labour is not usually expensive in developing countries, but the cost of management commonly makes up for this. Elsewhere, farms are mechanized and organized to run with minimum staff - though skinning expertise is impossible to avoid. In cool climates, heating can be a major expense.

It appears to be every farmer's experience that:

i) it takes longer than planned to establish a farm;
ii) it costs more than planned to establish a farm;
iii) returns are lower than planned.

Despite the above words of caution, crocodile farming does have the potential to be a viable and rewarding enterprise.

GLOSSARY OF TERMS

Albumen. The clear mucus-like substance surrounding the yolk in bird and reptile eggs - the egg "white".

Alligator. The American alligator, *Alligator mississippiensis.*

Appendix I. A schedule of species on CITES which are threatened with extinction, and are generally banned from commercial international trade, unless bred in captivity.

Appendix II. A schedule of species on CITES which may become threatened with extinction unless international trade is regulated. Export permits must be obtained before international trade may take place. All crocodilians which are not in Appendix I are in Appendix II.

Behavioural fever. If "sick", crocodilians may increase their body temperature above normal levels by basking for longer periods.

Bred in captivity. Defined in CITES Resolution Conf. 2.12 as "born or otherwise raised in a controlled environment, ... of parents that mated ... in a controlled environment". For crocodilians, this means offspring that hatched from eggs laid in captivity.

Candling. Where a strong light is applied to the surface of an egg in a darkened area, some details of the inside of the egg can be seen. It is very important that a strong light he used, but care needs to be exercised so that egg temperature does not increase above critical levels.

Caiman. South American members of the subfamily Alligatorinae (six species in three genera). Sometimes used only to refer specifically to members of the genus *Caiman.*

Captive-breeding. Producing captive-bred offspring (see "bred in captivity"). To qualify for exemption from the CITES ban on commercial trade in Appendix I species, a captive-breeding operation must be managed in a manner designed to maintain the breeding stock indefinitely and which has been demonstrated to be capable of reliably producing F2 generation offspring.

CITES. "Convention on International Trade in Endangered Species of Wild Fauna and Flora", concluded in Washington in 1973.

Classic skin. Crocodilian skin with unossified or poorly ossified belly scales. These skins command the highest price, and generally come from the genera *Crocodylus* and *Alligator.* The principal classics in trade are the Estuarine or Saltwater crocodile, the Nile crocodile, the American alligator and the New Guinea Freshwater crocodile.

Common caiman. Caiman crocodilus crocodilus and/or C. c. fuscus, which are found in Central and South America.

Controlled environment. An environment intensively manipulated by man, and designed to prevent animals entering or leaving.

Crocodilian. Members of the Order Crocodylia, comprising all members of the subfamilies Alligatorinae, Crocodilinae and Gavialinae.

Estuarine crocodile. Also known as the Saltwater crocodile, *Crocodylus porosus*.

F1 generation. The first generation bred in captivity; i.e. the offspring of parents collected from the wild.

F2 generation. The second generation bred in captivity; i.e. the offspring, both of whose parents were bred in captivity (F1 generation).

Farming. This term is not defined by CITES, but is often taken to refer to any operation raising (wild) animals in captivity. It thus includes both captive-breeding and ranching operations.

Hatchling. Usually refers to a crocodilian in its first year of life.

Management Authority. The government authority designated within each country as being responsible for administering CITES, including the issuance of export permits.

Metabolic rate. The rate of metabolism as determined by the amount of food consumed, heat produced or oxygen utilized.

Metabolism. The chemical or energy changes which occur within a living organism or a part of it which are involved in various life activities.

Mugger. A crocodile found in India, *Crocodylus palustris*.

Neonatal. Newly born or recently hatched.

New Guinea Freshwater crocodile. A crocodile of Papua New Guinea and Irian Jaya, *Crocodylus novaeguineae*, which appears to include two distinct races.

Nile crocodile. A crocodile found in Africa, *Crocodylus niloticus*.

Post-occipital. Behind the head. Post-occipital scutes refer to a row of enlarged scales immediately behind the head.

Quota system. Export quota system drawn up by CITES in 1985 under which species listed in Appendix I can be transferred to Appendix II subject to export quotas, controlled by CITES Resolutions Conf. 5.21 and 7.14.

Ranching. Ranching crocodilians involves collecting eggs or hatchlings from the wild and rearing them until they are large enough to sell. Defined in CITES Resolution Conf. 3.15 as "the rearing in a controlled environment of specimens taken from the wild". Under the terms of this Resolution populations of species listed in Appendix I can be transferred to Appendix II, subject to strict regulations.

Sustainable utilization. A level and frequency of harvest of a population that can be compensated for by the population and can thus continue indefinitely.

Thermoregulation. The regulation of body temperature. In crocodilians and all other reptiles this is achieved by behavioural means; e.g. basking in the sun, seeking shade or cool water.

FURTHER READING

There is a vast literature on crocodilians, which covers various aspects of their biology, conservation, management and farming. Some early publications have been superceded by new information, although others have not.

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SUSTAINABLE USE OF CROCODILIANS - CONSERVATION BENEFITS

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Introduction

Effective conservation of global biological resources requires a variety of strategies, tailored to suit the diverse range of cultural and socio-economic environments that prevail throughout the world. The conventional approach of applying total protection to wildlife and acquiring areas of habitat for dedication as national parks or nature reserves, is becoming increasingly less available in many parts of the world. Furthermore, such strategies may have little or no application in countries with policies directed towards the use of national resources to enhance economic development. Arguably this approach, while being feasible in past years, has less relevance today when many governments are under increasing pressure to use resources for economic development. Indeed, the initial cost of acquiring land and the subsequent on-going costs of management of such lands may represent an unacceptable expenditure of public funds.

Many governments, particularly those of developing countries, are adopting the alternative approach of recognising their wildlife as a renewable resource and a national asset to be utilised sustainably for conservation and economic development. This strategy provides a practical and increasingly acceptable complementary approach to protected area management. In doing so, an economic value is conferred on particular species, their habitat and other species dependent on the same habitat. Wildlife that was formerly regarded as a competitor with agriculture or predatory pest of livestock becomes perceived as a resource worth retaining. Previously "unproductive" wildlife habitat similarly becomes perceived as an asset. As an alternative to alienating rural communities, this approach provides a foundation for changing perceptions and creates incentives, among landowners, rural and indigenous communities who derive a living from the land, to conserve wildlife outside protected areas.

Crocodilians and other wild species exhibiting density dependent mortalities and other life cycle characteristics, can be managed to facilitate their sustainable use with no detriment to the long-term conservation of the wild resource. Most crocodilians exhibit an additional characteristic which mitigates against their conservation by the traditional approach of total protection. Some crocodilians compete with humans for certain resources and reduce the productivity of particular enterprises such as fisheries and agriculture. In extreme cases some species are predatory on humans and their life styles.

Historical Background

Crocodilians have been used by man for centuries either as protein or, in more recent times, for their skins as a source of revenue. In the past, exploitation of crocodilians was directed principally to obtaining as many skins as possible by the most efficient means available. This practice had the obvious result of depleting most wild populations. Species which possessed commercially superior skins were hunted more intensively. Populations of these species were depleted to a much greater extent than those with less valuable skins.

Following a resolution adopted at the 1972 UNCED meeting in Stockholm, a Plenipotentiary Conference was held in Washington DC in 1973 to conclude the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). At this time there was considerable concern that the wild crocodilian resource was unable to sustain the level of international skin trade had been experienced. As a consequence, all species of crocodiles and alligators were listed in either Appendix I or Appendix II to CITES at the Washington Conference. Parties to CITES have agreed to cooperate, by applying appropriate reciprocal trade controls, to curb the rate at which some species of crocodilians were harvested for the international skin trade.

Although there have been amendments to the specific listings of crocodilians on the Appendices to CITES since the 1973 Washington Conference, no species has been removed from the Appendices and all species continue to be subject to the provisions of the Convention.

During the twenty years of its implementation, CITES has undoubtedly been a positive force in contributing to efforts to conserve wild populations of crocodilians. Species considered in 1973 to be in danger of imminent extinction were listed in Appendix I and commercial trade in wild-harvested specimens was prohibited. During the early formative years of CITES, species were transferred to Appendix I in order to cease international trade in wild-caught specimens. These Appendix I species became the focus of research designed to provide the basis of managing them as a renewable resource according to the requirements of an Appendix II-listed species. As a result, species (or populations thereof) have been transferred to Appendix II from Appendix I to permit regulated international trade.

The Convention provides for commercial trade in specimens of Appendix I species which represent the progeny of closed system captive breeding operations on the basis that such trade can be conducted in isolation of the wild population. The affect of this management prescription has been to remove pressure from the wild resource to enhance its potential for recovery.

In 1981 the Third Meeting of the Conference of the Parties to the Convention acknowledged that some species of wildlife (or populations thereof) can benefit from being managed for commercial purposes. Resolution Conference 3.15 was adopted that enabled Appendix I species (or populations thereof) to be managed by "ranching". To achieve the support of Parties to CITES for this form of management, proponent Parties are required to satisfy particular criteria including demonstration that commercial ranching confers a conservation benefit on the wild resource. Although written to apply generally to certain Appendix I species, in practice this resolution has been applied exclusively to crocodilians to permit eggs and/or juveniles, life stages which exhibit high natural mortalities, to be harvested and grown under controlled conditions for their skins.

The captive breeding and ranching provisions of CITES have been adapted and extended to apply for species of crocodilians (eg *Alligator mississippiensis* and *Caiman crocodilus*)for which they were never initially intended. Species such as the North American Alligator and the Spectacled Caiman which have abundant wild populations are more appropriately managed by implementing sustainable wild harvests whereby harvest benefits are distributed more evenly among rural and indigenous communities situated in crocodilian habitat.

Additional resolutions have been adopted by Parties which further "freed up" the ability of government agencies to develop and apply strategies to manage crocodiles and alligators for sustainable commercial use thus enhancing incentives to conserve the wild resource. The introduction of annual export quotas for *Crocodylus niloticus* and the Indonesian population of *Crocodylus porosus* was designed specifically to provide for continued use of the wild resource during the formulation of more long-term ranching programs.

Present Situation

There is little doubt that the controlled commercial use of crocodiles and alligators has generally been beneficial to the conservation of wild populations. The extent and nature of benefits differ depending on the species, country and the form of management.

In addressing and evaluating the benefits of sustainable use of crocodilians, it is necessary to clarify and define the term "sustainable use". For the purpose of this presentation, sustainable use of a wild species implies a regime of wild harvest conducted *ad infinitum* with no detriment to the long-term conservation of the wild resource which contributes to the economic development of rural communities.

Ranching, as developed and applied by CITES, by definition imposes a regime of commercial use that is sustainable by the wild resource. Management that involves the removal of non-juvenile animals from the wild must be based on more extensive and robust data sets to ensure that harvest strategies and intensities are sustainable by the wild resource. Annual harvest quotas provide a mechanism for authorities to administer wild harvests and monitor the impact of such cropping on the wild population. Harvest quotas should represent that percentage of a population which can be removed without adversely affecting the capacity of the species to fulfil its functional role as a component of the ecosystem. Harvest quotas should be determined according to biological and ecological principles. It is essential that the process of quota determination is transparent and not driven by or perceived to be dictated by market demands.

Closed system captive breeding, as a conservation strategy should be confined to species, numbers of which in the wild are critically low rendering the species in imminent danger of extinction. Once it can be demonstrated that a wild population is capable of sustaining a limited off-take of eggs and/or juveniles, captive breeding has little or no application in further conserving the wild resource. Commercial operations undertake captive breeding for primarily commercial purposes to maximise skin production. Farms involved in ranching supplement the number of on-farm animals by captive breeding to ensure continuity of stock for slaughter and use in the skin trade. Under these circumstances, captive breeding is unrelated to the status of the wild resource, and thus confers little or no conservation benefit on the wild population. As such, captive breeding does not constitute sustainable use of a species.

What then are the benefits that accrue from the sustainable use of wild crocodilians? Crocodiles, alligators and their kin are used for their skins, flesh, organs and other parts. They may be used in the live animal pet trade; display at wildlife parks and zoological gardens or as trophy animals taken by clients of safari operations.

Operations located in crocodilian habitat, operated by or in association with rural communities, which rely on the wild population as a source of stock confer greater conservation benefits on the wild resource and its habitat than large scale commercial enterprises which are located away from the wild resource and derive stock principally from captive breeding.

The presence of crocodiles and alligators in their native wetlands not only preserves the ecological integrity of these ecosystems but also benefits local economies through eco-tourism by providing tour operators with spectacular animals for clients to view in relative comfort and safety. The multitude of support industries which service the tourism therefore benefit in direct proportion. However, because of the need to invest in essential infrastructure to cater for tourists, the short term economic benefits of eco-tourism are less in undeveloped remote areas. In some regions the potential for crocodiles and alligators to be attractions for game viewing is minimal when compared with other more "popular" wildlife available for viewing. As a conservation tool, eco-tourism is perceived by some agencies as a consequential luxury of, or secondary to, the immediate economic returns gained from the more direct consumptive use of wildlife. This is particularly applicable in developing countries which may not possess the resources to establish the necessary infrastructure for tourism. Such use of wildlife is an attractive management option for first world countries capable of funding tourist operations from revenue derived from utilising other natural resources.

Large males, particularly solitary, post-reproductive animals, represent a component of the population that can be removed with little or no effect on the intrinsic capacity of the population for recruitment. In Australia the removal of these animals is undertaken by government officers or licensed agents in the interests of public safety. The cost of removal is very often expensive and the animals are made available to crocodile farms. Such animals are rarely good farm stock, often damaging enclosures and injuring, sometimes killing, highly valued reproductive females. A preferable management option is to use these animals as trophies for licensed safari operations or as live animal exhibits in zoological gardens of wildlife parks. Relatively few animals are removed from the population. The method of removal is selective and has minimal impact on the population. The unit value of animals used as trophy specimens or as live exhibits is several orders of magnitude greater than their skin equivalent particularly during times when the skin market is depressed. Furthermore, the benefits of this approach to management are more spread more widely within the community.

Consumptive use in the form of safari hunting has very obvious advantages when considered in the context of crocodilian conservation management. Continued recovery of crocodilians, particularly species widely recognised as dangerous to humans, requires government management agencies to employ a range of strategies to enhance the broadest possible benefits to communities resident in areas frequented by crocodiles. Although similar values may be realised by using large crocodiles as live exhibits or as trophy animals, the attendant costs of using such animals for live exhibits are generally higher. The logistic difficulties associated with handling and transporting large, fragile animals - often from remote locations, preclude use of this strategy in all but a few instances.

Provided the levels of use remain within the capacity of the wild resource to sustain, enhanced long-term conservation of wild crocodilians will accrue from the commercial use of the wild resource. Commercial use without being subject to a management program which integrates elements of public education and awareness, research and conservation will do little more than deplete the resource and provide a means of returning to the conditions which prevailed in many parts of the world in the mid 1900s. When crocodiles are perceived as an economic asset by the public which has to co-exist with the species, political administrations become sympathetic to conserving the wild resource. Without this public support, there is no incentive for governments to foster research and develop conservation programs. The political sensitivities of conserving a species which is known to be dangerous to public safety can be discounted against the economic benefits deriving from retaining and utilising the wild resource. Clearly management strategies which are practical and capable of being implemented and which achieve broad based benefits to communities are likely to be more attractive politically.

The approach that crocodile farming has taken over the last 10-20 years while being appropriate for some species in some countries may not, when used broadly, be compatible with the sustainable use of some wild crocodilian resources. In many countries crocodile farming has become the provenance of wealthy businesses which possess the necessary financial resources to establish operations. Because of the necessity of deriving a profit from each operation, large commercial operations cannot rely on annual harvests of eggs and juveniles for their operations. Thus, the wild-harvested stock must be supplemented by on-farm captive-breeding.

The increasing number of successful programs involving the sustainable use of crocodilians and the manner in which IUCN, CITES and other international organisations have embraced the principles of sustainable use of wildlife is clear demonstration of the emerging role that regulated commercial trade has in conserving wild crocodilians.

The present operation of the IUCN/SSC Crocodile Specialist Group is evidence of the increasing international recognition of the importance of legitimate trade in facilitating open dialogue between industry representatives and resource managers. This relationship of trust is having a positive influence in establishing trade regimes which are sustainable by the wild resource and contribute to conservation of wild crocodilians and their habitats.

Directions and Prospects for the Future

In hindsight, the promotion of commercial farming and ranching of crocodilians as an effective tool for conserving the wild resource, because of its potential to over-supply the international market, has the potential of impacting negatively on conservation of wild crocodilians.

Ironically the commercial character of crocodile skins, one of the most important factors that contributed to their decline and the initial driving force for promoting the present strategy, may not be sustainable. An over-supply of skins onto the world market has undermined maintaining a high unit value for crocodile skins. Accordingly, many farming operations, particularly those which are inefficient and experience high production costs are no longer profitable. Many have scaled back production and the sale of less valuable skins while others have ceased operation altogether. This may be beneficial in the long term. However it does little to engender continued government support for commercial use programs. Clearly there is a need to differentiate between products derived form wild-harvested animals and those resulting from on-farm production. This requires a fundamental shift from current marketing practices which promote greater public acceptance of a product derived from an operation isolated from the wild population. This approach has been tailored specifically to respond to increasing pressure, in recent years, from the environmental lobby to restrict the commercial use of wildlife to products derived from captive breeding operations. If this policy is maintained there is considerable risk in devaluing the wild crocodilians to a point where there is no longer sufficient public support for their conservation.

Commercial operations which became established based on species which were listed on Appendix I of CITES were necessarily restricted to closed-system captive breeding. These operations contributed to enhancing the recovery of Appendix I crocodilians by providing a focus for promoting increased public awareness of crocodiles and stimulating greater government attention to effective management of wild crocodilians. Such establishments should not penalised by the improved conservation status of the species or populations of a species formerly included in Appendix I of CITES, which may permit more flexible approaches to be taken in managing the wild resource.

Future conservation of wild crocodilians must be based on programs which incorporate strategies which rely on maintaining viable wild populations, particularly in developed countries where there are alternative sources of revenue. In this regard the practice of establishing commercial crocodile farms in countries which do not possess a wild resource should be critically assessed. Competing interests which may be more efficient can seriously undermine the economics of ranching ventures in developing range states which, because they have been established as part of a national program to conserve crocodilians, are more dependent on the wild resource. This issue is allied closely to the issue of resource property rights and ecological concerns of trans-locating species to areas outside their natural distributions.

Additional to the problems associated with the uncontrolled production of crocodile and alligator skins, there is the problem of growing consumer opposition to using products derived from wildlife. Non-government conservation and animal rights organisations are campaigning vigorously in the western hemisphere against the use of wildlife products. Extreme elements of this movement which supports this campaign have, in the case of some species, practised acts of violence and mild forms of terrorism designed to intimidate consumers and retailers of animal products. Although crocodilians have not engendered the same degree of emotion as other more popular species such as whales, seals and other mammals there can be little doubt that the sale of crocodile products has suffered consequentially.

In concluding, it is apparent that the commercial use of crocodilians has had considerable benefits for both conserving the species and contributing to local economies. However, the ever-increasing number of crocodile farms which are being established around the world will inevitably lead to an over-production of skins. Whilst operations based on high valued species such as *Crocodylus porosus* may be able to sustain this competition, those producing skins from commercially inferior species will suffer. Such operations may respond by producing more smaller, and hence cheaper, skins in order to compensate for the reduction in the unit value of products. Careful consideration will need to be given to evaluating the affects this may have on wild harvest management regimes Clearly, new or modified strategies must be formulated and implemented based on the sustainable use of wild populations that differentiate in favour of wild-harvested skins.

Diseases, Parasites and Husbandry of Farmed Crocodiles: A Review of Major Problems and Some Solutions

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Introduction

Maintaining animals in a controlled environment immediately provides the opportunity to manage or eliminate many diseases, especially those of an infectious nature, and this has clearly occurred on most well established crocodile farms worldwide. Equally, however, intensification of livestock production generates its own, largely man-made disease problems and such problems are obviously the ones that need to be addressed if the efficiency of crocodile farms is to be improved.

In this presentation, the various diseases observed in crocodilians will be mentioned but emphasis will be placed on those which may be important on modern farms.

Disease Overview

Table 1 summarises the diseases that have been diagnosed in crocodiles worldwide. Details on these diseases are given in general papers by Foggin (1987), Jacobsen (1984) and Ladds and Sims (1990). Other, recent information is presented in notes prepared by Huchzermeyer (1992). In comparing the occurrence, prevention and control of diseases of crocodiles with similar diseases in traditional domestic livestock, however, several important differences emerge.

Tempersture is clearly paramount, and although crocodiles can to some extent thermoregulate by moving from land to water, sun to shade, etc their metabolism and therefore the efficiency of their inflammatory and immune responses appear to be determined by ambient temperature (Glassman & Bennett 1978; Smith et al. 1992), being highest at the optimal temperature range of say 30–32°C.

Stress is the other important consideration and it is relevant that in crocodile farming, a hitherto wild animal is being placed not only into captivity but into an intensive husbandry ("factory farming") environment. Recent studies on alligators have shown that elevated plasma corticosterone levels (an index of stress) and decreased growth rate were associated with stress caused by high density stocking rates (Elsey, Joanen, McNease & Lance 1990). The influence of thermal stress on C. *porosus* hatchlings as reflected by their plasma corticosterone, haematological parameters, immunoglobulin levels and growth rate is currently being studied (J Turton, unpublished).

Table 1: Diseases of crocodiles

- Viral
  - Poxvirus
  - Adenovirus
  - Arbovirus ? (e.g. Eastern equine encephalomyelitis)
  - Paramyxovirus ?
- Bacteria (General)
  - Gram negative organisms important
  - Acute disease — Septicaemia, Enterotoxaemia ?
  - Chronic disease — Hepatitis/splenitis – note *Aeromonas hydrophila*, *Salmonella* sp.
- Higher bacteria
  - *Mycobacterium* sp
  - *Dermatophilus congolensis* ?
  - Chlamydia
- Fungi
  - Superficial
  - Deep
- Protozoa
  - Coccidiosis
  - Haemogregarines
- Nematodes
  - Ascarids (gut and migrating)
  - Capillaria
    - gut
    - subcutis
- Trematodes
  - Intestinal
  - Renal
  - Blood
- Leeches
- Pentastomes
- Spargana (Melville 1988)
- Nutritional Disorders
  - Gout
  - Osteomalacia
  - Steatitis (Deficiency of Vitamin E)
  - Necrosis of muscle (deficiency of Vitamin E)
  - Deficiency of
    - Vitamin A
    - Vitamin B (Thiamine)
    - Vitamin C
    - Vitamin K ?
- Other
  - Giant cell enterohepatitis
  - "Bubble foot"
  - "Greasy crocs"

The interrelationship between various stressors such as temperature, overcrowding, and salinity, and the indices (e.g. plasma corticosterone) and consequences (impaired immunity and inflammation) of stress require further study. At least in response to acute stress in young alligators, total white blood cell counts were elevated and heterophils as a percentage of total white cell counts were also increased significantly at 48 hours — with a corresponding decrease in percentage of lymphocytes (Lance, V. 1990, pers. comm.). Such changes, which also occur in domestic animals, were not, however, observed in Nile crocodiles which were chronically stressed and often died as a result of repeated blasting for highway construction (Watson 1990).

In any consideration of diseases of farmed crocodiles emphasis must be placed on prevention of disease by effective quarantine and husbandry procedures and by minimising stress. Most diseases and mortalities of farmed crocodiles occur in young animals; they are seldom a problem once animals reach one year of age. Of the diseases listed in Table 1, note that artificial incubation of eggs with subsequent segregation of hatchlings from older crocodiles, and due regard to basic husbandry will prevent spread of most diseases. A recent study which compared diseases occurring on crocodile farms in the Northern Territory during their establishment phase (1984–87) and currently, has in fact revealed that this occurred — especially in relation to parasitic infections, which are now quite rare (Buenviaje et al. 1993).

Overwhelmingly, the important diseases in farmed crocodiles are now caused by opportunistic infections with ubiquitous bacteria or fungi, or by inappropriate nutrition. Most **bacterial** isolates from dead crocodiles are Gram negative and infections may be acute or chronic — the latter mostly affecting the liver and or intestines. Sudden death of fat hatchlings and the finding of "wet" oedematous tissues and haemorrhage at necropsy suggest an enterotoxaemia-like syndrome (Ladds & Sims 1990). Chlamydial infection is considered an important cause of illness in young crocodiles in South Africa (Huchzermeyer 1992); it has not yet been observed in Australia.

Fungal infections appear mostly to be precipitated by sub-optimal temperature. The skin is especially involved and pale gelatinous areas or discrete white foci may develop on any part of the body. Ulcers may result if this material is sloughed. In deep mycosis pale foci may be present in any organ but especially the liver and lungs.

Gout is probably the most important nutritional disorder in farmed crocodiles and is characterised by white crystalline precipitates around joints or in deeper organs, particularly the kidneys. Overfeeding for maximum growth with high protein diets appears to be the cause and at least during its early stages gout can be controlled by fasting animals for several weeks.

Osteomalacia is characterised by "rubber jaws", glassy teeth and extreme weakness in hatchlings, and permanent skeletal deformation in older animals whose diet has since been corrected (Huchzermeyer 1986). All meat diets with no mineral supplement are usually the cause.

Steatitis occurs only in crocodiles fed fish which has deteriorated and causes lesions which make the meat (especially of the tail) unsuitable for sale (Larsen et al. 1983).

Thiamine deficiency in crocodilians may be due to the thiaminase in frozen fish, and perhaps sulphides in preserved meat. Jubb (1992) has recently described a thiamine responsive nervous disorder in C. *porosus* hatchlings. Signs included loss of righting reflex and crocodiles typically were found floating or lying on their sides with their jaws open. The biggest, fastest growing animals were most affected. Treatment with thiamine hydrochloride (100 mg/ml – two; 30 mg doses, 24 hours apart) caused rapid recovery.

Vitamin C deficiency has been observed to cause an ulcerated gingivitis in farmed crocodiles in South Africa (Huchzermeyer 1992).

Other diseases currently being studied on Australian crocodile farms include a **giant cell enterohepatitis** (GCEH) of hatchlings and "bubble foot". In GCEH there is thickening of the intestinal wall by macrophages and giant cells which contain characteristic "bodies" which are probably micro-organisms but have yet to be identified. As in Johne's disease in cattle the massive macrophage proliferation compromises intestinal function and affected crocodiles are severely emaciated and often die.

"Bubble foot" has now been observed on several farms. Subcutaneous gas accumulations on the feet interfere with normal swimming (and therefore feeding) activities and loss of digits may subsequently occur. Preliminary microscopic studies show a "mixed" inflammatory response around the bubbles" and suggest infection.

"Greasy crocs" are the result of accumulated fat (from fatty food, e.g. pork) in pond water; such animals appear to have increased susceptibility to fungal infections of their skin.

In all surveys of hatchling ill thrift and mortality, the problem of **"maladaption"** and or **"runt"** animals has been revealed as significant. Essentially these crocodiles refuse to eat normally and become emaciated. Detailed necropsy and follow up laboratory examination however fails to reveal any infectious cause. Although there is some evidence that (labour intensive) temporary "force feeding" of such animals may induce them to feed and grow, this approach is generally considered to be uneconomic. A high occurrence of runts may be related to clutches being incubated at inappropriate temperatures (see below).

Some Management–Disease Associations

Introduction of wild caught hatchlings may facilitate spread of (especially parasitic) infection so it is relevant that most stock in Australia now comes from eggs that have been artificially incubated. Some diseases, e.g. adenovirus infection may still be transmitted through the egg (Foggin 1987). Much research has concerned the preferred method of egg handling and incubation and excellent results are now achieved (see Manolis & Webb 1991). Important "clutch effects" have been recognised and may sometimes be related to egg incubation temperature. For example Joanen, McNease and Ferguson (1987) found that a high percentage of "runt" alligators (*Alligator mississippiensis*), which never grew well, occurred in clutches from eggs incubated at temperatures that were above or below the optimum 31.7°C.

The use of a darkened ("black out") environment to reduce stress is debated but is nevertheless widely adopted. Obviously provision of adequate artificial light to permit cleaning, etc needs to be made, but the question of whether almost constant darkness may interfere with Vitamin D conversion needs to be resolved and kept in mind in formulating rations.

"Controlled environmental chambers" will of course be housed indoors. For outdoor pens suitable netting may be required to exclude, e.g. dogs, cats, rodents, frogs and birds which may be attracted to feed and could perhaps help passive spread of (e.g. bacterial, parasitic) infection from one pen to the next. In the context of spread of some (e.g. viral, protozoal) diseases by biting insects there may possibly be situations where insect-proofing of pens is justified.

Depending on location (and especially latitude) partial shading of pens (with, e.g. shade cloth) may be necessary. In this regard it is important to remember that the crocodile (at least post-hatchling) will effectively regulate its own body temperature by moving between water, sunlight and shade; pen design (and stocking density) should therefore permit the animal to achieve this.

Quite high mortalities may occur after blockage of drains from ponds has prevented cleaning and permitted excessive buildup of (especially bacterial) contamination of pond water (see below). Also, to avoid spread of infection, water overflowing from one pen must not drain to the next.

Availability of abundant uncontaminated fresh water is essential for a crocodile farm and of course this has been achieved by use of underground (bore) water on many farms. Infection with, e.g. coccidiosis has resulted from use of water pumped from contaminated streams. Likewise fluke infestation may occur if snails are introduced into ponds via water from adjacent streams.

Water clarity *per se* may not be important and indeed Goudie (1989) notes that crocodiles appear to prefer cloudy water. Cloudiness of water due to excretement and uneaten feed may however favour the proliferation of pathogens such as *Salmonella* sp and in this regard Manolis et al. (1991) have suggested that a difference in feeding behaviour between C. *porosus* and C. *johnstoni* may be important; whereas the latter species will eat on land, the former will take feed into the water before eating it.

Although unlikely to be a problem on most farms, elevated salinity (1% or higher) could perhaps result from evaporation and is associated with stress and mortality of young animals (Lauren 1985).

It is generally agreed that water should be changed daily, preferably after feeding. The temperature of water flowing into pens after cleaning is important; temperature "shock" has resulted from this water being too cold so heating of incoming water may sometimes be necessary.

The exact contribution of noise to stress and therefore reduced growth and perhaps disease seems unclear, but as fright may be an inevitable response to unusual or intermittent noise, a common practice is to have continuous music (preferably ABC FM!) "piped" into pen areas.

Maintenance of temperature at or very near 31.5°C is perhaps the single most important requirement for minimising the occurrence of disease. Immune response in reptiles is temperature dependent as is time required for protein digestion and absorption. In alligators, Coulston and Coulston (1986) found such times to be twice as long at 20°C than at 28°C.

Foggin (1988) compared mortalities of C. *niloticus* hatchlings kept at different temperatures and found that susceptibility to (mostly opportunistic) infection was much greater at 26°C than 32°C. Likewise 36°C induced mortality. Studies by Buenviaje et al. (1993) confirmed the importance of sub-optimal temperatures in favouring opportunistic infections of young crocodiles, especially during winter and on those farms located at higher latitudes. Even though some form of heating was provided on all farms studied, it appeared to be inconstant and/or inadequate. In planning suitable "controlled environment" pens, both air and water temperature need to be considered.

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THE CONSERVATION, MANAGEMENT AND FARMING OF CROCODILES IN WESTERN AUSTRALIA

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INTRODUCTION

Two species of crocodile occur in the north of Western Australia - the Estuarine or Saltwater Crocodile *Crocodylus porosus* and the Australian Freshwater Crocodile *C. johnstoni*. Since the review of the status of crocodiles and their management in Western Australia by Burbidge (1987), a crocodile farming industry has been established and there has been a substantial increase in knowledge of the status of crocodiles as a result of population surveys.

DISTRIBUTION OF *CROCODYLUS POROSUS* AND *C. JOHNSTONI* IN WESTERN AUSTRALIA

Crocodylus porosus is found in coastal and near coastal parts of the Kimberley region of Western Australia, from the Northern Territory border to King Sound, and with fairly frequent occurrences further south to the Broome area (Figure 1). In recent years, several *C. porosus* have become resident a considerable distance further south, in the vicinity of Port Hedland in the Pilbara region (Figure 2).

C. johnstoni is found throughout the freshwater rivers and billabongs of the Kimberley region. It occurs well inland along the two largest river basins, the Ord and Fitzroy rivers (Figure 1).

GENERAL DESCRIPTION OF WESTERN AUSTRALIA IN RELATION TO AREAS WHERE CROCODILES OCCUR

Western Australia consists of almost one-third of Australia's landmass but has only about one-tenth of the nation's population (Table 1).

Table 1: Land area and human population of Western Australia relative to Australia

	Western Australia	Australia	WA as proportion of Australia
Area of land	2,525,500 km^2	7,682,300 km^2	32.9%
Human population at 30/6/91	1,665,945	17,335,933	9.6%

(source: Australian Bureau of Statistics, 1992)

In the decade from 30 June 1980 to 30 June 1990, Western Australia's average annual rate of population increase was 2.56% compared with a national figure of 1.52% (Australian Bureau of Statistics 1992).

The Kimberley has a low human population. At 30 June 1990, when Western Australia's population was 1,633,825, the estimated resident population in the three local government areas which cover all of the distribution of *C. porosus* in the Kimberley, and almost all of the distribution of *C. johnstoni*, was 21,852 or only 1.3% of the State's population (Table 2 and Figure 2).

Table 2: Human population distribution by local government area in the Kimberley

Local government area	Area (km^2)	Estimated resident population at 30/6/90	Towns in each area
Wyndham-East Kimberley	121,189	6,444	Kununurra, Wyndham
Derby-West Kimberley	102,706	7,488	Derby, Fitzroy Crossing
Broome	56,000	7,920	Broome
		21,852	
Halls Creek (a)	142,908	2,991	Halls Creek

(source: Australian Bureau of Statistics, 1992)
(a) includes a relatively small area of *C. johnstoni* habitat.

In addition to the towns listed in Table 2, there are scattered Aboriginal settlements. Much of the coastal Kimberley region is virtually uninhabited.

The recent appearance of several *C. porosus* in the vicinity of Port Hedland is in an area where the estimated resident population at 30 June 1990 was 13,707 in the Port Hedland local government area, and 16,707 in the adjacent Roebourne local government area (Figure 2). In both areas most of the population live in coastal towns.

In the Kimberley, most of the coastal and near-coastal land from King Sound to the Northern Territory border is included in Aboriginal reserves, with the remainder made up of vacant Crown Land, conservation reserves and a Commonwealth (i.e. national government) defence training area. In these areas land-use activities which would be detrimental to crocodile habitat and conservation are generally limited. Most of the inland Kimberley, as well as coastal areas in the vicinity of Derby and Broome, is pastoral leasehold land used for open range cattle grazing.

HUNTING OF CROCODILES IN WESTERN AUSTRALIA

Aboriginal harvests

Crocodile meat and eggs have been used as a food source by Aboriginal people for some 20,000 to 40,000 years prior to European contact (McBryde 1979; Flood 1983). This use continues but the size of the harvest is unknown. Aboriginals are very skilled hunters who are especially adept at locating nests of both *C. porosus* and *C. johnstoni*, and the impact of their harvesting "should not be lightly dismissed"(Webb *et al.* 1987).

Hunting for the skin trade

C. porosus was extensively hunted for the skin trade in the 1950s and 1960s. The pre-harvest population size is unknown. While there are no accurate statistics on the harvest in Western Australia, Webb *et al.* (1984) estimated that between 270,000 and 330,000 *C. porosus* were killed in Australia from 1945 to 1972, with the upper estimate comprising 271,500 skins exported, 13,500 assumed killed and not retrieved, and 45,000 juveniles killed for the curio trade. Based on Webb *et al*'s estimate that 10% of the skin harvest was from Western Australia, it therefore seems likely that some 25,000 *C. porosus* were harvested in Western Australia from 1945 until 1970 when they were legally protected under the *Wildlife Conservation Act 1950.*

In contrast, no intensive legal hunting of *C. johnstoni* occurred in Western Australia, but according to Bustard (1970) and Burbidge (1987) there was significant poaching in accessible habitat during the 1960s and early 1970s. Burbidge considered that *C. johnstoni* populations in the north-west Kimberley were not affected by European hunting because of the rugged, inaccessible nature of the country. There are no published estimates of the numbers of *C. johnstoni* killed in Western Australia for the skin trade. The species has been legally protected in Western Australia under the *Wildlife Conservation Act* since 1958.

STATUS OF THE *CROCODYLUS POROSUS* POPULATION IN WESTERN AUSTRALIA

The first documented report on the status of *C. porosus* in Western Australia was that of Bustard (1970), who conducted limited boat spotlight surveys in several areas. Bustard concluded that *C. porosus* "has been hunted to the verge of extinction" and his recommendation that the species be protected for ten years was the basis of the Government's action to protect the species in 1970.

The first systematic surveys of *C. porosus* populations in Western Australia were conducted in 1977 and 1978 (Messel *et al.* 1977; Burbidge and Messel 1979). These boat spotlight surveys covered the estuarine portions of major river systems across most of the range of *C. porosus* in Western Australia, and the combined results yielded the following estimates of the non-hatchling populations in the surveyed portions of each river system:

Ord	235-306
Lawley	44-57
Mitchell	60-78
Hunter	51-67
Roe	177-230
Prince Regent	190-246
Glenelg	200-259
Total	957-1,243

Extrapolating from these results to correct for unsurveyed areas, Burbidge and Messel (1979) estimated that there were about 2,000 non-hatchling *C. porosus* in the whole of Western Australia.

In 1986, most of the areas surveyed in 1977 and 1978 were resurveyed, as well as some additional areas (Messel *et al.* 1987), resulting in a Kimberley-wide population estimate of 2,500 non-hatchling *C. porosus*. The 1986 survey revealed a significant increase in the proportion of large crocodiles in the population, and showed that the largest populations are in the Cambridge Gulf, Prince Regent and Roe River systems.

Since 1986, no further large-scale population surveys throughout most of the range of *C. porosus* in the Kimberley have been conducted. However, the *C. porosus* population in King Sound and Stokes Bay was surveyed for the first time in 1989, resulting in an estimated population of about 25 (G Webb Pty Ltd 1989a). The low density of *C. porosus* in the King Sound area reflects a generally poor environment at the extremity of the main part of the range of *C. porosus*.

Associated with the Western Australian Government's 1988 decision to permit crocodile farming in the State, the West Arm river systems in Cambridge Gulf (Figure 3) which had been surveyed in 1986 were resurveyed in 1989, 1990 and 1992 (G Webb Pty Ltd 1989b, 1990 and 1992). In 1992 the Ord River, which had been partly surveyed in 1978 and 1986, was fully surveyed for the first time (G Webb Pty Ltd 1992). The results of these surveys in Cambridge Gulf are summarised in Table 3.

Table 3: Summary of *C. porosus* population surveys in the Cambridge Gulf system, east Kimberley

Area and distance Surveyed	ESTIMATED POPULATION OF NON HATCHLINGS				
	MONTH/YEAR OF SURVEY				
	7/78	*7/86*	*10/89*	*9/90*	*7/92*
East Arm & Ord River					
- 98.8 km	245-297	221-271	ns	ns	240
- additional 20 km	ns	38(a)	ns	ns	55
- additional 59.5 km	ns	ns	ns	ns	84
					379
West Arm					
- West Arm, Parrys Ck, Sellers Ck, Forrest R, Patrick R, Durack R, Canal Ck, King R, Pentecost R. (203 km)	ns	187-233	-	-	-
- as above plus West Arm side creek and Bulla Nulla Ck (215.2km)	ns	ns	256	202	198

ns = not surveyed
(a) count only, i.e. not a population estimate.
(sources: Messel *et al.* 1987; G Webb Pty Ltd 1989b, 1990 and 1992)

Cambridge Gulf has been the principal source of *C. porosus* for crocodile farms in Western Australia. The results in Table 3 indicate that the population in Cambridge Gulf has not been adversely affected by the removal of about 140 non-hatchling *C. porosus* between the 1986 and 1992 surveys, or by the egg/hatchling harvest in the King River which has taken place each breeding season from 1988/89 to 1991/92.

A helicopter survey was conducted in the 1988/89 breeding season to locate *C. porosus* nests between Cambridge Gulf and the Prince Regent River (G Webb Pty Ltd 1989c). The river systems in which nests were found, and the number of nests found, are listed below:

Cambridge Gulf	
Ord River	6
King River	8
Drysdale River	1
Admiralty Gulf Creek	1
Roe River	20
Prince Regent River	1
Total	37

The 1988/89 survey confirmed previous conclusions (Messel *et al.* 1987; Burbidge 1987) that nesting habitat and levels are limited in Western Australia, particularly in comparison with prime areas in the Northern Territory.

In summary, it is considered that the total population of *C. porosus* in Western Australia is only of the order of a few thousand non-hatchlings. Nesting habitat is limited. Nevertheless, *C. porosus* appears to be recovering from past hunting, and still occupies its historical range. Burbidge (1987) makes the following comments in relation to *C. porosus* habitat in the Kimberley:

> "The areas of the Kimberley inhabited by *C. porosus* differ markedly from most of the Northern Territory ... The Kimberley coastline and hinterland are chiefly composed of steep, rugged, ancient, deeply faulted sandstones. Access up many rivers is blocked to crocodiles by waterfalls and their associated gorges. There are few areas of floodplain and very few freshwater swamps; hence breeding habitat is scarce. It would appear, therefore, that the carrying capacity of the Kimberley river systems and the Kimberley as a whole is much less than that of the Northern Territory."

STATUS OF THE *CROCODYLUS JOHNSTONI* POPULATION

Prior to 1989, there had only been very limited surveys of freshwater crocodile populations in parts of the Ord River, including Lake Kununurra.

In 1989, boat spotlight surveys yielded non-hatchling population estimates of 25,000 in Lake Argyle and 7,500 in Lake Kununurra (G Webb Pty Ltd 1989d). The earlier construction of two dams on the Ord River impounded Lake Kununurra (in 1963) and the very large Lake Argyle (in 1972). Also in 1989, boat spotlight and helicopter surveys yielded a population estimate of 13,000 non-hatchling *C. johnstoni* along 172 km of the Fitzroy River and in some of its tributaries and Seventeen Mile or Camballin Dam (G Webb Pty Ltd 1989a). A boat spotlight survey in 1992 yielded an estimate of more than 2,000 *C. johnstoni* in the Ord River downstream of the Diversion Dam which forms Lake Kununurra, all within 90 km of the Dam (G Webb Pty Ltd 1992).

There has not been a survey of the total Western Australian *C. johnstoni* population and therefore there is no scientific estimate of the total population size. Nevertheless the species is clearly common in suitable habitat.

CROCODILE MANAGEMENT AND FARMING

Kulumburu Crocodile Farm

Applied Ecology Pty Ltd established an experimental *C. porosus* farm at the Kulumburu Aboriginal Mission in 1973. Applied Ecology Pty Ltd was a company established by the Commonwealth Government to research and develop natural resource based industries for the benefit of Aboriginal and Torres Strait Islander communities.

The farm never developed beyond a small-scale experimental operation and was discontinued by the Kulumburu Mission in 1983 after Applied Ecology Pty Ltd was disbanded in 1981. Records are incomplete but the available information indicates that the farm took 10 *C. porosus* from the wild and raised 132 hatchlings from wild harvests of eggs/hatchlings. Most of the crocodiles died either due to disease or predation, 10 were transferred to the Broome Crocodile Park in 1983, and the final two were released into the wild in 1988.

Broome Crocodile Park

This park began acquiring crocodiles in 1983 and opened to the public as a display park in 1985. It acquired 10 *C. porosus* from Kulumburu in 1983 and up to the end of 1988 it had trapped about 25 non-hatchling *C. porosus* in the wild, primarily in accordance with the problem crocodile removal program. Thirty *C. porosus* hatchlings were collected in 1987 and nine *C. johnstoni* were also collected from the wild for display.

1988 Government approval for crocodile farming

In October 1988, the Western Australian Government decided to allow the recommencement of crocodile farming in Western Australia. This followed expressions of interest from a number of private entrepeneurs, and an analysis of existing data on crocodile populations by the Department of Conservation and Land Management (CALM). At that time crocodile farming had already been well established elsewhere in Australia, in Queensland and the Northern Territory.

The approach taken in Western Australia in 1988 was to allow a single farm to be established in the east Kimberley, to farm both *C. porosus* and *C. johnstoni*. This farm was established at Wyndham in 1989. In addition to breeding in captivity, ranching was adopted.

CALM's analysis in 1988 emphasised to the Government that data on crocodile populations in Western Australia were limited, and CALM recommended that further surveys be conducted to establish the numbers of crocodiles which could be taken from the wild for farming purposes. Surveys of various areas were conducted accordingly in 1989 and are reported on above.

In 1990, the Government decided to allow two crocodile display parks, in Broome and Fremantle (established in 1989) to become licensed as crocodile farms. As a consequence, there are now three licensed crocodile farms in Western Australia, at Wyndham, Broome and Fremantle.

Management aims

CALM has prepared a management program for the two species of crocodile in Western Australia, and a comprehensive Departmental policy statement on the conservation and management of crocodiles.

The four main aims of crocodile management in Western Australia, as detailed in the management program, are:

1. "Maintain viable wild populations of crocodiles and conserve the habitats on which they depend"; and

2. "Facilitate the recovery of *C. porosus* populations which have been depleted by past hunting", to be achieved through:

    - the establishment and management of a conservation reserve system where crocodiles and their habitats are totally protected;

    - the legal protection of crocodiles throughout their natural range, with taking from the wild subject to licensing and restrictions on location and extent;

    - ongoing monitoring of crocodile populations and harvests; and

    - re-establishment or replenishment of wild populations from farm-raised stocks, if required.

3. "Provide for public safety by maintaining public awareness and removing "problem" crocodiles", to be achieved through:

    - a public education and awareness campaign designed to encourage public support for the conservation of crocodiles, while at the same time informing people of the potential dangers posed by *C. porosus*, and promoting safe behaviour in crocodile habitats; and

    - problem crocodile control involving removal of crocodiles where they pose a public threat.

4. "Provide for the commercial utilisation of crocodiles through controlled farming and harvesting", to be achieved through:

   - captive breeeding on licensed farms;
   - regulated sustainable harvesting of live animals from wild populations, under licence;
   - regulation and supervision of farming and trade; and
   - monitoring and assessment of harvested populations.

With respect to aim 4, a key element of CALM's approach to crocodile management is to build and maintain broad community support for the protection of crocodiles and their habitats, in part by providing for the harvesting of wild crocodiles and thus conferring commercial value on them.

The conservation reserve system

Conservation reserves (national parks, nature reserves and other conservation reserves) provide secure areas where crocodiles and their habitats are totally protected. Figure 1 shows existing and proposed conservation reserves within the range of *C. porosus* and *C. johnstoni* in Western Australia, and existing conservation reserves are listed in Table 4.

Table 4: Existing Western Australian conservation reserves inhabited by crocodiles

Conservation Reserve	Area (ha)	*C. porosus*	*C. johnstoni*
Prince Regent Nature Reserve	634,952	Present	Present
Drysdale River National Park	448,264	Absent	Present
Ord River Nature Reserve	79,842	Present	Present (*)
Parry Lagoons Nature Reserve	17,421	Present	Present
Purnululu (Bungle Bungle) National Park and conservation reserve	319,325	Absent	Present
Geikie Gorge National Park	3,136	Absent	Present
Windjana Gorge National Park	2,134	Absent	Present
Coulomb Point Nature Reserve	28,676	Present (*)	Absent

(* indicates that the species occasionally occurs in the reserve)

The identification and declaration of conservation reserves is continuing. CALM has proposed a number of additional conservation reserves which include crocodile habitat, most of which are documented in Burbidge *et al.* 1991 and shown in Figure 1.

Given the importance of the Cambridge Gulf area for crocodile conservation and also as a source of crocodiles for the farming industry, particular attention is being paid to the conservation reserve system in that area (Figure 3). In 1992, the Ord River Nature Reserve was more than trebled in size, by the inclusion of the area known as the False Mouths of the Ord. In addition, the creation of a reserve in which continued egg/hatchling collection would be permitted is being considered for an area of the King River, to protect the only area in the entire Cambridge Gulf system where there is known to have been *C. porosus* nesting each breeding season from 1988/89 to 1991/92. It is also intended that the King River nesting area will be fenced to protect nesting habitat from degradation by cattle.

Public safety and problem crocodiles

A key element of CALM's approach to crocodile management is to build and maintain broad community support for the protection of wild crocodiles and their wetland habitats. One way to do this is to make crocodiles a valuable tourist and farming asset. There is, however, also the need to increase public awareness of crocodiles and protect the public from unacceptable risks of attack from *C. porosus*. While *C. johnstoni* are generally not dangerous, there have been instances of injuries and small children and pets may be at risk.

In addition to a public awareness and education program CALM has zoned *C. porosus* habitat as follows:

- Crocodile Control Zones, which are areas around selected centres of human population or activity where effective control of crocodiles is practicable. In these areas attempts will be made to remove all *C. porosus*. Control Zones include the Ord River upstream of the Diversion Dam, the Broome area and selected areas in the Pilbara region.

- Crocodile Management Zones, which are areas where *C. porosus* may be managed as a renewable resource. There is a Crocodile Management Zone in Cambridge Gulf (Figure 3).

- Crocodile Protection Zones, which are areas outside Control and Management Zones.

Problem crocodiles are defined as animals within or near settled areas or recreational use areas which present a threat to humans and/or livestock. All *C. porosus* in a Control Zone are problem crocodiles and so will be removed. Decisions on reported problem animals in other areas are made on a case by case basis. Wherever removal of problem crocodiles is proposed, the first option will be for those animals to be offered to a licensed farm, rather than destroy them. Problem crocodiles are normally captured by CALM staff or persons employed by licensed farms, with specific permission from CALM.

Harvesting for crocodile farms

Western Australia's three crocodile farms have acquired their stock through a combination of capture of adult and juvenile crocodiles from the wild, the collection of eggs and hatchlings from the wild, and the purchase of animals from licensed crocodile farms in the Northern Territory and Queensland.

From 1989 to the end of 1992, a total of about 170 non-hatchling *C. porosus* and 134 *C. johnstoni* have been taken from the wild for crocodile farms. The *C. porosus* have been taken mostly from Cambridge Gulf, and the *C. johnstoni* from Lake Argyle. In addition, about 450 *C. porosus* eggs and hatchlings have been collected from the King River (in the Cambridge Gulf area) since 1988/89, and over 5,000 *C. johnstoni* eggs and hatchlings have been collected from Lake Argyle.

In accordance with the management program, wild harvest limits are set taking into account:

- current trends in population size and structure;
- seasonal effects on breeding, recruitment and survivorship;
- management objectives for specific areas;
- proportion of the total habitat subject to harvesting;
- review of previous harvests; and
- review of research information.

C. porosus harvests have been, and will continue to be, concentrated in Cambridge Gulf (Figure 3). Within the Gulf area, no harvest (apart from the removal of problem crocodiles) is permitted in the lower Ord River or the False Mouths of the Ord, in keeping with the nature reserve status of much of this area, and to protect a known nesting area in the vicinity of Parry Lagoons Nature Reserve. Furthermore, no harvest of adults and juveniles is permitted from the King River, in order to protect breeding animals in a known nesting area where ranching is concentrated.

The rationale for concentrating on Cambridge Gulf for the harvesting of *C. porosus* is that it contains a relatively large population, is accessible for harvest operations and population monitoring surveys, and is an area for which adequate baseline data population exists. In addition, a significant proportion of the instances of problem *C. porosus* in Western Australia occur in the Cambridge Gulf system, and harvesting may be of some assistance in meeting CALM's public safety objectives.

In contrast, in the remainder of the coastal Kimberley region, the largest *C. porosus* populations are in existing and proposed conservation reserves, nesting habitat elsewhere which could support ranching is very limited, and much of the region is extremely rugged with difficult access, thus making harvesting and associated population monitoring very expensive.

In the case of *C. johnstoni*, the largest single known population is in Lake Argyle. Although surveys have shown that other areas support abundant populations which could be harvested, harvesting is being restricted to Lake Argyle because the population is large enough to support farming requirements, and because such an approach minimises the populations for which monitoring is required in association with harvesting operations.

Regulation of farming and trade

Both species of crocodile in Western Australia are protected under the Western Australian *Wildlife Conservation Act 1950* administered by CALM. The taking of crocodiles from the wild and farming, processing and trade are regulated by a system of licences, keeping of records, submission of regular returns (i.e. reports on licensed operations), and identification procedures (skin tagging and product marking or labelling) enforced under the *Wildlife Conservation Act 1950.*

Regulatory requirements are detailed in the management program that has been prepared for consideration by the Commonwealth Government pursuant to the Commonwealth *Wildlife Protection (Regulation of Exports and Imports) Act 1982*, which is the legislation governing export and import of crocodile products out of and into Australia. Procedures in place pursuant to the *Wildlife Conservation Act 1950* and the management program satisfy the requirements of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

The three crocodile farms in Western Australia are still at a relatively early stage of development, concentrating on building up stocks and on captive breeding. In addition to collecting from the wild in Western Australia, the farms have purchased *C. porosus* from licensed farms in the Northern Territory and Queensland to help establish their stock levels. The Wyndham and Fremantle farms are owned by the same proprietor, who is farming *C. johnstoni* as well as *C. porosus*, which is the primary commercial species. The Fremantle farm has carried out some processing and export. The Broome proprietor is only farming *C. porosus*.

Monitoring and research

The principal monitoring requirement is to detect any significant decline in populations of either species in sufficient time to effect remedial action. Monitoring is also required to provide information on rates of change in population size and structure in harvest areas to provide a basis for review of harvest levels and locations.

Baseline population data exist for *C. porosus* in the Cambridge Gulf system and for *C. johnstoni* in Lake Argyle, where harvesting is concentrated. The current approach is to monitor these populations on an annual basis. In particular, work is being carried out to compare boat spotlight and helicopter counts in those areas, with the aim of relying mostly on helicopter counts in the future.

Large-scale surveys of the *C. porosus* population across most of the Kimberley were conducted in 1977-78 and 1986. It is intended that similar surveys be carried out periodically in the future, but this will be subject to the availability of resources because of the high costs involved.

Discussion - the future

The future for both *C. porosus* and *C. johnstoni* in Western Australia appears secure at least in the medium-term, with neither species considered to be threatened in the wild. *C. johnstoni* is regarded as being abundant. In contrast, *C. porosus* is far less numerous, but it nevertheless still occupies its historical range and the available data indicate some recovery from past uncontrolled hunting. However, with no information on pre-harvest population size, the extent to which *C. porosus* has recovered towards its former numbers is unknown.

There are no proposals current, or likely, to change the protected status of either species. Proposed additions to the conservation reserve estate in the Kimberley, when implemented, will afford additional protection to crocodiles and their habitat in a number of important areas.

As far as crocodile farming in Western Australia is concerned, access to *C. porosus* from the wild will continue to be limited in the foreseeable future, because of the relatively low population size, the rugged and remote nature of much of its habitat, and the limited nesting levels. Farms will need to successfully breed *C. porosus* in captivity as the major source of their stock.

Much larger harvests of *C. johnstoni* would be acceptable on biological grounds, but the species is of considerably less commercial value.

Notwithstanding the general prognosis for the future of the two species in Western Australia, losses through drowning in fishing nets and illegal shooting occur with both species. There are grounds for concern that these losses could impede population recovery, or even cause declines, in the case of *C. porosus* in certain areas.

The incidence of problem *C. porosus* can be expected to increase. This together with the establishment of a crocodile farming industry and the associated increased requirements for monitoring and regulation are imposing an increased demand on the staff and financial resources of CALM. Additional staff have been appointed to CALM's Kimberley regional offices in recent years, and the crocodile farming industry is being required to contribute to the extra costs borne by CALM because of crocodile farming. Nevertheless, the provision of sufficient staff and financial resources to meet crocodile management requirements remains an issue requiring attention.

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Figure 1.

CONSERVATION RESERVES IN THE KIMBERLEY REGION OF WESTERN AUSTRALIA

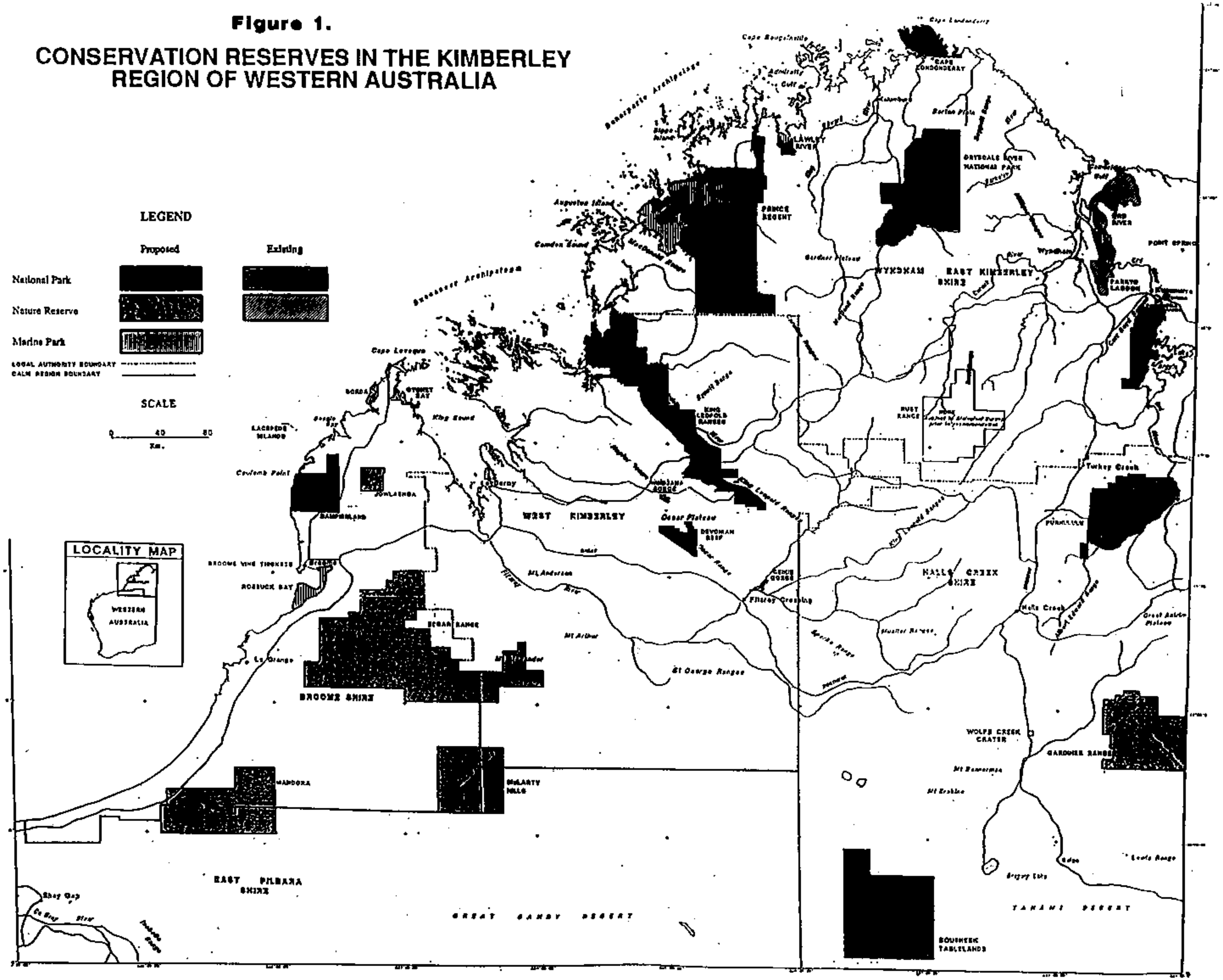


Figure 2.

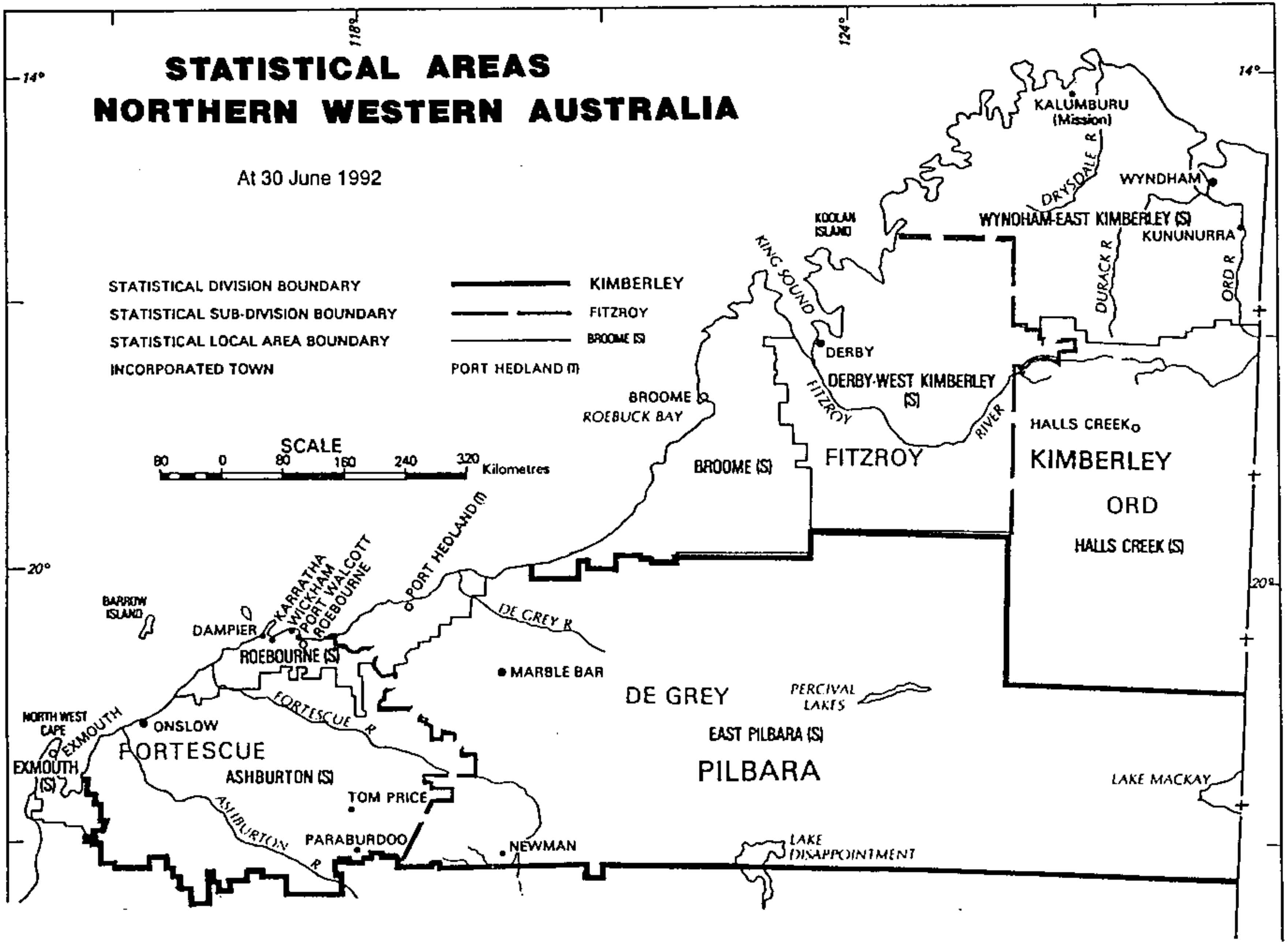
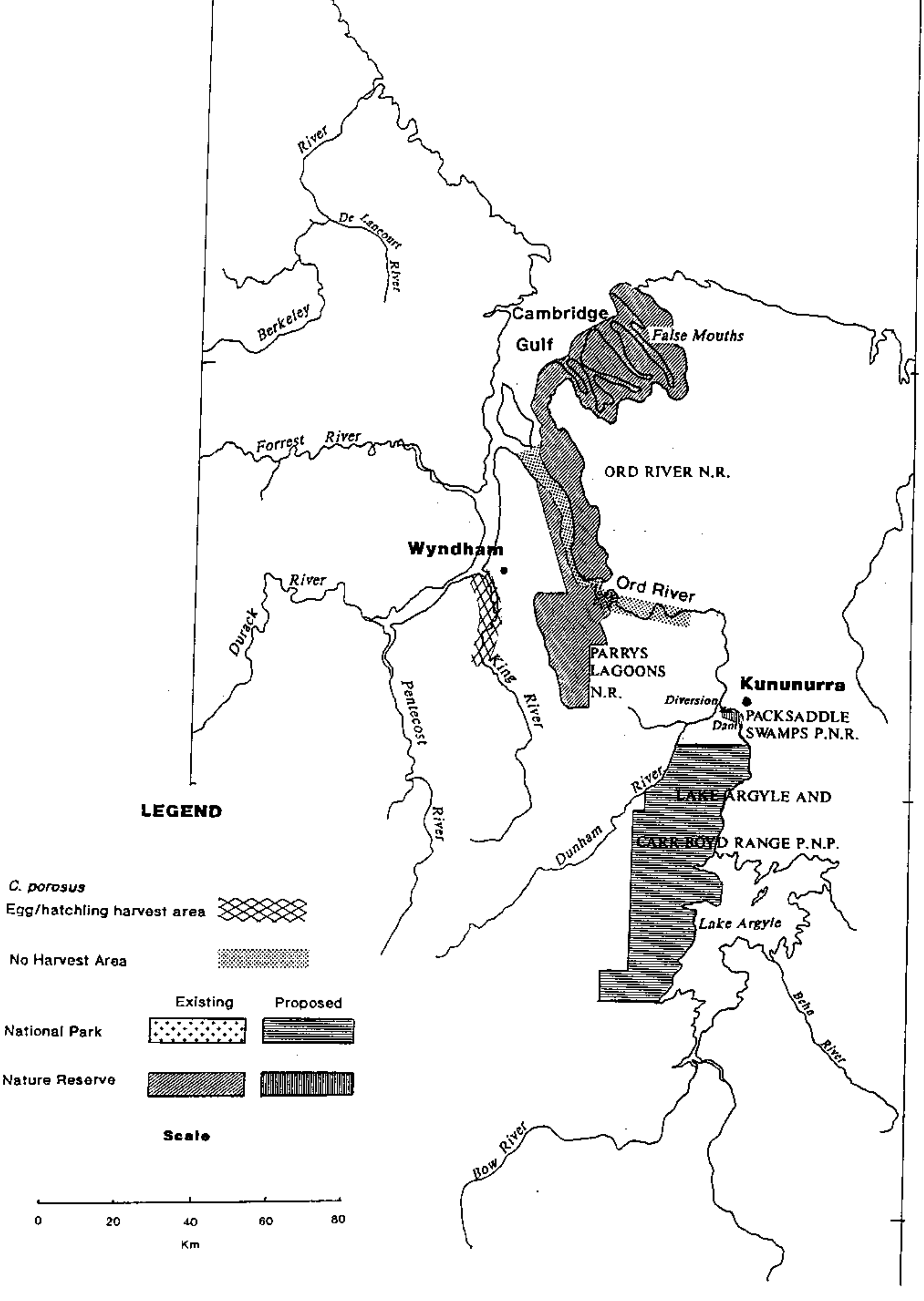

STATISTICAL AREAS
NORTHERN WESTERN AUSTRALIA
At 30 June 1992
STATISTICAL DIVISION BOUNDARY
KIMBERLEY
STATISTICAL SUB-DIVISION BOUNDARY
FITZROY
STATISTICAL LOCAL AREA BOUNDARY
BROOME (S)
INCORPORATED TOWN
PORT HEDLAND (T)
SCALE
80 0 80 160 240 320 Kilometres
118°
124°
14°
20°
KALUMBURU (Mission)
DRYSDALE R
WYNDHAM
WYNDHAM-EAST KIMBERLEY (S)
KUNUNURRA
DURACK R
ORD R
KOOLAN ISLAND
KING SOUND
DERBY
DERBY-WEST KIMBERLEY (S)
FITZROY RIVER
BROOME
ROEBUCK BAY
HALLS CREEK
KIMBERLEY
ORD
HALLS CREEK (S)
BROOME (S)
FITZROY
PORT HEDLAND (T)
KARRATHA
WICKHAM
PORT WALCOTT
ROEBOURNE
DAMPIER
ROEBOURNE (S)
BARROW ISLAND
DE GREY R
MARBLE BAR
DE GREY
PERCIVAL LAKES
EAST PILBARA (S)
PILBARA
NORTH WEST CAPE
EXMOUTH
EXMOUTH (S)
ONSLOW
FORTESCUE
FORTESCUE R
ASHBURTON (S)
TOM PRICE
ASHBURTON R
PARABURDOO
NEWMAN
LAKE DISAPPOINTMENT
LAKE MACKAY

Figure 3. CAMBRIDGE GULF

CROCODILE MANAGEMENT ZONE



REVIEW OF THE STATUS OF CROCODILIANS

IN THE PACIFIC ISLAND NATIONS

OF

PALAU, SOLOMON ISLANDS AND VANUATU

by

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SECOND REGIONAL CONFERENCE

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ABSTRACT

A systematic survey of the crocodile populations of the Pacific Island Nations of Palau, Solomon Islands and Vanuatu was carried out by Messel and King during the years 1991, 1989 and 1992 respectively. These surveys established that in each instance the crocodile populations in the wild were approaching extinction and that little or no action was being taken to halt this.

The present review paper provides a general background on each of these generally little known Island States and traces the history of the near extirpation of the crocodilians on them.

A brief discussion of the results of the surveys is given as well as conclusions and recommendations. Little or no action has been taken to date to implement the recommendations, except in Vanuatu where there is hope to save the saltwater crocodile along with other important marine species.

INTRODUCTION

The Crocodile Specialist Group (CSG) of the Species Survival Commission (SSC) of the World Conservation Union (IUCN) has prepared an Action Plan for conserving the crocodilians of the world. This plan provides the most up-to-date assessment of the conservation status of the various species and it highlights the critical problems which must be addressed to ensure their conservation and to maintain biological diversity.

One of the highest priorities of the CSG Action Plan is to determine the status, size class and distribution of crocodilians in areas that have not been systematically surveyed in recent times. The Republics of Palau, Vanuatu, and the Solomon Islands in the western Pacific Ocean are such areas.

Unfortunately the crocodilians of these smaller Pacific Island nations received scant scrutiny by the scientific community until the late 1980s. The larger crocodile populations of Papua New Guinea and Australia were in need of urgent attention and received it from the early 1970s.

Palau, Solomon Islands and Vanuatu, though also in need of urgent attention, did not. Crocodile hunters were well aware of this and with the encouragement and help of the islanders, who looked upon crocodiles as vermin, did their best, during the past 30 years, to extirpate the relatively small crocodile population there. They almost succeeded – though not quite. However, it precluded the establishment of a viable local sustainable utilization program.

This issue is of some importance. Firstly, there is the important matter of the conservation of a keystone species and the maintenance of bio diversity. The removal of a crocodilian from the top of the food chain is likely to have damaging, unforeseen, and far-reaching consequences. Secondly, there is the issue of the severe degradation of a valuable economic resource, usually in developing economies, struggling to increase or even maintain a standard of living.

There is now much evidence that one of the most powerful tools for conserving certain species of crocodilians is the sustained utilization of the wild populations based on the biological requirements of the species. Presently, countries such as Australia, Papua New Guinea, Venezuela, the USA, and Zimbabwe, have been operating successful sustainable use conservation programs for their crocodilians for some time. Economic incentive has been turned into a valuable conservation tool to the benefit of both wildlife and the local people. IUCN-The World Conservation Union has embraced sustainable use of wildlife as one of its cornerstones for helping to preserve bio diversity.

During the period 20 July - 8 September 1989, Messel and King (1990) carried out an extensive and systematic survey of the crocodile populations of the Solomon Islands. This was followed by a systematic survey of the crocodile populations of the Republic of Palau during the period 8-24 June 1991, Messel and King (1991), and a survey in Vanuatu during the period 16-22 August 1992 by Messel and King (1992). The purpose of the surveys was to determine the conservation status of the crocodilians in the countries concerned and the potential for developing a sustainable use project for the resource. Most of the material given in the present review is abstracted verbatim from the lengthy reports on the above surveys. However, because of the overall interest of the Vanuatu Report, it is given here in full.

SOLOMON ISLANDS

GENERAL

The Solomon Islands are a scattered double chain of some 900 islands which extend for 1646 km in a S.E. direction from Bougainville Island PNG. (Figs 1 & 2) There are some 4000 villages of which more than 50% have less than 35 people living in them – a subsistence economy. The Melanesian-Polynesian population is some 350,000 and at a growth rate in excess of 3% annually, has the second highest population growth rate in the world. Herein lies a great problem. Average longevity is 43 years. You don't see many old people about and those you see are much respected.

Mendana, the 25 year old nephew to Peru's Spanish Viceroy, discovered the Solomon Islands (S.I.) in February 1568. He remained in the islands for 6 months and spent much of his time fighting the islanders. He returned to Peru in August 1568 and did not come back until 1595, bringing some 300 would-be colonists with him. He discovered Nendo Island of the Santa Cruz group and tried to establish a settlement there. It lasted only 10 weeks. Mendana died of malaria (at present over 3000 persons die of malaria annually in the S.I.). After sickness, internal squabbles and much fighting with the islanders, the remnants of the expedition limped back to Peru via the Philippines.

Quiros, a Portuguese, and Mendana's chief pilot on the 1595 expedition, led another expedition to the S.I. in 1605. He missed Nendo and his expedition also ended in disaster. This signalled the end of Spanish interest in the Solomons.

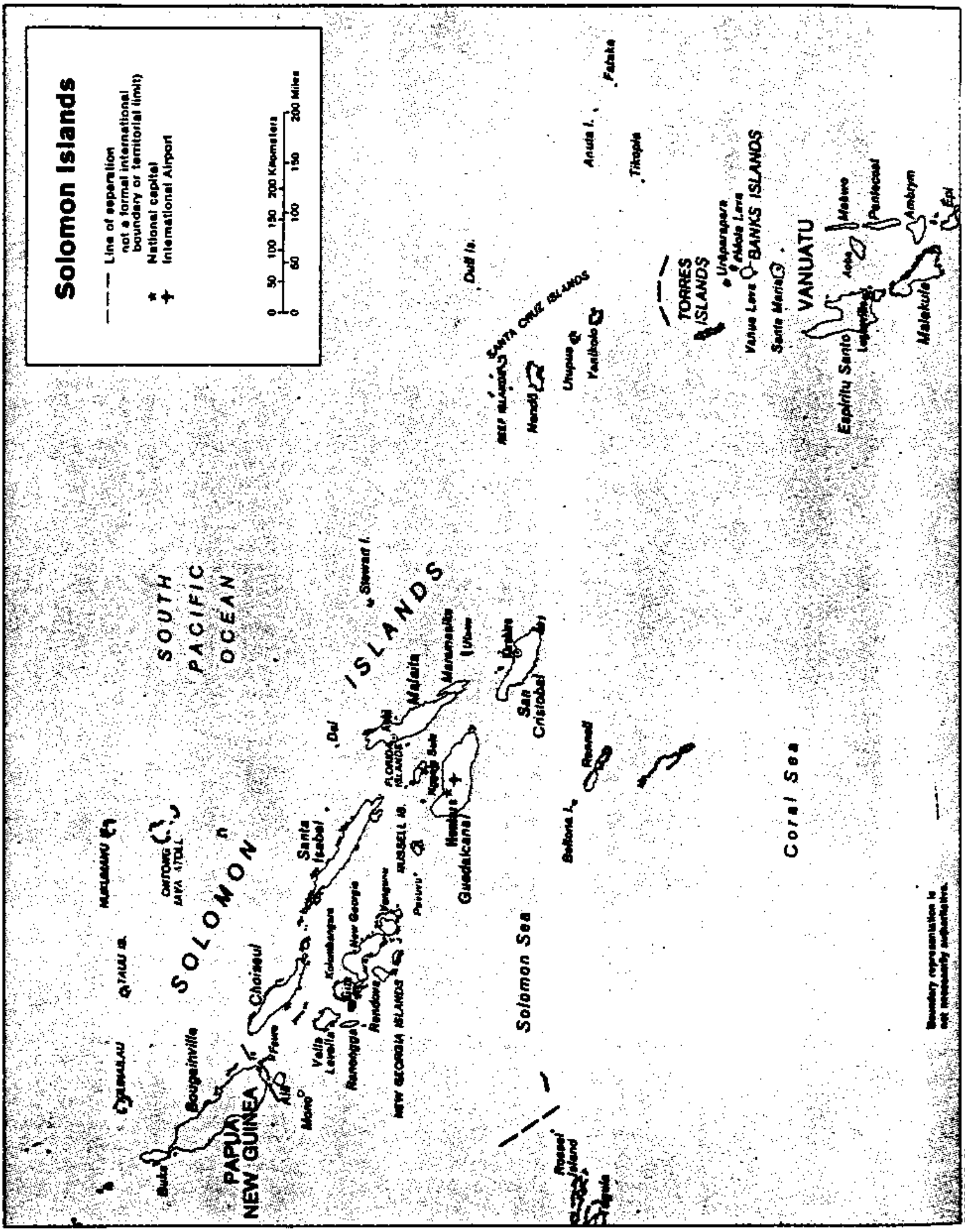
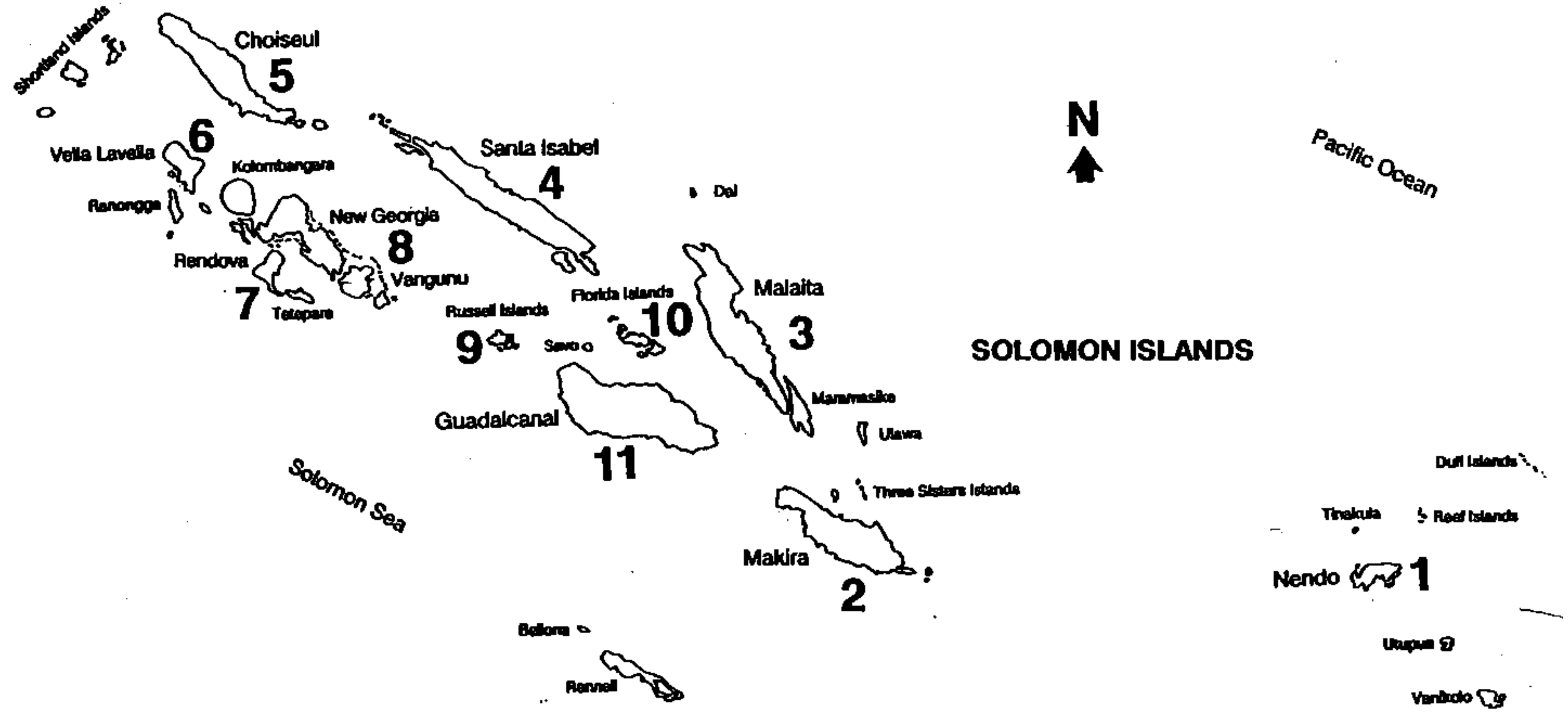

Solomon Islands
Line of separation not a formal international boundary or territorial limit)
National capital
International Airport
Kilometers
Miles
SOUTH PACIFIC OCEAN
SOLOMON ISLANDS
Solomon Sea
Coral Sea
PAPUA NEW GUINEA
Bougainville
Buka
Choiseul
Vella Lavella
Ranongga
Rendova
NEW GEORGIA ISLANDS
New Georgia
Santa Isabel
RUSSELL IS.
Guadalcanal
Honiara
FLORIDA ISLANDS
Malaita
Maramasike
San Cristobal
Rennell
Bellona I.
Stewart I.
SANTA CRUZ ISLANDS
REEF ISLANDS
Duff Is.
Utupua
Vanikolo
Anuta I.
Fatake
Tikopia
TORRES ISLANDS
BANKS ISLANDS
Vanua Lava
Santa Maria
VANUATU
Espiritu Santo
Malakula
Ambrym
Pentecost
Maewo
Aoba
Epi
Boundary representation is not necessarily authoritative.

FIGURE 1



Shortland Islands
Choiseul
5
Vella Lavella
6
Kolombangara
Ranongga
New Georgia
8
Rendova
Vangunu
7
Tetepare
Santa Isabel
4
Dai
Florida Islands
10
Russell Islands
9
Savo
Malaita
3
Guadalcanal
11
Maramasike
Ulawa
Three Sisters Islands
Makira
2
Solomon Sea
Bellona
Rennell
N
Pacific Ocean
SOLOMON ISLANDS
Duff Islands
Tinakula
Reef Islands
Nendo
1
Utupua
Vanikolo

FIGURE 2

In 1978 S.I. gained independence from the British – after being pushed into it by the British. For the past 15 years S.I. has been learning what it is like to be flat broke and independent. With its rapidly growing population and rapidly depleting natural resources, it is a prime candidate for the international dole – and permanently.

It was with this background that we undertook to survey the saltwater crocodile population of the Solomon Islands on behalf of CITES and the Solomon Islands Government during July-September 1989. This was difficult and a bit dangerous, but a most interest undertaking. The danger was not from the crocs – as there are very few left – but from surveying with various kinds of canoes and travelling long distances over the open sea in them. You don't have many deaths from car accidents in the islands, but plenty of drownings from canoe travel instead.

DISCUSSION

A. Habitat Generally speaking, the habitat for crocodiles in the Solomon Islands is at best, marginal. There are no extensive wetlands and few long meandering rivers, the preferred home of the saltwater crocodile, as there are in Papua New Guinea and Australia. Most rivers and creeks rise in the steep hills and mountains immediately behind a narrow coastal fringe of vegetation and as a consequence are unusually short. Because of heavy rainfall, the input of freshwater is high and the rivers, creeks, and springs are normally fresh down to within a few hundred meters of their mouths. Some of these provide good habitat for crocodiles and the alluvial soils are excellent areas for village gardens. Farmers treat the crocodiles as vermin

Two Dutch expeditions passed by to the north of the main S.I. during the next 40 years and then in 1767 the English Captain Cartaret blundered into Nendo and Malaita. He at first refused to believe he had rediscovered the S.I. A stream of British and French explorers followed including whalers and assorted traders. Many of these were eaten, as cannibalism was rife in the islands, lasting pretty well until the 1939 war.

The Germans were also active in this area in the 1800s but in 1898 the British and the Germans made a deal and the S.I. were absorbed by the British. Thus was established the British Solomon Islands Protectorate. British objectives for the Protectorate were very limited: law and order, stopping head-hunting and cannibalism, and ensuring that the islanders and their lands were not exploited by anyone else other than the British.

Missionaries arrived in large numbers – many were eaten – and life went on quietly the same; until life was shattered in 1942 with the Japanese occupation. This set the stage for some of the bloodiest battles of World War II, with US landings on Guadalcanal in August 1942. Tens of thousands of lives were lost and the Coral Sea is littered with sunk fighting ships. Some 49 major ships were sunk off Honiara in Iron Bottom Sound. Thousands of relics of these fierce battles still remain scattered throughout the islands.

Post war recovery was slow but the resource exploiters, Australian, New Zealanders, US, Canadian, Korean, Taiwanese, British and Japanese were not. While there was a slow awakening and move towards independence, the resource croppers started in earnest the stripping of the islands of their valuable resources – timber, fish, birds, crocodiles – you name it!

and quickly clear them from the area. With an annual human population growth of over 3 percent, pressure for use of fertile soils is great. The crocodile has little or no chance for survival in such areas.

The coasts of most of the islands in the Solomon Island chain are fringed by coral reefs, and many shallow, mangrove-fringed bays contain numerous patch reefs as well. For crocodiles, this is formidable terrain and is used when they are excluded from more favourable areas when travelling from one area to another.

Though the Solomon Islands lacks extensive freshwater swamps, it does have a small number of freshwater or brackish lakes, often shown on maps as lagoons. These are found on small islands, some 50 to 100m from the seashore, or up to 2km inland on the larger islands. Access to these lakes can be very difficult. They are often drained to the sea by very small creeks. These lakes appear to now provide the last haven of refuge and breeding areas for the remaining crocodiles in the Solomon Islands. Unfortunately, there are only a few of these lakes scattered throughout the island chain that are remote enough not to be negatively impacted by nearly villages. Hunters are also well aware of the lakes, as are hopeful 'crocodile farmers' who obtain their crocodile stock from the lakes. Most have been cleared of crocodiles or are severely depleted.

B. Status. There remains only one small real population of saltwater crocodiles in the Solomon Islands; Lauvi Lagoon on Guadalcanal. The next two largest populations are in Lake Tatae in the Russell Islands and in Ghahirahobo Lagoon on Santa Isabel.

In separate columns in the Table below we show the numbers and size classes of crocodiles sighted in Lauvi Lagoon, in Lake Tatae, in Ghahirahobo Lagoon, and those found in all other localities, and the totals. Those sighted in other localities consisted of a number of stragglers – the widely scattered surviving remnant of a once healthy population. Sadly, the crocodile resource of the Solomon Islands essentially has been destroyed.

Number of Crocodiles

	Lauvi	Ghahirahobo	Tatae	Other Locales	Total
Hatchlings	9	7	18	7	41
2-3' (0.9-1.2m)	31	3	-	5	39
3-4' (0.9-1.2m)	10	1	-	1	12
4-5' (1.2-1.5m)	1	-	-	1	2
5-6' (1.5-1.8m)	-	-	-	4	4
6-7' (1.8-2.1m)	-	-	1	1	2
>7' (>2.1m)	1	-	1	9	11
EO<6' (<1.8m)	26	2	1	8	37
EO>6' (>1.8m)	4	1	4	4	13
EO	10	1	2	3	16
Total	**92**	**15**	**27**	**43**	**177**

Over 86%, 153 out of 177, of the crocodiles were sighted in the freshwater lagoons. Almost all (134) of these were sighted in three lagoons only. Of the 177 crocodiles sighted, 41 were hatchlings, and every one of these hatchlings were sighted in the enclosed freshwater lagoons. Not one was sighted in the

30 rivers and creeks surveyed, many of which had good breeding habitat. These waterways had been essentially cleared of breeding stock and only stragglers remained.

One may ask what fraction of the crocodile containing habitat was surveyed by us. It is difficult to answer this with precision. Almost all of the areas, which knowledgeable hunters felt were worth surveying, were surveyed.

Because of the few animals we encountered, using statistical means to gain an estimate of the actual number of crocodiles in the Solomon Islands is meaningless. We believe that there may be another freshwater lagoon or two equivalent to Ghahirahobo or Lake Tatae that was not surveyed, but there certainly is not another equivalent to Lauvi Lagoon. Based on surveying experience in Australia, we can generously assume that the sighting fraction for crocodiles in the enclosed lagoons was only 50 percent. In addition to cover the unsurveyed waterways, the number of crocodiles seen in the saltwater lagoons, and rivers and creeks, can be liberally multiplied by 10 and that of the bays and channels by 20. This produces a 'guesstimate' of [2(153+42)+(10x7)+(10x8)+(20x9)] = 720 crocodiles, as a maximum.

It should be stressed that, other than in the small enclosed lagoons, the remaining crocodiles are widely scattered throughout the some 900 islands of the chain and the chance of breeders meeting must be small.

D. Number of Crocodiles in Former Times. How many crocodiles were there in the Solomon Islands in former times? One will never know for certain because, as elsewhere, no systematic survey of the crocodile population had been carried out. Furthermore, in former times, records of exports of crocodile skins were not maintained and even in recent times records have been scant. We are thus compelled to rely upon information provided by former and present day crocodile hunters. It is difficult to assess the reliability of such information other than by obtaining it from many hunters on different islands. This we did.

The following broad picture emerges. Apparently the crocodile, even though it, along with the shark, appears on the national emblem of the Solomon Islands, has been looked upon generally as vermin and treated as such. Thus when Australian expatriate hunters, who became well acquainted with the Solomon Islands during the second world war, started shooting crocodiles in the late 1950s and during the 1960s and early 1970s they were welcomed. Many of the older hunters and guides who helped us with the present survey, worked gladly with the expatriates to help shoot out the crocodiles. One of the Masters of our survey vessel, Harry Mamata, was one such individual who helped. On all the islands we surveyed, the name of Dennis Rome came up time and time again as one of the expatriate shooters. Freddie Forsythe Kaye was another name which was mentioned. Everyone of the indigenes stated that the crocodile resource had been large and could be gauged by the fact that in the 1950s and 1960s the hunters obtained, on average, 4 to 5 skins of large animals each night. On some nights, they obtained as many as 20 large animals. During the present survey, only in Lauvi Lagoon did we sight a few large animals and because of their wariness only one could be approached.

Apparently, even though the majority of the habitat for crocodiles in the Solomon Islands is marginal, the population size was large and must have taken a very long time, measured in centuries, to reach that size. We are unable to say more than perhaps it was as large as the crocodile population of Australia, but less than that of Papua New Guinea. We cannot substantiate this further.

E. Protective Measures. By the mid-1970s, the valuable crocodile resource had been severely depleted and the expatriate hunters departed. The indigenes, however, continued to hunt the animal both as vermin that occasionally attacked humans, pigs, dogs, and chickens, and because crocodile hide prices were high. They provided valuable supplementary funds for individuals of a local subsistence economy. By this time, India, Australia, and Papua New Guinea had recognized the danger of losing the crocodiles and took steps to implement management plans, ensuring the survival of the species and their eventual utilization on a sustained yield basis. The Solomon Islands was at this time in the throes of gaining independence and did not follow the lead of India, Australia, and Papua New Guinea. The killing continued, without general recognition that a valuable economic resource was being destroyed. Even as late as 1982, an expatriate hunter was welcomed to help clear the remaining vermin crocodiles. However, in 1972, legislation was enacted to prohibit the export of skins smaller than 50cm wide in the belief that it might help protect the crocodile resource. By allowing the adult breeders to be killed off, it did the opposite.

In the Solomon Islands, crocodiles are grouped with fish in the Fisheries Act of 1972. 'Fish' is defined as "any aquatic animal, whether piscine or not and includes...crocodile and turtle, and young and eggs thereof..."

Regulation 10 of the Act covers crocodiles and in 1977 was changed to read: "Any person who sells or exposes for sale – any crocodile or crocodile skins the belly width of which is less than 50 centimetres... shall be guilty of an offence... provided that this regulation shall not apply in relation to any crocodile, or skin of any crocodile... reared in a farm licensed under any Regulations..."

As far as we have been able to ascertain, this regulation has not been enforced. The export of skins of crocodiles of all sizes taken from the wild could be sanctioned. At any rate, since saltwater crocodiles do not start breeding until they are at least 2m (females) to 3.5m (males) long and have a belly width of 45cm, enforcement of the legislation would ensure that the crocodiles breeding resource would be severely depleted – as it has been – and perhaps, finally be totally destroyed. It should be noted the saltwater crocodile is on Appendix I of CITES.

F. Crocodile Skin Exports We have the following official figures for the export of crocodile skins from the Solomon Islands:

	Belly inches	Value (S.I.$)
1985	4163	10,405
1986	4350	10,873
1987	6445	32,093
1988	4772	99,852

No reliable data is available for the many previous years when crocodile skins were exported. However, the scant data available indicates exports of less than 1000 skins annually.

G. Crocodile 'Farms' and Ranching During the course of the survey, every opportunity was taken to visit crocodile 'farms'. These so-called 12 farms contained from 1 to 54 animals each. The Table below shows the size classes and total captive crocodiles seen.

Captive Crocodiles

Size in Feet (meters)	Number of Crocodiles
Hatchling	19
2-3' (0.6-0.9)	23
3-4' (0.9-1.2)	34
4-5' (1.2-1.5)	33
5-6' (1.5-1.8)	13
6-7' (1.8-2.1)	5
>7'	4
Total	**131**

CITES defines captive propagation as intensive management under captive conditions which reliably will produce and F_2-generation (second generation) from parents born or hatched in captivity. Such an operation which produces offspring from parents bred in captivity is defined as a 'farm'. Operations which obtain eggs or young from the wild, not from captive parents, for rearing in captivity is defined as a 'ranch'. Farms are closed-cycle operations independent of the wild populations, while ranches are open-cycle operations dependent on wild eggs or young.

There is no viable crocodile farm in the Solomon Islands at the present time and there is unlikely to be one unless a much more professional approach is taken. One or two, or even 54, immature animals does not constitute a crocodile farm. It takes 8 to 10 years for a female crocodile and 15 to 16 years for a male crocodile to reach breeding size. None of the captive animals seen in the 'farms' had bred in captivity, and since none of the 'farm' enclosures contained pools sufficiently large and deep (>1.5m), it is unlikely that they ever will breed under the current husbandry conditions. The existing 'farms' cannot even operate as ranches since, without a healthy wild population, neither eggs nor hatchlings can be collected from the wild for stocking the ranches.

Practically every hopeful crocodile farmer we spoke to expressed great interest in crocodile farming and wanted more information on it. They were most anxious to commercially farm the very resource which so many of them as hunters had helped to destroy in the wild. Most of them expressed sorrow at not having realized what impact their hunting was having.

Every commercially successful crocodile enterprise in the world depends to a varying degree upon tourism and/or ranching. Lauvi Lagoon is the only site in the Solomon Islands which in the near future might, with proper protection and effective management, become a tourism/ranching enterprise. Other lagoon sites will require stringent protection for at least 5 to 10 years before their populations will have recovered sufficiently to allow any sustained yield exploitation. However, this will require careful annual checking before any animals are taken.

CONCLUSIONS AND RECOMMENDATIONS

1. Crocodiles in the Solomon Islands have been and still are generally looked upon as vermin, and not as a valuable resource.

2. The crocodile resource of the Solomon Islands has been severely depleted and only a very small, widely scattered remnant population remains.

3. Unless urgent and strict measures are taken to protect the species, the saltwater crocodile may soon become extinct in the Solomon Islands.

4. There is, at present, no commercially viable crocodile farm or ranch in the Solomon Islands and this will not change unless immediate action is taken now to conserve the wild population.

5. The remaining crocodile resource is so small that a crocodile ranching proposal is out of the question for a number of years.

6. There does not exist in the Solomon Islands any effective legislation to protect and conserve the crocodile.

7. Few Solomon Islanders, with the exception of the crocodile hunters, are aware that the crocodile populations are so dangerously depleted.

We recommend that:

A. The wild crocodile population of the Solomon Islands remains on Appendix I of CITES.

B. A total export ban on crocodile skins of all sizes and from all sources in the Solomon Islands immediately be established and effectively implemented. Such a ban should remain in effect for a minimum of 5 years, after which it should be reviewed.

C. A permanent ban on skins taken from the wild, whose belly width is greater than 45cm should be imposed to protect the breeding stock.

D. The Solomon Island central government and provincial authorities immediately commence the task of educating the public about the vital importance of conserving their natural resources and the national heritage, including crocodiles, for the future benefit of their citizens.

E. The central and/or provincial governments find some way to protect and conserve the remaining crocodile resource. We recognize that in the Solomon Islands, wildlife belongs to the traditional landowner, but if the scant resource is to be saved the governments must find a way of convincing the landowners to protect the wild populations and their habitats. Special areas such as the freshwater lagoons should be given priority consideration.

F. The governments discourage taking crocodiles from the wild to stock so called 'farms'; which are unlikely to become economically viable, except as a tourist attraction.

G. The status of the crocodile populations in Lauvi and Ghahiarahobo Lagoons, and in lakes Tatae, Korea, and Matimi and those in Renard Cove be monitored annually.

As far as I am aware, little has been done in the islands about the recommendations made and an attitude of benign neglect appears to prevail. However the Solomon Islands would find it very hard to trade in crocodiles since their normal former buying nations are complying (?) with the CITES regulations.

PALAU

GENERAL AND HISTORY

The Republic of Palau, located on the western edge of Micronesia is about 1000km east of the southernmost island of the Philippines and 650km north of the equator (Fig 3). It consists of an elongated chain of some 340 islands stretching for approximately 650km in a north-south direction and has land mass of roughly $450km^2$. Only 8 of the islands are inhabited and the majority of the country's 15,000 population live in the capital, Koror (Figs 4 and 5).

While in Palau, we managed to research the early history of crocodiles and crocodile management in the country. Using a number of reliable sources we documented the fascinating but sad story of the decimation of the crocodiles of the Republic. The responsibility for the decimation must be attributed largely to the recommendations and actions (or lack of action) of the US Department of the Interior, Office of Territorial and International Affairs, Trust Territories Administration (hereinafter US Administration), during the 1960s and 1970s and of the Chief Conservationist and Entomologist in Palau, Mr Robert P Owen.

We located two important scientific papers by Sigeru Motoda (1937,1938) of the Tropical Life Sciences Research Center, Koror, Palau. These were published in Japanese, but fortunately English translations were available to us. Motoda states that a survey was conducted by the Ministry of Education, Special Education Bureau, immediately after the Japanese took possession of the islands in 1914. According to Motoda, the results of the surveys by Messrs Narabayashi, Ishibashi, and Horii appeared in 1916 and 1917 and were

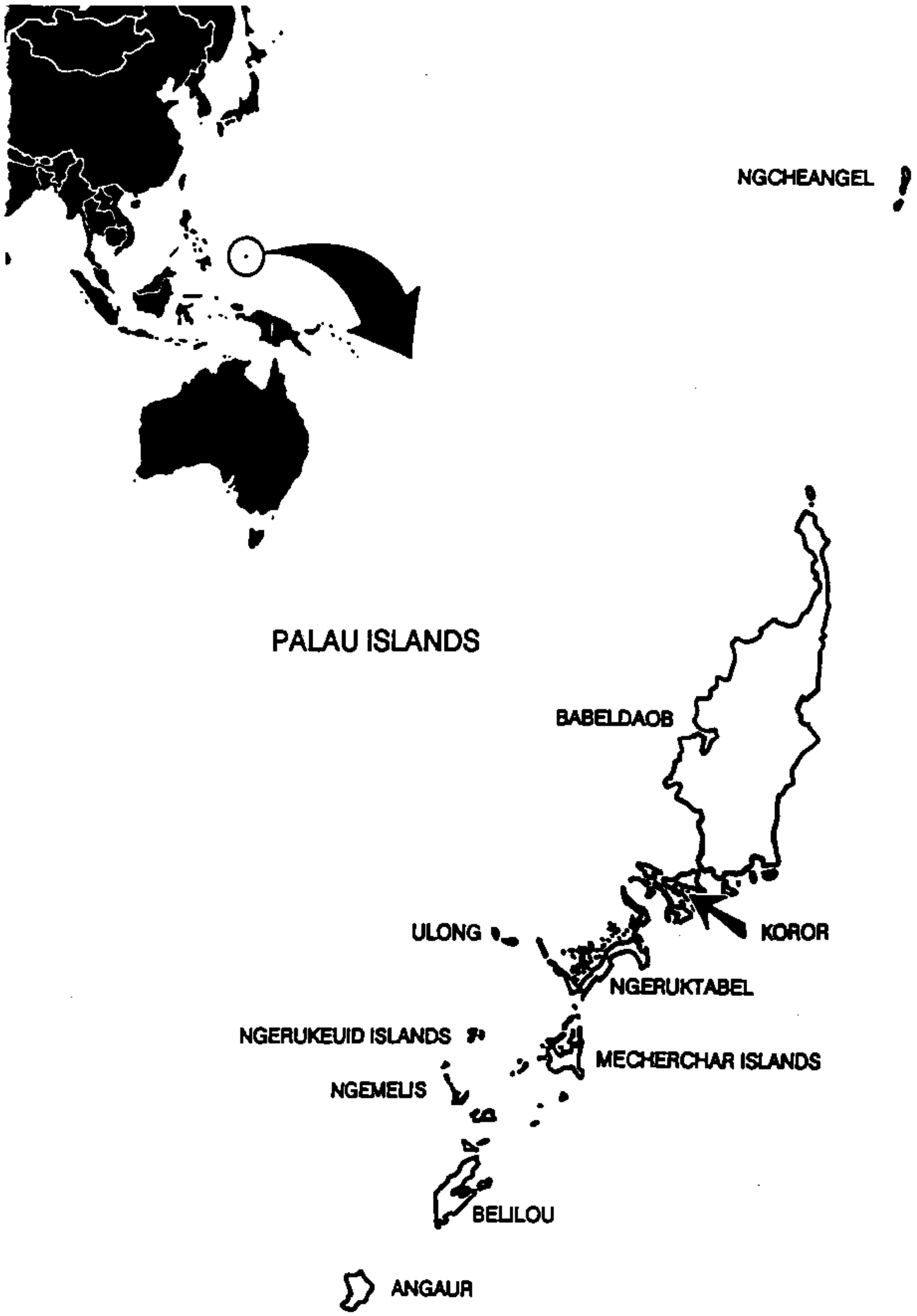


Figure 3. The Palau Islands archipelago lies on the Palau-Kyushu Ridge approximately 1,290 km southwest of Guam and 960 km east of the Philippines. The southwest island group of Fana, Sonsorol, Pulo Anna, Merir, Helen Reef, and Tobi lies 240 km southwest of Angaur and 300 km northeast of Indonesia, has no crocodile habitat, and is not shown here.

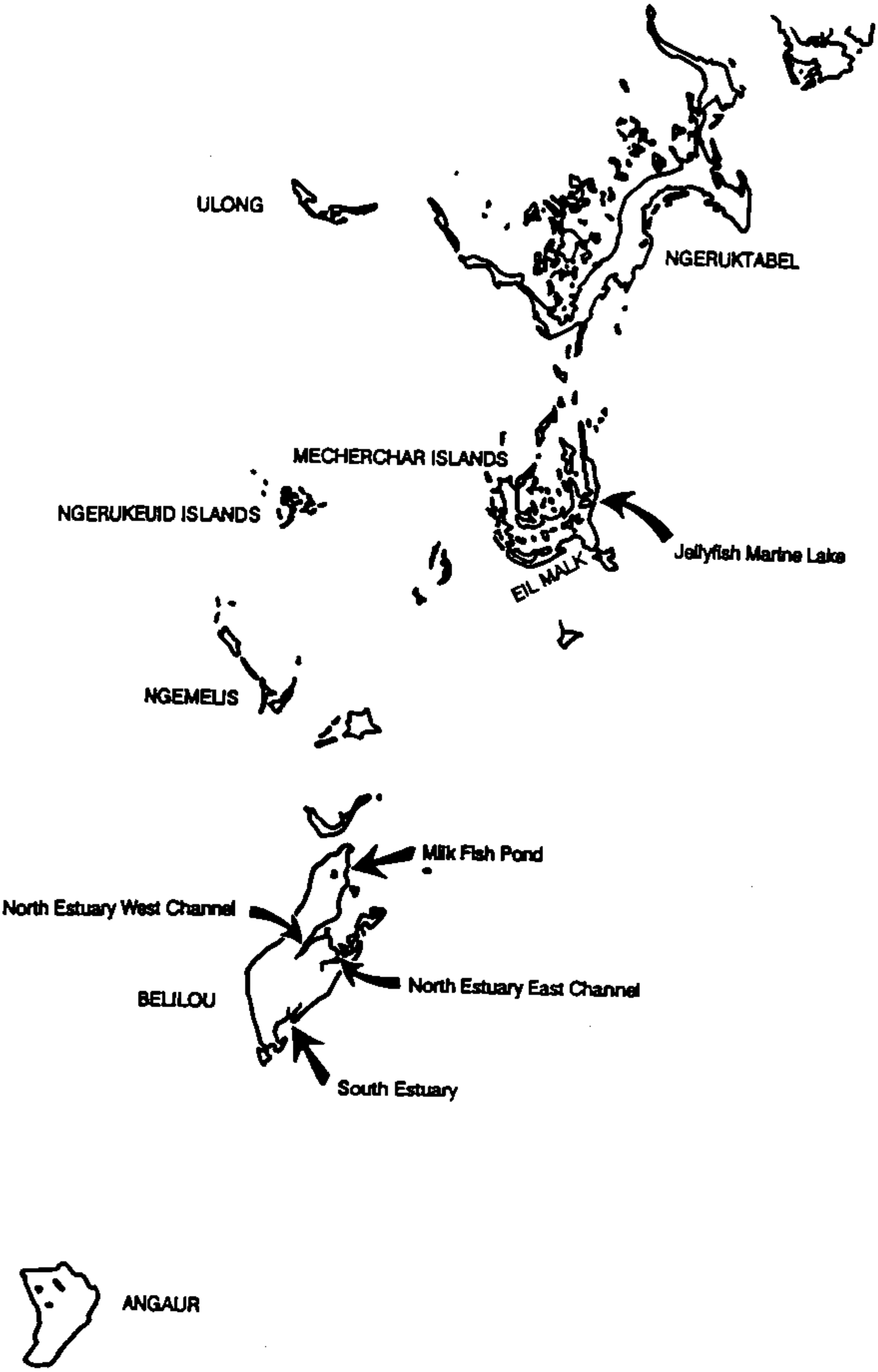


Figure 4. Waterways surveyed in Belilou and the Rock Islands. Island names are capitalized; survey localities are in capitals and lower case.

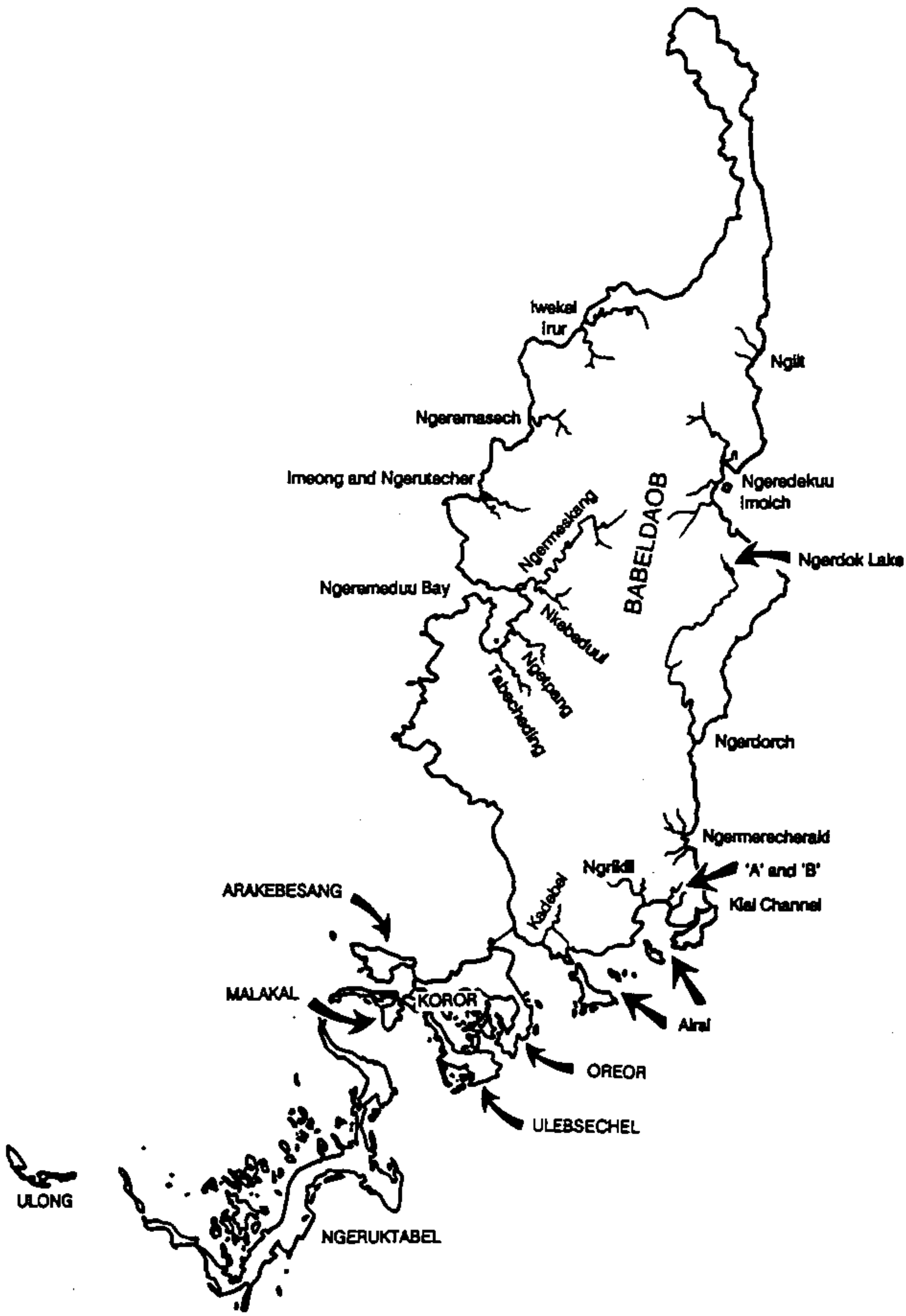


Figure 5. Waterways surveyed in Babeldaob and the vicinity of Koror. Island and city names are capitalized; survey localities are in capitals and lower case.

reprinted in the 1928 "Report on the Survey of the Mandate Islands of the Pacific". Each of them declared that crocodiles were found in Palau, and that a few crocodile attacks had occurred. Mr Risabura Kyota who had been living in Ngeremlengui since 1910 also gave information on crocodiles in Palau and his observations on nesting and behaviour appeared in the 25 February 1937 South Pacific News Magazine. The first crocodile reported to be caught in Ngatbang (= Ngeremeduu Bay) was between 1898 and 1905 when the islands were administered by the Germans. Most of the crocodiles were between 2 and 3 feet in length. Interestingly, the German administration prohibited the capture of crocodiles in Ngatbang Bay in order to conserve them.

Motoda reported a number of crocodile attacks, some of which were fatal, for the period 1915 to 1920. He also enumerated the 54 crocodiles captured during the period 1915 to 1936 and reported that crocodiles were observed 20 times in four years in Galmiskan. While individual nuisance crocodiles were trapped, both the German and Japanese administrations apparently were determined to coexist with the crocodiles of Palau and there is no record of trying to exterminate them.

In 1947, Palau became a trust territory of the United Nations administered by the US government. We were unable to discover much information about crocodiles for the period 1947 to 1958 by which time Mr Robert P Owens was the US Adminsitration's Staff Entomologist in Koror and apparently was responsible for overseeing many wildlife matters, including the crocodiles of Palau.

Then on 28 December 1965, while spear fishing at night, Mr Ngiramulei Yoroi of Koror was attacked and killed by a 12 foot 7 inch crocodile weighing 427 pounds. This crocodile was trapped on 8 January 1966, was put on public display, and the public charged a fee to view this man-eater. Yoroi's widow eventually received $70.00 from the viewing fees. The public display of this crocodile so enraged the public that several people attempted to kill it. It died several days later, allegedly after being poisoned. Its remains eventually were shipped to the US National Museum of Natural History, Smithsonian Institution, in Washington DC. The US Administration in Palau had hoped to sell the crocodile to a zoo or private collector for a large sum of money, part of which was to be paid to the deceased's family and the remainder to be used to purchase materials for constructing traps for eliminating the crocodiles. In response to the exceedingly unfortunate death of this one fisherman, the Administration launched not a program to control individual crocodiles that threaten humans but a campaign to eradicate all crocodiles in Palau, no matter where they occurred. It was little more than a war against the species.

It should be noted here that prior to the death of Yoroi, hatred of crocodiles by local Palauans was not as pervasive as it was after the publicity given his death by the US Administration. In fact, local villages regarded crocodiles as special collaborators if not friends.

The unfortunate death of Yoroi thus appears to have determined the fate of the crocodiles of Palau under the US Administration for alarm bells immediately were set ringing and calls were made for the destruction of all crocodiles. No attempt was made to calm the citizens of Palau or to discourage eradication. The October 1966 session of the Palau Legislature passed Resolution No 7-10-66 which requested the District Administrator of the Palau District to provide for construction of crocodile traps to be distributed to all municipalities. In July 1968, a Bill was introduced in the Congress of Micronesia providing for a bounty for killing of crocodiles and alligators for the purpose of encouraging the destruction of these animals which "... have increasingly posed a menace to the health, life and limb, safety and welfare of the people of the Palau District". Interestingly, we were unable to find any record of dissent.

During the period 4 December 1967 to 8 January 1968, a crocodile survey of Palau was carried out by a group under the direction of David Imes and Jack Hardy (Australians?). They made 21 crocodile counting sorties, spent $1000, and only sighted 23 crocodiles. The surveys were initiated by the US Administration officials in an attempt to determine whether or not the crocodiles of Palau could be harvested profitably for the benefit of locals. Apparently the results of these surveys did not confirm the belief of the US Administrators who were convinced that Palau was infested with thousands of crocodiles. As a result, nothing much appears to have come from this effort to establish a crocodile fishery even though an allocation of $16,200 was proposed by the Fisheries Division of the US Administration.

However, in November 1967, a Mr Rene Henri of various addresses in Melbourne, Australia, (after a previous meeting) contacted Robert Owen, then Staff Entomologist in Palau, with a proposal to have Australians from "crocodile shooting clubs" come to Palau to shoot crocodiles for sport and for their skins. [Interestingly, after 40 years in Australia and working there for 21 years on crocodiles, the author of this report (HM) has never heard of such clubs.] Robert Owen wrote to Mr Henri on 23 January 1969 (only 12 months after the Imes and Hardy surveys had found only 23 crocodiles) stating that he thought there were approximately 5000 crocodiles of all ages in the Palau Islands.

After a very lengthy organizational and bargaining period, on 24 June 1969, the government of Palau, under US Administration, entered into a contractural agreement with the "Australian Crocodile and Big Game Association" of which Mr Rene Henri was President. Apparently no check was made on the credentials of the Association. This agreement granted the Association exclusive rights for three years to hunt, kill and skin crocodiles in the District of Palau and to sell the hides and remains. In return, the Association contracted to train local Palauans in the killing and skinning of crocodiles and the marketing of hides. Importantly, the contract drawn up by the US Administration required the Association "... to kill all crocodiles which it had the opportunity to exterminate regardless of size". As Peter T Wilson, the Fisheries Management Biologist in Palau, stated in May 1969, "We find the people of Palau have one unanimous desire and this is to get rid of all crocodiles". The US Administration apparently was doing its best to see to it that this desire was met.

However, the Australian Crocodile and Big Game Association quickly tired and disappointed the government. After only two months (11 August 1969) they broke their 3-year contract and left in their ship the "Mia-Mia" for further shores. The Association had found that contrary to what the government reported to them earlier there were at best only several hundred crocodiles of a size suitable for commercial hunting and that these were best left to their local trainee, Rik-Rik Spis. They had shot a total of 85 and reported that only 6 remained in areas where they could threaten humans and these would be eliminated within a month or two. Amazingly, Mr Henri was congratulated for his efforts by Robert Owen and the High Commissioner of the Trust Territories. Fortunately, this strange episode did not wipe out the crocodiles of Palau.

Rik-Rik Spis continued hunting crocodiles and it is recorded that by 1972 he had shot almost 200, but thereafter the enterprise appears to have come to a halt.

By 1975, the crocodile population of Palau was gaining the attention of a number of overseas scientists and naturalists. James H Powell Jr, of Plainview, Texas USA, contacted Robert Owen, by now the Chief Conservationist of Palau. Powell visited Palau during the period October-November 1975 using an Explorers Club of New York grant to study crocodilians in the field. His objective was to "Determine from first-hand field observations the distribution and status of *Crocodylus porosus* populations through the Palau Islands, from Kayangel in the north to Angaur in the south". He also wished to do the same for *Crocodylus novaeguineae* which Owen had stated was present in Palau. Such a project would be a major undertaking requiring considerable logistic support.

Powell reported on his visit in an unpublished document dated 2 February 1976 which was circulated by him privately. From his report, it appears that he was singularly unsuccessful in his mission and only sighted one crocodile in Palau and this animal was swimming in open but shallow sea.

During 1976, Professor W A Dunson, Pennsylvania State University, expressed an interest in studying the crocodiles of Palau (with the aid of a

National Science Foundation grant) and specially the issue of which species of crocodilians were present in the islands. He was scheduled to arrive in Palau on 9 March 1977, but we were unable to locate any report on the results of his visit.

In July 1978, Dr Ian R Swingland, Oxford University, UK, and currently of the SSC Tortoise and Freshwater Chelonian Specialist Group, also showed interest in studying the crocodiles of Palau. However, it appears that his visit did not eventuate. If it did, we have not located a report on it.

During the late 1960s, Inoue Tanning Company of Tokyo showed considerable interest in starting a crocodile farm and hide production industry in Palau, but nothing came of this. Strangely, though Owen had received extensive information from Max Downes on the important SYU crocodile program in Papua New Guinea (PNG) as early as 1968, he was not interested. Owen was aware that in 1965-66, the export of hides was worth $1,000,000 to PNG. While the Papua New Guinea program protected adult crocodiles greater than 9-feet in length, so they would continue to breed and produce eggs and hatchlings that could be reared on farms, Owen stated in a letter to Downes dated 18 October 1968 that he was doing just the opposite, he was exterminating the adult breeders in Palau. Owen negotiated the contract with the Australian Crocodile and Big Game Association following this exchange with Downes.

In December 1977, in a letter to John Lever, PNG Crocodile Project, Owen stated, "I will continue to gather what information I can and possibly initiate a small farming project in hopes that some economic benefit can be derived for the people of Palau from crocodile farming without endangering the existence of the species here". Apparently, the decision to exterminate the crocodiles in Palau had been dropped, but by then many people in Palau hated the crocodiles and economic incentives for their conservation were minimal.

The final major assault on the crocodiles of Palau came in the period 1979-1981. It is difficult to find the actual reports documenting this; however, in late 1978 or early 1979, a joint enterprise between two Palauans, Kikuo and Hashida, and two Japanese, Hasegawa and Oshima was established for shooting crocodiles in Palau and selling their skins. This enterprise used three hunting boats and apparently was under the supervision of Joshua Eberdon, who was the local member of the Messel-King crocodile survey team. He states that between 500 and 1000 crocodiles of all size classes were shot, from all parts of Palau, before the enterprise folded in 1981. Toshio Yamanaka, President of Yamatoshi Hikaku Co Ltd which purchased the skins, reports that Hasegawa and Oshima "sent approximately 200 skins and the number of skins for one shipment was in the region of 30/50 skins ... The size of the skins was mostly 30 to 40cm of belly width and about 10% of the lot were 50cm". The money from the sale of the skins was to be used in part to establish a crocodile farm in Palau. A few pens were built and about 50 animals captured, but one night all of the animals were stolen so Yamatoshi Hikaku Co Ltd abandoned the project.

At the present time, Eberdon has 41 *Crocodylus porosus* on a farm in Koror. Because *Crocodylus porosus* is listed on the US Endangered Species List and Eberdon lacks permits from the Office of Management Authority, US Fish and Wildlife Service (FWS), the crocodiles on his farm are illegal. They range from 3 to 11 feet in length and are in excellent condition. Eberdon states the crocodiles were all caught during the past 2 to 3 years (1989-1991), that this pretty well cleaned out the wild population, and that only remnant crocodiles remain here and there. While the government of Palau does not operate a program to remove nuisance crocodiles that might threaten humans, Eberdon has operated one privately. Whenever he hears by word of mouth that some village is trying to kill a crocodile, he has tried to discourage this. When the village or individuals involved are unrelenting in their determination to kill the crocodile, Eberdon has volunteered to catch it alive and place it in his farm.

We also inspected two (7-8') and two (9-10') *Crocodylus porosus* belonging to ex-Senator Baules in concrete pens behind the "Crocodile Lounge: in Airai, Babeldaob. In addition, we examined the single (6-7') *C. porosus* in a small enclosure on Belilou Island. Mark Vereen, Angaur Island, came to see us in Koror and discussed his desire to establish a crocodile farm on Angaur. He currently has 4 (6-7') *C. porosus* in a pen at his house, and Baste Terulii has a (9-10') *C. porosus* in excellent condition in a concrete pen, both in Koror. FWS permits have not been issued for any of these captive crocodiles in Palau, hence all of them are held illegally.

SPECIES IDENTIFICATION OF THE PALAU CROCODILES.

Unwarranted confusion has surrounded what species of crocodile occurs on the Palau islands; all the Palau crocodiles are the saltwater or estuarine crocodile, *Crocodylus porosus*. No other species occurs in Palau.

Motoda (1937 and 1938) stated that the Palau crocodiles were the same species as occurs in India, *Crocodylus porosus*, or possibly *Crocodylus palustris*. All other early published records of the crocodiles of Palau referred to *Crocodylus porosus* until Wataru Kimura (1968) reported finding three species of crocodile in Palau during his trip to the islands in 1967, the Philippine crocodile, *Crocodylus mindorensis*, and the New Guinea crocodile, *Crocodylus novaeguineae*, in addition to *Crocodylus porosus*. Without questioning the accuracy of Kimura's identification, most subsequent authors simply repeated his declaration that the three species occur in Palau.

Kimura (1968) reported that prior to World War II, a Mr Saeki, of the Kimi Marine Products Company, operated a crocodile farm on Arakabesang Island, in the Koror area of Palau. In 1938, Mr Saeki stocked the farm with 900 crocodiles from Davao in the Philippines; 1000 crocodiles were purchased but 100 died in transit. These imported crocodiles could have included *C. porosus* and/or *C. mindorensis*. In addition, 10 native crocodiles from Palau were captured for the farm and 10 American alligators also were obtained from a Mr Tahasaki in Tokyo. A second 1000 crocodiles were later imported from the Philippines to replenish the farm stock, and 10 crocodiles also were imported from New Guinea. The crocodiles from New Guinea could have been *C. porosus* and/or *Crocodylus novaeguineae*. One of the crocodiles from New Guinea, a 12-foot long specimen, was sent to the Atami crocodile farm in Japan, the rest stayed in the Palau farm. Prior to the start of World War II, the farm stock had been reduced to approximately 200 animals. During the war, soldiers ate many of the crocodiles, and few if any remained by the end of the war. Some may have escaped, though Mr Saeki, who was interviewed by a third person in 1948, did not believe that the wild crocodiles of Palau were derived from escaped or released farm stock. Kimura (1968) agreed.

Kimura (1968) did not explain how he distinguished between C. *porosus*, C. *mindorensis* and C. *novaeguineae*, but apparently it did not involve the morphological characters used by most crocodile biologists, the presence in *mindorensis* and *novaeguineae* of four enlarged, bilaterally symmetrical (ie two on each side of the midline) postoccipital scutes on the nape between the skull and the enlarged nuchal cluster, and their absence in *porosus*. Possibly Kimura recognized different forms based on skin colour as in February 1969, he wrote to Robert Owen, a biologist for the US Department of the Interior, Office of Territorial and International Affairs, Trust Territories Administration, seeking replacements for "New Guinea black skin crocodiles" from Palau that had died. Possibly he mistakenly believed that the occasional C. *porosus* with one slightly enlarged postoccipital scale on one side of the neck was C. *novaeguineae* or C. *mindorensis*.

Kimura (1968) reported that *Crocodylus novaeguineae* was found in the east coast rivers of Babeldaob, while *Crocodylus porosus* and *Crocodylus mindorensis*, and a few *Crocodylus novaeguineae*, occurred in the west coast rivers. We found only C. *porosus* in Palau's rivers, estuaries, and in the freshwater Ngerdok Lake. We also examined every captive crocodile that we could in Palau (see list below) and two specimens in the Balau National Museum; without exception they are all C. *porosus*.

More recently several popular publications (eg Thyssen 1988) have suggested that two species of crocodiles, *Crocodylus porosus* and C. *novaeguineae*, are found in Palau and that a third form, a hybrid between the two, now is widespread through the islands. There is no evidence that C. *novaeguineae*, ever occurred in Palau and there is no evidence of any hybrid on the islands.

Until evidence to the contrary is produced we will continue to believe that *Crocodylus porosus* in the only species of crocodile that occurs in Palau.

DISCUSSION

Habitat. The quality of the habitat for crocodiles in Palau generally is good, but the quantity of it is very limited. There are a number of small Type 1 tidal-freshwater systems and some of these have associated freshwater swamps. Such systems provide excellent breeding habitat. Often such systems are also associated with hypersaline coastal creeks (known as Type 3 systems) which provide rearing areas for subadult crocodiles.

The total land area of Palau is roughly 450km^2. The largest island, Babeldaob, constitutes about 90 percent of this area and is roughly 40km long and 16km wide at its broadest point. Thus, there are no long meandering tidal waterways. The rivers and creeks rise in the hills immediately behind a narrow coastal fringe of mangroves and are short. Often there are villages upstream and the villagers trim the mangroves back from the edge of the waterway. Downstream *Rhizophora stylosa* the stilt-rooted mangrove dominates the saltwater channels.

During the rainy season, June-July, when we surveyed, heavy tropical downpours ensured that there was a heavy input of freshwater into the waterways. Thus, many of the coastal creeks, and tributaries of Type 1 freshwater systems, had salinities below that of seawater. During the dry season many of these waterways would be hypersaline or Type 3 waterways.

The swamp habitat associated with the tidal waterways is likewise limited, but is of great importance for breeding. Unfortunately, some of this habitat has been drained for agriculture. Ngerdok Lake is the only major freshwater lake on inland Babeldaob. It has a perimeter of 1.8km. It is heavily fringed with lily-like vegetation and provides excellent habitat for crocodiles.

The famous Rock Islands of Palau do not provide breeding habitat for *C. porosus* even though stragglers are often seen in the channels between the islands. These are either adult crocodiles on the move and feeding, or as mentioned previously, subadults which have been excluded from the breeding area by the territorial adults. Some of the marine lakes on the rock islands are used by these excluded crocodiles and thus when crocodiles are sighted in them, they are usually subadults. The Rock Islands certainly are not prime crocodile habitat.

The best overall crocodile system in Palau is the Ngerdorch River. Unfortunately, the crocodiles on this system have long since been shot out.

Aside from the fact that present-day Palauans hate crocodiles and kill them on sight, the additional major threat to *C. porosus* is destruction of habitat. Waterway after waterway is being trimmed and used as a boat highway. It is unlikely that this will decrease and hence one can predict the contraction of the areas where crocodiles can live. At best, we believe that a number of well chosen reserves need to be established where the habitat and crocodiles are protected.

Status. *Crocodylus porosus* is nearing extinction in Palau, after a determined effort by the US Administration, with the help of Palauans, to eradicate the animal. We give below a summary of the results of our surveys.

Area	km surveyed	crocodiles sighted
Belilou Island	8.6	17
Airai	23.0	1
East Coast	34.5	0
Ngeremeduu Bay	25.7	3
Mid-west Coast	17.8	3
Ngerdok Lake	1.8	17
Jellyfish Lake	1.0	1
Totals	**112.4**	**42**

It is evident that only two very small viable populations of crocodiles remain in Palau, each with 17 animals sighted. The remaining 8 crocodiles sighted are remnants of former larger populations. It is important to note that we did not see a single hatchling or one year old crocodile on the 112.4km of waterways surveyed.

What fraction of crocodile habitat was surveyed by us and how many crocodiles remain in the wild in Palau? After studying topographic maps, talking with former crocodile hunters, and reviewing the published literature and government records, we believe we surveyed at least 75 percent of those waterways worth surveying. Similarly, we surveyed at least 50 percent of the coast worth surveying.

Because of the few animals we encountered, using statistical means to gain an estimate of the actual number of crocodiles in Palau is meaningless. We do not believe that there is another viable population in Palau the size of those in Ngerdok Lake and on Belilou Island.

There undoubtedly are more straggler crocodiles scattered throughout Palau than we sighted, but scattered singletons do not make a breeding population. Based on our estimate that 75 percent of the important waterways were surveyed, multiplying the 7 stragglers sighted, including the one in the marine lake, by 1.25 would provide an estimate of the number of crocodiles in Palau's waterways. Instead, we have been generous and multiplied the number of 10. Similarly, we have multiplied the one crocodile sighted along the coast by 10 instead of 2, thus making a huge correction for crocodiles not sighted. These two sources thus lead to a charitable estimate of 80 crocodiles. When standardized methods are used for surveying crocodiles, 66 percent of the crocodiles present are sighted and 33 percent remain unseen. Again, using a sighting fraction of 50 percent, rather than the usual 66 percent, for the 34 crocodiles in the two small viable populations yields an upper limit of [(2x34) + 80] = 148 crocodiles. However, since too few animals were sighted to estimate the actual number of crocodiles in Palau, rather than use 148, which is an exact number and implies exact results, we prefer to say that there are fewer than 150 crocodiles remaining in the wild and it highlights the serious plight of the crocodile resource in Palau.

How many crocodiles were in Palau in former times? There is no way to know for certain because no systematic survey of the crocodile population was ever conducted before and complete records of exports of crocodile skins were not maintained. Thus, we are forced to rely upon information from former crocodile hunters and to some degree upon guesses made by the US Administration.

Robert Owen in 1969 estimated that there were 5000 crocodiles in Palau though he apparently never made any personal attempt to verify that estimate with night-time surveys and actively ignored the lower estimates of others. The Australian hunters estimated there were some 500 crocodiles in 1969. Rik-Rik Spis is reported to have shot some 200 by 1972. Joshua Eberdon estimates that between 500 and 1000 crocodiles were shot during the crocodile hunting operation he oversaw in 1979-1981. There is no way to determine whether or not Hasegawa and Oshima sold additional skins to other buyers, but Yamatoshi Hikaku Co Ltd only received about 200 skins. From this we are guessing that the population was never more than about 1500 animals in all size classes. This population, managed on a sustained yield utilization basis could have provided a valuable economic resource providing a substantial annual income to Palau. Instead, the resource has been almost destroyed. It will require a concentrated effort by the authorities to nurture the present scant resource, to conserve it and turn it to economic gain. It can be done and we make recommendations to this effect.

CONCLUSIONS

1. During the German administration of Palau, 1899-1914, crocodiles were tolerated and protected in some areas. During the Japanese administration of the islands, 1914-1945, crocodiles were able to exist side by side with the general population – an easy peace existed.

2. Since the beginning of the administration of Palau by the Office of Territorial and International Affairs, US Department of the Interior, overseeing the Government of the Trust Territory of the Pacific islands, dislike and active hatred of crocodiles by Palauans has increased. This was sparked by the crocodile fatality in Koror on 28 December 1965. The wish of many Palauans is to see the crocodile exterminated.

3. The US Administration, during the late 1960s and 1970s did much to see that the wish of the Palauans was fulfilled and instituted a deliberate policy to eradicate crocodiles. That policy has been in violation of the US Endangered Species Act of 1973 (ESA) since at least 18 December 1979 when the *Crocodylus porosus* was listed as Endangered. Section 2(c) of the ESA requires that "... all Federal departments and agencies shall seek to conserve endangered species and threatened species and shall utilize their authorities in furtherance of the purposes of this Act ..."; Sec.3(12) specifically includes the Trust Territory of the Pacific Islands in the definition of 'States': Sec. 6(f) states that,

> "... Any State law or regulation which applies with respect to the importation or exportation of, or interstate or foreign commerce in, endangered species is void to the extent that it may effectively (1) permit what is prohibited by this Act or by any regulation which implements this Act ..."

and Sec.7 states that,

> "... All other Federal departments and agencies shall, in consultation with and with the assistance of

> the Secretary, utilize their authorities in furtherance of the purposes of this Act by carrying out programs for the conservation of endangered species and threatened species listed pursuant to Section 4 of this Act and by taking such action necessary to insure that actions authorised, funded, or carried out by them do not jeopardize the continued existence of such endangered species and threatened species ..."

Clearly, the 1979-1981 crocodile hunt in Palau authorized by the US Administration was in violation of these provisions of the ESA. If the statute of limitations has not run out, the USDI officials responsible should be prosecuted under the ESA. The US Government is responsible for the present sorry plight of crocodiles in Palau and for the wastage of a valuable economic resource.

4. The crocodile resource of Palau has been severely depleted and only a very small, widely scattered remnant population remains. We found only two small viable populations covering various size classes – the 17 crocodiles sighted on Belilou Island and the 17 sighted in Ngerdok Lake. We estimate that the maximum number of crocodiles remaining in the wild in Palau to be fewer than 150.

5. Unless urgent and strict measures are taken to protect the species, the saltwater crocodile will soon become extinct in the wild in Palau and cause a further severe decrease in the species' range.

6. In view of the possible extirpation of C. *porosus* in the wild in Palau, the only viable genetic bank for Palauan C. *porosus* is the 41 crocodiles in Joshua Eberdon's farm. It is vital that this Palauan C. *porosus* gene bank be preserved.

7. The Eberdon crocodile farm has the potential to become an economically viable operation. The other much smaller captive crocodile operations contain too few animals and their facilities are unsuited for breeding and commercial propagation.

8. The crocodile resource remaining in the wild is so small that a crocodile ranching proposal is out of the question for a number of years.

9. There does not exist in Palau any legislation to protect and conserve the crocodile.

10. In spite of widespread and continued discussion over the past 30 years that 3 species of crocodiles exist in the wild of Palau, *Crocodylus porosus, Crocodylus mindorensis,* and *Crocodylus novaeguineae,* there is no evidence to support this belief. Only *Crocodylus porosus* occurs in Palau.

RECOMMENDATIONS

We recommend that:

1. The wild crocodile population of the Palau remain on Appendix I of CITES and listed as 'Endangered' on the US Endangered Species Act.

2. The total export ban on crocodile skins of all sizes and from all sources in Palau be effectively implemented and policed until such time as the wild crocodile population is recovered in Palau and/or a Palau crocodile farm becomes productive and is registered with the CITES Secretariat.

3. The Palau national and state government authorities immediately commence the task of educating the public about the vital importance of conserving their natural resources and their national heritage, including crocodiles, for the future benefit of their citizens.

4. The Palau national and state governments find some way to protect and conserve the remaining scant crocodile resource. The killing or taking of crocodiles in the wild should be prohibited except by a licensed nuisance crocodile trapper.

5. The government institute a program to control individual nuisance crocodiles which pose a potential threat to humans. Such animals should be captured by a licensed trapper. Small crocodiles should be released in a reserve and large ones placed in a crocodile farm.

6. The US Fish and Wildlife Service, co-ordinating with Palau's Bureau of Resources and Development, should act immediately to place the illegally held (ie, non-permitted) crocodiles from the various small holdings in Palau onto one major crocodile farm which would serve as the gene bank for Palauan C. *porosus*. This farm of Palauan C. *porosus* could be made into an economically viable operation and, more

importantly, into a major public education centre for crocodile conservation.

7. Since his farm is the only program in Palau which has the chance to become a bona fine crocodile propagation centre, the US Fish and Wildlife Service, again co-ordinating with Palau's Bureau of Resources and Development, should immediately issue the necessary permit to Joshua Eberdon to hold his present crocodiles and to receive large crocodiles captured by the licensed nuisance crocodile trapper and to propagate them for conservation and commercial purposes. The permit should be issued contingent upon the Eberdon farm making available to conservation officials 15 percent of the (3-4') size class crocodiles raised on the farm for restocking specified areas where they can be adequately protected and where they pose no threat to humans, until such time as the wild population is well re-established.

8. The Eberdon farm should function as a professionally operated crocodile education and research centre. Facilities and materials for such a centre should be provided by the US Government immediately and should include the provision of captive breeding.

9. The US Fish and Wildlife Service, co-ordinating with Palau's Bureau of Resources and Development, should assist in the establishment of two additional captive breeding crocodile farms and assist each of them to obtain 50 pairs of breeding *C. porosus* from overseas sources. Even though they will ulitize the same species, to preserve the genetic diversity of the Palauan crocodiles, offspring from these extra-national sources must not be released into the wild.

10. The appropriate Palauan authorities should establish a profitable sustained use program for crocodiles through encouraging wildlife tourism based on boat tours of scenic waterways with small and large crocodiles.

11. Establish three or four reserves, one on the east coast of Babeldaob, one on the west coast waterway, and one on a southern waterway.

12. The government provide wildlife conservation curriculum material to the public schools of Palau so the role of important predators such as sharks and crocodiles can be understood.

13. The status of *C. porosus* in the wild of Palau be monitored systematically and carefully, at least once every three years.

Again, as is the case of the Solomon Islands, little appears to have been done about the recommendations. The US Fish and Wildlife Service has threatened to confiscate Eberdon's crocodiles and is seeking further advice as to the course of action it will follow. The President of the Republic of Palau is anxious that the gist of our recommendations be implemented.

VANUATU

The full report on the Vanuatu survey follows the Reference page.

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SURVEY AND PLAN FOR RECOVERY OF THE CROCODILE

POPULATION OF THE REPUBLIC OF VANUATU,

SOUTHWESTERN PACIFIC OCEAN

AND

A PROJECT FOR THE SUSTAINABLE USE OF WILDLIFE RESOURCES BASED AT PORT PATTESON ON VANUA LAVA, BANKS ISLANDS, IN THE BANKS-TORRES CONSERVATION REGION.

A REPORT
TO THE GOVERNMENT
OF THE REPUBLIC OF VANUATU, PORT VILA, VANUATU

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INTRODUCTION

The New Hebrides in the Pacific Ocean (Fig. 1) were ruled by a condominium – a joint government operated by Britain and France until 30 July 1980. On this date the islands were granted independence and renamed as the Republic of Vanuatu. The present population is some 160,000 and consists predominantly of Melanesians (some 94 percent). There is a smattering (approximately 1%) of indigenous Polynesians and other Pacific Ocean Islanders. The majority of the Caucasian population is of English and French descent. Australians and New Zealanders are rapidly becoming more involved with Vanuatu and the French and British involvement is waning.

The first European to reach Vanuatu was the Portuguese Pedro Fernandez de Quiros who led an expedition of three small ships from Peru in 1605, in the service of the Spanish Crown. In 1766 the French nobleman Louis Antoine de Bougainville led an expedition of two ships and visited a number of the larger islands of Vanuatu. It was Captain James Cook, on his second Pacific expedition, in 1774, who named the New Hebrides – a name which lasted over 200 years. It is thus not surprising that many of the islands have had a variety of names of Spanish, French and British origin. Confusion over names still exists today.

The 74 populated and some 270 other small and tiny islands and rocky outcrops of Vanuatu have a total area of only 12,336 sq km (Fig. 1). The ni-Vanuatu, as the people of Vanuatu are called, rely mainly on subsistence agriculture – as do the peoples of most of the Pacific Islands. And as in most of the Pacific Islands, one is witnessing the depletion of the marine resources at a frightening and unsustainable rate, encouraged by the rapacious appetite of tourists and the developed countries' resource croppers.

With the world-wide publicity being given to the World Conservation Union's (IUCN) "Caring for the Earth: a strategy for sustainable living", the signing of the Biodiversity Convention at the June 1992 Earth Summit in Rio de Janeiro by some 153 nations – including Vanuatu – and the hundreds of millions of dollars being spent world-wide on producing elaborate documents, such as national conservation strategies, for governments on sustainable development, it is sad to see the increasingly rapid depletion of the marine and forest resources in the Pacific Islands – including Vanuatu. ("Naika", March 1991 issue).

National Conservation Strategies have little effect unless implemented. Often, it appears that their acceptance in too many developed and developing nations of the world is used as a cover for unsustainable development – for the destruction of habitat and the severe depletion of a nation's wildlife resources. And usually this is done to meet the wants of the developed nations or is a consequence of rapid population growth.

Increasing global tourism can be of considerable value for sustainable development but too often it also impacts negatively upon a nation's wildlife resources. And yet, it is these resources, used sustainably, which could ensure the livelihood of millions of people in developing nations.

One can appreciate readily the acceptance of quick rewards by peoples whose livelihood is based upon subsistence agriculture and subsistence use of marine resources. But the rewards are usually short term and illusory. One has only to witness the impact of the severe depletion of these resources in such nations as the Solomon Islands. Unhappily it appears that Vanuatu is allowing the same thing to happen. However, it is not yet too late to arrest the unsustainable use of this new island nation's wildlife resources.

In 1981, Dr. Brian Groombridge of the Species Conservation Monitoring Unit in Cambridge England forwarded to Professor Wayne King, then Chairman of the IUCN/SSC Crocodile Specialist Group (CSG), a report in "Naika", Journal of the Vanuatu Natural Science Society, on the *Crocodylus porosus* population, on Vanua Lava in the remote Banks Islands of Vanuatu (Fig. 1). The journal had been forwarded by David Dickinson, Chairman of the Society to Dr. Groombridge, with the request for advice on what, if anything, should be done about the population. Professor King promptly forwarded the documents to Professor H. Messel in Australia in January 1982. On 4 February 1982, Professor Messel phoned his longtime friend Mr. Hermon Slade, Chairman of the Hermon Slade Foundation, resident in Port Vila, Vanuatu. Hermon Slade knew David Dickinson as they had founded the Vanuatu Natural Science Society. Professor Messel encouraged Hermon Slade to do everything possible to have this small but important population of *C. porosus* surveyed and fully protected. This led to the Hermon Slade Foundation funding a survey of the *C. porosus* population by David Luders, a former research officer of the Australian Antarctic Research Group, then working on the possible aquaculture of prawns in Vanuatu. The survey was carried out during two weeks, from 21 April 1983. The report to the Foundation, on the survey, was forwarded to Professor Messel on 14 October 1983 and was also summarized in the September 1983 issue of "Naika". David Luders did not see any crocodiles during the day or night but gathered important local information on the crocodile in Vanua Lava.

In his report Luders stated:

> "Prior to 1972, Mr. Jimmy Jones occupied the plantation on the Sulphur river. Daily sightings were common. Crocodiles frequently basked on the sandbanks near the mouth of the river and they were known to go some distance inland to take pigs or even cattle. Crocodiles of all sizes were seen. The largest quoted was one shot by Mr. Jones which measured 5.5 metres (and was losing its teeth).

"The 1972 cyclone destroyed the English school at Port Patteson, but prior to that it was common for the students to see numbers of crocodiles 'floating' in the sea in the northern anchorage of Port Patteson, near 'Red Water'. Tracks across the sandbar to 'Red Water' were seen daily. Former students of the school describe a battle between a crocodile and a bullock (from which the bullock escaped) witnessed by a number of them. Another account of a crocodile in this stream suggests a length of around 4m.

"Description of the population on the 'Alligator' river suggests that it was at least equivalent to that on 'Red Water". Other sightings have been occasional, and of single crocodiles. Locations include the mouth of the Tes, a river in the north-west of the island, and one on the south-west where a crocodile was speared and eaten.

"Nests were occasionally found in the Sulphur river area, and the population included all sizes. There is little doubt that it was a breeding population, and total numbers may have ranged up to 200.

"THE EFFECT OF THE 1972 CYCLONE

"The cyclone was a severe one. The wind from east to north drove huge seas across the peninsula joining Nousa point to the main island. The force of this destroyed the school totally. With flooding from rain, the combined effect was a vast body of water which could well have washed the crocodile population out to sea."

In his commentary and conclusion Luders stated:

"It seems certain that the 1972 cyclone reduced the crocodile population of Vanua Lava almost to nil. The actual cause of this decline is a matter for conjecture, but two things seem likely:

– that the bulk of the population was simply washed out to sea and suffered an unknown fate;

– the habitat of the main centre of population (Sulphur river) was altered unfavourably.

"It seems reasonable to suppose that the first is the primary cause. Otherwise, there would now be significant populations of all sizes in the other two streams.

"There seems to be no worthwhile basis for research into the crocodiles on Vanua Lava unless it be long-term monitoring of a return to former levels. That would presumably require only the recording of sightings for quite some years until numbers began to be significant. Any research contemplated would be better done on Vanikolo in the Solomon Islands where there is still a substantial population.

"The crocodiles of Vanua Lava ought not to be disturbed, by researchers or others. Formal steps to protect them are hardly necessary, since there is no likelihood of disturbance as things stand. The best course is probably the easiest – that of laissez-faire."

It is difficult to accept that the crocodiles of Vanua Lava were reduced to almost nil by the 1972 cyclone. *C. porosus* is known to be a very strong swimmer and may stay submerged for periods in excess of an hour. Furthermore they are known to have a homing instinct. Problem crocodiles have been known to return to Darwin Harbor in northern Australia after having been translocated to rivers in excess of 100 km away. One may conjecture a more sinister end – as Australian crocodile hunters, who were busily endeavoring to extirpate the *C. porosus* population of the Solomon Islands during the 1970's, with the help of the Solomon Islanders (Messel and King, 1990) were known to have come to hunt *C. porosus* on Vanua Lava.

Little more was heard of the crocodiles in Vanuatu until the report "The Status of the Estuarine Crocodile (Crocodylus Porosus Schneider 1801) in Vanuatu" by M.R. Chambers and D. Esrom of the Environment Unit, Ministry of Lands, Port Vila, Vanuatu was produced in 1989 and summarized in the March 1991 issue of "Naika". Their executive summary states:

> "This project was carried out to assess the current status of the estuarine crocodile in Vanua Lava, the only island in Vanuatu known to have a breeding population. The study was carried out by a combination of a site visit coupled with interviews with villagers and the local distribution of a questionnaire."
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> "The findings show conclusively that there are very few crocodiles remaining on the island, perhaps only two or three. No young ones have been seen for several years. It thus appears that breeding has ceased and if this is the case then the crocodile will become extinct in Vanuatu. Previously high numbers of crocodiles appear to have been decimated by a severe cyclone in 1972. Some survivors of this event were subsequently shot, and coupled with natural mortality perhaps increased by later cyclones, this sequence of events appears to have brought the crocodiles down to a non-viable population size. The available habitat for the crocodiles appears to be extensive and in good condition."

"There is a strong belief in Vanua Lava that crocodiles were accidentally introduced to the island in the mid-19th century. There is no independent corroboration for this. However they came to be there, they are not popular. They undoubtedly eat domestic animals and have recently begun to attack people. In view of the expense and difficulty of attempting to build up the crocodile population, and that it would be unpopular amongst the islanders, it is recommended that nothing be done to attempt to save the crocodiles from probable extinction. If they were to become extinct this would mean a shrinkage of the crocodile's extensive range, as Vanuatu is the easternmost limit of this range."

It is this latter recommendation which is unacceptable to the conservation world. It goes completely against the accepted principles of conservation and of the necessity for the preservation of biodiversity. No crocodiles were sighted by Chambers and Esrom.

The Crocodile Specialist Group of IUCN is unable to sit idly by and watch the crocodiles in the Pacific extirpated in one island nation after the other with a consequent drastic decrease in the historical range of *C. porosus*. The Vanua Lava population of *C. porosus* constituted the easternmost limit of this range. The next easternmost population is some 250 km northwest, on Vanikolo Island in the Solomon Islands. The survey of the crocodile populations of the Solomon Islands by Messel and King in 1989 has shown that crocodiles there are highly endangered and the same applied to Palau, surveyed by Messel and King in 1991. The crocodiles in the Philippines are even more endangered and thus the easternmost population of *C. porosus* which is not highly endangered is in Papua New Guinea.

We must also comment on the tale that the crocodiles in Vanua Lava were introduced by Bishop Patteson in the mid 1860's. Six biographies of Bishop Patteson were studied by Chambers and Esrom and there was no mention of crocodiles. Yet the Bishop was known to have been a meticulous and accurate recorder of what he saw and did. The crocodile populations, though small, on Nendo and Vanikolo Islands in the Solomon Islands are only some 250 to 300 km to the northwest of Vanua Lava – a mere stone's throw away for the strong and long distance swimming *C. porosus*. A lone *C. porosus* has been sighted as far away as the northern islands of New Zealand and the Cocos Keeling Islands in the Indian Ocean! Thus we must disagree with the Bishop Patteson tale. We strongly suggest that the crocodile population on Vanua Lava was a natural extension of the populations of the Solomon Islands.

The sporadic sighting of *C. porosus* in the waterways of Espiritu Santo (Fig. 1) are also easily accounted for, as animals probably originating from Vanua Lava or even the Solomon Islands.

Following the Chambers-Esrom report, a systematic survey of *C. porosus* in Vanuatu was given a high priority by CSG. Funding for the survey was quickly pledged by the Hermon Slade Foundation, Conservation International of Washington, DC, and the Nagao Foundation of Japan. Mr. Ernest Bani, Principal Environment Officer of the Environment Unit of the Government of Vanuatu held discussions with Professor Messel during the CITES Kyoto conference in March 1992 and offered the support of the Unit. In the meantime Mr. Hermon Slade arranged for the participation of his colleague Mr. Aaron Hanghangkon, a very knowledgeable and respected citizen of Vanuatu. On 16 August 1992, Professor Messel and Mr. Paul Slade, a Patron of the CSG, proceeded to Port Vila, Vanuatu, where a series of meetings were held with various government departments. Ernest Bani then accompanied them to remote Port Patteson (the primary area for *C. porosus*) on Vanua Lava (Fig. 2) in order to help with logistical arrangements and to carry out a preliminary survey. Such preliminary work and planning for surveys in remote areas is vitally important, if much time and large sums of money are not be wasted. This has occurred far too often for crocodile surveys carried out in various countries in the past.

Goodwill Training Centre, an Anglican school for ni-Vanuatu teenagers is situated at Port Patteson, a $2\frac{1}{2}$ hour beach walk from Sola airstrip on Vanua Lava. There are no roads. It is an idyllic spot and no wonder that *C. porosus* migrated to it! The Director of the Training Centre is Father Luke Titinsom Dini, Senior Priest, Banks and Torres Region. A cabinet minister in the pre-independence government of Vanuatu, he gave up politics in order to lead his people – those of the Banks and Torres Region. He became a priest and returned to his native Banks Island – landing at Port Patteson at the spot where the Training Centre is presently situated. There he built, with the aid of his followers and his own hands, using bush materials, an educational training centre for teenage boys and girls. Training is given on soap making, subsistence agriculture, carpentry, home duties, health, general cleanliness and all the other aspects of leading a happy, healthy life in this remote area of the world. It is hoped that the students will choose to remain on their traditional lands in the Banks and Torres Islands and not migrate to urban centers where they often are relegated to being second class citizens. The Centre's total budget for salaries, food, equipment and maintenance is some US$500 per MONTH!

At the time of Father Luke's arrival at Port Patteson in 1986, the reefs in the area were teeming with marine life, a wide variety of reef fish, giant clams, trochus shells, green snails, lobsters (crayfish and rock lobsters), and on the land, coconut crabs. By just walking onto the reef at low tide one could fill a large sack with lobsters in half an hour. Large numbers of green, hawksbill and lesser numbers of loggerhead turtles nested on the beaches, especially on nearby Ravenga Island. There was no shortage of food for the people. This has changed drastically over the past six years and the reefs in the area have been harvested to almost total depletion in order to meet the requirements of the ever increasing number of tourists coming to Vanuatu as well as the export trade. The harvesting and depletion of the marine resources has occurred at a frightening rate. It was done on a totally unsustainable basis. We were shocked by what we found but quickly realized that the Port Patteson area provided an excellent opportunity for the conservation of wildlife species there through sustainable use and development. It had all the ingredients which we felt were necessary: education, religion, remoteness of a small subsistence population and the determination of Father Luke to protect, conserve and utilize sustainably the wildlife resources for his people, with emphasis on ecotourism.

The funding requirements for an important conservation project at Port Patteson, through sustainable use and development, which could provide hope and an example for other Banks and Torres Islands and South Pacific Ocean islanders to follow, would not be astronomical. Professor Messel immediately undertook to raise the necessary funds including his own personal contribution. He provided the necessary cash funds on the spot for the immediate construction of a cottage, on Port Patteson, to be used as the conservation project's headquarters and which he will donate to the Training Centre for their use. The Slade family has since provided the funds for the construction of a second conservation cottage and the Professor Wayne King family the third one.

Father Luke immediately undertook to call a meeting of the six village chiefs and traditional land owners to obtain their agreement to petition the government of Vanuatu to declare the Port Patteson area a Conservation Region. They would protect it, for they now had experienced the sad consequences of the unsustainable use of their wildlife resources.

In the meantime two preliminary daytime surveys were carried out by us of the waterways in the area. While bailing out a canoe, a young lady had been attacked by a large crocodile some two months previously - so the story went. The villagers had speared it, but the spear didn't hold. They then tried to shoot it. Was it all true? Were there any crocodiles left on Vanua Lava or were they now extinct in Vanuatu? None had been seen during the Luders survey or the Chambers-Esrom survey.

Fortunately in mid-afternoon of 19 August and at low tide we spotted a 14-16 foot male *C. porosus* on a mud bank. It slid slowly into the water leaving a giant belly slide, which we photographed. We had been so surprised on spotting the large animal that we pointed the tape recorder rather than the camera at it. No photograph. *C. porosus* was not extinct in Vanuatu! No signs were seen of other crocodiles during the daytime preliminary survey. The planned systematic spotlight survey by us, commencing 5 September 1992 would provide us with the required information on the population size and structure.

In the meantime, we were obtaining the agreement of the villagers that the crocodiles must be conserved along with the other wildlife resources. We pointed out that the crocodiles were an important component of the ecosystem. The villagers could learn to live with and utilize crocodiles sustainably as do many other peoples in Papua New Guinea, Australia, Indonesia, Africa, America and so forth.

It has always been somewhat of a mystery to us why the people of the Pacific Islands, including Palau, Solomon Islands and Vanuatu fear and dislike crocodiles so strongly. This is just a recent phenomena for in former times there appeared to have been a truce between the crocodiles and the islanders (see Messel and King 1990, 1991). The appearance of the white hunter seems to have ended the truce and helped fire the fear and consequent dislike by the islanders of the crocodiles of the Pacific. Yet nearby in Papua New Guinea and Australia the truce still holds - and as strongly as ever in PNG.

On 2 September 1992, Professors Messel and King, and Mr. Paul Slade flew to Port Vila in Vanuatu, where they joined Ernest Bani and Aaron Hanghangkon. The group flew to Espiritu Santo and on to Sola airstrip on Vanua Lava on 5 September. Mr. Kaltau Ayong, Deputy Director of Radio Vanuatu also accompanied the group. It was fortunate that the Rotary Club of New Zealand had gifted a 12 ft dinghy with a 25 hp outboard motor to the training centre at Port Patteson. Thus on this occasion we were able to transport the survey gear by boat rather than on our backs. A 20-foot wood hulled Fisheries vessel was used for carrying personnel and also for crocodile surveys.

METHODS

The survey methods for repeatable night spotlight censusing of crocodile populations are given in detail in Messel *et al* 1981, Monograph 1 of 'Survey of Tidal River Systems in the Northern Territory of Australia and Their Crocodile Populations'. This publication is one of 20 monographs on crocodile surveys by Professor Harry Messel and co-workers and published by Pergamon Press. Since the Vanua Lava Island crocodile survey is only concerned with their number, size class and distribution, it was not essential to measure and record a number of parameters usually recorded in a survey. State of the tide, amount of bank exposed, water salinity and temperature were monitored. Salinity measurements indicate whether the aquatic habitat is a freshwater system or not. This is of importance as salinity generally determines the suitability of the particular waterway as a potential breeding area - see Monograph 1, page 100.

Normally, on long hazard-free tidal waterways, with a team of three (i.e., spotter, recorder-navigator and driver), surveys are made at a speed of 20 to 30 km per hour and cover from 40 to 100 km per night before the tide rises and the amount of exposed bank decreases to less than 60 cm making it harder to see the crocodiles.

On Vanua Lava, which is only 331 sq km in size, matters were different. The ni-Vanuatu on the small island were well acquainted with the area which the former *C. porosus* inhabited. It was centered on Port Patteson and the ni-Vanuatu lived right there. Crocodiles had been known to inhabit only three of the waterways in the area. These waterways were well known and often frequented by the islanders during their daily living. Thus our survey task was greatly simplified. But knowing that a very large crocodile lived in those narrow shallow streams alerted us to use extreme caution while surveying. Instead of using the 12 ft aluminum dinghy with its 25 hp outboard motor which we used during the 19 August daytime survey, we used a 20 ft wood hulled Fisheries boat with high sides and 8 and 25 hp Yamaha outboard motors.

The waterways are tidal, short, narrow and shallow. Each waterway was surveyed from the zero point at its mouth to the upstream terminal point that was determined by shallow water that prevented navigation further upstream.

The tidal variation between high and low water was only 0.7 to 0.8 meter during 6-9 September 1992 but this still required careful planning both for daytime reconnaissance of the survey routes and for the nighttime surveys. Surveys should be done on a +1/4 to 1/2 tide.

We were fortunate to be able to engage the services of Messrs. Kalep Wilkins, Harrison Ford, Norman and Jimmy Wona and Edwin Tagar of the Port Patteson area. Their intimate knowledge of the area and its waterways made it possible for us to work safely and efficiently. Their knowledge of where the remaining crocodiles of Vanua Lava were most likely to be found proved accurate and saved us valuable time. They said we would see one, or at most two, and they were right.

Optimum months for surveying are during the dry season months, May to October. However, 30 to 40 knot southeasterlies blow during much of September and October with only little respite. These give rise to fine sunny days and cool nights. While Port Vila is beginning to warm during these months, Port Patteson experiences its coolest period. Throughout Vanuatu, January to March are the wet months and Vanua Lava experiences some 3000 mm of rainfall per year. This is also the cyclone period and Vanua Lava is in the most cyclone prone area.

Quick response probes for temperature measurement, a temperature compensated refractometer for rapid salinity measurements, a Magellan GPS NAV 1000 PRO for fast and accurate determination of latitude and longitude, and 5-cell Magnalites for spotlighting, were used. In addition, survey sheets and books, large scale maps, cameras, photographic film of various speeds, cassette tape recorder, and a laptop computer and portable printer were used. These are requisites for systematic and repeatable day and nighttime surveys and rapid data analysis.

RESULTS

Our findings are presented and discussed separately for each of the areas surveyed. Only one map sheet is required: Carte de la Melanesie a 1/100,000, Vanuatu, Feuille No. 2. Iles Banks-Nord.

1. Alligator River (local name).

During the day and night of 6 September 1992 this short waterway, not shown on the map sheet and barely distinguishable on the relevant aerial photograph, was surveyed systematically. The mouth of the river is distinct on the aerial photograph.

	Longitude	Latitude	Survey length (km)
Alligator River	167°32'52"E	13°49'06"S	1.25

The waterway is heavily vegetated with mangroves and had to be cleared of overhanging limbs prior to the daytime survey on 6 September. Because of the dense tree canopy overhead, a GPS latitude and longitude reading could not be obtained at the natural survey terminal point. The distance surveyable by boat is approximately 1.25 km, but during our daytime survey we were able to follow the Alligator River for a further 500 m or so on foot, wading along and through the narrow stream, about 1 m wide and from a few cm to 0.5 m deep. The stream drains a forested swamp of several square km.

Two and a half hours after low water, the salinity at the mouth of the waterway was 33 o/oo and at the survey upstream terminal point it was 12 o/oo. Thus, the Alligator River is a small but good TYPE 1 breeding system, draining swampland.

During the day we saw what the guides claimed were faint belly marks and indistinct tracks of a crocodile. We remain unconvinced. If the tracks were those of a crocodile, it was certainly much smaller than the animal we saw on the Selva River on 19 August.

The nighttime survey was carried out under ideal conditions of exposed bank but no crocodiles were sighted.

2. Selva--Pagpaglog (Tahiti, local name) Rivers, Walter Creek.

During the day and night of 7 September 1992 this system of waterways was surveyed systematically. We also carried out a resurvey of these waterways on the night of 9 September. The map shows separate mouths for the Selva and the Tahiti (Pagpaglog) Rivers, however, now only the south mouth remains open and the Tahiti River may be treated as a tributary of the Selva River. There is also a short navigable side creek of the Selva at km 0.8 just to the north of the Tahiti River (Fig. 2), known locally as Walter Creek.

	Longitude	Latitude	Survey length (km)
Selva River	167°32'27"E	13°50'47"S	1.6
Tahiti River	167°32'27"E	13°50'47"S	1.8
Walter Creek	167°32'24"E	13°50'20"S	0.8

Gaining entrance to the Selva River at 1/2 tide requires manhandling the boat in, over the shallow bar. This would be of little consequence were it not for the fact that we sighted the 14-16 ft (4.5-5 m) crocodile only 200 m upstream from this point. It is also at this point that the ni-Vanuatu wade across the Selva River on foot when visiting Sola airstrip and villages on the south of the island.

The Selva River had a measured salinity of 3 o/oo both at its mouth and at the upstream terminal survey point at km 1.6. The river shallows rapidly and navigation upstream of km 1.6 is not possible. Upstream of this point there are many dead trees, shoals, and other obstacles. There are numerous basking areas along the river; the banks are heavily vegetated. The river appears totally devoid of aquatic life beyond km 0.8, apparently the result of highly acidic waters, containing sulfur and other minerals from active fumaroles and hot springs on the side of the still thermally active volcano at the headwaters, being poured into and flushed through the river. On 7 September sufficient acidic water flushed through the river to discolor much of the bay outside the river's mouth with a milky yellow precipitate. Two days later both the river and bay were clear. Were it not for these periodic acidic flushings, the waterway would provide excellent habitat for *C. porosus*.

Walter Creek is a narrow, 5 to 6 m wide freshwater system. The banks are heavily vegetated with vines drooping into the water along much of its 0.8 km surveyed length, thus making it difficult to obtain more than 0 cm exposed bank for surveying. Salinity was 2 o/oo at its mouth and 0.5 o/oo at the upstream terminal survey point at km 1.6. We saw many mullet in the stream and it would provide good nesting habitat for *C. porosus*.

Similar remarks apply to the Tahiti River which is an excellent TYPE 1 breeding system for *C. porosus*. The salinity at the upstream terminal point was 0 o/oo and the water was sweet for drinking. The stream was teaming with fish, large and small.

During our daytime survey, we saw two large belly slides, some days old, probably those of the large crocodile we had viewed on 19 August. They were between 200 m and 300 m upstream of the mouth of the Selva River.

The nighttime surveys of the three waterways were carried out under ideal spotting conditions, but no crocodiles were sighted.

DISCUSSION

The crocodiles of Vanua Lava are on the verge of extinction. There is one large male *C. porosus* remaining for certain and there might be a second animal, smaller in size. Since no juvenile crocodiles were sighted, if there is a second animal then it is a second male or an immature female. There is no longer a breeding population remaining; though breeding used to occur in the past. Confirmation of this is available from many inhabitants at Port Patteson. Mr. Frank Hosea Wokeke, Treasurer of the Banks-Torres Local Government Council, regularly saw crocodiles of all size classes when he was a student at the Port Patteson school. On 10 September 1992 on Kwakea Island, we also had a very interesting discussion with Jimmy Jones, a well known local personality. He lived on the Selva River for many years in the area now occupied by the Custom landholder, Norman Wona. Mr. Jones saw many crocodiles of all sizes during the 1960's and 1970's and shot some; the last one in 1978 was 5.5 m in length, and we saw a photograph of it. He is brimming with informarion and has become an ardent conservationist in recent years. He is most anxious to include Kwakea Island, and the beautiful waters surrounding it, in the Banks-Torres Conservation Region. He holds a 30 year renewable lease on the island.

It is unlikely the *C. porosus* population at Port Patteson can recover on its own. Only a restocking program will save *C. porosus* there. And the ni-Vanuatu at Port Patteson are now prepared to support restocking as part of a program proposed by us for conservation of their wildlife resources through sustainable use and development, based on ecotourism in the first instance.

The Custom landholders and the chiefs of Eastern Vanua Lava have already signed documents agreeing to set the area aside as a region for the conservation and sustainable use of the species listed in Appendix 1.

RECOMMENDATIONS

1. That the Government of Vanuatu set aside the area of Eastern Vanua Lava shown in Fig. 2, with the possible immediate extension to include Kwakea Island, as a conservation region for the following species:

Trochus shell (*Trochus niloticus*)
Lobsters (*Panulirus* spp., both crayfish and rock lobster)
Green snails (*Lunatica marmoratus*)
Giant clams (*Tridacna* sp.)
Coconut crabs (*Birgus latro*)
Saltwater crocodiles (*Crocodylus porosus*)
Marine turtles (*Chelonia mydas, Eretmochelys imbricata*, and *Caretta caretta*)

It is reported that the Government will be passing a National Parks and Conservation Law during the forthcoming session of Parliament. The above recommendation could be covered by this new law or by existing legislation.

2. That commercial trade in any of the above species, taken from the conservation region, be totally prohibited and to take effect immediately after the declaration of the conservation region -- Eastern Vanua Lava.

3. That the conservation region -- Eastern Vanua Lava -- be restocked in accordance with the recommendations made by Father Luke Dini, as set forth in Appendix 1. In addition, the area be restocked with giant clams and saltwater crocodiles.

4. That the restocking of the area be carried out sequentially starting with coconut crabs and proceeding to lobsters, green snails, trochus shells, giant clams, and crocodiles. The source stock for all of these can probably be obtained in Vanuatu, with the exception of the crocodiles. Both the giant clams and the saltwater crocodile would require CITES export and import permits if obtained from other countries. The cost of restocking to be met by outside donors, arranged by Professor Messel.

5. That harvesting of the named species in the conservation region -- Eastern Vanua Lava -- be totally prohibited for a period of 3 years to give the populations a chance to establish and grow. After this initial period, the prohibition will be re-evaluated. Harvest quotas will be established for those species whose populations have recovered sufficiently to be able to withstand a sustainable harvest.

6. That the quotas be decided by a conservation committee in consultation with the Ministries of Environment and Fisheries. Committee members will be dawn from the inhabitants of the conservation region -- Eastern Vanua Lava -- and the donors of the project.

7. That the Conservation Region - Eastern Vanua Lava -- serve as a pilot project for conservation of the wildlife resources through sustainable use and development, based in

the first instance upon ecotourism. Success in this project could serve as a model for the Banks-Torres Region and all of Vanuatu.

8. That the inhabitants of the Conservation Region -- Eastern Vanua Lava -- be its major beneficiaries, acting as guides, boat drivers, hostel operators, and the like. Once the area is restocked, the area will only require careful vigilance and protection against poaching.

9. That the Anglican Diocese of the Banks and Torres Region and the Goodwill Training Centre become the focus for conservation through sustainable use education in the area.

10. That the peoples of the region be made aware that their livelihood and that of their children depends critically upon sustainable use of their wildlife resources, which at the present time are being rapidly depleted through unsustainable over exploitation.

11. That five conservation cottages be constructed for use by the conservation project, the Goodwill Training Centre and for use by ecotourists. Three of these cottages are pledged and one is under construction already. Professor Messel will endeavor to arrange immediate funding for the other two so that earnings may quickly start flowing to the local inhabitants.

12. That an easily replaceable timber foot bridge be constructed over the Selva River and also one over the Alligator River so that inhabitants traveling between Sola, Goodwill Training Centre and villages to the north do not have to wade these two streams. This will remove much of the risk from any crocodiles in the area.

13. That two boats be obtained for use by the sustainable development project. The boats presently used by Fisheries are the ideal type and could be used for protecting the wildlife resources in the conservation region and for ecotourism.

ACKNOWLEDGMENTS

Without the quick funding support from the Hermon Slade Foundation, Australia; Conservation International, Washington DC; and the Nagao Foundation, Japan; the present survey of the crocodile population at Port Patteson on Vanua Lava could not have taken place. Importantly, the pilot project for conservation of wildlife resources through sustainable use and ecotourism in the Banks and Torres Conservation Region -- Eastern Vanua Lava area may not have been forthcoming. Within four days of the preliminary survey came the pledges to help finance the restocking of the wildlife species given in the report. Here was real conservation action at the grass roots level by the local inhabitants and the donors.

The Hermon Slade Foundation, Messrs. [redacted] Ishii (friends of Prof. Messel) from Japan and Conservation International quickly joined Prof. Messel in the funding, and hopefully others also will join.

Father Luke Dini met with the Customs landholders and chiefs of the proposed conservation region and won their enthusiastic support, which they recorded in a written contract. The signed contract was delivered to Professor Messel and the Government of Vanuatu within 10 days -- an incredible achievement.

Discussions with government officials and Ministries took place concurrently. Unlike other countries in which we have carried out surveys and made recommendations, the Government and people of Vanuatu -- especially those in the proposed conservation region -- acted immediately.

The success of the project depends upon many people: Ernest Bani of the Vanuatu Government Environment Office; Aaron Hanghangkon of the ADAB office of the Australian High Commissioner David Ambrose (who was most supportive); and Hermon and Paul Slade were actively involved from the planning stage. The moral and financial support of Conservation International with its President, Dr. Russell Mittermeier and Tim Werner was critical; as was the Nagao Foundation with Professor Satoo and Dr. Yoshio Kaneko; and Messrs. Hamano and Ishii of Japan, who agreed to help fund the project the moment they heard of its importance.

Then there are the local chiefs and Custom landholders, without whose support and active assistance as guides and boat operators the survey would have been difficult if not impossible. More importantly, the future success of the project depends on their continued support and involvement.

Special thanks must go to Father Luke Dini and his friendly and helpful staff, headed by Kalep Wilkins, and the students of the Goodwill Training Centre. They climbed many a coconut tree to keep us supplied with drink, and made our evening hours pleasant with communal singing. Our thanks go to them with the wish that each of them becomes an ardent conservationist.

We have not mentioned the food prepared by Kalep Wilkins and his charming wife Lilian and their helpers. Here are cordon-bleu chefs on bush-tucker. One could easily write a paper on their preparation of natural and unadulterated foods of the area; in an earthen oven! And so the list goes on -- everyone helped. Never have we met such friendly and enthusiastic people. The future of the project augurs well.

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Messel, Harry, and F. Wayne King. 1991. Survey of the Crocodile Populations of the Republic of Palau, Caroline Islands, Pacific Ocean, 8-24 June 1991: A Preliminary draft to the Government of the Republic of Palau, Koror, Palau. Proceedings of the 11th Working Meeting of the Crocodile Specialist Group, Victoria Falls, Zimbabwe.

Messel, Harry, and F. Wayne King. 1990. Report on the CITES and Solomon Islands Government National Survey of the Crocodile Populations of the Solomon Islands, 20 July -- 8 September 1989. Report to the CITES Secretariat and Solomon Islands Ministry of Natural Resources. Proceedings of the 10th Working Meeting of the Crocodile Specialist Group, Gainesville, Florida, U.S.A.

APPENDIX I

(1) <u>Contract between the Land Owners and Chieves of Eastern Vanualava for the Conservation and Sustainable use of the Seven (7) Species on Vanualava in the Banks/Torres Region, Vanuatu.</u>

1. Trocus Shells.
2. Lobsters.
3. Coconut Crabs.
4. Green Snails.
5. Clam Shells.
6. Turtles.
7. Crocodiles.

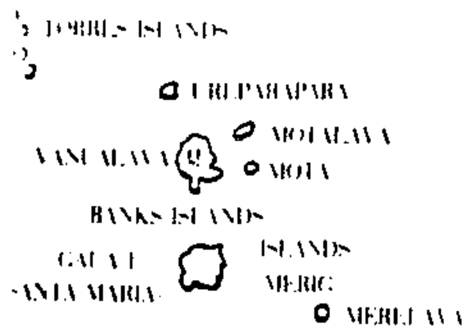
We the undersigned the rightful Land Owners of Seremba, Sulphur river, Metlo, Tahiti river, Qanlap, Nawono, Alligator river, Ravenga Island, after hearing enough explaination on the preservation and Conservation of the Seven Species. We fully agreed to conserve the species in our land.

	Thumb print		
Mr. Norman Wona	[thumb print]	Signature ....N Wona....	Date 28.8.92
Mr. Edwin Tagar	[thumb print]	Signature ....E Tagar....	Date 28.8.92
Mr. Alban Vagon	[thumb print]	Signature ....Alban......	Date 28.8.92

Fr. Luke Dini, Anglican Church Representative

Fr. Luke Dini. On behalf of the Conservation Donor's

Thumb print [thumb print] Signature ...... Date 28.8.92



Fr. Luke Titinsom Dini
Senior Priest
Banks and Torres Region
Vanualava
Vanuatu

20/03/92.

Proffesor: Harry Mesel,
Bond University,
Australia.

SUBJECT:- <u>Environmental Conservation Prospective for the Banks/Torres Region Vanuatu</u>.

Dear Sir,

Find attached herewith two (2) estimated cost of farming 4 species which are to be Conserve within the areas, from Ravenga Island to Tahiti river, including Metlo reefs. You will note that no:1 we are looking at todays prices, which is encourage by the Government of Vanuatu. No: 2 we look at the prices we work in a Christian and Melenesian way.

I have also attached the report, which you will find on page 7, paragraph 2 Sub-Heading (c) Marine aqua - Culture which talks about the conservation of the species.

With Love & Prayers,

SENIOR PRIEST
REV. LUKE T. DINI
BANKS AND TORRES VANUATU

Fr. ~~Luke Dini~~,
Senior Priest,
Banks & Torres Region.

No.(2)

ESTIMATES COST OF FARMING.

4 SPECIES

NAWONO , PORT PATTESON , EAST VANUALAVA

BANKS / TORRES REGION,

VANUATU.

Coconut Crabs.	Torres Church Council	1.000,000 Vatu
Green Snails.	Ureparapara Church Council	1.500,000 Vatu
Lobsters.	Motalava Church Council	1.000,000 Vatu
Troucus Shells	Gaua Church Council	500,000 Vatu
Transport		500,000 Vatu
Handling & Caring		500,000 Vatu
	TOTAL	5.000,000 Vatu

NO (1)

ESTIMATES COST OF FARMING.

4 SPECIES

NAWONO , PORT PATTESON , EAST VANUALAVA

BANKS / TORRES REGION,

VANUATU.

	KILO:		PRICE:		TONES:	TOTAL:
Coconut Crabs[a]	1000	x	450	x	3	1.350,000
Green Snails[b]	1000	x	1000	x	3	3.000,000
Lobsters[c]	1000	x	800	x	3	2.400,000
Troucus Shells[d]	1000	x	200	x	3	600,000
Transport						350,000
Handling Charges						432,000
					TOTAL	8.132,000

a = Birgus latro
b = Lunatica marmoratus
c = Panulirus spp (both crayfish and rock lobster)
d = Trochus niloticus

Giant clam = Tridacna gigas

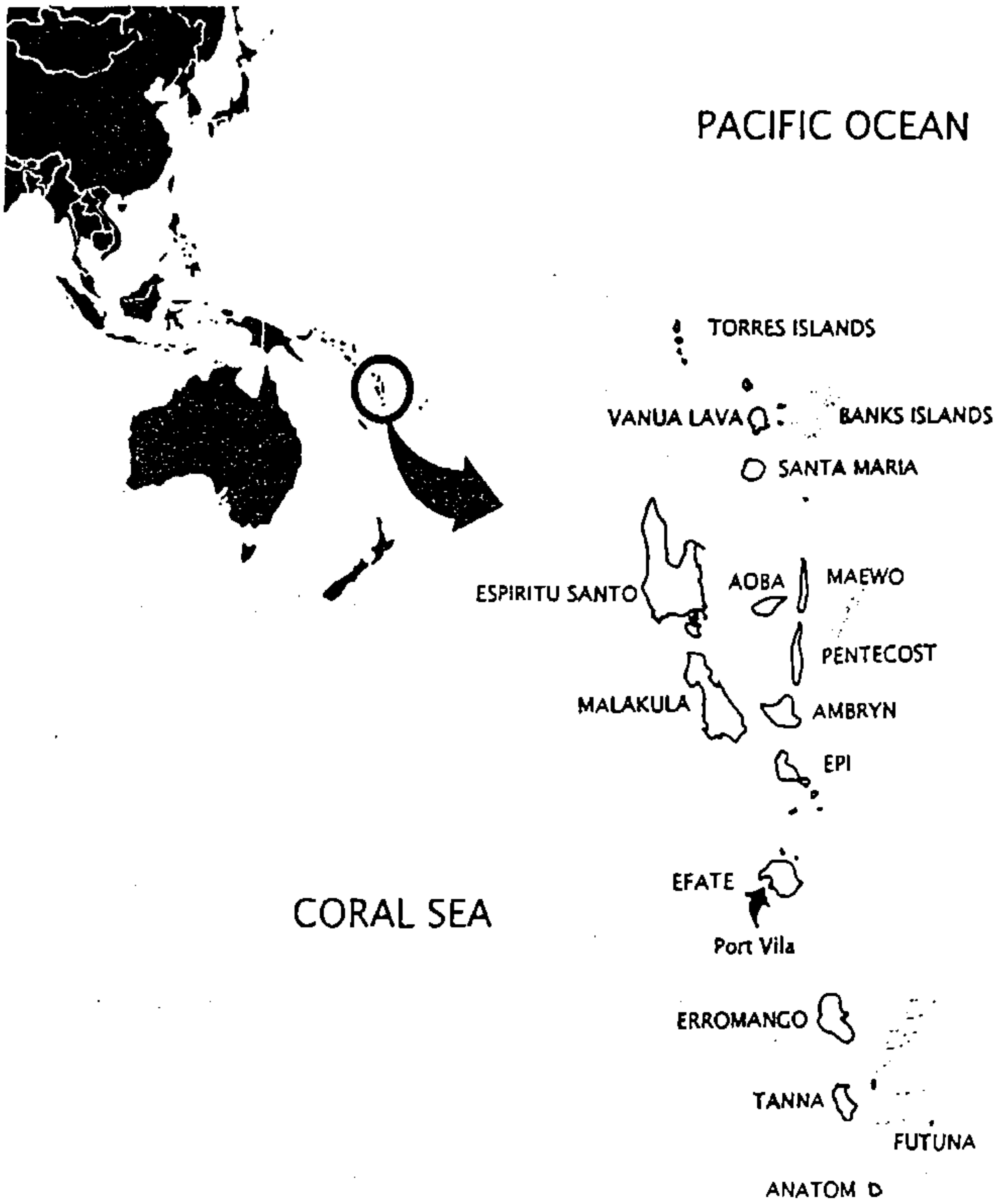


Figure 1. Republic of Vanuatu.

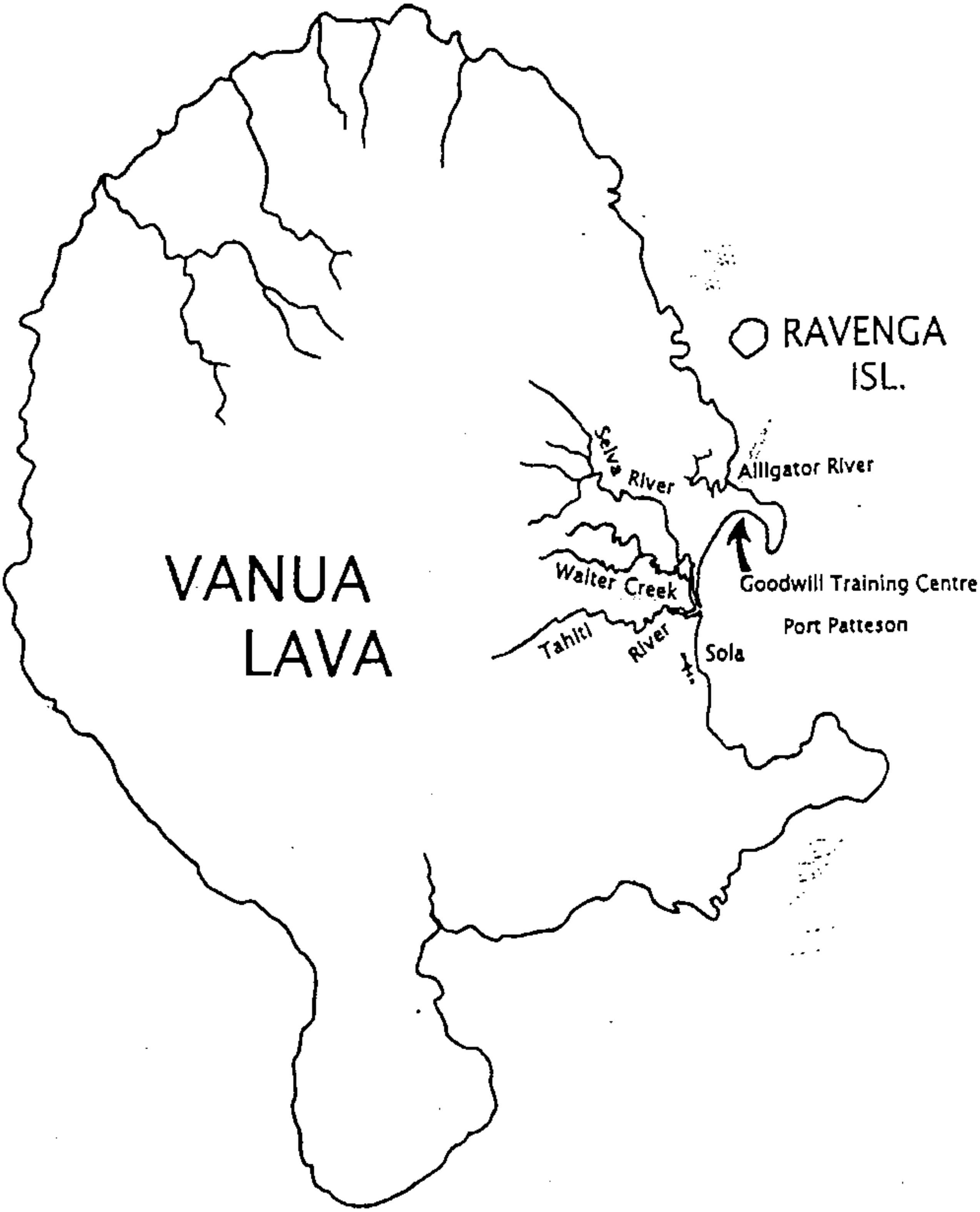
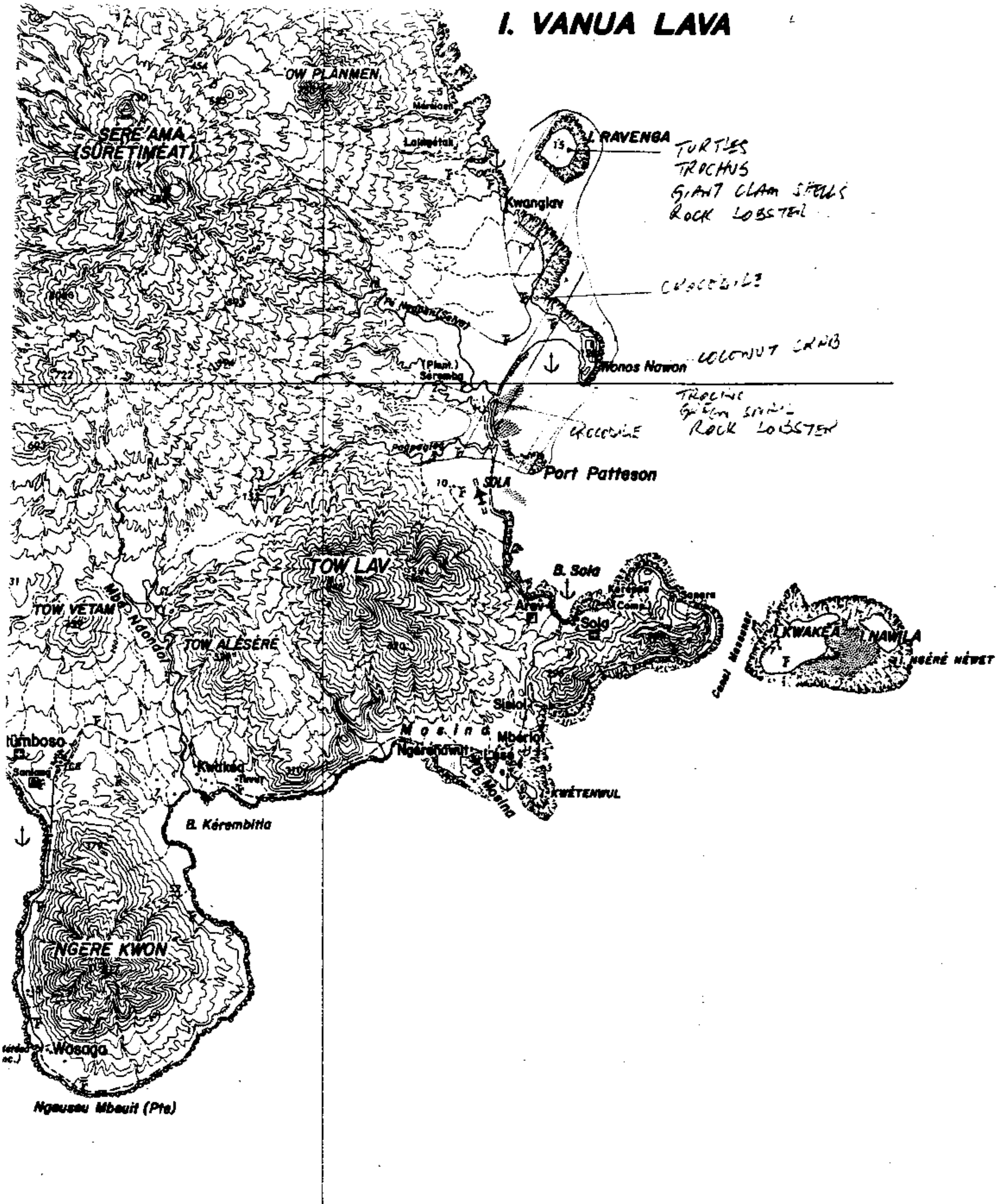


Figure 2. The eastern-most breeding population of *Crocodylus porosus* is recorded from the Selva River, Tahiti River, Walter Creek and Alligator River of Vanua Lava Island, Banks Islands, northern Vanuatu.


I. VANUA LAVA
OW PLANMEN
SERE'AMA (SURETIMEAT)
I. RAVENGA
TURTLES
TROCHUS
GIANT CLAM SHELLS
ROCK LOBSTER
Kwanglav
CROCODILE
Nonos Nawon
COCONUT CRAB
TROCHUS
GREEN SNAIL
ROCK LOBSTER
CROCODILE
Port Patteson
SOLA
TOW LAV
B. Sola
Sola
Arep
TOW VETAM
TOW ALÉSÉRE
I. KWAKEA
I. NAWILA
I. NGÉRÉ NÉVET
Sisiol
Mbériot
Mosina
KWÉTENWUL
B. Kérembitia
Kwdikäo
NGERE KWON
Wosaga
Ngausau Mbeuit (Pte)
167° 30'

SECOND WORKSHOP TO REVIEW THE AIMS, OBJECTIVES AND OPERATION OF THE CROCODILE FARMING INSTITUTE (CFI): PALAWAN, REPUBLIC OF THE PHILIPPINES

(7-8 March 1993)

Harry Messel, Jonathan Hutton
Grahame J.W. Webb

IUCN-SSC Crocodile Specialist Group

1. Introduction

The RP-Japan Crocodile Farming Institute (CFI) is located at Puerto Princesa City, on the Island of Palawan, Republic of the Philippines. It's construction and operation is the result of a co-operative development project between the Governments of Japan and the Philippines. The facility now belongs to the Government of the Philippines, and its operation is funded jointly by Japan and the Philippines.

The CFI was both a bold and imaginitive development project, in the true spirit of "conservation through sustainable use". Its two primary aims were to conserve the two species of crocodile within the Philippines (Crocodylus mindorensis and C. porosus), and, through the application of scientific technology, develop strategies through which crocodiles could become the focus of a sustainable industry for the benefit of Filipinos.

Given that both species were critically depleted within the Philippines, and the endemic species (C. mindorensis) was one of the most poorly known of all living crocodilians, the task before the CFI was a very challenging one indeed. Made all the more difficult by neither Japan nor the Philippines having had a long history of involvement in crocodilian biology, conservation, management or farming.

In terms of facilities, the CFI now represents the finest establishment in the world devoted to crocodilian conservation and utilisation. However its operational costs are high, and due to the depleted nature of the wild populations, its acquisition of stocks has been delayed. Both these factors affect the ability of the CFI to be a self-sustaining operation at present.

This situation led to the IUCN Crocodile Specialist Group (CSG) being invited to attend a workshop at the CFI, in February 1992, to discuss all aspects of the CFI operation. The CSG team was headed by Professor Harry Messel (CSG Chairman), and comprised Professor Wayne King (CSG Deputy Chairman), Dr. Grahame Webb (Vice-Chairman responsible for Eastern Asia, Oceania and Australasia) and Mr. Charles Ross (CSG member familiar with crocodiles in the Philippines).

That team made a report which included a brief assessment of the CFI's development and operation. Most important, it listed a series of recommendations aimed at overcoming difficulties being experienced by the CFI, and areas where it felt the CFI could contribute more positively to the conservation of both species of crocodiles, in the wild, within the Philippines.

On 7-8 March 1993, a second CSG review mission was undertaken. The team included Professor Messel and Dr. Webb from the previous team, and Dr. Jonathan Hutton, the CSG Vice-Chairman reponsible for the African region. This review committee examined the extent to which previous recommendations had been acted upon, discussed and evaluated new proposed initiatives and research findings, and addressed the central problem - the long term sustainability of the CFI.

2. Review of Previous Recommendations

The initial task of the review committee was to determine the extent to which the 12 recommendations made by the previous review committee had been acted upon:

R1-4. Expertise and Technology Transfer

Rationale. A major difficulty with the CFI was that it developed somewhat in isolation of recognised established technology in the field of crocodile conservation, management and farming. Notwithstanding that CFI staff have subsequently solved a great many problems, it was recommended that some staff be sent to an overseas breeding facility for training, that a CSG expert be brought in to advise on priorities, that CFI representatives attend CSG meetings, and a second review committee be established to examine progress.

Result. The second review committee has now been convened. However, no significant technology transfer has occurred. The CFI is still operating in isolation of international directions and has not sought outside CSG assistance to review priorities. It has not implemented overseas training of its staff nor did the CFI send representatives to the CSG meeting in Zimbabwe. No representatives from CFI will attend an international course derived with CSG expertise specifically for technology transfer. The review committee was made aware that JICA guidelines do not allow funding to be allocated to either the import of expertise from developed nations, other than Japan, nor the training of Filipino staff in developed natios, other than Japan. Nevertheless, a number of initiatives and commitments regarding overseas training and attendence at international conferences are planned for 1993.

R5. Review staffing structure at next review committee meeting

Rationale. In the opinion of the previous review committee, the number of staff involved in the project was excessive relative to the CFI's operational needs and output.

Result. The CFI staff allocation of 66 Filipino staff was not utilised; actual Filipino staff has been reduced from 56 to 54. Japanese staff during this period has increased from 4 to 5.

R6. Efforts be made to establish sanctuaries for wild C. mindorensis and C. porosus

Rationale. The conservation of both species of crocodile in the wild in the Philippines is a major objective of the CFI, and an area of international conservation concern.

Result. No sanctuary has yet been established for either species. The Government has passed a new Act (NIPAS - National Integrated Protected Areas System) establishing a protocol for fast-tracking such projects, although it is currently experiencing teething problems. Some investigations have been undertaken on the possibility of securing Lake Manguao (north Palawan), Lake Naujan (Mindoro) and Agusan Marsh (Mindanao) as sanctuaries.

R7 That the program to acquire C. mindorensis from the wild be continued

Rationale. Given the status of C. mindorensis in the wild, the most responsible conservation action is to establish a large and secure captive population of this highly endangered species.

Result. An additional 64 C. mindorensis have been obtained since the last review; total stocks of C. mindorensis at the CFI are now 497, of which 64 are adults.

R8. That surveys be carried out with a view to locating any populations suitable for ranching

Rationale. Ranching provides a management option that could be used to consolidate the conservation of some local populations.

Results. There has been a cursory spotlight examination of Lake Manguao and Lake Naujan, but no systematic surveying has been carried out.

R9. Increased public education about crocodiles and crocodile conservation

Rationale. Public education about crocodiles is fundamental to developing a positive public attitude towards crocodile conservation.

Results. A series of public education initiatives have been implemented.

R10. The possibility of a crocodile establishment near Manila be investigated as a centre of public education

Rationale. A back-up facility should something happen to CFI and a possible source of revenue generation through tourism.

Result. Some preliminary investigations have been carried out, but no serious consideration or planning. It would need the active participation of JICA or some other aid agency.

R11. Review, refinement and acceptance of an overall CFI Strategy.

Rationale. Without a set strategy it would be impossible for CFI to operate in a co-ordinated and efficient manner.

Result. The strategy is still under review and will be reviewed again following the current visit.

R12. Renewed effort to consolidate the conservation of the two species in the Philippines by expanding captive breeding.

Rationale. The captive population represents conservation insurance.

Results. Captive breeding of both species continues to increase.

Past Recommendations - Summary and Conclusions

The central problem recognised by the previous review group was a lack of expertise and experience with crocodilians, in both the Philippines and Japan. This constrained both research and production at CFI, and prevented the CFI taking its rightful place as an international leader in the field of crocodile farming, that could in turn extend technology within the Philippines and to other developing nations.

The stated reason why CFI had not been able to comply with the recommendations was that JICA funding did not allow travel to developed nations for training, regardless of whether or not such training was only available in those countries. Such a policy clearly is a major constraint on the CFI being able to achieve its goals in an efficient and cost-effective manner.

Progress has clearly been made with some of the initiatives, but given that 12 months has passed since the recommendations were made, none is overly impressive. There has been the continuing pursuit of isolated research projects that can be undertaken within CFI, without funding, and virtually no pursuit of any issues requiring resources.

Again, the general impression is that the administrative structure is such that the CFI is totally constrained - it is virtually impossible for the CFI to recognise a priority and expediently co-ordinate its own impressive resources and direct them at the solving of the problem.

3. Sustaining the CFI in the future

The review committee and all attendants at the workshop were unanimous that the fundamental problem facing the CFI is the lack of a strategy through which the CFI's operations can be refined, streamlined and sustained in the future. This could prevent it being consolidated as an important asset to the Republic of the Philippines.

In considering the various arguments, the review committee identified a number of fundamental constraints:

1. The concept of operating a single establishment such as the CFI, with separate streams of funding, staff, operational guidelines and objectives is a fatal flaw.

2. To date, the CFI has basically been in an establishment phase, which should be recognised as a discrete STAGE 1. This stage will terminate in August 1994, coinciding with the termination of JICA financial support for STAGE 1 (extended).

3. The operational phase of the CFI, in which crocodiles begin to make a commercial return, should commence in August 1994. This should be the start of STAGE 2, which should be pursued for a minimum of 5 years.

4. STAGE 2 operation needs to be planned carefully and pragmatically such that future operation of the CFI can be guaranteed. In essence, the funding to date has been directed at establishment, and no framework for long-term sustainability of the CFI is yet in place.

5. In order to design STAGE 2, an independent audit needs to be carried out of all aspects of the current CFI's operation and goals. Such an audit should not be constrained by supporing any particular group, and needs to have a single aim - to determine the most efficient and cost effective method of allowing the CFI to achieve its goals.

6. The structure of the organisation that operates the CFI, and indeed the operation and perhaps expanded goals of the CFI, will need to be derived through that independent audit. However, the review committee felt that it should suggest how a restructured CFI may operate:

6.1. The CFI goals should be examined to determine whether or not they should be expanded to include other wildlife suited to conservation through sustainable use. That is, other wildlife that could pass through the stages of feasibility, research, development of production technology, extension to local people and consolidation of conservation advantages - all areas the CFI is well suited to pursue.

6.2. The CFI should be established as a Government Corporation, or semi-government, non-profit organisation, such that funds derived by the CFI could be used by the CFI. The CFI should be restructured such that it can head towards financial independence from both granting agencies and the public purse. It should aim to become a self-supporting establishment.

6.3. Japanese funding should be sought both for the capital inputs for STAGE 2, and for the operational costs (excluding the salaries of Filipinos staff).

6.4. Critical to the future operation should be a Board of Directors who allocate budgets and hire and fire staff. The CFI needs to be run on business principles to avoid waste.

6.5. With this structure, the plan to run the CFI should consider operational cells such as those outlined in Fig. 1. Areas where income can be earned and areas where real conservation and humanitarian goals can be achieved.

4. Recommendatations

1. An independent audit of all aspects of CFI operation be carried out.

2. A detailed and realistic plan for STAGE 2 be prepared which ensures that the CFI is self-sustaining as it continues to contribute to crocodile conservation.

3. The current research and planned extension activities of the CFI be subject to critical review by experts with a view to ensuring no waste of effort and resources.

4. Research results achieved by the CFI to date be submitted for publication to international journals of repute.

5. That renewed efforts be made to increase training opportunities and the transfer of technology from overseas to the CFI.

6. That every effort be made to continue with the programs aimed at acquiring sanctuaries. This should perhaps include the formulation of a specific aid proposal for that purpose.

7. That the administrative structure of CFI be changed as soon as possible such that the complete operation comes under the direction of a board of directors. The Board should be advised on crocodile matters by a CSG Advisory Group.

8. That discretionary funds be made available to the Board for utilization as directed by them, in order to assist CFI. Such funds should preferably be derived in Japan through a foundation or other direct sponsors.

Crocodile Nutrition

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The types of diets fed to captive crocodilians are determined by a number of factors, of which availability and cost are usually foremost. However, regardless of the type of diet or crocodilian species being farmed, feeds are usually composed of some type of meat base (e.g. red meat, chicken, fish, turtle, snake, etc.). In countries where crocodilian farming must compete with people for animal protein, the range of feeds available is more restricted than in countries like Australia, where there is a ready supply of meat protein.

The development of a formulated feed for the American alligator was a significant advance which improved the efficiency of farming this species. Formulated rations are now used to supplement or even replace (pellets) "raw meat" diets. The alligator success story has yet to be emulated for crocodiles, and exemplifies the differences that can exist between different crocodilian species. Nevertheless, research continues, and there is a general acceptance that formulated rations will play a significant role in crocodilian farming in the future.

The purpose of this paper is to provide a broad overview of the prerequisites that a crocodilian feed must fulfill, regardless of the form it takes, and outlines other factors to be taken into account when assessing the suitability of a particular diet.

Initiation of feeding

The suitability of a diet must be assessed on the basis of two factors- survival and growth. The first step is to determine whether the animals will readily accept particular foods. Once this is achieved, then the problem of maximising growth can be examined. It is more important that feeding is initiated quickly, soon after hatching, or later growth can be compromised.

Within the first month of life, *C. porosus* hatchlings showed clutch-specific preferences for certain foods (Manolis *et al*. 1989). Likewise, Garnett and Murray (1986) noted that *C. porosus* hatchlings preferred pork and beef to fish, and Foggin et al. (1989) found that C. niloticus hatchlings performed better, in terms of survivorship and growth, when fed beef rather than fish.

There are almost certainly species-specific differences with regard to the acceptability of different foods. It appears that C. porosus hatchlings avoid foods that are "smelly", such as fish (Manolis et al. 1989). The addition of a vitamin supplement with a strong odour resulted in C. porosus starving to death rather than eat the food offered. From a survival point of view it is probably important for C. porosus hatchlings to avoid strong smells which may attract larger crocodiles and other potential predators. On the other hand, American alligator hatchlings feed readily soon after hatching, and appear to be less "fussy" about their food.

Composition

The second step in assessing a diet is to broadly examine the major components of the food, as its composition can greatly affect growth rates.

Protein: Crocodilians are able to metabolise large amounts (<70%) of protein. Coulson and Hernandez (1983) reported that crocodilians are unable to hydrolyse vegetable protein, but it now appears that prior "cooking", by extrusion or other methods, allows vegetable proteins to be assimilated (Staton and Vernon 1991). American alligators fed rations containing plant and animal protein outgrew those on rations containing solely plant or animal protein (Kercheval and Little 1990). However, these authors reported feeding problems, and did not use a control diet similar to that used in the industry (Staton and Vernon 1991).

The amino acid profile of the protein fed should approximate that of the crocodile. However, as muscle is structurally similar in all classes of animals, amino acid content varies little between meat from different animal groups. When formulating a diet using different protein sources, it is important to ensure that the amino acid composition is not deficient. The amino acid composition of the diet for fast-growing crocodiles (up to 25 kg in weight) is outlined by Staton and Vernon (1991).

Fat: Fats are digested and absorbed rapidly, and are readily stored by crocodilians (Garnett 1985, 1988; Coulson and Hernandez 1983). High levels of fat in the diet (48% on a wet weight basis) led to decreased protein digestion in C. porosus hatchlings (Garnett 1988), and in A. mississippiensis, amino acids were assimilated 50% faster in a fat-free diet (Coulson et al. 1987). In general, the diet of wild crocodilians is low in fat. For example, Webb et al. (1991) found that the diet of juvenile C. porosus (0.3-1.2 m total length) in a tidal river was composed of 3.0-4.5% fat (10.1-15.9% on a dry weight basis).

Although the amount (proportion) of fat in the food is important, both from a nutritional and husbandry point of view, the composition of the fat itself should be considered. For wild, juvenile C. porosus eating mainly small crabs and prawns (Webb et al. 1991), there is a greater proportion of polyunsaturated fatty acids of the ω^3 series in the diet. Terrestrial animals usually have much higher proportions of polyunsaturated acids in the ω^6 series (Manolis et al. 1989). Garnett (1985) suggested that C. porosus may require certain long-chain, polyunsaturated fatty acids [eicosapentaenoic (C20:5) and docosahexanaenoic (C22:6) acids] which are present in high concentrations in marine species. With A. mississippiensis, animals grew better, and converted food more efficiently with a dietary source of arachidonic acid (C20:4) (Staton et al. 1990a).

Crocodilians fed high-fat diets are usually heavier and wider (belly width) for a given total length than their wild counterparts. From the skin buyer's point of view, short-wide (fat farmed) skins are not as desirable as short-normal (lean farmed or wild) skins. The latter produce less wastage at the manufacturing level.

Carbohydrate: Although alligators have been reported to be unable to digest carbohydrates (Coulson and Hernadez 1983), Staton et al. (1990b) reported that the incorporation of carbohydrate into diets, at the expense of protein, led to improved growth - carbohydrate was used as an energy source instead of protein. The use of carbohydrates in artificial diets is discussed later.

Minerals: Calcium and phosphorus are two elements that are of great importance in crocodilian diets, particularly for hatchlings. As a significant portion of a hatchlings early growth is in bone, there is a greater demand for calcium and phosphorus than would be expected in raising and breeding stock (Manolis et al. 1989).

The levels of calcium and phosphorus used in hatchling diets varies. For C. porosus minimum levels of 2% calcium and 1% phosphorus (6.7% and 3.3% respectively on a dry weight basis) appear adequate, and do not result in any visible deficiencies. With A. mississippiensis, high levels of calcium and phosphorus resulted in decreased growth, and the best growth was achieved with levels of 1% and 0.5% respectively (dry weight basis; Staton et al. 1988). Smith and Coulson (1992) suggest levels of 2.0% calcium and 1.5% phosphorus in a typical diet for C. niloticus. The ratio of calcium to phosphorus should be about 1:1 to 2:1, although higher ratios can probably be handled by the animal.

Deficiency syndromes attributable to a lack of calcium and phosphorus ("spongy" jaws) can often be reversed by adding these elements to the diet, but future growth may be compromised if the condition is allowed to persist for a long period of time. Such syndromes can be caused by a number of factors, including: inadequate amounts of calcium and phosphorus in the diet; excess phosphorus (low Ca:P ratio) leading to calcium excretion to dispose of the phosphorus; high fat levels which may cause insoluble calcium soaps to be formed in the digestive tract (Strauss 1977; Garnett 1988); and, vitamin deficiencies (see below).

Vitamins: Considering the effect of vitamin deficiencies on growth and survivorship, and their relatively low cost, vitamin supplements should be provided as insurance (Staton and Vernon 1991). They are of particular importance when crocodilians are raised in dark conditions, especially Vitamin D, which is required for normal bone growth. Vitamin A deficiencies are also likely to occur in carnivores fed exclusively on meat (Wallach 1970). Deterioration of fish, leading to fatty acids becoming rancid and reducing levels of Vitamin E, is known to lead to steatitis. Dietary Vitamin E may need to be increased to counteract this effect, and the use of an antioxidant when storing the food may be warranted.

Vitamin premixes are added to the diet at between 1-4% of the dry weight of the food (Joanen and McNease 1987; Staton et al. 1988; Manolis et al. 1989). Composition of various vitamin premixes are presented in Joanen and McNease (1987), Staton and Vernon (1991) and Smith and Coulson (1992).

Conversion rates

One measure of the efficiency with which animals turn food eaten into bodyweight is termed conversion rate. Conversion rates for hatchling crocodilians in the first few months of life tend to be high, but drop off markedly as they grow. We have recorded conversion rates of up to 40% (on a wet weight basis) in one month old C. porosus fed a variety of diets. Garnett and Murray (1986) obtained simialr rates for C. porosus fed pork (37%) and beef (34%). For C.

niloticus fed beef, conversion rates of 36% were obtained by Foggin et al. (1989). For both C. porosus and C. niloticus fish diets have resulted in lower conversion rates (17% and 24% respectively: Garnett and Murray 1986; Foggin et al. 1989).

Examination of wild, juvenile C. porosus living in a tidal river revealed much higher conversion rates (>80%; Webb et al. 1991) than are obtained in captivity. The reasons for this are unknown, although the composition of the diet may be implicated. Other factors, such as the relatively crowded conditions in captivity are possibly involved.

The rate of feeding can have a significant effect on conversion rate. Crocodylus porosus hatchlings fed daily showed a mean conversion rate of 28%, compared to 40% for animals fed each two days (Webb et al. 1990).

Formulated Diets

A formulated ration has been developed for the American alligator, and research is now being carried out in other parts of the world (e.g. Zimbabwe, South Africa, Colombia, Australia, Papua New Guinea, Indonesia) to develop similar types of rations for crocodiles. The advantages of these types of diet include: no requirement for freezing; minimal preparation; cheaper and more readily available protein sources can be used; composition can be altered on the basis of nutritional needs; and, pellet size can be altered to suit crocodile size. By increasing the dry matter content of the diet, the amount of energy in each bite the crocodile takes is also increased (Staton and Vernon 1991).

Apart from the nutritional composition, other factors such as the physical characteristics of the feed must be taken into account, or undue wastage may occur. As many of the ingredients used in formulated rations are dry in nature, a binder is usually required to hold the food together.

It is generally agreed that formulated diets will become very important for crocodilian farmers in the future. Food is a major portion of a farms' operating cost, and formulated (pelleted) diets can not only reduce this cost, but have the potential to improve growth rates by providing a good, nutritionally balanced diet.

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CROCODILES IN QUEENSLAND: A brief review.

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Abstract

Two species of crocodiles occur in Queensland: the freshwater crocodile, *Crocodylus johnstoni* and the saltwater crocodile, *C. porosus*. In 1974, Limpus (unpub. data) began a detailed and long-term study of *Crocodylus johnstoni* population biology. Later, Magnusson *et al.* (1980) and Messel *et al.* (1981) conducted surveys of *C. porosus* nesting habitat and numbers along western Cape York Peninsula. Taplin (1987, 1990) surveyed eastern and western Cape York Peninsula between 1984 and 1988. These studies have identified areas of high conservation value; the most important of which is north-western Cape York Peninsula. Surveys have shown that saltwater crocodiles in Queensland exhibit low density populations and geographicly diffuse reproductive effort (Taplin 1990). Recent monitoring of saltwater crocodiles (Krieger unpub. data) has been focused in the Tentpole Creek area north of Weipa which has the highest density of the areas surveyed. The research conducted on crocodiles to date has been used to develop guidelines for crocodile management which is particularly important along the populated eastern coast. Future research and monitoring will provide continuity with previous efforts and address specific management issues.

Introduction

The two species of crocodiles (the freshwater crocodile, *Crocodylus johnstoni* and the saltwater crocodile, *C. porosus*) inhabit rivers, creeks and wetlands in Queensland. Both are widespread in the northern part of the state; however, only the saltwater crocodile occurs naturally along the southeastern coast, albeit in low numbers (Taplin 1987).

Although there are few reliable data concerning the historical levels of crocodile populations in Queensland, the populations of both species were severely depleted during 30 years of hunting, based on the number of skins reported (e.g. Roff 1966). For the most part, the populations have not recovered substantially from the impact of this earlier hunting and other anthropogenic causes of mortality operating since they were protected under the Queensland Fauna Conservation Act in 1974. Although the historical information concerning pre and post hunting population levels is of interest and would make the current task of managing crocodile populations easier, it is more important to understand the current situation for crocodile populations.

The present report provides a brief summary of the status of the freshwater crocodile and the saltwater crocodile in Queensland. Information has been drawn from several sources including Limpus (unpub. data), Magnusson *et al.* (1980), Messel *et al.* (1981), Taplin (1987, 1989, 1990), the 1992 Crocodile Management Plan (draft) (QDEH 1992) and internal Departmental reports prepared by Taplin Bayliss & Krieger (1988), Taplin & Krieger (1989) and Krieger (1991).

Freshwater Crocodile

Previous Research

In 1974, Limpus (unpub. data) began a detailed, long-term study of the population biology of the freshwater crocodile (*Crocodylus johnstoni*) on the Lynd River in the central portion of southern Cape York Peninsula. The study focused on determining the population structure and dynamics as well as reproductive biology of the freshwater crocodile. Limpus (1984) reported on the use of laparoscopy to assess the breeding condition of freshwater crocodiles. Although snout-vent length alone was inadequate to identify potential breeders, laparoscopy and cloacal examination (provided the urine was voided from the bladder) were successful in determining the presence or absence of mature ovarian follicles and oviducal eggs (Limpus 1984). Intense population marking and assessment were conducted during the first few years of the study and monitoring of growth, dispersal, survivorship and reproductive periodicity is still continuing.

Distribution

In general terms, the freshwater crocodile, *Crocodylus johnstoni*, inhabits the freshwater streams and permanent waterholes of the lowland plains south of the Gulf of Carpentaria and the adjacent uplands as well as the non-tidal reaches of waterways on Cape York Peninsula (Cogger 1992, Limpus unpub. data) (Fig. 1). The natural range of the freshwater crocodile appears to exclude the eastern coast of Queensland south of Cape Melville except for the upper Herbert River which originates close to the headwaters of the rivers of the Gulf of Carpentaria; isolated freshwater crocodile populations found along the eastern coast are probably the result of released individuals becoming established rather than being remnants of natural populations. The distribution of breeding populations in all river systems is unknown.

Principle Threats

Management practices on properties and, more generally, within catchments provide the primary threat to species as well as the primary protection of the species. Local practices such as illegal netting of streams for fish can result in incidental mortality; when combined with other sources of mortality (nest destruction by feral animals, shooting, etc.) local populations may be reduced (albeit unquantified).

Status

The details of the status of the freshwater crocodile in Queensland are not known. However, at least some freshwater crocodiles have been found in the inland river systems that have been examined in the Gulf Plains and in central Cape York Peninsula. Some areas have apparently depleted populations while others host relatively dense populations (Limpus unpub. obs., Taplin unpub. obs.). For the most part, negative factors that influence populations are localised and the species is considered not to be at risk in the short and medium term. As a result of the innocuous behaviour of the freshwater crocodile (i.e. it is not a threat to livestock or humans), in conjunction with the restricted access to its habitat through remote properties on which it occurs, an extra degree of protection is conferred on it.

Saltwater Crocodile

Previous Research

Systematic surveys of nesting habitat (Magnusson *et al.* 1980) and counts along waterways (Messel *et al.* 1981) in 1979 provided the initial assessment of saltwater crocodiles in Queensland (Fig.2). During February 1979, using methods developed in the Northern Territory, Magnusson *et al.* (1980) conducted an aerial survey of 32 coastal rivers and the coastline along the western side of Cape York Peninsula. The purpose was to identify actual and potential nesting areas for the species. Areas were assigned to categories (GOOD, MARGINAL 1 MARGINAL 2, POOR, INTERMEDIATE) based on the type of vegetation, the likelihood of flooding and the accessibility to open water (see Magnusson *et al.* 1978 for details).

South of the Embley River, they found no GOOD habitat but found that the Nassau and Staaten River systems contained large areas of MARGINAL 1 habitat. North of the Embley River, two areas of GOOD nesting habitat (Wenlock and Dulcie Rivers) were identified along with a number of habitats suitable for adult crocodiles (Fig. 2).

Messel *et al.* (1981) used vessels to survey the Nassau, Staaten, and Gilbert Rivers as well as Duck Creek of southwestern Cape York Peninsula in April 1979. They located "only 4 hatchling and 154 non-hatchlings altogether on the 4 rivers". This gives a density of 0.4 non-hatchling crocodiles per kilometre. In November 1979, Messel *et al.* (1981) also surveyed the Wenlock and Dulcie River systems plus the Escape River on the northern end of Cape York Peninsula. The density of non-hatchling crocodiles was calculated to be 1.8/km, which is very similar to the average density determined for TYPE I rivers in the Northern Territory (see Messel *et al.* 1981 for details) (Fig. 2).

In 1984, Taplin (1987) began surveying crocodile numbers and habitat along coastal Queensland with a view to assessing the population status and to developing a management plan for crocodile conservation in Queensland.

In a detailed assessment of crocodile habitat and factors which influence the status of the populations, Taplin (1987) considered the known distribution of *Crocodylus porosus* in terms of the climate and physiography of Queensland as well as the pattern of the human population and agricultural development. Following aerial and vessel based surveys, he found that northwestern Cape York Peninsula contained "the best *C. porosus* habitat and the largest breeding population known" in Queensland (Taplin 1987). Other areas of importance identified during the surveys included Princess Charlotte Bay (Kennedy & Normanby Rivers) and Iron Range (Lockhart River). Low numbers of crocodiles of various size classes were found throughout coastal areas of Cape York Peninsula (Taplin 1990).

More recently (1990-1992) Krieger (unpub. obs.) has been conducting surveys in the Wenlock River and Tentpole Creek areas north of Weipa. These surveys have focused on assessment of the population but have also included surveys of nesting sites and the marking of hatchlings.

Distribution

The current distribution of the saltwater crocodile in Queensland extends from just south of Rockhampton northward along the coast (seldom more that 50 km inland) to the border with the Northern Territory; the range includes slightly more than 12.5 degrees of latitude (Taplin 1987, 1990) (Fig. 3).

The distribution along the eastern side of Cape York Peninsula is restricted by the relatively narrow band of lowlands bisected by relatively short river systems. The exceptions include the Burdekin and Fitzroy River systems in the south which offer only marginal habitat and the North Kennedy, Bizant, Normanby and Marriott Rivers in Princess Charlotte Bay which host relatively high numbers and/or densities of saltwater crocodiles. Much of the historic or potential habitat along the southeastern coastal lowlands is now utilised for intensive agriculture or urban development; further north, large areas of eastern Cape York Peninsula are unsuitable silica dune/wetland habitat. The northwestern portion of Cape York Peninsula (Port Musgrave region) contains the best crocodile habitat and populations located in the surveys (Taplin 1987, 1990).

Further south along the western coast of Cape York Peninsula, the marginal habitat of the Mitchell-Nassau-Staaten River systems hosts low density populations and nesting, at least in some years. The Gulf Plains area of the bottom of the Gulf of Carpentaria offer only marginal habitat that is subject to seasonal flooding.

In explaining the low numbers of crocodiles found in most areas, Taplin (1987, 1990) argued that, as a result of the shape of Cape York Peninsula and the north-south gradient in climate (rainfall, temperature, seasonality) that occurs over the range of the saltwater crocodile in Queensland, there is only a restricted amount of good crocodile habitat available. However, historically the saltwater crocodile utilised the upstream, non-tidal portions of the rivers of western Cape York Peninsula and the Gulf Plains as well as the wetlands of the eastern coast of Queensland. The low numbers of saltwater crocodiles in these areas today probably results from a synergism among the impact of previous hunting, pressures of development for agriculture and urbanisation, removal of large crocodiles, and the consequential low recruitment into the population as well as climatic factors.

Principle Threats

Throughout the range of *C. porosus* in Queensland, incidental mortality resulting from netting (both legal and illegal) and habitat modification (rural and urban development) together with other sources of mortality (illegal shooting, etc.) have impacted on the already depleted populations that inhabit the comparatively widespread (albeit marginal) habitat in Queensland (Taplin 1989).

The removal of problem crocodiles has also contributed to the reduction of populations along the populated eastern coast, principally from Cooktown southward. This management practice, although protecting humans, has reduced the number of breeding crocodiles and the potential for recruitment into the breeding populations along the southern portion of the eastern coast. Between 1984 and 1991, 172 crocodiles (larger than 0.9m) were removed from the proximity of human use areas along the eastern coast.

Status

Because several years have elapsed since the last detailed assessment was made, the status of estuarine crocodile populations throughout Queensland requires review. The density of crocodiles varies within six physiographic regions which were defined by 'more or less common characteristics' (see Taplin 1987 for details). These regions include (Fig. 4):

- Southern Gulf Plains (Subregion 1a, 1b, 1c)
- Northern Gulf Plains (Subregion 1d)
- North-west Cape York (Region 2)
- North-eastern Cape York (Region 3)
- Princess Charlotte Bay (Region 4)
- Eastern Coastal Plains - Cape Melville to Cape Flattery (Subregions 5a, 5b, 5c)
- Burdekin & Fitzroy River Systems (Subregions 6a, 6b)

The area with the highest density of non-hatchling crocodiles as determined by spotlight indices (number of crocodiles per kilometre of waterway surveyed, see Taplin 1987, 1990 for details) was region 2 (mean= 1.608); region 4 (Lakefield National Park in Princess Charlotte Bay) had the next highest spotlight index (mean= 0.87)

The variation in the quality of habitat and physiography of northern Queensland is reflected in the different numbers of small crocodiles located during the surveys (Taplin 1990). The principle areas for small crocodiles are Lakefield National Park in Princess Charlotte Bay, Iron Range/Lockhart River, North-western Cape York Peninsula, Port Musgrave, and Albatross Bay at the top of Cape York Peninsula.

Following various surveys of the eastern and western sides of Cape York Peninsula (Magnusson *et al.* 1980, Messel *et al.* 1981, Taplin, Bayliss & Krieger 1988), Taplin (1990) identified five areas of importance to the conservation management of crocodiles: (1) Port Musgrave, (2) North-western Cape York Peninsula, (3) Lakefield National Park in Princess Charlotte Bay, (4) Iron Range /Lockhart River National Park, and (5) the Mitchell-Nassau-Staaten Rivers systems (Fig. 5).

Current Management

In accordance with the Nature Conservation Act 1992, the Department of Environment and Heritage is in the process of developing conservation plans for a number of species including crocodiles. The purpose of the conservation plan is two fold: (1) to ensure provisions exist for the recovery of threatened taxa and (2) to ensure that any exploitation is ecologically sustainable.

The management of crocodiles in Queensland is guided by the Crocodile Management Plan 1992 (draft). The management plan, which is reviewed periodically, includes guidelines for conservation, commercial utilisation through farming and tourist enterprises, the identification of crocodiles products, as well as other subjects.

The Crocodile Management Plan 1992 (draft) provides for a Crocodile Consultative Committee with 12 representative members including a community-based conservation group, the tourist industry, the Crocodile Farmer's Association, Aboriginal community, QDEH and non-QDEH research groups, among others. Their task is to advise the minister on matters concerning problems, policies and procedures which relate to crocodiles.

Probably the greatest change from previous plans concerns the handling of problem crocodiles, particularly when they occur near a centre of human population along the eastern coast and near towns in more remote areas. The policy for dealing with problem crocodiles is based on the principle of "removal or destruction of individual crocodiles only in situations when a genuine problem is identified through a formal review process".

Queensland Crocodile Management Plan 1992 (draft) was implemented to achieve the following long-term objectives:

to maintain viable wild populations of *C. porosus* and *C. johnstoni* in Queensland across their natural ranges;

to ensure the maintenance of wetland habitats upon which *C. porosus* and *C. johnstoni* are dependent sufficient to maintain viable populations;

to permit, where feasible, the controlled development of legitimate commercial enterprises, including the sustainable utilisation of wild populations in specified areas within their respective ranges;

to assist the public to appreciate the ecological significance of crocodiles;

to educate the community to the view that living with crocodiles is an acceptable proposition; and

to provide the general public with a level of protection commensurate with the need to maintain viable populations of crocodiles across their ranges.

To achieve these objectives, the following priority tasks have been identified:

assessment of population status;

identification of primary foci of recruitment and key areas for conservation initiatives;

identification of sites for future intensive study of crocodile biology;

development of procedures for problem crocodile management for the populated east coast between Rockhampton and Cooktown, in particular and Queensland in general;

review of regulatory procedures following changes in the CITES status of estuarine crocodiles and subsequent changes in opportunities for domestic marketing of crocodile products.

Current Research

Queensland Department of Environment & Heritage (QDEH) officers have been monitoring a population of freshwater crocodiles, *Crocodylus johnstoni*, in the Lynd River catchment in the central portion of southern Cape York Peninsula for over 18 years (Limpus unpub. obs.). Results of this work and that of other researchers, who have used or are using that marked population, will be reported when complete. The numbers of saltwater crocodiles, *C. porosus*, in the Wenlock River and Tentpole Creek area are monitored annually. Surveys of other coastal rivers occur on an irregular basis. Management of problem crocodiles provides some morphological and bahavioural data.

Because several years have elapsed since the last systematic surveys were conducted, there is a clear need to obtain another set of accurate data on the nesting, distribution and abundance of saltwater crocodiles in Queensland. These surveys are needed before estimates of the size of the total population can be made and before any trends in the populations can be deduced; these results are also necessary before the existing conservation management practices can be altered.

As a general guideline, the Department of Environment & Heritage will support ecological research projects that are relevant to the conservation of viable populations of saltwater crocodiles in Queensland.

The objectives of the crocodile research program are:

> To determine the distribution and status of populations;
>
> To conduct intensive investigations on population dynamics and reproductive biology;
>
> To identify the biological constraints which are not negotiable in the development of conservation management action plans;
>
> To further develop strategies for management of crocodiles in remote and populated areas;
>
> To further develop a public education program aimed at improving attitudes and behaviour towards crocodiles.

In the short term, monitoring of the *Crocodylus porosus* population in the Wenlock river and

Tentpole Creek area of Cape York Peninsula will continue. The methods used to collect data (spotlight from vessels and aerial surveys, see Bayliss 1987) will continue so that continuity with previously collected data is maintained.

In support of this research effort, a proposal for aerial and vessel-based surveys of the important areas identified by Taplin, Bayliss & Krieger (1988) is being prepared. Surveys of these areas will be conducted as part of continuing assessment of the populations and nesting habitat. A GIS mapping project of the Gulf Plains area and western Cape York Peninsula utilising remote sensing imagery and ground truthing of vegetation is in progress (Blackman unpub data); crocodile survey data (known nesting and distributional records) will be layered over these base maps to identify areas of potential nesting habitat and to guide investigation of the distribution of the populations.

As noted by Taplin (1987), the amount of space required to maintain a viable population of *Crocodylus porosus* remains unknown as do the details of dispersal patterns and habitat utilization. The establishment of park boundaries which include key nesting areas and adjacent waters where adult and juvenile crocodiles live as well as creeks and rivers into which young crocodiles disperse is essential to the conservation management of crocodiles. Queensland has created a few large National Parks along the coast including Lakefield NP (537,000 ha), Jardine River NP (235,000 ha) and Iron Range NP (34,600 ha) which provide at least a temporary buffer for the existing populations. The establishment of other parks (such as the proposed Wenlock River and Tentpole Creek Wetlands National Park (approximately 50,000 ha), Krieger 1991) in the high density and some marginal areas will be required to ensure the long-term survival of the species in Queensland.

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FIGURE CAPTIONS

Figure 1. Generalised map of the distribution of the freshwater crocodile, *Crocodylus johnstoni*, in Queensland. Freshwater crocodiles typically are found in non-tidal inland streams and wetlands but may occur in the tidal portions of waterways. Star indicates the position of the Lynd River study site.

Figure 2. Areas surveyed by Magnusson *et al.* (1980), Messel *et al.* (1981) and Taplin (1987, 1990). Magnusson *et al.* (1980) surveyed 32 rivers and the coastline between the Norman River and the Jardine River. Messel *et al.* (1981) surveyed Duck Creek, as well as the Gilbert, Staaten, and Nassau Rivers in southwestern Cape York Peninsula; they also surveyed the Wenlock and Dulhunty Rivers in the northern portion plus the Escape River. Taplin (1987, 1990) surveyed the eastern and western coasts of Cape York Peninsula as well as the Gulf Plains area using vessels and helicopters.

Figure 3. Generalised map of the distribution of the saltwater crocodile, *Crocodylus porosus*, in Queensland. Saltwater crocodiles typically inhabit the tidal portions of rivers but may also be found in non-tidal portions of rivers and wetlands.

Figure 4. Physiographic regions of Queensland (Taplin 1987) and mean sighting indices calculated for each region (Taplin 1990). Regions: Southern Gulf Plains (Region 1, Subregions a, b, c), Northern Gulf Plains (Region 1, Subregion d), North-west Cape York (Region 2), North-eastern Cape York (Region 3), Princess Charlotte Bay (Region 4), Eastern Coastal Plains - Cape Melville to Cape Flattery (Region 5, Subregion a, b, c), Burdekin & Fitzroy River Systems (Region 6, Subregion a, b) (See Taplin 1987, 1990 for detailed descriptions of regions). Spotlighting Indices x= mean, sd= standard deviation, n= number of rivers surveyed. No data are available for Region 6.

Figure 5. Areas of importance to the conservation management of crocodiles in Queensland identified by Taplin, Bayliss & Krieger (1988) and Taplin (1990): (1) Port Musgrave, (2) North-western Cape York Peninsula, (3) Lakefield National Park in Princess Charlotte Bay, (4) Iron Range/Lockhart River National Park, and (5) Mitchell-Nassau-Staaten Rivers. Shaded portions indicate the general areas only.

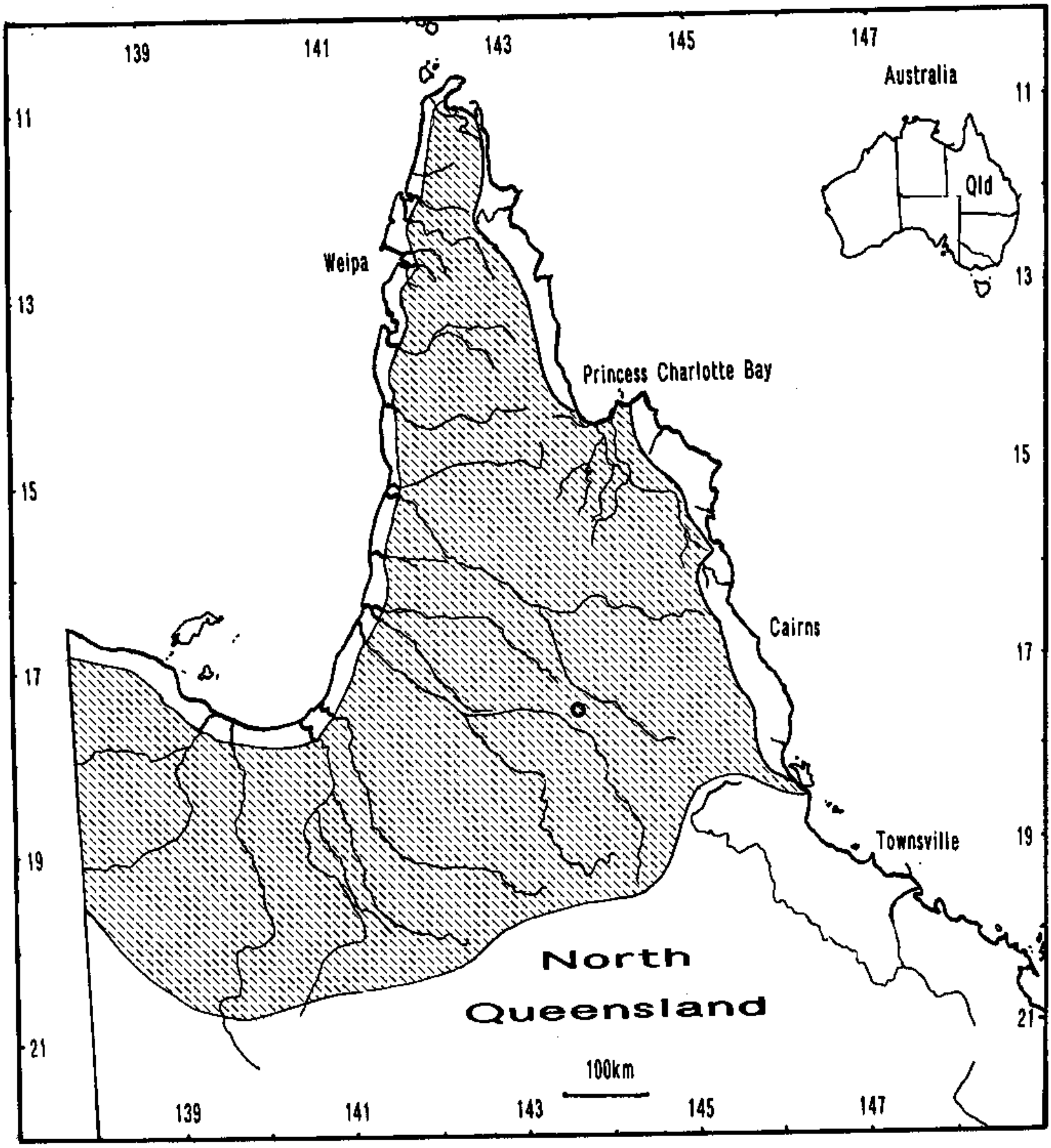
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Fig 1.

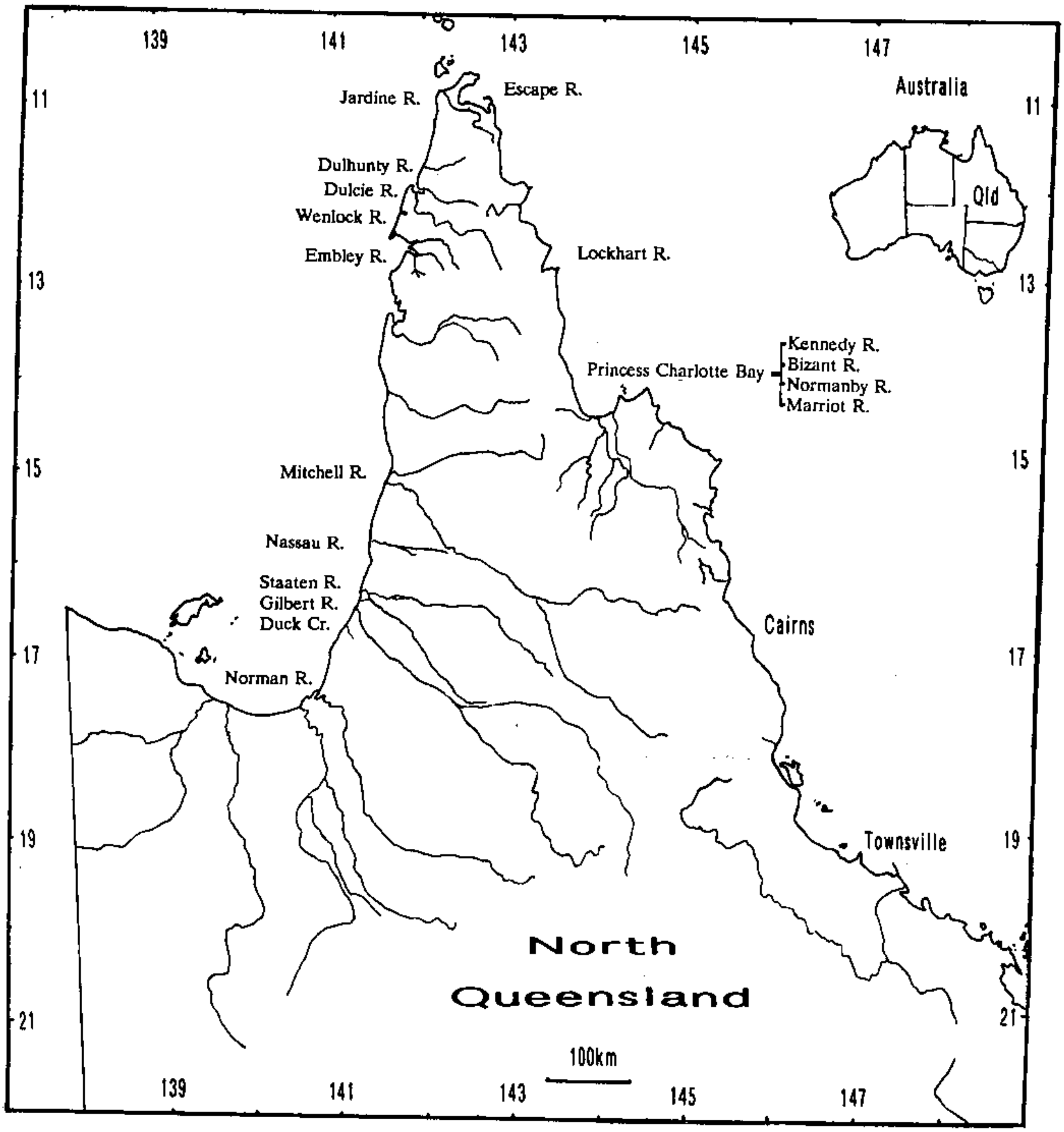
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Fig 2.

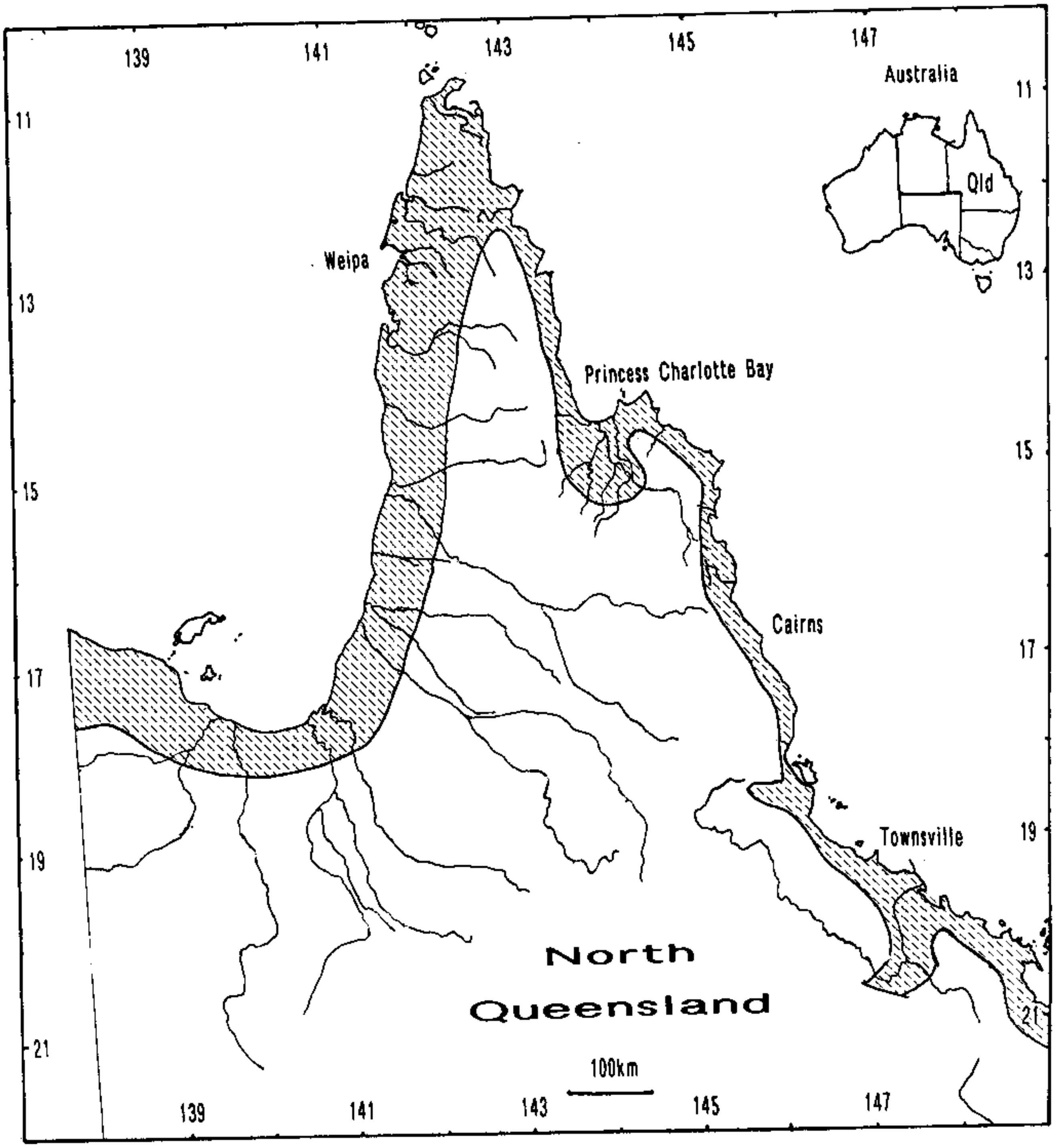
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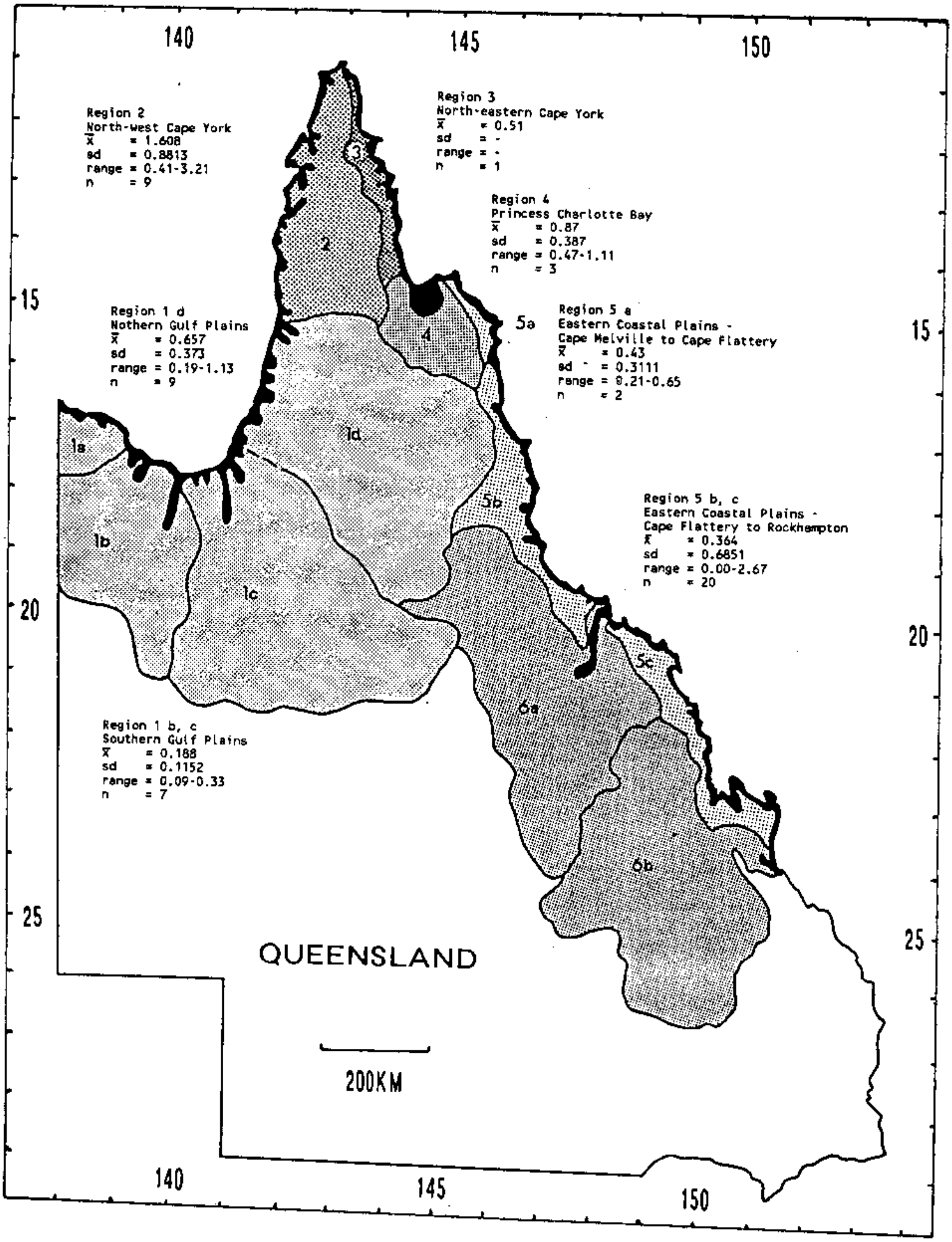
Fig 3.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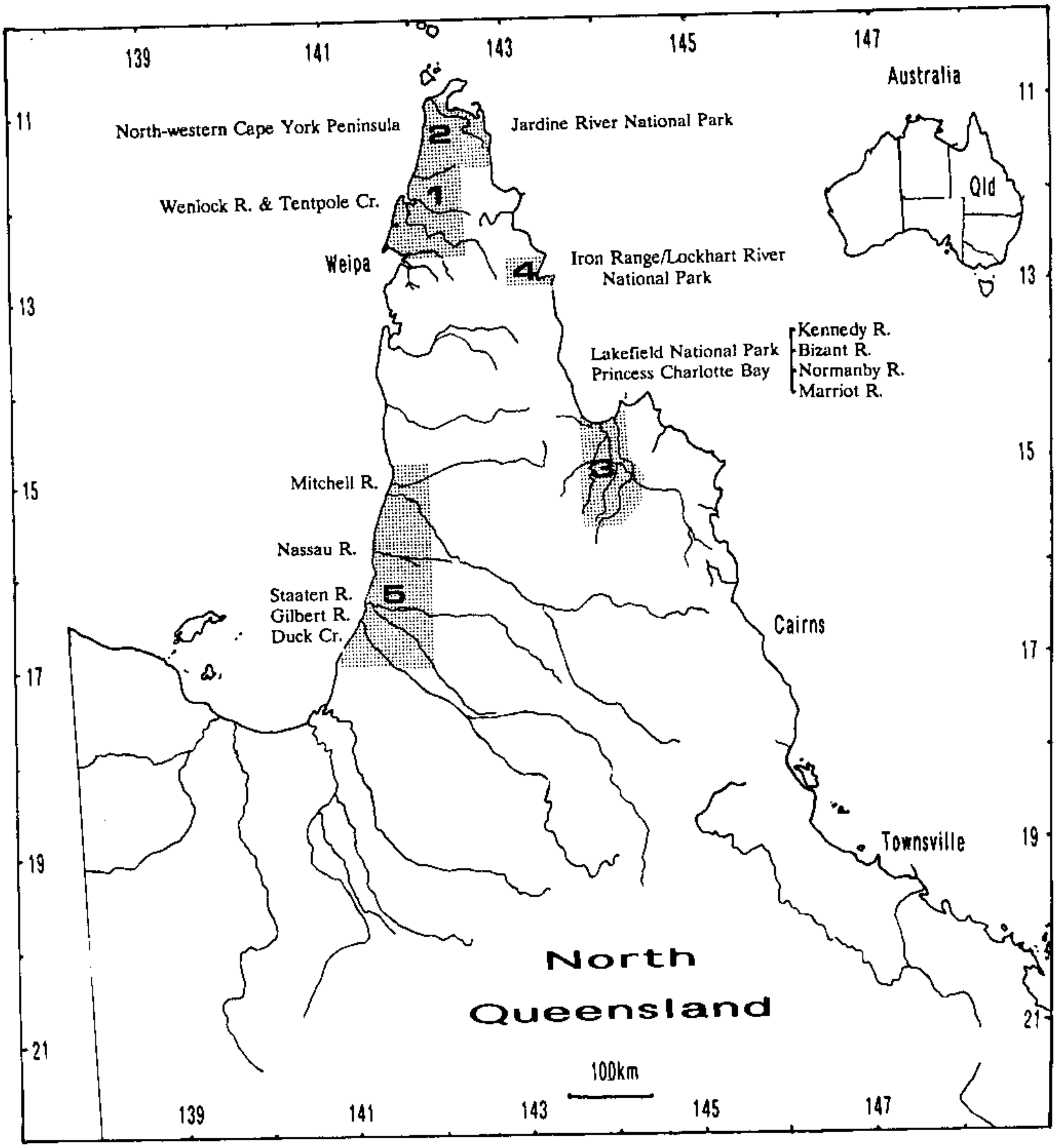
Region 2
North-west Cape York
x̄ = 1.608
sd = 0.8813
range = 0.41-3.21
n = 9
Region 3
North-eastern Cape York
x̄ = 0.51
sd = -
range = -
n = 1
Region 4
Princess Charlotte Bay
x̄ = 0.87
sd = 0.387
range = 0.47-1.11
n = 3
Region 1 d
Nothern Gulf Plains
x̄ = 0.657
sd = 0.373
range = 0.19-1.13
n = 9
Region 5 a
Eastern Coastal Plains -
Cape Melville to Cape Flattery
x̄ = 0.43
sd = 0.3111
range = 0.21-0.65
n = 2
Region 5 b, c
Eastern Coastal Plains -
Cape Flattery to Rockhampton
x̄ = 0.364
sd = 0.6851
range = 0.00-2.67
n = 20
Region 1 b, c
Southern Gulf Plains
x̄ = 0.188
sd = 0.1152
range = 0.09-0.33
n = 7
1a
1b
1c
1d
2
3
4
5a
5b
5c
6a
6b
15
20
25
QUEENSLAND
200KM

Fig 4.



139
141
143
145
147
Australia
Qld
11
13
15
17
19
21
North-western Cape York Peninsula
Jardine River National Park
Wenlock R. & Tentpole Cr.
Weipa
Iron Range/Lockhart River National Park
Lakefield National Park
Princess Charlotte Bay
Kennedy R.
Bizant R.
Normanby R.
Marriot R.
Mitchell R.
Nassau R.
Staaten R.
Gilbert R.
Duck Cr.
1
2
3
4
5
Cairns
Townsville
North Queensland
100km

Fig 5.

CONSERVATION, MANAGEMENT AND FARMING OF CROCODILES IN THE PHILIPPINES

by Gerardo V. Ortega, D.V.M.[1] and Patrick A. Regoniel[2]

INTRODUCTION

General Description of the Philippines

Geographically, the Philippines is considered a part of southeast Asia. The country is located between the Equator and the tropic of Cancer, between latitudes 4° 23' and 21° 25' N, and between longitudes 116° 00' and 127° 00' E. It is bounded in the north by the Bashi Channel, the east by the Pacific Ocean, in the south by the Celebes Sea, and in the west by the South China Sea (Fig. 1).

The Philippines is located in the "Pacific Ring of Fire", a region of frequent volcanic activity. The country also lies on the western Pacific earthquake belt which is a region of frequent land movements (Scott 1989). The small area of the islands precludes extensive river systems. Most rivers are less than 20 miles (30 km) long, turbulent, and seasonal in their flow. The largest, the Cagayan, is only 200 miles (320 km) long. Other major rivers are the Agno, Pampanga, Pasig, and Bicol in Luzon, and the Rio Grande de Mindanao and Agusan in Mindanao (Encyclopedia Americana 1989). There are some large internal plains between the main mountain ranges, and narrow coastal plains around most of the larger islands (Scott 1989)

.

The Philippine archipelago is endowed with rich terrestrial, wetland and marine resources. There are around 8,000 species of indigenous flowering plants and about 4,000 species of pteridophytes, bryophytes, fungi, algae and lichens. There are more than 2,500 species of wild fauna (except insects and invertebrates) identified in the archipelago. These are composed of 196 species of mammals, 62 species of amphibians, 171 species of reptiles and between 950 to 975 species and subspecies of birds, including the migratory ones. The seas and coastlines around the islands and islets are the habitat of about 400 species of corals and between 2,300 to 2,400 species of fish, 69 species of algae, 125 species of protozoans and 6 species of sea grass (adapted from PAWB brochure).

Size of the Philippines

The Philippines is one of the world's largest archipelagoes, but more than 60% of the land is mountainous.

The country is 1,150 miles (1,850 km) long and 680 miles (1,060 km) wide (Encyclopedia Americana 1989).It contains 7,109 islands, only 462 of which exceeds 2.5 sq km in area. The Philippines has an extensive coastline stretching 34,600 km, the longest in the world (NSO 1990). The archipelago is somewhat elongate in shape, extending for 1,840 km from north to south, and about 1,000 km from east to west at its broadest. The total area is approximately 300,000 sq km, 92.3% of which is contained within eleven (11) largest islands. The country is divided into three major island groups: Luzon (141,395 sq km), Mindanao (101,998.9 sq km), and Visayas (56,606.4

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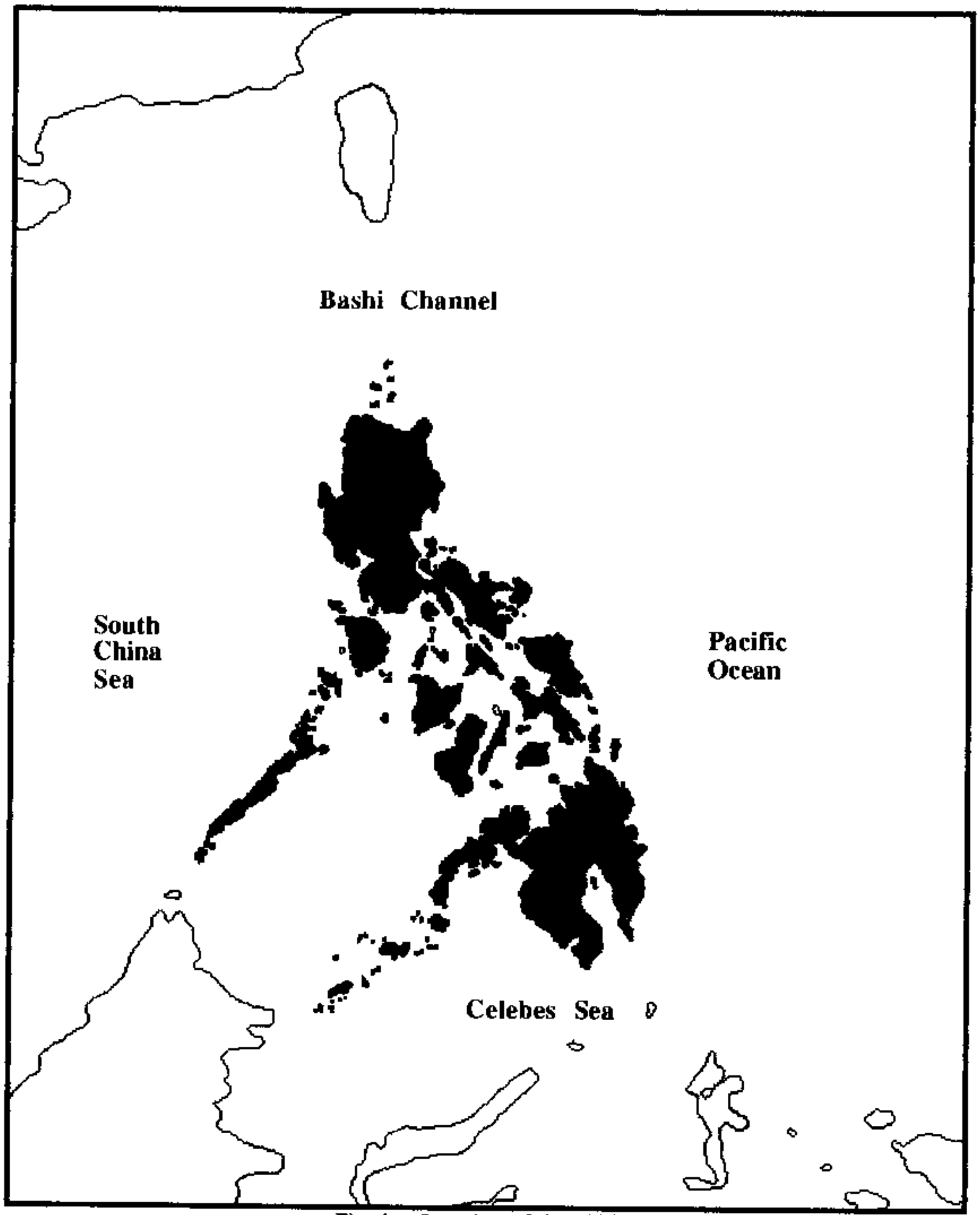

Fig. 1. Location of the Philippines.

sq km). There are fourteen (14) regions, 73 provinces, 60 cities, 1,532 municipalities and 40, 904 barangays (NSO 1990). The Philippine waters cover a total area of 1,666,300 sq km, which is five times more than the total land area of the country. Manila is the capital city and seat of the national government.

Human Population and Rate of Increase

The growth of the Philippine population is mainly due to natural increase or the excess of births over deaths, for net international migration is relatively nil (NSO 1990). The population rose from 19.2 million in 1948 to 42.1 million in 1975 and to 48 million in 1980. Although the rate of natural increase declined to an average of 2.4 % a year for 1975-1980, it was well above the world average (Encyclopedia Americana 1989).

On May 1, 1990, the Philippines registered a total population of 60,703,206 persons. This indicates an increase of 12,612,746 persons over the 1980 census figure of 48,098,460. The population in 1990 is about eight times its size in 1903, the year the first census [that counted the entire population] was undertaken. If the average annual population growth rate of 2.35 percent continues, the Philippine population is expected to double in less than 30 years. At this rate of growth, population increases by an additional 1.4 million every year or about 3 persons per minute (National Statistics Office 1990). Population density as of 1990 is 202.33 persons per square kilometer.

Dominant Forms of Land Use

Loss of ninety-five percent (95%) of the Philippine forest cover was due to conversion into agricultural lands and similar uses while only 5% was due to logging damage.

Of the original 17 million hectares of forest cover in 1934, only a little over 6.2 to 6.4 million hectares of forest remain today.

The country's experience of the use, misuse and abuse of its forest confirmed FAO findings. Rate of deforestation for the period 1986 to 1990 is 100,000 hectares per year.

The reasons for the massive loss of Philippine forest include the inconsistent and changing policies of the government and the lack of land use plans and sustainable programs, population pressure on uplands and forest lands, unemployment and poverty in rural areas, inability of the agencies to protect the forest and conflicting programs of government agencies to forest lands (Arias 1993).

As of 1988, forest lands comprised 15.88 million hectares or 52.94% of the country's total land area of 30 million has. Of the total forest lands, 15 million were classified into the following categories: established forest (21.81%), established timberland (66.76%), national parks, game refuge and bird sanctuaries/wilderness areas (8.95%), military and naval reservations (0.87%) civil reservations (1,11%) and fishponds (0.50%). The remaining 0.88 million has were still unclassified.

General Status of Wetlands

The Philippines is endowed with extensive wetland areas (Fig. 2). These include such water bodies as lakes, rivers, ponds, inland and coastal marshes and swamps, estuaries and mangrove swamps. The total area of freshwater lakes has been estimated at about 114,000 ha, that of swamps and estuaries about 527 ha, and that of brackish ponds about 175,000 ha. In addition, there are some 130,000 ha of man-made reservoirs (Scott 1989).

Mangroves have come under considerable pressure from coastal development, forestry exploitation and particularly conversion to aquaculture ponds. Over 300,000 ha of an original estimated 450,000 ha of mangroves have been cleared legally and illegally over the last 60 years (Alvarez 1984), and this destruction of mangroves continues. According to the Philippine Mangrove Committee (1987), the area of mangrove forests decreased from 450,000 ha in 1920 to 146,139 ha in 1978.

However, according to Saenger *et al* (1983), in 1978, the Philippines had 246,699 hectares of mangrove forest. For the period 1967-1976, the area of mangroves declined from

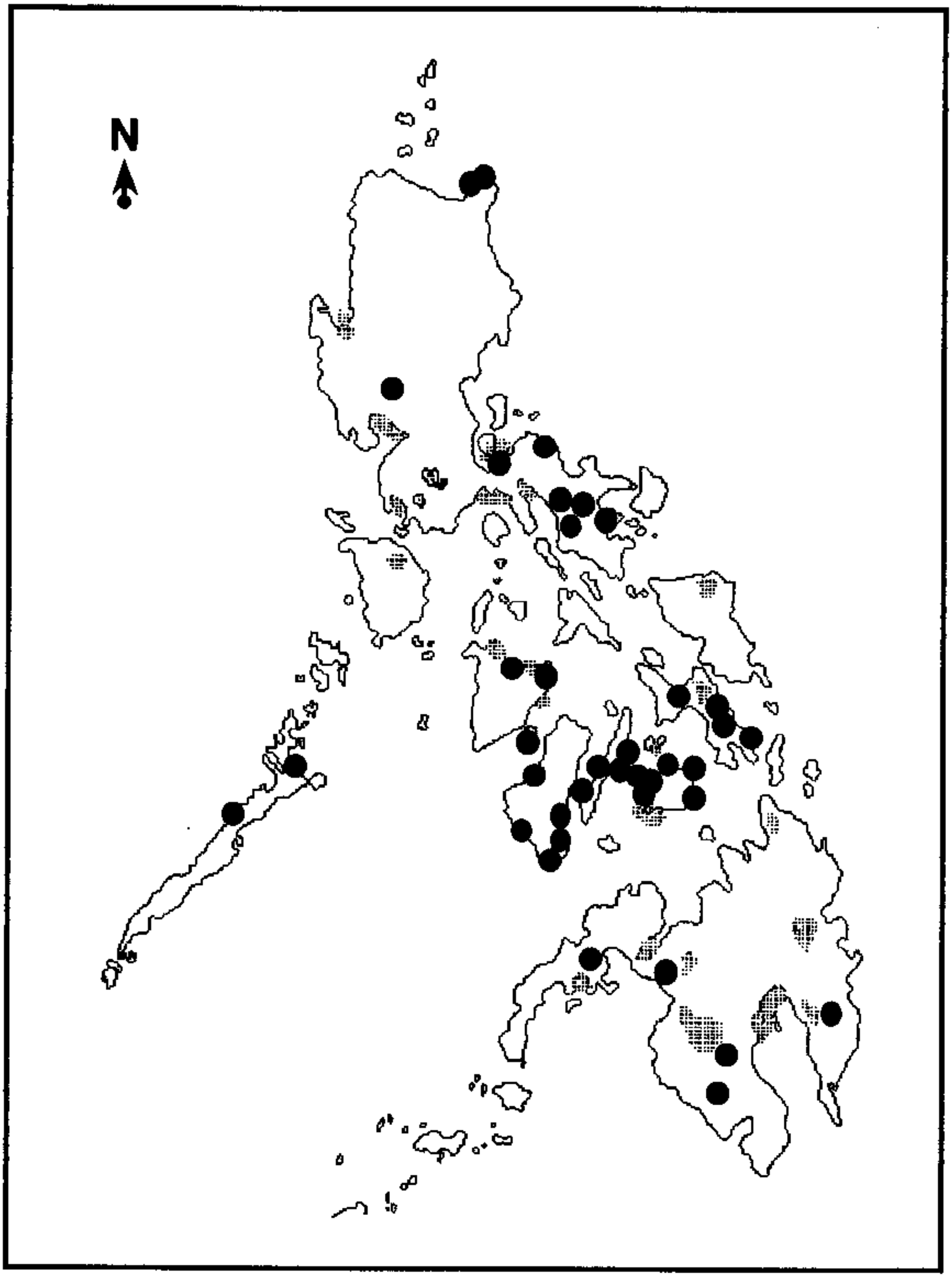

Fig. 2. Location of Philippine wetlands (Scott 1989).

418,990 ha to 249,138 ha, or approximately 16,741 ha annually. These areas were cleared for fishponds or denuded of fuelwood and timber. The rate of decline has slowed; from 1977 to 1978, the cleared area was 2,439 ha.

Currently, the major bulk of mangrove forests lie on the islands of Palawan and Mindanao. According to SPOT Satellite Data collected by the Swedish Space Corporation

(SSC) and 1985 photos interpreted by the Palawan Integrated Area Development Project (PIADP), there are 33,100 hectares of mangrove forests remaining in Palawan. Further, there are 800 hectares of mangrove fishpond derived from mangrove. In Mindanao, based on SSC satellite data results in 1987-88, virgin mangrove and residual mangrove reproduction was 79,300 hectares while fishpond derived from mangrove was 40,200 hectares.

Climate

The south-west monsoon brings rain from June to October while the north-east monsoon brings rain between November and February and provides the eastern Pacific coasts with a prolonged wet season. The western coasts of Luzon, Mindoro, Panay, Negros and Palawan receive little rainfall from the north-east monsoon, because of intervening mountain ranges, and these western parts have distinct wet and dry seasons. Typhoons bring 25-35 per cent of the annual rainfall and sweep north and west across the central and northern parts of the archipelago from July to November (Collins *et al* 1990).

Thus, four main climatic zones based on the distribution of rainfall in tbe Philippines have been identified and categorized as follows:

Type I: pronounced wet and dry seasons, the wet season during the months of June to November, and dry from December to May.

Type II: no proper dry season but with a very pronounced period of maximum rainfall in December, January and February.

Type III: an intermediate type with no pronounced period of maximum rainfall and a short dry season lasting from one to three months only.

Type IV: rainfall uniformly distributed throughout the year (Fig. 3).

At sea level throughout the islands, the temperature averages about 80° F (27°C). The humidity is high, and for every 300-foot (90-meter) rise in elevation, the temperature decreases approximately 1 Fahrenheit degree (0.55 Celsius degree). Thus, Baguio, on Luzon, is usually 15 to 20 Fahrenheit degrees (8-11 Celsius degrees) cooler than the lowlands; Bukidnon and Lanao, on Mindanao are 5 to 10 Fahrenheit degrees (3-6 Celsius degrees) cooler than the coast (Encyclopedia Americana 1990).

SPECIES

Two crocodile species, the Saltwater Crocodile (*Crocodylus porosus*) and the endemic Philippine Freshwater Crocodile (*Crocodylus mindorensis*) have been recorded from the Philippine Islands (Schmidt 1935, Mertens 1943, Schmidt 1956, Hara 1981, Ross and Datuin 1981, Ross 1982, Ross and Alcala 1983, Ross 1984 and Groombridge 1987).

The Philippine Crocodile was originally described as a full species *Crocodylus mindorensis* by K. P. Schmidt in 1935. Most authors since then have regarded those populations as constituting only a subspecies of the freshwater crocodile in the New Guinea area, *C. novaeguineae*, i.e., *C. n. mindorensis*. However, it has been stated that all specimens of *mindorensis* can be readily distinguished morphologically from all New Guinea

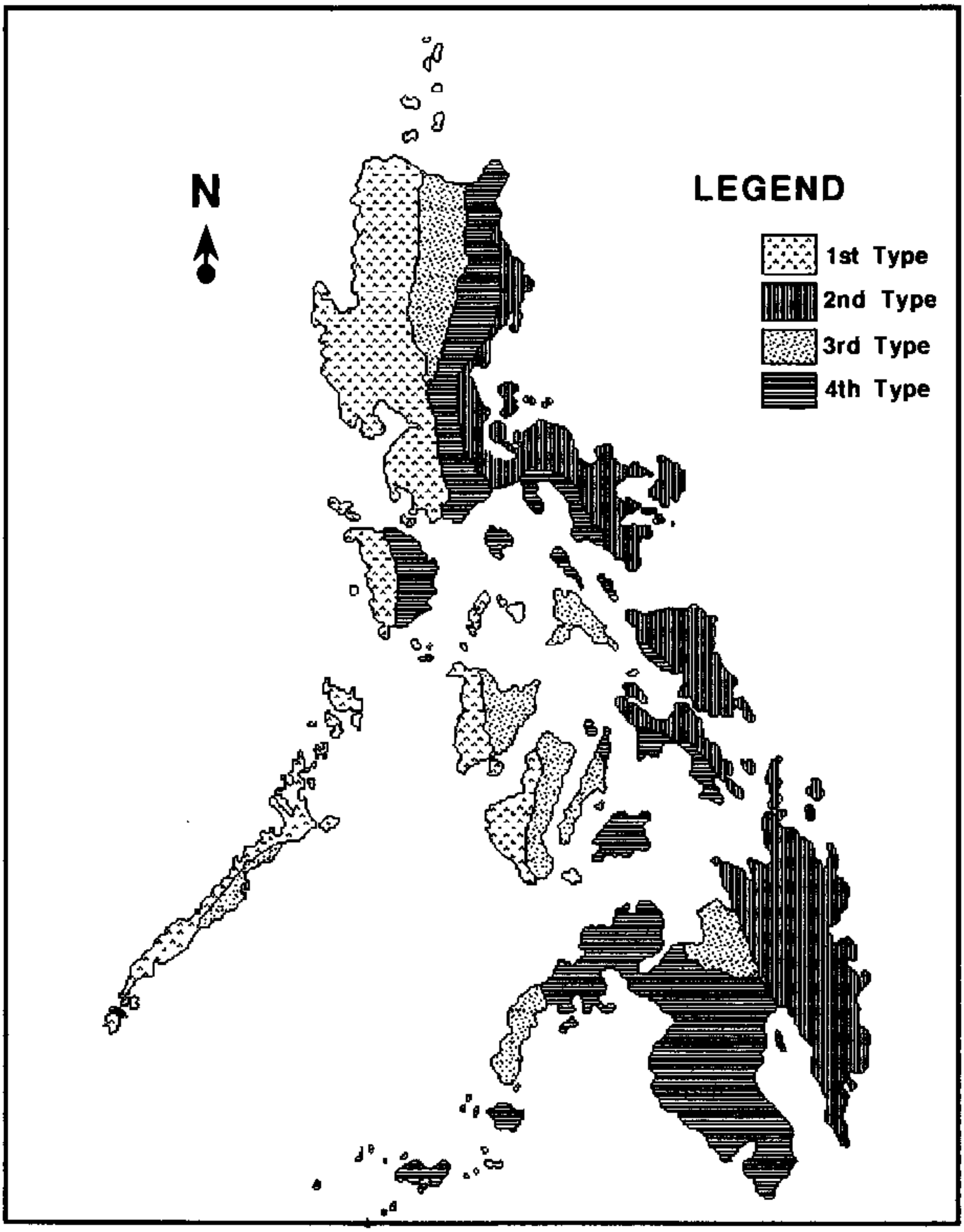

Fig. 3. Types of Climate in the Philippines (PAGASA 1976)

specimens, and recent field workers and taxonomists have treated the Philippine form as a full species again. This opinion is not yet universal (Groombridge 1982).

STATUS

Distribution of *C. porosus*

C. porosus is extensively distributed from Sri Lanka, eastern India and Bangladesh, Western Carolines, and south through Indonesia to Papua New Guinea and northern Australia, through coastal southeast Asia to the Philippines, east to the Solomon Islands and Vanuatu. In the Philippines alone, it was previously found on the islands of Luzon, Mindoro, Masbate, Panay, Palawan, Negros, Cebu, Leyte, Samar, Bohol, Mindanao, Jolo, Culion and Busuanga (Groombridge 1982, Groombridge 1987)(Fig.5). Currently, Crocodile Farming Institute (CFI) researchers noted that most of the remaining populations are found mainly on the island of Mindanao and Palawan, On Southwestern Mindanao, particularly in Tamontaka River, Gayonga and Taviran in Maguindanao, Rio Grande de Mindanao and Panatan in Cotabato, Mapantig River and Lutayan in Sultan Kudarat, and Liguasan Marsh, an undetermined but numerous number of crocodiles was identified (Uc-Kung pers. comm. 1992). On Western Mindanao, remnant crocodiles were observed in Pisaan, Labangan, Kabgan, Dimataling, Binuatan and Simpolo Rivers, Zamboanga del Sur (Ishmael *et al.* pers. comm. 1992). Also, Kumaykay Creek in Bukidnon was known to contain crocodiles (Geollegue and Serna pers. comm. 1992). In the island of Siargao, some crocodiles were still believed present after CFI trapping activities. Based on CFI crocodile acquisitions and confirmed sightings on the province of Palawan, crocodiles were present in more than 44 rivers. A considerable portion of the population congregate at the southern portion of the island though distribution in the island is widespread. Also, the islands of Balabac, Bugsuk, Pandanan, Dumaran and Busuanga in the province of Palawan, are still probable sites containing crocodiles; lately (October 13, 1992), a crocodile was trapped in Pandanan. Remnant populations still occur in Cagayan River and rivers at the east side of Sierra Madre in Luzon (Paat *et al.* pers. com. 1992)(Fig. 4).

Abundance of *C. porosus*

The former number of *C. porosus* in the Philippines was not determined but early residents reported large numbers. However, during the 1950's crocodiles were hunted intensely by local and foreign hunters for their valuable skins leading to the elimination of a significant number of crocodiles distributed on various islands of the Philippine archipelago. During 1950-51 in Palawan Island alone, there were reportedly around 2,000 crocodiles killed and skinned for shipment by a noted Philippine crocodile hunter in just a few months. Rampant hunting continued until the 1970's then gradually waned, probably as a result of a greatly depleted population in the wild.

The ever increasing human population in the Philippines and consequently increasing activities in areas suitable for aqua- and agriculture, led to the conversion of a significant portion of wetland areas into fishponds and farmlands which greatly reduced *C. porosus* habitat. A case to illustrate this is the situation in Liguasan Marsh in Mindanao, a major habitat not only for *C. porosus* but also for the endemic *C. mindorensis*. The surrounding fertile areas of the marsh is being utilized for agricultural activities like alternate rice and corn planting all year round. In addition, local Maguindanaons fish a lot in the area and consider it a "fishermens' sanctuary" because of noted abundant fish resources (Uc-Kung pers. comm. 1992).

Recently, attempts to estimate the population of *C. porosus* through spotlighting on the province of Palawan as a pilot study area, revealed very few crocodile sightings. This was also found inapplicable because generally, crocodile river habitats are short, narrow and shallow; thus low carrying capacity. The results indicate than only a small number of crocodiles remain in the province's mangrove and marshland habitats.

The number of CFI acquisitions provided one of the major alternatives by which the

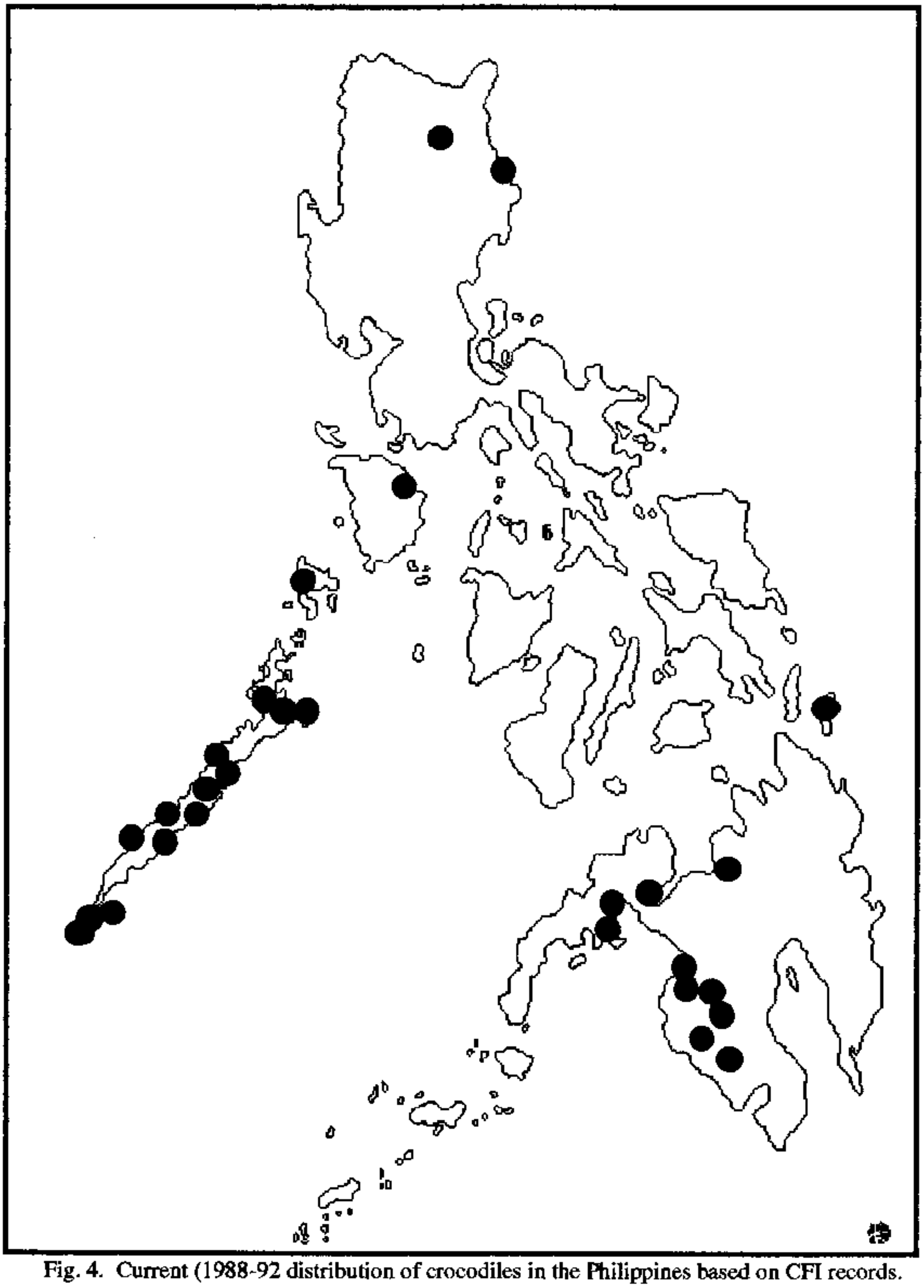

Fig. 4. Current (1988-92 distribution of crocodiles in the Philippines based on CFI records.

status of crocodiles in the province could be assessed. Only a total of 141 *C. porosus* from the province of Palawan had been captured intentionally and accidentally by fishermen and farmers as well as CFI personnel within a period of 5 years. In addition, only three nests were found in the province of Palawan during the same period, indicating very few breeding individuals in the wild. Two nests contained eggs but the breeding females were believed to have been trapped before the eggs were discovered. Aside from this, there were very few reports of sightings of animals left uncaught in the wild. The remaining wild crocodiles probably consist of intermediate size classes or juveniles.

In the island of Siargao where crocodiles had become a major concern to local inhabitants because of repeated and fatal attacks on 11 fishermen, the expertise of CFI trappers was sought. In the trapping process, a total of 8 crocodiles including a 15-foot man-eater, were captured.

Distribution and Abundance of *C. mindorensis*

The known historical distribution of *C. mindorensis* is on northern Luzon, Central Luzon, Samar, Masbate, Mindoro, Negros, Jolo, Mindanao and Busuanga (Ross 1982)(Fig. 5).

A relatively small crocodilian, endemic to the Philippines, which formerly occurred in freshwater marshes, ponds and tributaries of large rivers, on the islands of Luzon, Mindoro, Busuanga, Masbate, Negros, Samar, Mindanao and Jolo. Now critically endangered, with small populations at a handful of sites on Mindoro, Negros and Mindanao, and reportedly no more than 100 individuals in total remaining in the wild. The initial decline is attributed to excessive hunting for skins, but the present skin trade appears minimal and the primary current threat is habitat modification due to expanding agri- and aquaculture projects. A [recent] Smithsonian effort (1980-1982) has involved extensive field surveys, publicity, and the establishment of a crocodile breeding facility in conjunction with Silliman University (Dumaguete, Negros). Captive breeding is seen by the personnel involved in the project as a primary measure in conservation of *C. mindorensis*. Two three-year-old young have been released in Calauit Wildlife Sanctuary, northern Busuanga (Groombridge 1987).

After [recent] field surveys through much of the Philippines group, *C. mindorensis* is reported in critical danger of extinction. The total number surviving (presumably non-hatchlings) is estimated at 500-1000, no large population is known to exist in any one area. It has recently been confirmed that *C. mindorensis* still occur at Nabunturan, Calarian Lake and Macasendy Marsh on Mindanao, and in the Pagatban River in Negros Occidental. The species appears most numerous in Mindanao and the Sulu Archipelago. Probably already extinct in Masbate, Jolo and Busuanga (Groombridge 1982; Ross 1982). However, in May 1991, a 2-meter female *C. mindorensis* was caught by local fishermen near Dipuyai River, Busuanga and brought to the CFI. This indicates some remnant individuals still thrive in Busuanga.

Further, a total of 202 *C. mindorensis* was acquired by the CFI from 1987-92. The majority of these (n = 145) was acquired from a private crocodile collector in Davao. Presumably, these originated from Liguasan Marsh which is near Davao.

Supplementary Notes on Crocodiles

In Mindanao, particularly in areas adjoining Liguasan Marsh and in Agusan River, DENR personnel working in the area reported an unconfirmed (due to poor peace and order situations) but apparently large number of crocodiles on Cotabato, Sultan Kudarat, Maguindanao and Zamboanga del Sur areas. CFI acquisitions from the area (n = 115 *C. porosus*; 196 *C. mindorensis*), mostly came from private collections. The sources of these animals were not properly documented but CFI personnel believe majority of these were taken from Liguasan Marsh and adjoining rivers.

A recent visit (September 1992) to Luzon indicate remnant *C. porosus* populations still thrive in Cagayan River and rivers east of Isabela. Though there were still sightings in Cagayan

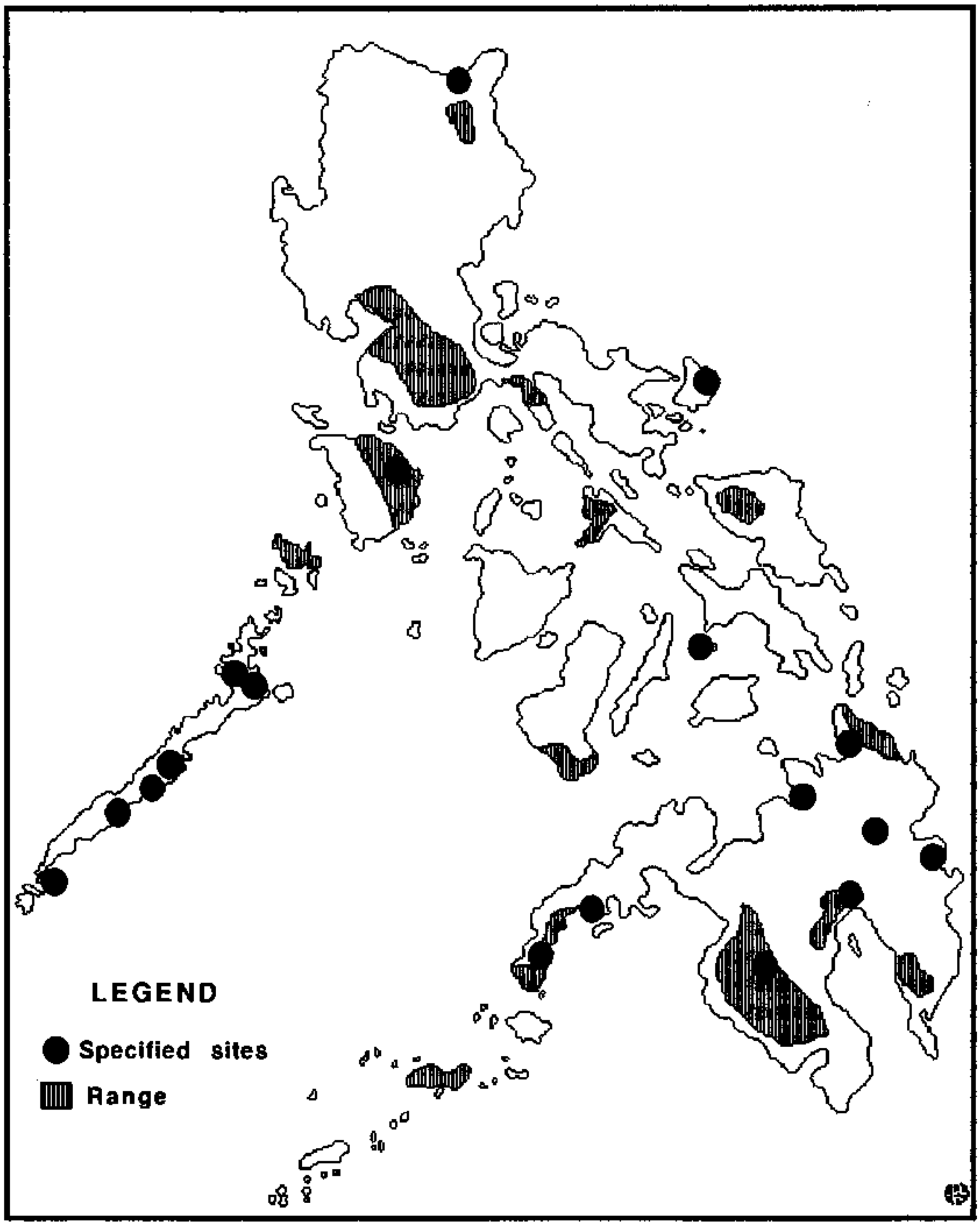

Fig. 5. Known historical distribution of C. mindorensis and C. porosus (based on Ross 1982).

River in northern Luzon,the river appears unfavorable for continued crocodile survival because of forest denudation and increasing human population along its course. The eastern part of Sierra Madre may be the last remaining viable habitat for crocodiles in the island of Luzon.

LEGISLATION

An Integrated Protected Areas System (IPAS) law or Republic Act No. 7586 (see section on Protected Areas) was enacted by the Philippine legislature on o1 June 1992. This programme calls for strategically located protected areas encompassing wetlands and areas of vital importance for the conservation of the diverse Philippine flora and fauna while not stifling development in the region.

Another conservation initiative, the Strategic Environmental Plan (SEP) for Palawan was recently launched (August 15, 1992) by virtue of Republic Act 7611 for protection of Palawan's diverse flora and fauna which are biologically distinct from other Philippine islands. Preceding R. A. 7611, Proclamation 219 served as a wildlife regulating measure. This proclamation provides that collection of wild animals from the islands of Palawan province is strictly prohibited.

Other legislation, Presidential Decrees, and policy issuances that influence or impact on the IPAS relate to tourism, mineral exploration, timber extraction, and agricultural land use.

FARMING

The Philippine government with assistance from the government of Japan started farming crocodiles in the country with the end in view of conserving, through sustainable utilization, the remaining crocodile populations in the wild. This materialized upon the formal inauguration of the RP-Japan Crocodile Farming Institute (CFI) situated at Barangay Irawan, Puerto Princesa City, Palawan on March 4, 1988.

The CFI started acquiring crocodiles from private collectors and from the wild. Its original aim was to secure 200 breeding individuals and utilize these as founder stock but this proved to be an impractical target since crocodiles in the country are very much depleted (see section on Status). CFI has to scrounge whatever was left for breeding purposes. It originally started with a little more than 70 individuals, mostly immature ones. Despite this initial failure to meet the required number of animals for a full-blown farming operation, CFI, after almost 5 years, managed to produce a considerable number of F1 generation from its available breeders. As of September 1992, the percentage of farm-bred animals exceed that of the founder stock (1154 > 478). Of the farm-bred crocodiles, 349 (30 %) are *C. mindorensis* and 805 (70 %), *C. porosus*. It must be noted, however, that these offsprings are still immature for breeding purposes (Table 2).

The acquisition programme of CFI may have reduced the number of wild crocodiles, however, without it, the animals would have fallen into the hands of poachers or illegal crocodile skin traders, and of course subject to plain eradication by local people, who are considering it as vermin. Besides, this initiative was considered a last-ditch effort to save the remaining crocodiles faced with probable extinction as a result of generally rampant habitat modification or destruction. Moreover, the acquisition programme had in some way instilled to trappers/catchers the relative importance of a ferocious, living crocodile to a harmless, dead one.

REGULATION OF TRADE

There is little commercial utilization of native crocodiles and collection of crocodiles or their skins is not a major concern owing to lack of organization and low volume of trade (Ross 1982).

At the moment, trade on crocodiles, being an endangered animal species, is prohibited.

Table 2. Number of crocodiles from the wild and bred in captivity.

Source	Number of Crocodiles *Crocodylus porosus*	*Crocodylus mindorensis*	Total
Mindanao	115	196	311
Siargao	8	0	8
Palawan	141	1	142
Negros	7	5	12
Bohol	1	0	1
Panay	1*	0	1*
Mindoro	0	1	1
Luzon	3 (2*)	1	4
Farm-bred	805	349	1154
Farm-hatched (from the wild)	9	0	9
T O T A L	1090	553	1643

* not original source

IMPORTS AND MANUFACTURING

Though there are two species of crocodilians in the Philippines, several of the tourist shops in Manila import crocodilian products, for sale to affluent Filipinos and tourists. These were manufactured from *Alligator mississippiensis*, *Caiman crocodilus*, *Crocodylus porosus* and southern New Guinea population of *C. novaeguineae* (see Ross 1982).

RESEARCH

Presently, only CFI undertakes specialized research on crocodiles in the Philippines. Researches on CFI site are conducted to develop a crocodile farming technology that will ensure sustainable utilization of both species, thus, contribute to the economic upliftment of many Filipinos. Researches off-site aim to provide natural habitat to crocodiles through the establishment of legislated and protected sanctuaries as well as recommend crocodile conservation policies.

PROTECTED AREAS

An act referred to as the "National Integrated Protected Areas System Act of 1992" or NIPAS (Republic Act No. 7586) was enacted by the Philippine legislature on 01 June 1992.

On 29 June 1992, an Administrative Order was issued by the Department of Environment and Natural Resources (DENR) to set forth in detail the processes by which DENR and other concerned institutions and agencies will establish, administer and manage the NIPAS, focusing particularly on the twin objectives of biodiversity conservation and sustainable development. It states that the basic policy of the State provides that the management, protection, sustainable development, and rehabilitation of protected areas shall be undertaken primarily to ensure the conservation of biological diversity and that the use and enjoyment of protected areas must be consistent with that principle. It is further acknowledged that the effective administration of the NIPAS will require a partnership between the Government, through the DENR, and other interested parties including the indigenous cultural communities.

The scope of the order shall apply to all areas that, prior to the effectivity of the Act on 01 June 1992, have been designated or set aside, pursuant to a law, presidential decree, presidential proclamation or executive order as a national park, game refuge, bird and wildlife sanctuary, wilderness area, strict nature reserve, watershed, mangrove reserve, fish sanctuary, natural and historical landmark, protected and managed landscape or seascape as well as to identified virgin forests. It shall also apply to other protected areas that may later be established pursuant to the Act (adapted from DENR Administrative Order 1992).

Of significance to the crocodiles, three protected areas have been identified by CFI. These are Agusan Marsh in Mindanao, Lake Naujan in Mindoro and Lake Manguao in Palawan. These are all covered by the NIPAS Law.

DISCUSSION

The government must be lauded for giving priority (although minimal) to the cause of conservation and its commitment to the principle of sustainable development - notwithstanding its socio-economic plight. And for as long as our economy is stagnant and for as long as our population growth trend continues, crocodile conservation will remain a major challenge to tackle in the Philippines. At the moment, captive breeding and rearing in the CFI serves to ensure the existence of these animals. Moreover, CFI plans to disseminate crocodiles for rearing by the local people in the near future. Commercial venture (skin trade and other sustainable strategies) will be pursued after CITES approval of CFI as a legitimate crocodile farming operation. This will somehow alleviate the burden of the government in breeding, propagating, and rearing crocodiles at the Institute. However, the success of this scheme has yet to be realized especially considering that a majority of Filipinos have economic difficulties. It is very likely that low income Filipinos will consider the new venture of secondary priority to his other conventional economic activities.

The main issue to address then is the continued existence of crocodiles in the wilderness of the Philippine archipelago, particularly in viable and known distribution areas of both species of crocodiles. At this point, the successful implementation of the IPAS programme which covers a considerable portion of crocodile-inhabited areas such as wetland habitats will be a great boost to crocodile conservation in the Philippines.

The increasing awareness and alarm over wanton exploitation of Philippine natural resources that led to passing laws and regulations to protect what remains of the country's vast and diverse flora and fauna spells a decisive and serious concern for the country's wildlife.

What remains to be done in the Philippine situation is political will and the effective implementation of legislations which aim for protection of some strategically located (i.e. representative biogeographic realm) areas in the archipelago.

The present favorable trend for nature conservation in the Philippines as response to the increasing global trend on wise and sustainable use of resources as well as protection of remaining wildlife makes crocodile conservation a part of the ideal scenario being envisioned by conservationists. This could further bloom into maturity with nurturing and support of citizens who are the primary beneficiaries of a renewable resource. Educational campaign will be an effective tool to attain this end, more specifically in changing people's views and attitude towards crocodiles.

There is no doubt that the number of captive-bred crocodiles will increase in the coming years at the CFI. At such time when a considerable number of crocodiles are produced, the issue of reintroduction will come to light. It is anticipated to be met with apathy. For this reason, the protection and maintenance of crocodile-inhabited areas should be a major concern at present time.

The CFI as a concerned agency tasked in crocodile conservation in the Philippines will play a pivotal role in the management of wild crocodiles in protected areas in the near future especially in sustaining it in the face of pressing socio-economic and political problems in the country.

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MANAGEMENT OF CROCODILE IN INDONESIA : CURRENT STATUS

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SUMMARY

Management strategy of crocodilians in Indonesia is aimed at the conservation of such species, as well as their utilization on the sustainable basis. The Government of Indonesia recognises the importance of preserving these animals in their ecosystems, and also the benefit of utilising these animals to the local economy of villages and to the overall economic development of the Provinces as well as of the country. Large area of swamps, wetlands and tracts of pristine habitat suitable for crocodile still exist, particularly in Kalimantan and Irian Jaya, indicating the potential of these animals development.

The Directorate General of Forest Protection and Nature Conservation [PHPA], within the Ministry of Forestry, designated as the CITES Management Authority for Indonesia, is the national administrative body responsible for protection, conservation and utilisation of wildlife in Indonesia. PHPA is advised by LIPI [Indonesia Institute of Sciences] on scientific issues associated with CITES. Within their activities, PHPA and LIPI are supported by farmers associations, Indonesian Crocodile Farmers Association [ICFA] and Indonesian Flora and Fauna Traders Association [IFFTA] Data monitoring and reporting is carried out by Indonesian Crocodile Conservation Task Force [ICCTF], a unit established by the recommendation of CSG Steering Committee, and works under the auspices of PHPA.

Four species of crocodiles are currently recognised as occuring in Indonesia. *Crocodylus novaguineae* is endemic and confined to the Province of Irian Jaya, and is in the Appendix II

category of CITES. *Crocodylus porosus* is scattered throughout the archipelago in varying densities and fall in the Appendix II of CITES with quota. *Crocodylus siamensis* and *Tomistoma schlegelii*, the two species believed among the most endangered crocodilians are discovered in Kalimantan, and also in Sumatra for *T. schlegelii*. *C. siamensis* and *T. schelgelii* are under the Appendix I of CITES. The commercial use of crocodiles in Indonesia is only applied to *C. porosus* and *C. novaguineae*. Initially, the people in Indonesia, especially those who live in Irian Jaya and co-exist with saltwater or freshwater crocodiles utilised crocodiles for non-commercial purpose, e.g. for protein consumption [meat and eggs]. The commercial uses of crocodiles developed in the 1960s in response to the international demand for crocodile skins. The drastic increase of the demand had caused a great exploitation of the crocodiles, which could be disastrous to the wild population unless they are managed appropriately

There is two types of management program of crocodiles utilization currently adopted in Indonesia. The management program for crocodiles outside of Irian Jaya, which is strictly ranching and captive breeding; and for crocodiles in Irian Jaya, which includes harvest of wild skin. PHPA [Central, Regional and Sub Regional] together with Department of Forestry Provincial Offices are responsible for managing the development of national regulations [elaborate permitting system for wildlife utilisation and trade], Three different permits are required for capture, transport and export. Program for controlled hunting, cooperation between industry and hunter-gatherers [nucleus-plasms (PIR) system, enforcement, data monitoring and reporting, and also extension to industry as well as to rural hunter-gatherers were also established.

Control of illegal activities is conducted by special forest police [Directorate Forest Protection] enforced with extensive cooperation and coordination with customs, local police, military forces and the public prosecutor. Launching the new Act concerning the Conservation of Living Resources and Their Ecosystems [Act No.5/1990], which provide more defined management policy for wildlife conservation and utikization, including more severe penalties to the illegal activities, less illegal conducts is expected. From 1988 to 1992, there were 12 cases of illegal crocodile skins shipment. Skins were seized and the person was sentenced from 1 month to 1,5 years imprisonment plus Rp. 1,5 million charge.

To more implementing the Act 5/1990, PHPA called upon people or company who hold wildlife species to report/register their animals, by October 1992. Those who failed to do so would automatically be subjected to this law. As a results, some companies registered their crocodiles. Together with new registered farms, there are additional 815 *C. novaguineae*, more than 7137 *C. porosus* and 42 *T. schlegelii* held in the farms.

Several program to monitor crocodile population *in situ* and *ex situ*, and skins traded internally or externally are in operation. Except for wild population which is monitored by PHPA, monitoring of live animals raised in farms and skins trading activities is conducted by PHPA and ICCTF. By end of 1992, there were more than 91,129 crocodiles held in 49 farms throughout Indonesia. Of the total, *C porosus* were more than 28,221; *C. novaguineae* were 62,311, *T. schlegelii* were more than 252 and *C. siamensis* were less than 345. Skin inventory at various size showed a total of 16,450 pieces, in which 13,180 were *novaguineae* and 3254 were *porosus*. Statistics of 1992 on the CITES tag distribution indicated 1250 *porosus* and 10,000 *novaguineae* skins were exported.

Wild population monitoring was carried out several times by various investigators and regularly from 1988 - 1991 by FAO project,particularly in the Province of Irian Jaya. Sharp decline of *C porosus* population, by night counts method was reported. Similar observation using the same methodology occurred for *C novaguineae*. Notwithstanding, using the nest count method, which is considered more appropriate, there are 8 % increase per year of the *C novaguineae* population. Recent survey results, carried out by PHPA staffs in Irian Jaya [Sorong and Jayapura] indicated a slight increase of the population, which could be results of low demand for the skins.

The presence of FAO-UN project in 1988 - 1991 has helped achieving some objectives in the management of crocodiles. Many had been carried out including 'controlled hunting' program, husbandry of ranching and farming, monitoring wild population regularly, reducing numbers of illegal skin trading, promoting rural development through extension, training and developingdemonstration plot in various rural areas and also conducting researh on hatching [egg incubation] and nutritional care for hatchlings.

Despite most progress have been achieved, some constraints still exist. Short of expertise, lack of funding, insufficient flow of communications, logistic difficulties, illegal activities are among those problems. Nevertheless, the Government of Indonesia, together with all relevant organisations do every possible efforts to improve the management of crocodiles for better conservation [including designating some protected areas] and utilisation on the sustainable basis.

LIMNOLOGICAL STUDIES AND THEIR APPLICATION TO THE CONSERVATION AND MANAGEMENT OF CROCODILIANS

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ABSTRACT

The analysis of the crocodilian habitat is essential where large scale rehabilitation of captive reared crocodiles into wild is taking place. Data on limnology and population status were obtained from three different types of crocodile habitats (river, lakes , and reservoir) in Central India. The limnological data were used to compare the habitat requirements of gharial and mugger. Both gharial and mugger occur in the riverine habitat, but only mugger is present in lakes and reservoirs. Mugger is considered to be a hardy species adopted for different habitats including rivers, lakes and reservoirs. Various parameters such as pH, temperature, turbidity, transperancy, dissolved oxygen and Co_2, alkalinity, dissolved solids, nitrites, chlorides etc, analysed in the water of different crocodile habitat types are discussed in this paper. The data collected will form a basis for identifying future rehabilitation sites for captive reared crocodilians.

INTRODUCTION

Wetlands including lakes, reservoirs and rivers in India support vast number of wildlife. The success of these animals in nature is largely subjected to their coordination with the conditions of the aquatic body where they live.In India, three species of crocodiles occur in different habitats. They are Gharial (Gavialis gangeticus), mugger (Crocodylus palustris) and salt water crocodile (C. porosus). Among these the gharial and mugger are present in North India.

During 1975, the Government of India has taken up a conservation programme for all three species of crocodiles present in different States (F.A.O., 1975). The Crocodile Project in India is based on the protection of remaining wild crocodile populations and rehabilitation of crocodiles in their former distributional range. Such a programme requires considerable knowledge on the biology and habitat requirements of crocodiles. All three species of Indian crocodiles had been extensively studied in different corners of the country (Singh, 1978, 1985; Bustard, 1980; Kar, 1981; Choudhury, 1981; Whitaker and Basu, 1983; Rao, 1988; Whitaker and Whitaker, 1989), but the micro-habitat of the crocodiles was not studied in detail. Studies on the water quality in crocodile habitats are lacking. Immediate priority has been given to study the habitat requirements of crocodiles to identify the suitable habitats for rehabilitation of crocodiles in future.

Detailed studies on limnological aspects of crocodile habitats are not taken place. Information on selection of different habitats by crocodiles is necessary to take proper measures for crocodile conservation. Since microhabitat distribution occur between sympatric crocodilian species it is necessary to analyse the habitat condition. A study on limnological characteristics of different aquatic ecosystems where crocodiles inhabit is proposed. For the present study three different habitats have been selected where crocodiles are present for a comparative study of the habitats. The habitats are river, lake and reservoir. The present study will help to define the habitat conditions of gharial and mugger and thus facilitate to take suitable measures for successful rehabilitation programmes for crocodiles in the Madhya Pradesh and also in the other parts of the country.

STUDY AREAS

This study was conducted in three protected areas (Fig.1). They are :

(1) National Chambal Sanctuary

(2) Madhav National Park

(3) Great Indian Bustard Sanctuary

The water bodies selected in these protected areas and their geography, climatic conditions and other faunal and floral characteristics are as follows :

MADHAV NATIONAL PARK :

Two lakes named Chandpata lake also called as Sakhya Sagar, and Madhav lake, inside the Madhav National Park, District Shivpuri which is located 105 km South of Gwalior, were selected for the present study (Fig.2).

These lakes were formed by the construction of dams over the Manihar river during 1918 by the Maharaja. Water supply to Shivpuri town is from Sakhya Sagar and Madhav lake. Water from these lakes is released for irrigation during rabi crop and a minimum level of water is maintained in the lakes to assure water supply to the Shivpuri town during the summer months.

The Sakhya Sagar is a small freshwater lake of 309 hectares with fringing reed-weed. The lake has rockey and slopy treeless banks and so during the winter hundreds of migratory and other water birds come there to wintering. The lake was once the game preserve of the Maharaja of Gwalior. It has a maximum depth of about 12 metres. The water level fluctuating over two metres between the wet and dry season. The lake is bounded along its Eastern Shore.

The area of the Madhav lake is about 40 hectares and is situated about 500 metres away on the Eastern side of the Sakhya Sagar.

The lake has steep rocky banks and is surrounded very closely by tree growth. The number of birds visiting this lake is less.

From winter onwards the nallah which was feeding the lakes got dried up and only the used water of Shivpuri town flows into these lakes. Wild animals over a considerable area in the National Park depend on these lakes for water.

Principal vegetation :

Vegetation consists of *Hydrilla varticella*, *Valesneria spiralis*, *Chara* sp. and *Potamogeton* sp. The floating vegetation is dominated by *Nymphaea muchalis* and *Nymphaides* sp. and the emergent vegetation by species of *Scirpus*, *Typha* and Phragmites.

The natural vegetation of surrounding areas is mixed dry deciduous forest interspersed with grassy lands.

Climate :

The climate of this district is characterised by a summer and general dryness except in the southwest monsoon season. The year may be divided into three seasons. The cold season from October to February is followed by the hot season from March to about the middle of June. The period from mid June to about the end of September is the monsoon season.

Rainfall :

The average annual rainfall in the district is 816.2 mm. The rainfall in the district decreases from the south-east towards the north-west in general. About 92 percent of the annual rainfall in the district is received in the monsoon months June to September, July being the rainiest month. The variation in the rainfall from year to year in the district is appreciable. In the fifty year period, 1901 to 1950, the highest annual rainfall in the district amounting to 200 percent of the normal occurred in 1902. The lowest annual rainfall which was 0.47 percent of the normal occurred in 1913. In this same period annual rainfall less than 80 percent of the normal occurred in 11 years.

On an average there are 37 rainy days (i.e. days with rainfall of 2.5 mm or more) in a year in the district.

The heaviest rainfall in 24 hours recorded at any station in the district was 317.5 mm at Shivpuri on 25th June 1933.

<u>Temperature</u> :

A meteorological observatory at Shivpuri is functioning since 1960. The description of the climate which follows is based on the available data for Shivpuri supplemented by records of observatories in the neighbouring districts having similar climate. Temperatures rise progressively from about the end of February. May is the hottest month with the mean daily maximum temperature at about 40°C and the mean daily minimum at about 23°C. The intense heat in May and June with hot dust-laden winds which blow on many days make the weather very uncomfortable. On individual days the maximum temperature may reach 46°C. Afternoon thundershowers which occur on some days bring welcome relief though only temporarily. With the onset of the south-west monsoon after about the second week of June there is an appreciable drop in temperatures and the weather is milder. After the withdrawal of the monsoon by about the end of September there is a slight increase in the day temperature but the nights become progressively cooler. From November both day and night temperatures decrease rapidly. January is generally the coldest month with the mean daily maximum temperature at about 23°C and the mean daily minimum at about 5°C. In the winter season the district is affected by cold waves. In the rear of the passing western disturbances and the minimum temperatures may go down to about the freezing point of water.

The highest maximum temperature recorded at Shivpuri was 46°C on 21st June, 1964, while the lowest minimum temperature was 4.0°C on 13th January, 1967.

Humidity :

In the monsoon season the relative humidity is high being over 70 percent. In the post monsoon and winter season, the relative humidities are between 50 percent and 65 percent in the mornings while in the afternoon they are about 30 to 40 percent. The driest part of the year is the summer season with the relative humidities less than 20 percent in the afternoon.

CHAMBAL RIVER

The study was conducted in the river Chambal which flow through the States of Madhya Pradesh, Uttar Pradesh and Rajasthan between the parallels of latitude 25° 52' N and 29° 23' N and longitude 76° 28' E and 79° 01' E (Fig.3). A portion of the river is under the management of the National Chambal Sanctuary.

The Chambal river is a deep fast river flowing from south-west to north-east. After originating from Vindhyan Range in Madhya Pradesh the river runs through Rajasthan. From Pali (Chambal and Parbati confluence) it borders Madhya Pradesh and Rajasthan and from Rheo upto Barecha it borders Madhya Pradesh and Uttar Pradesh. Down Barecha the river flows entirely through Uttar Pradesh until it join Yamuna at Bhareh. There are a series of three dams at Gandhi-Sagar (Madhya Pradesh), Rana Pratap Sagar (Rajasthan) and Jawahar Sagar (Rajasthan), and a barrage at Kota (Rajasthan).

The average annual discharge of the river is about 4193 million cubic metres from its large catchment area of 22,533 sq.km. River gauging indicates that the annual run of Chambal varies from a minimum of 1450 million cubic metres during drought years to 10,900 million cubic metres in good years (Singh, 1969).

During monsoon the river floods naturally and high extents of erosion and deposition of soil take place.

Water samples were collected from the Chambal river at Barhi which is 18 km north of Bhind and about 100 km north-east of Gwalior (Fig.3).

TIGHRA RESERVOIR :

The Tighra reservoir is situated about 20 km west of Gwalior city (Fig.4). Geographically reservoir is located 73^{o} 30' E longitude and 26^{o} 12' N latitude. The catchment area is 414 sq. km. Average rainfall in this area is 660 mm.

The reservoir is surrounded by hills from three sides. The Sank river join the reservoir through a gorge on the south-western end. From the hill slopes about a dozen of small nallah has drain into reservoir. In the north-east of the reservoir is a concrete masonry wall of 1.5 km with a height of 24 m.

The maximum length of the reservoir along the south-west-north-east axis is 5.7 km and maximum width is 3.8 km, the maximum depth of the reservoir is 18 m.

The construction of Tighra reservoir was started in year 1909, across the Sank river by late Maharaja Madhav Rao Scindhia. It was completed in the year 1919 and was then known as "Madav Sagar". Later it is being known as Tighra reservoir after the name of the Tighra village.

The reservoir was primary constructed to fulfil the water supply of Gwalior city. On the other hand now about 3,500 acres of land get irrigated by this reservoir. The reservoir is also used as stocking pond by Fisheries Department of Madhya Pradesh. This reservoir is located in the Great Indian Bustard Sanctuary which is specially created to protect Great Indian Bustard in addition to other mammals like Chinkara, Black buck, Cheetal, Nelgai etc.

METHODOLOGY

(A) CROCODILE SPECIES IDENTIFICATION :

1. Identification of crocodiles was based on direct sightings, from the dead animals, from the interviews with local people and from the published distributional records. In order to distinguish between the crocodiles the morphological characters given by Smith (1933); Singh (1984) were followed.

(B) HABITAT PREFERENCE AND POPULATION STUDIES :

1. Habitats occupied by the crocodiles in the Northern Madhya Pradesh were surveyed. Studies have been taken up on the habitat preference of crocodiles by following the methods given by Singh (1978); De Vos (1982); Rao (1988).

2. Field observations from September 1990 to June 1991 consisted of short visits to the study areas.

(C) LIMNOLOGICAL STUDIES :

To evaluate the habitat conditions of the crocodiles limnological studies were carried out at four different water bodies. They are :

1. Chandpata lake, Madhav National Park
2. Madhav lake, Madhav National Park
3. Chambal river, National Chambal Sanctuary
4. Tighra reservoir, Great Indian Bustard Sanctuary

The observations were taken at regular intervals from March to June 1991. Four water samples were collected at different sites in the study areas (Fig.1 to 4). The superficial water samples were collected in the plastic bottles during the forenoon between 8.00 A.M. to 10.0 A.M.

The following abiotic components were measured and determined : water colour, transparency, temperature, pH, conductivity, turbidity, solids, dissolved oxygen, free carbon dioxide, carbonate, bicarbonate, alkalinity, hardness, chloride, calcium, magnecium and chemical oxygen demand.

All the above parameters were analysed by following different methods suggested in APHA (1985) and Trivedi and Goel (1986).

(D) METEOROLOGICAL PARAMETERS

Meteorological data of the different study **areas** from September 1990 to August 1991 were collected from the following centres. (Table-5)

1. Meteorological Station, Gwalior (M.P.).
2. Meteorological Station, National Chambal Sanctuary, Deori, Morena.
3. Central Water Commission, Udi, (U.P.).
4. Civil Hospital and Dist. Tahsil, Office, Shivpuri (M.P.).

Air and water temperatures were recorded at various times during each field days. Wherever applicable these data have been used to interprete the habitat conditions of the crocodiles.

Geographical coordinates and elevations were calculated from standard atlas.

(E) DATA ANALYSIS

Data were analysed using standard statistical methods. Throughout the text means are expressed with one standard deviation (SD), the sample size (N) and range extremes.

RESULTS

(I) SPECIES IDENTIFICATION

The crocodile species identified from the Chambal river were Gharial and Mugger. ~~Many taxonomists.~~

The results of the surveys in different study areas show that gharial and mugger occur sympatrically in the Chambal river whereas mugger occrs in the Chandpata and Madhav lake in the Madhav National Park. The interviews conducted with fishermen at Tighra reservoir, revealed that once mugger was very common in the Tighra reservoir but its population was very much reduced in the recent time. Occasional sightings of young mugger from this reservoir was reported. During this study period no mugger was either sighted or reported by the fishermen operating in the reservoir.

(II) Crocodile habitat :

(A) Chambal river :

The crocodile habitat in Chambal river was characterised by expansions of open sand and rocky stretches. Two types of habitat were identified where crocodiles were observed.

(1) At some places both the banks were sandy or one bank was sandy and other bank was muddy or hard soil formed by the erosion of ravines.

The river was 2 to 15 m deep. Occasionally sand bars and sand peninsulas were present where gharial were found basking. Mid river islands with alluvial deposits were also present.

(2) At some places sand was present on one bank and rocks on other bank. Mid river islands were also formed by rocks. These islands were covered with vegetation including *Tamarix dioca*, *Acacia* and *Zizypus* species.

(B) Chandpata lake :

This lake is situated at southern border of the Madhav National Park. The lake has rocky and muddy soil banks with friging read-weed. There is less vegetation on the bank. A huge masonry wall is situated on the eastern side of the lake. A nallah from the Shivpuri town joins the lake in the southern bank of the lake. On the western side of the lake there is a temple and a tourist guest house. A forest road passes on this side of the bank. The mugger bask on the western bank of the lake. Big and small rocks were also present, half submerged in the centre of the lake, on which mugger basks. Earlier this lake was extensively used for irrigation and boating recreation purposes.

(C) <u>Madhav lake</u> :

The habitat of mugger in the Madhav lake was characterised by deep water pools with steep rocky banks. The lake is surrounded by a number of trees and at some places grases were also present. Some natural and artificial rocky islands were present in the mid waters. These islands were covered with thick growth of vegetation. The mugger was found basking on the rocks on the banks and on the island. The eastern side of the lake is bunded with masonry wall and water from this lake is drawn from this side of the lake. This lake is situated about 500 m away from the Chandpata lake. Presently, the lake and its surrounding area are located in the Tiger safari of the Madhav National Park.

(D) Tighra reservoir :

The mugger habitat in the Tighra reservoir was characterised by deep water body and good fish population. The reservoir is surrounded by hills from three sides and the north-east side of the reservoir is bunded by a concrete masonry wall. The land area near the hill side of the reservoir banks are used by mugger for basking and nesting purposes. Fishing in the reservoir is taking place. A number of tourists visit the dam site regularly.

(III) Crocodile Population :

(A) Chambal river :

Two species of crocodiles were observed in the Chambal river. The populations of crocodiles in the study area (Barhi to Gyanpura, 15 km) were estimated on the basis of direct sightings, published reports and interviews with locals. A total of 28 gharial in different size groups were present in the study area (Table 1). Only one male and 3 females were found. The total crocodile population in the study are consisted of thirty, out of which gharial contributed 93% (N=28) and the rest 7% (N=2) was by mugger (Table 2).

In the Chambal river (300 km stretch of National Chambal Sanctuary), a total of 1473 gharial and 28 mugger were released during different years by the Uttar Pradesh Forest Department (Table 3) in addition to other rivers in the country.

Breeding of gharial in Chambal was successful. The nesting season of gharial was from late March to mid April. One nesting site at Gyanpura village on Madhdya Pradesh side of the bank was identified. This nesting site was located 365 km (approx.) downstream of the point where Parvati river joins with Chambal river. It is an open steep sand bank approximately 100 m long. The river is deep and moving slowly. Maximum depth of the river during summer is 6 m and the width is approximately 200 m. A total of two nests were located at this site, each nest containing 50 and 35 eggs (Table 4).

(B) Chandpata lake :

Muggers were present in the Chandpata lake. This lake is not suitable for gharial. Records on the mugger population in this lake are not available. Many people who visited the Madhav National Park as tourists reported that in the past large number of mugger were seen basking on the banks of the lake. The estimated mugger population at this lake was 8 (Table 2). Saxena (in press) also reported sighting of 8 mugger in January 1988. There may be more mugger present in the lake as a total of 25 mugger were released in this lake during 1979 (Table 3).

One mugger nest was located on the south-eastern bank of the lake during hatching time on 15th June 1991 (Table 4). A total of 31 eggs were found in the nest. On 17th and 29th June 1991, a total of 7 and 8 eggs were hatched, respectively (Saxena per. commu.). The breeding of mugger was observed in this lake during 1987 when a nest was hatched on the same bank (office records).

(C) Madhav lake :

A total of 3 mugger were present in the Madhav lake (Table 2). One adult mugger of about 9' was found basking on rocks on 20th February 1991. Two more muggers reported to be young were also present. Nesting of mugger was not reported from this lake.

(D) Tighra reservoir :

Data on populations of mugger in the Tighra reservoir was not collected. It is not known whether mugger still exist in the reservoir or became extinct due to human activities. The local fishermen, however, reported that mugger hatchlings were found occasionally on the north-western side of the reservoir far away from the dam site.

(IV) PHYSICO-CHEMICAL PARAMETERS

All four water bodies namely Chambal river (three stations), Tighra reservoir (five stations), Chandpata lake (five stations) and Madhav lake (four stations) were surveyed for the physicochemical properties of the water such as water colour, water temperature, ambient temperature, water depth, transparency, turbidity, total solids, total dissolved solids, total suspended solids, conductivity, dissolved oxygen, free carbon dioxide, carbonate, bicarbonate, total alkalinity, pH, total hardness, chloride, chemical oxygen demand, calcium and magnecium during summer season from March to June,1991.

The results of the physicochemical characteristic of the each station in different water bodies are presented in tables 6, 7, 8 and 9. The range and mean value with standard deviation have been given in table 10.

DISCUSSION

In India many rivers, lakes and marshes offer a variety of habitats that are exploited by three species of crocodiles. The early records reveal that these crocodiles were at one time very abundant throughout their distributional range (FAO, 1974). However, due to commercial exploitation and habitat destruction their populations were reduced to near extinction. A timely action was taken during 1975 when Govt. of India initiated a crocodile project to save all three species of crocodiles by giving protection to them as well as to their habitats through Indian Wildlife (Protection) Act, 1972, besides a rehabilitation programme (Bustard, 1980). Since then attempts have been made to evaluate population levels and other ecological aspects of crocodiles in India (De Vos, 1982). These studies give fairly clear accounts on the behaviour and population trends. Effective habitat management requires detailed information about how and when crocodilians utilize various habitats. Information on many aspects of habitat selection and micro-habitat condition in crocodile habitats in India is scanty. Therefore, there is very little scope to compare the limnological aspects of crocodile habitats and draw any hard core conclusions. However, the interrelationships between various physico-chemical parameters of waters in different crocodile habitats and their usefulness in selection of habitat by crocodiles are worth discussions. Although this study is in its initial stages of progress, results of this study indicate that it is possible to use the results of this study to examine the habitat conditions of the crocodiles in the country.

Among the three species of crocodiles occur in India two species - gharial and mugger occur in North India. Recently, Rao and Choudhury (in press) gave a detailed account on the distribution of these crocodiles. According to them the major rivers where gharial and mugger inhabit sympatrically are Chambal, Son, Ken, Yamuna, Ramganga, Ghaghra, Girwa, Kosi and Mahanadi. Mugger occur in the same locality in other habitats than rivers, particularly in the large lakes. Populations living in different habitats like lakes and rivers respond in different ways to critical environmental factors. The quality and quantity of critical resources within habitat differ. Critical habitats includes physical features, such as water availability and protection from extreme temperatures and biotic factors, such as food availability, protection from predators and interactions with conspecifics (Lang, 1987).

In the present study among the three habitats the Chambal river is the most successful crocodile habitat particularly for the gharial. Large rivers are the major habitats for G. gangeticus, where as large rivers and lakes are normally the habitats for C. palustris (FAO, 1974). Fairly good populations of mugger are present in different States, particularly in the protected areas but the gharial is found only in the protected areas. Large number of gharial are present in the river where the mugger population is surprisingly low (Rao and Choudhury, in press). Unlike gharial which is thriving well in all its range, the low density and low recruitment of mugger in the Northern Indian river suggests that they are not adaptable to deep and fast flowing Himalayan fed rivers. With a diverse habitat and dietary preference, unlike gharial which is exclusively fish eater and seems to be selective to deep fast flowing rivers, the more adaptable mugger somehow tends to fail in competition with gharial in sympatrically distributed area. The present study indicated that mugger occur in all three types of habitats, however, gharial is present only in the riverine habitats. The mugger seems to be a hardy species adopting for different habitats. In a small water body like Madhav lake (40 hectares) the mugger is adopted for successful living.

The local distribution of crocodiles within the aquatic habitat is affected due to different seasons

(Singh, 1978; Whitaker and Basu, 1983; Rao, 1988). In some parts of the southern Philipine island of Mindanao, where rainfall is evenly distributed throughout the year and forest cover is still good, rivers do not dry up or flood and the concentration of crocodilians in pools is not evident at any time of the year. However, dry season tend to concentrate to riverine populations in river pools. In some regions of South America, caiman can be confined to river pools for 4-5 months of the year until floods return in the wet season (Alcala and Dy-Liacco, 1989). In the present study it is observed that in the Chambal river during summer low water level makes the habitat into small segments by the appearance of fords and sand peninsulas. The crocodiles restricted into the deep pools in between the river segments. At Jawai reservoir in Rajasthan when the river was dried up due to drought conditions around 40 muggers in the river confined to the water pool of 10 hectares near the dam (Choudhury and Rao, 1988). Around 200 mugger at Hiran lake in Gir forest of Gujarat also confined to a small pool (50-60 acres) of water and also lived in caves during drought conditions in 1985 (Choudhury and Rao, 1988). The weather conditions at the present study areas are most suitable for muggers. Although the water level decreases considerably at Tighra reservoir and in both the lakes in the Madhav National Park, there is still sufficient water for the existence of mugger. The water conditions during summer in different study areas indicated that a good mugger population can live in these water bodies. In addition to the water-spread area the land area away from the water-line is most suitable in all the study areas for mugger for basking, nesting and burrowing purposes. The still waters of the lakes and also the waters in reservoirs offer crocodilians a habitat that is rich in food organisms. The edges of lakes and marshes are favourite haunts of mugger, since they relay on both water and land for their activities. In comparing to the upper reaches of the river where the water is cooler, fast flowing and usually clear silt, the waters are relatively warmer in the lower reaches of the river with plenty of plant and animal life. The lower reaches of the river supports a large population of crocodiles (Alcala and Dy-Liacco, 1989). The present study revealed that good population of both gharial and mugger occur in the riverian habitat, where as the lakes and reservoirs are most suitable for mugger crocodilian.

Human - beings interact with crocodilians, directly or indirectly, they too are part of the habitat and have emerged in many parts of the world as the crocodilians major competitor for space and other resources. The human activities have an adverse impact on the crocodiles and their habitats (Rao, 1987). In the present study it is observed that some illegal activities like fishing, agriculture and sand mining by human have adverse impact on the crocodiles. Although all the study sites are present in the protected areas, the human activities are still continuing. This causes alarming situation for the existence of crocodiles in these areas.

In the fresh water habitats various physical and chemical parameters of water have interrelationships which have a cumulative effect upon the growth of plankton and other aquatic organism. The physical parameters studied in different habitat types indicate a good planktonic production in these water bodies. The Chambal river experiences a significant change in the water flow during different seasons. This change in water flow is perhaps most suitable for gharial to fulfil its biological needs. The other water bodies in the present study are lentic water bodies and are suitable for mugger. Temperaure is basically important for its effect on most of the biochemical and physiological reactions taking place in the organism inhabiting aquatic media (Lang , 1987). The water temperature in different habitats in this locality changes during different seasons which has a role on Crocodilian behaviours. The habitats are quite suitable for Crocodiles for basking and resting activities. In Chambal river the Crocodiles inhabit in different depths. The deep pools are suitable for adults for breeding and shallow water for both adults and young to get food easily. The pH measured in different water bodies indicated the alkaline nature of the water. The chemical parameters such as dissolved oxygen, free carbondioxide, COD, conductivity, dissolved solids, in different water bodies under study indicate the water quality standards where crocodiles inhabit. These measures can be taken as a baseline data for assessing the water quality of other areas in the country where crocodiles are proposed to rehabilitate.

The limnological characteristics of different water bodies discussed above varies in different seasons. The seasonality prevailed in the different study areas due to monsoon climate and three clear cut seasons viz. summer, winter and rains had profound influence on the microhabitat conditions of the crocodiles. This study suggests that there is an ecological relationship between the limnological characteristics of the habitat and the crocodilians that occurs there.

A few guidelines for effective crocodile rehabilitation in the study areas emerge out of the discussions. The waters in the study areas need to be monitored for assessment of their quality. A thorough check should be made not to release any domestic as well as industrial effluents into these areas. There is an urgent need for effective monitoring programme for the released crocodiles.

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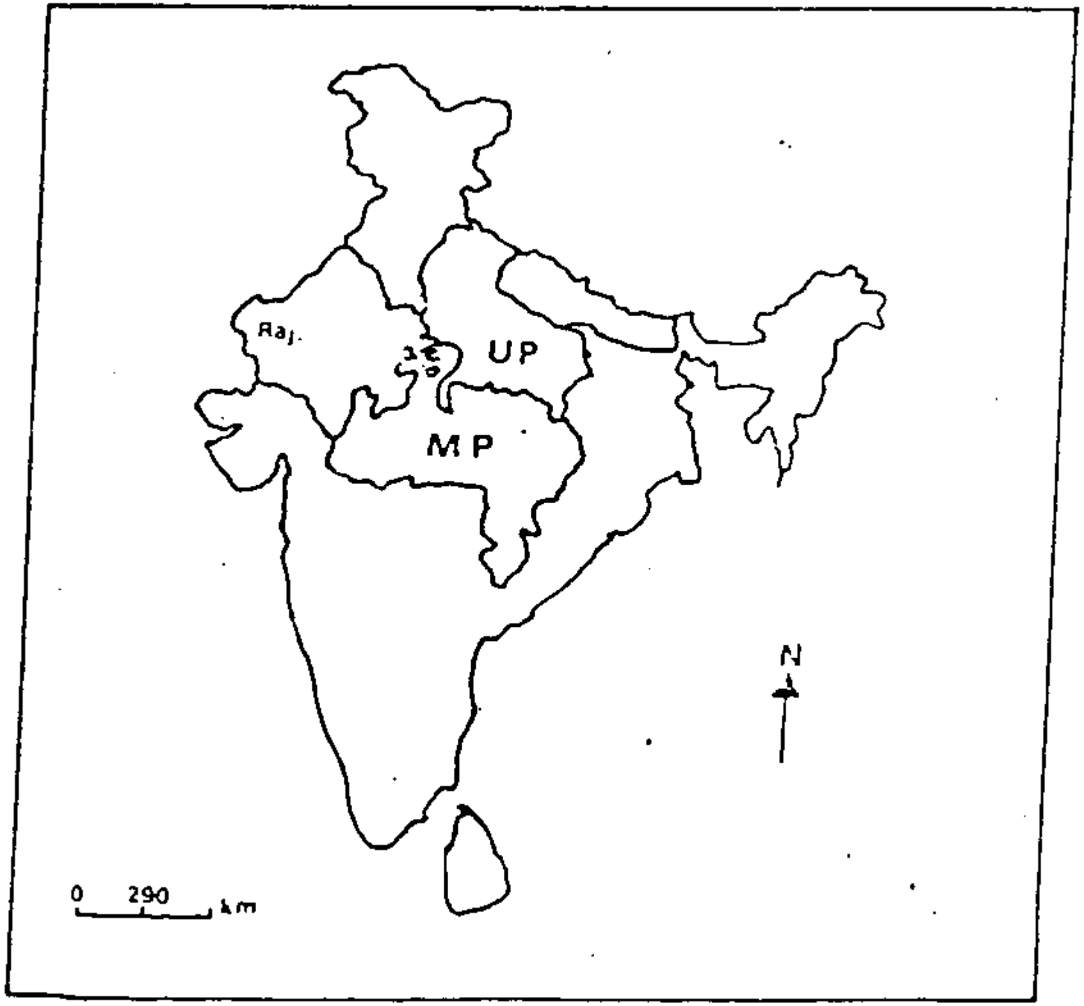

Fig : 1

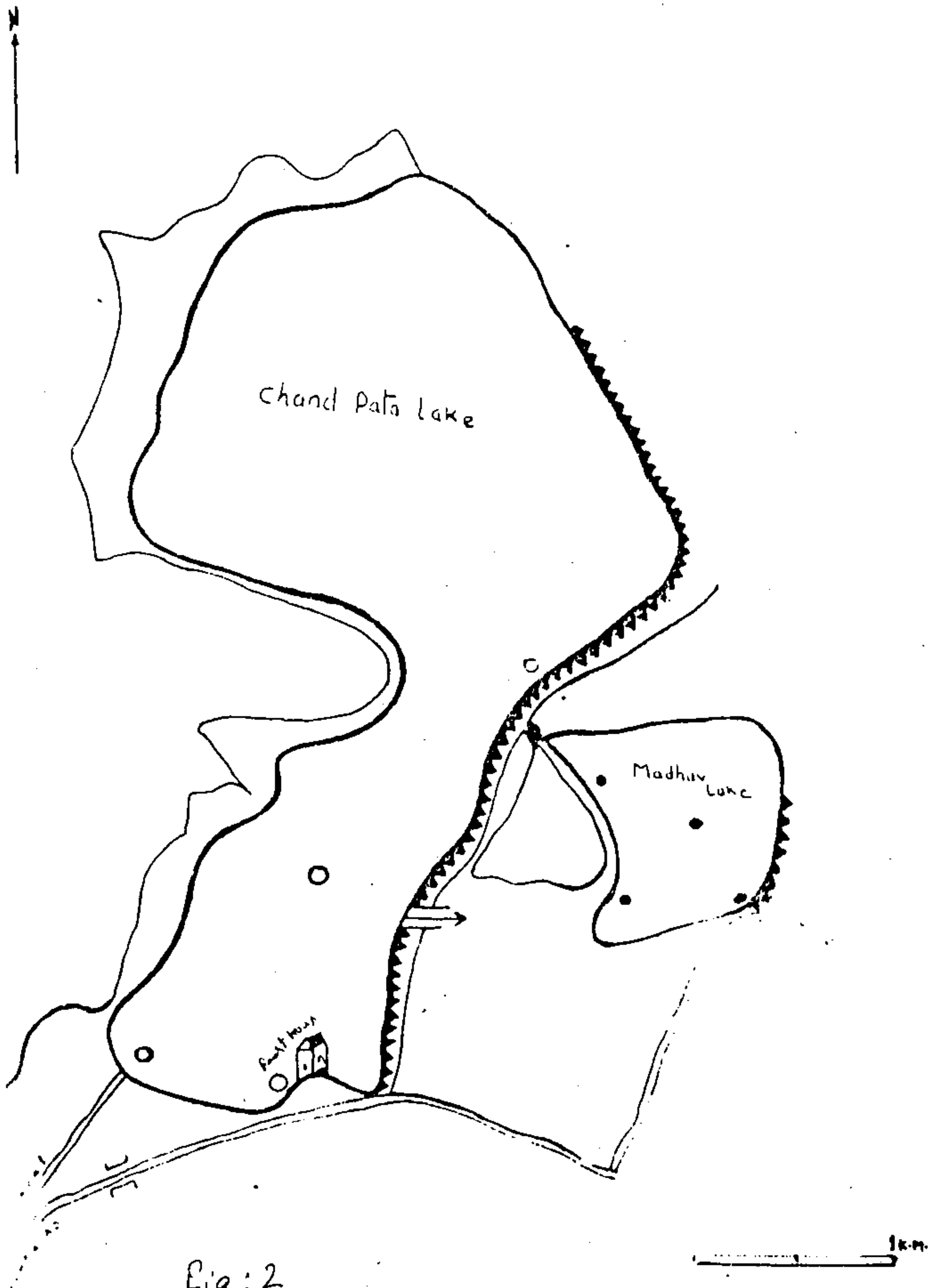

fig : 2

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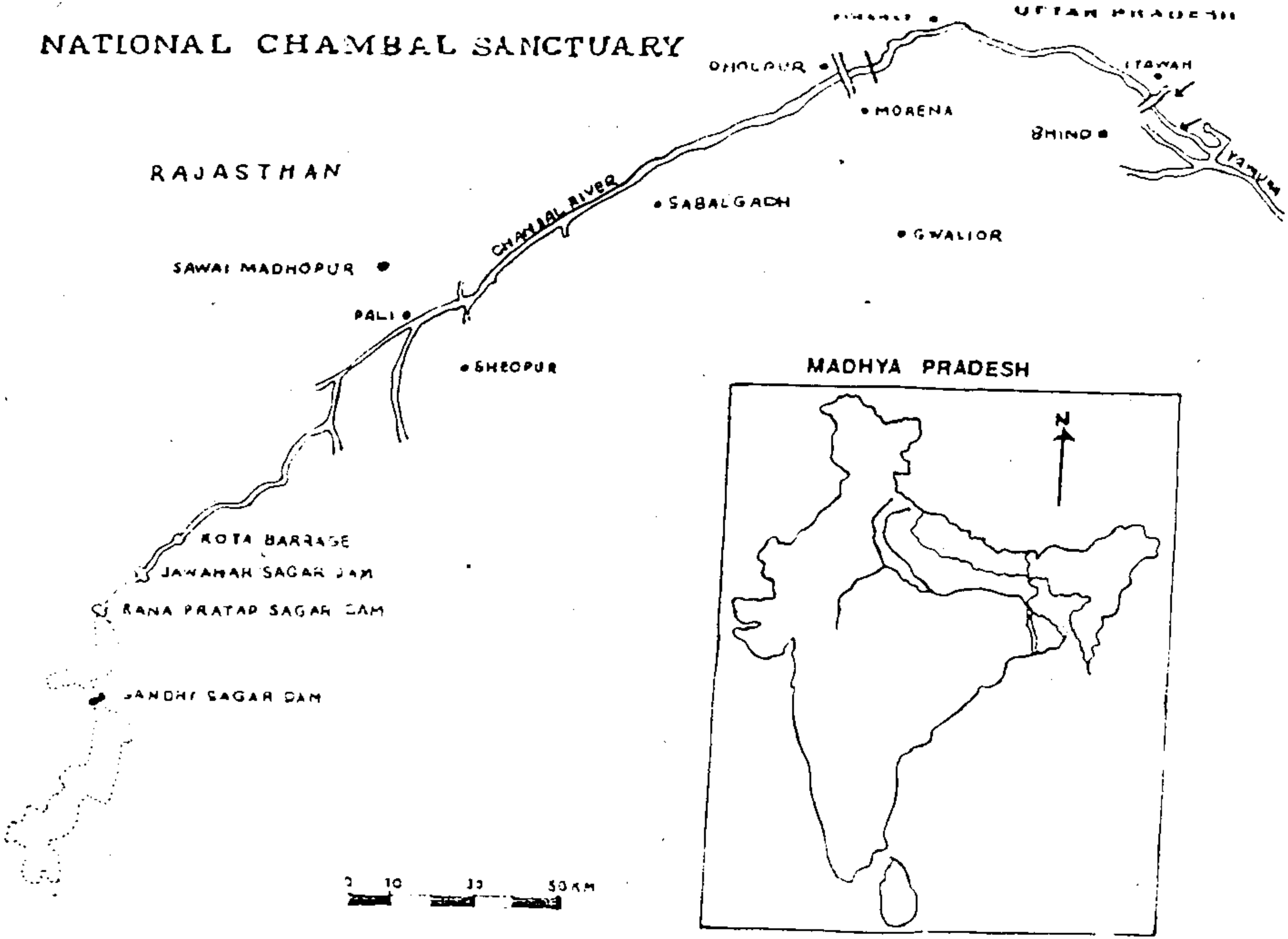

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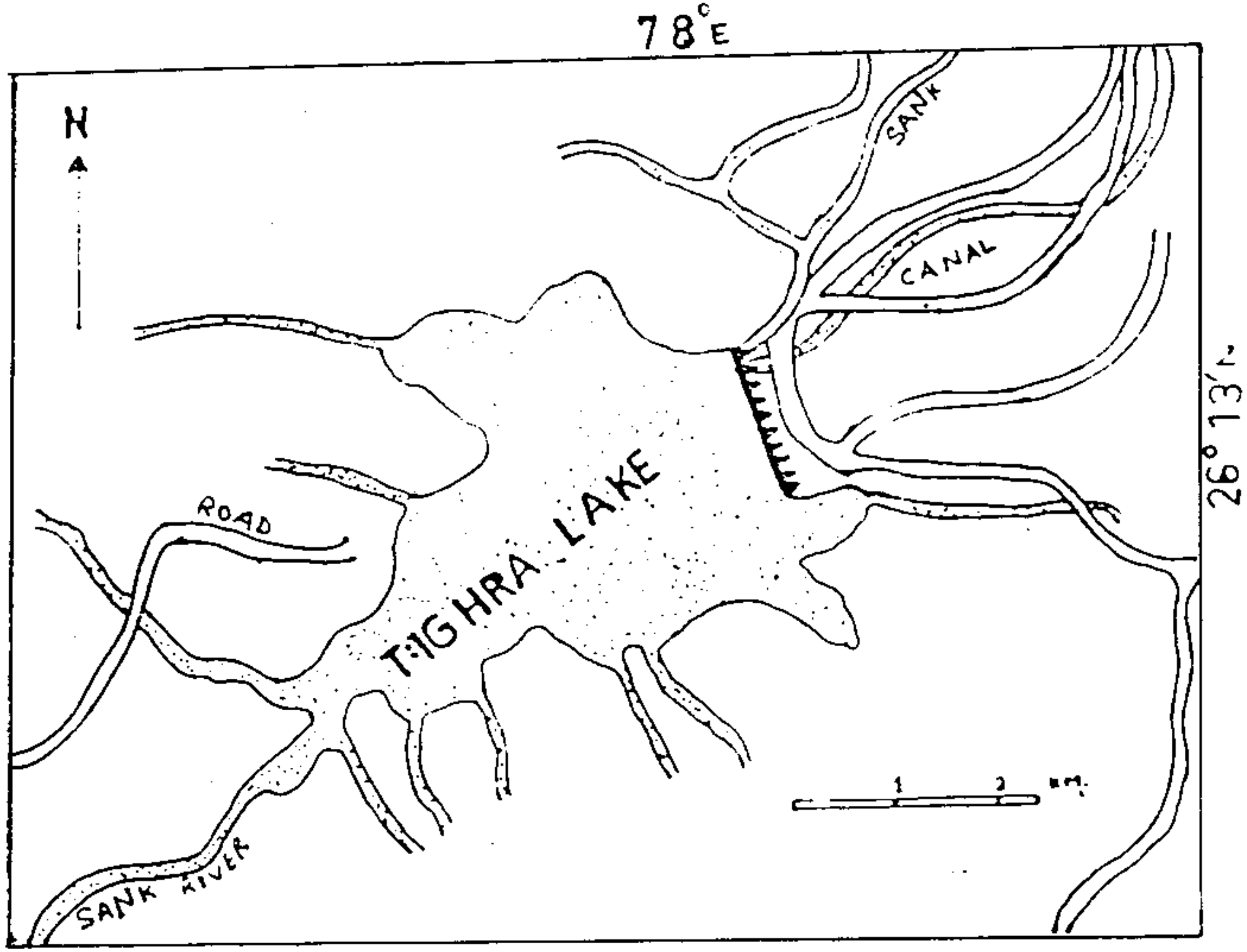

Fig: 4

Table 1. Number of gharial in the Chambal river (1990-1991) (Barhi - Gyanpura - 15 km)

Size (metres)	Number
Below 1.5	11
1.5 - 2.7	13
Above 2.7 - females	3
Above 2.7 - males	1
Total	28

Table 2. Number of crocodiles in the study areas (1990-1991)
(Hatchlings were not counted)

Study areas	Gharial	Mugger
Chambal river	28	2
Chandpata lake	0	8+
Madhav lake	0	3
Tighra reservoir	0	0

Table 3. Number of crocodiles released in the study areas.

Area	Year	Gharial	Year	Mugger
Chambal river (400 km)	1979-1991	1473	1984	28
Chandpata lake	-	0	1979	25
Madhav lake	-	0	-	0
Tighra reservoir	-	0	-	0

Table 4. Number of crocodile nests in the study areas (1990-1991).

Area	Number of nests
Chambal river (Gyanpura)	2 (Gharial)
Chandpata lake	1 (Mugger)
Madhav lake	0
Tighra reservoir	0

Table 5. Meteorological data collected from three study areas during January 1989 to July 1991.

	BHIND			GWALIOR			SHIVPURI		
	Temperature		Rainfall (mm)	Temperature		Rainfall (mm)	Temperature		Rainfall (mm)
	Minimum °C	Maximum °C		Minimum °C	Maximum °C		Minimum °C	Maximum °C	
January 1989	10.03	19.93	Nil	4.71	22.36	Nil	9.0	12.90	6.0
February	14.29	23.37	Nil	8.22	26.3	Nil	12.5	25.8	Nil
March	20.96	29.01	20.4	14.9	31.6	3.9	15.55	30.97	3.14
April	26.58	35.58	Nil	19.9	38.1	Nil	20.72	35.38	Nil
May	34.14	43.59	3.2	25.5	43.0	Nil	25.71	41.45	Nil
June	[illegible]	41.75	35.4	27.17	33.7	92.9	26.12	37.72	13.5
July	[illegible]	36.61	65.3	26.4	35.6	91.0	24.37	31.29	173.3
August	30.61	35.51	113.4	26.1	34.2	242.0	23.12	30.12	164.1
September	29.45	33.43	71.4	24.7	34.2	120.2	23.77	33.34	83.2
October	23.35	33.30	Nil	17.37	35.4	Nil	18.33	33.25	Nil
November	21.7	27.46	Nil	12.5	30.3	0.7	13.53	29.83	Nil
December 1989	10.12	19.38	6.0	7.6	23.1	1.8	10.30	24.35	Nil
January 1990	10.27	17.88	Nil	8.2	26.1	Nil	9.43	25.87	Nil
February	11.69	19.32	10.4	11.3	25.3	31.7	12.31	25.41	33.6
March	15.56	32.72	Nil	14.5	31.2	Nil	15.53	30.49	Nil
April	21.3	36.75	Nil	21.78	39.27	0.4	23.26	37.60	Nil
May	27.5	40.50	6.6	27.7	40.68	0.49	26.92	38.39	13.5
June	39.2	39.3	35.5	29.72	42.2	50.2	26.55	37.53	64.9
July	26.37	32.73	154.6	26.29	32.59	211.3	24.44	30.40	322.2
August	27.00	35.37	60.2	25.9	33.3	284.7	24.40	30.78	264.4
September	25.88	36.12	251.6	25.05	31.90	38.1	24.51	30.27	5.0
October	22.35	34.03	Nil	13.60	33.94	15.0	21.83	31.56	Nil
November	19.06	28.8	Nil	12.55	29.35	Nil	16.50	27.68	Nil
December 1990	11.70	23.16	3.3	3.33	24.59	6.0	12.45	24.72	5.0
January 1991	11.13	21.79	Nil	5.73	22.39	Nil	10.30	23.91	1.3
February	14.21	26.62	5.3	11.60	26.11	18.8	13.36	27.57	2.94
March	17.93	30.8	Nil	15.34	32.59	0.4	19.47	32.9	Nil
April	22.96	37.35	1.4	20.5	37.47	19.3	24.61	35.73	12.6
May	29.05	44.35	1.7	26.33	41.54	12.7	29.76	40.33	Nil
June	30.11	44.13	Nil	29.71	41.43	Nil	28.37	37.57	30.2
July 1991	Nil	Nil	Nil	25.50	37.63		26.91	34.21	

Table 6. Physico-chemical characteristics of water in the Chambal river.

		Station-I	Station-II	Station-III
Water colour		Transparent green	Transparent green	Transparent green
Water temperature °C		34	35	34
Ambient temperature °C		41	44	43
Water depth cm		102	*	78
Transparency cm		44	*	41
Turbidity JTU		12	8	12
Total solids $mg.l^{-1}$		980	840	880
Total suspended solids	$mg.l^{-1}$	560	440	440
Total dissolved solids	$mg.l^{-1}$	420	400	440
Conductivity	micros	594	594	660
Dissolved oxygen	$mg.l^{-1}$	6.08	6.08	6.48
Free carbon dioxide	$mg.l^{-1}$	Nil	1.99	Nil
Carbonate	$mg.l^{-1}$	26	Nil	8
Bicarbonate	$mg.l^{-1}$	168	178	184
Total alkalinity	$mg.l^{-1}$	194	178	192
pH		9.2	8.3	8.7
Total hardness	$mg.l^{-1}$	174	166	178
Chloride	$mg.l^{-1}$	54.98	52.98	50.98
Chemical oxygen demand	$mg.l^{-1}$	32	44	32
Calcium	$mg.l^{-1}$	30.46	30.46	32.86
Magnesium	$mg.l^{-1}$	23.89	21.94	23.41

* = Not observed.

Table 7. Physico-chemical characteristics of water in the Tighra reservoir.

		Station-I	Station-II	Station-III	Station-IV	Station-V
Water colour		Transparent green	Transparent green	Transparent green	Transparent green	Transparent green
Water temperature	^{o}C	36	33	33	37	35
Ambient temperature	^{o}C	41	38	37	43	42
Water depth	cm	*	194	*	*	77
Transparency	cm	*	149	*	*	49
Turbidity	JTU	12	32	20	20	26
Total solids	$mg.l^{-1}$	200	280	260	180	300
Total suspended solids	$mg.l^{-1}$	120	140	180	100	200
Total dissolved solids	$mg.l^{-1}$	80	140	80	80	100
Conductivity	micros	198	198	165	198	198
Dissolved oxygen	$mg.l^{-1}$	9.32	10.13	9.72	10.54	10.54
Free carbon dioxide	$mg.l^{-1}$	Nil	1.99	Nil	Nil	Nil
Carbonate	$mg.l^{-1}$	14	Nil	6	6	10
Bicarbonate	$mg.l^{-1}$	70	78	68	74	80
Total alkalinity	$mg.l^{-1}$	84	78	74	80	90
pH		7.2	7.5	7.4	7.3	7.4
Total hardness	$mg.l^{-1}$	74	80	68	72	78
Chloride	$mg.l^{-1}$	19.99	12.99	19.99	21.99	23.99
Chemical oxygen demand	$mg.l^{-1}$	8	12	12	8	12
Calcium	$mg.l^{-1}$	24.84	22.44	24.84	24.84	27.25
Magnesium	$mg.l^{-1}$	2.92	5.84	1.45	2.43	2.42

* = Not observed.

Table 8. Physico-chemical characteristics of water in Chandpata lake (Sakhya Sagar)

		Station-I	Station-II	Station-III	Station-IV	Station-V
Water colour		L.Y.G.	L.Y.G.	L.Y.G.	L.Y.G.	L.Y.G.
Water temperature	^{o}C	29	32	34	31	28
Ambient temperature	^{o}C	36	36	40	36	36
Water depth	cm	80	445	166	455	*
Transparency	cm	36	36	41	29	Clear
Turbidity	JTU	59	56	20	73	8
Total solids	$mg.l^{-1}$	320	280	280	240	380
Total suspended solids	$mg.l^{-1}$	100	100	140	40	160
Total dissolved solids	$mg.l^{-1}$	220	130	140	200	220
Conductivity	Micros	330	297	264	330	330
Dissolved oxygen	$mg.l^{-1}$	6.39	6.48	5.67	6.08	5.27
Free carbon dioxide	$mg.l^{-1}$	Nil	Nil	Nil	Nil	1.99
Carbonate	$mg.l^{-1}$	6	12	10	10	Nil
Bicarbonate	$mg.l^{-1}$	90	78	88	90	82
Total alkalinity	$mg.l^{-1}$	96	90	98	100	82
pH		7.7	7.7	8.1	8.9	7.5
Total hardness	$mg.l^{-1}$	86	100	90	86	83
Chloride	$mg.l^{-1}$	23.99	22.39	29.99	31.99	37.93
Chemical oxygen demand	$mg.l^{-1}$	64	55	56	60	72
Calcium	$mg.l^{-1}$	28.85	30.46	32.05	28.35	27.25
Magnesium	$mg.l^{-1}$	3.40	5.34	2.42	3.40	4.86

L.Y.G. = Light yellow greenish; * = Not observed.

Table 9.* Physico-chemical characteristics of water in the Madhav lake.

		Station-I	Station-II	Station-III	Station-IV
Water colour		Yellowish green	Yellowish green	Yellowish green	Yellowish green
Water temperature	^oC	29	31	31	29
Ambient temdperature	^oC	31	37	39	30
Water depth	cm	102	99	260	51
Transparency	cm	36	28	32	26
Turbidity	JTU	47	49	64	39
Total solids	$mg.l^{-1}$	220	260	260	280
Total suspended solids	$mg.l^{-1}$	180	160	170	220
Total dissolved solids	$mg.l^{-1}$	40	100	90	60
Conductivity	Micros	264	330	330	264
Dissolved oxygen	$mg.l^{-1}$	4.45	3.64	5.57	4.05
Free carbon dioxide	$mg.l^{-1}$	Nil	Nil	Nil	Nil
Carbonate	$mg.l^{-1}$	14	4	12	8
Bicarbonate	$mg.l^{-1}$	84	84	100	84
Total alkalinity	$mg.l^{-1}$	98	88	112	92
pH		7.5	7.8	8.1	7.7
Total hardness	$mg.l^{-1}$	90	92	104	100
Chloride	$mg.l^{-1}$	28.39	30.99	33.98	29.99
Chemical oxygen demand	$mg.l^{-1}$	92	100	72	84
Calcium	$mg.l^{-1}$	27.25	33.66	30.46	23.05
Magnesium	$mg.l^{-1}$	5.35	1.94	6.31	7.31

Table 10. Physico-chemical characteristics of water in different water bodies in the study areas.

		Chambal River			Tighra reservoir			Chandpata lake			Madhav Lake		
		Range	Mean	S.D.	Range	Mean	S.D.	Range	Mean	S.D.	Range	Mean	S.D.
Water [illegible]													
Water temperature	°C	34-35	34.33	0.47	33-37	34.8	1.6	28-34	30.8	2.13	29-31	30.00	1.00
Ambient temperature	°C	41-44	42.60	1.24	37-43	40.2	2.31	36-40	36.8	1.6	30-39	34.25	1.83
Water depth	cm	78-102	90.00	-	0-184	130.5	-	80-465	289.25	169.14	51-280	133.00	87.24
Transparency	cm	41-44	42.5	-	0-149	99.0	-	29-41	28.4	14.70	26-36	30.5	3.84
Turbidity	JTU	8-12	10.66	1.88	12-32	22.0	6.69	8-73	43.2	24.81	39-64	49.75	9.03
Total solids	$ml.l^{-1}$	840-980	900.0	58.87	180-300	244.0	46.30	240-380	300.0	47.32	220-280	255.0	21.79
Total suspended solids	$mg.l^{-1}$	440-560	480.0	56.56	100-200	148.0	37.09	40-160	108.0	41.18	160-220	182.5	22.77
Total dissolved solids	$mg.l^{-1}$	400-440	420.0	16.32	80-140	96.0	23.32	180-220	192.0	29.93	40-100	72.5	23.84
Conductivity	Micros.	594-660	616.0	31.11	165-198	191.4	13.2	264-330	310.2	26.4	264-330	297.0	33.00
Dissolved oxygen	$mg.l^{-1}$	6.08-6.48	6.21	0.18	9.32-10.54	10.05	0.47	5.27-6.89	6.07	0.57	3.64-5.67	4.45	0.75
Free Carbon dioxide	$mg.l^{-1}$	0.00-1.99	0.66	0.93	0.00-1.99	0.398	0.796	0.00-1.99	0.398	0.79	Nil	Nil	Nil
Carbonate	$mg.l^{-1}$	0-26	11.33	10.87	0-14	7.2	4.66	0-12	7.6	4.27	4-14	9.5	3.84
Bicarbonate	$mg.l^{-1}$	168-184	176.66	6.59	68-90	74.0	4.56	78-90	85.6	4.8	84-100	88.0	6.92
Total alkalinity	$mg.l^{-1}$	178-194	188.00	7.11	74-90	81.2	5.45	82-100	93.2	6.52	88-112	97.5	9.09
pH		8.3-9.2	8.73	0.36	7.2-7.5	7.36	0.10	7.5-8.8	7.90	0.46	7.5-8.3	7.82	0.29
Total hardness	$mg.l^{-1}$	166-178	172.66	4.98	68-80	74.4	4.27	86-100	90.0	5.21	90-104	96.5	5.72
Chloride	$mg.l^{-1}$	50.98-54.98	52.98	1.63	12.99-23.99	19.79	4.147	22.99-37.98	29.38	5.49	28.99-33.98	30.98	1.66
Chemical oxygen demand	$mg.l^{-1}$	32-44	34.0	5.65	8-12	10.4	1.96	56-72	61.6	5.98	72-100	87.00	10.34
Calcium	$mg.l^{-1}$	30.46-32.86	31.26	1.13	22.44-27.25	24.84	1.52	27.25-32.06	29.49	1.63	27.25-33.66	29.85	2.49
Magnesium	$mg.l^{-1}$	21.94-23.89	23.08	0.81	1.46-5.54	3.01	1.49	2.42-5.34	3.96	1.21	1.94-7.31	5.35	2.05

Conservation, Management and Farming of Crocodiles in Thailand

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Abstract

Sixty years ago, crocodilians were so common for Thai peple who lived near by water; river, canal, swamp, creek, estuarine and wetland. But now they quite extincted from the wild but present only in captivities, crocodile farms.

To bring back and return crocodiles in to their previous habitat is an important way of crocodile conservation which are fully support by crocodile farmers and government. Then restoration of wild stock can be established. Meanwhile trade in crocodile have to be controled strickly by government and non government organization according to national and international regulations and laws.

Application of modern technology in crocodile propagation is a big change in crocodile farming in Thailand to be a center for conservation, management and farming of crocodiles in south-east Asia.

Introduction

Thailand is located in the middle of mainland south-east Asia between 20° 40′ and 5° 40′ north latitude and between 97° 30′ and 105° 45′ east longitude. It is bordered in the north and west by Myanmar (Burma), in the east by Laos and Cambodia (Kampuchea) and the south by Malaysia at the end of peninsular which has Andaman Sea in the west and the Gulf of Siam in the east.

The total area of Thailand is 542,373 Sq. Kilometres (209,410 Sq. Miles).

In 1990, the population of Thailand which predominatly Thai is 55.7 million with an average growth rate of 1.5% per year (1982-1989).

Land utilization can be classified as ; 28.0% Forest land, 46.1% Farm Holding land and 25.9% Unclassified land (Swamp land, Sanitary District area, Municipal area, Rail roads, Highways, Public area).

Wetland in Thailand, especially those historical for crocodilians habitats could be identified in both tidal and nontidal. Those major wetlands are Bung borapet fresh water reservoir in Nokornsawan Province the middle part, Pa Phru, a wetland in Narathiwat Province, south-western part of Thailand and etc.

Thailand has a tropical climate dominated by the monsoons. In most regions there are four distinct seasons:

The dry season, January - February

The hot season, March - May

The rainy season, June - October

The cool season, November - December

Normally, average annual temperature of Thailand is 27.6°C (range 23.7-32.5) and the average relative humidity is 74.4% (range 66.0-82.8%).

Crocodilians in Thailand

There were 3 crocodilian species ever known to be occured in Thailand as reported by Taylor (1970).

1) Siamese Freshwater Crocodile, *Crocodylus siamensis* , Schneider 1801.

Local name is Jara-Kae-Num-chued.

2) Saltwater Crocodile, *Crocodylus porosus*, Schneider 1801.

Local name is Jara-Kae-Num-Kem.

3) Malayan False Gharial, *Tomistoma schlegelli*, S.Muller 1838.

Local name is Takong.

Taylor (1970) said that it has long been presumed that *C.palustris* was present in Thailand since it is known in Burma and in the southern part of the Malay Peninsula. However, Smith (1919a) concluded that after examined a large number of crocodiles from various parts of Thailand, no *C.palustris* ever found anywhere in this country.

Until now, no report on any evidence of *C.palustris* ever reported in Thailand.

Status of Crocodilians in Thailand

(I) Siamese Freshwater Crocodile (C.siamensis) were widely distributed in the low altitude wetlands of central and eastern Thailand. They all believe that this species was extincted from Thailand because of overhunting and habitat destruction. The last specimen was collected from Bung borapet freshwater reservoir, central part of Thailand in 1971 (FIG.1).

In a couple of years ago, there were many occurrances of C.siamensis in the wild with some evidences. Pieces of crocodile skin were collected after bombing by fisherman in a creek at Yod-Dome, adult crocodile was killed in Pang Seda and skull was collected. (FIG.2) The latest information was foot imprints and clawing tract were observed in Sanam Chai Kate.

Status of C.siamensis categorized by IUCN (1971)is quite rare, approaching extinct in the wild, IUCN Red List (1990)is Endangered, CITES (1979) is in Appendix I and USFWS (1980) is Endangered. Principle threats are illegal and overhunting with habitat destruction.

(II) Saltwater Crocodile (C.porosus) These animals used to be found in estuarine and coastal water adjoining the Andaman sea and the Gulf of Siam such as Suratthani, Choomporn province and Taru Tao island. (FIG.3) The last report was in 1987, young crocodiles were observed in Pa Pru southern part of Thailand(FIG.4).

Status of <u>C.porosus</u> categorized by IUCN (1971) is almost extinct in the wild in Thailand, IUCN Red Data Book (1979) is Vulnerable, greatly reduced in numbers throughout its range, CITES (1979) is in Appendix I and USFWS (1980a) is Endangered. Principle threats are illegal and overhunting with habitat destruction.

(III) Malayan False Gharial (<u>Tomistoma</u> <u>schleglli</u>).

<u>T. schleglli</u> formerly occured in southern Thailand. in Perak river close to the southern border of Thailand (Taylor 1970).Tomistoma is one of the most endangered of the world's crocodilians.Little is known about their biology and ecology. In 1979, IUCN reported that a few individuals may still exist in the Suratthani province. Pa pru was also reported to have Tomistoma (FIG.5)

Status of <u>T.schegelli</u> in Thailand categorized by IUCN (1971) is almost extinct in the wild in Thailand, IUCN Red list 1990 is Endangered, CITES (1979) is in Appendix I and USFWS (1980a)is Endangered. Principle threats is habitat destruction.

Legislation

Thailand had "Wild Animal Reservation and Protection Act B.E.2503"since 1960. It was the first law concerned to wildlife in Thailand under authorization of Royal Forestry Department, Ministry of Agriculture and Cooperatives. By this law only T.schegelli was protected and this law did not include wild species which were not endemic in Thailand. Then CITES regulations and agreements could not be implemented efficiently eventhough Thailand is a member of CITES. In 1992, the new "Wild Animal Reservation and Protection Act B.E.2535" was declaired. This law,the present law, has more advantages than the previous one in many major aspects and the most important one is to fit and serve for international wildlife trade according to rules and regulation of CITES.

Action of government officers in order to conserve wildlife are more stronger and powerful than before. Numbers of illegal trade of wildlife are decreased day by day.

C.porosus and C.siamensis are going to be in the list of Wild Animal Reservation and Protection Act B.E.2535 under controlled of Royal Forestry Department. These 2 species are already protected in "Fishery Act" for many years ago but never get in to action.

At this moment Royal Forestry Depertment still control import and export permit of crocodilians and both "Scientific and Management Authorities "are under authorization of "Head of Wildlife Conservation Division"

Farming

Crocodile farming in Thailand has been started since 1937. The first captive breeding and raising of crocodile were attempted in Bung borapet which is water reservoir with plenty of wild C.siamensis. Egg were collected and incubated in semi-natural way. After the eggs hatched, hatching were sold out of their farm. Some small farms starting with one or two pairs of breeder and they harvest 1 to 2 clutches of hatchlings every year.

Now the operations are expanding in many areas of Thailand and 4 major types of crocodile farming in Thailand could be classified accoroding to purpose of their farm into:-

1. Backyard farming ; Chicken and pig farmer keep crocodiles in order to eliminate carcasses from their own farm. They usually have a small number of crocodiles raise in social pond. When these animals grown up or too crowded, they will be sold to crocodile dealers.

2. Small Breeder ; Some farmers keep a few pairs of crocodile for breeding purpose only. They will sell hatchlings out from their farm every year. Crocodiles will be raised in a pair breeding pen or small social pond. Eggs were incubated in a semi-natural technique but very fruitful, high fertility and servival rate.

3. Cooperative type ; Some breeders and farmers are forming a group which breeders supply hatchlings to members of their group for raising until reaching a desireable

size, these animals will be bought back by the original breeders. Then crocodiles will go to slaugther house or another farms who want to keep them as breeder or etc.

4. Complete cycle type ; The industrial type or complete line of business. This type of farm can support themself by producing their own hatchlings, raising, until finished products and export.

In December 1992, Fishery department, Ministry of Agriculture and Cooperatives conducted crocodile farming survey in Thailand. They classified these farms into 3 groups according to breeding efficiency as followed:-

1) Captive breeding ; hatchling can be produced by their own breeders.
2) Collecting ; buying from many crocodile breeding farms (1) and pooled together.
3) Both captive breeding and collecting ; producing and buying (1 & 2).

Number of farms and crocodiles are shown in table 1.

Table 1

Type	Number of farms	Number of crocodiles
1. Captive breeding	14	
2. Collecting	145	
3. Captive breeding & Collecting	27	
Total	186	52,902

Number of provinces those crocodile farming are operated as shown in table 2.

Table 2

Part of Thailand	Number of provinces with crocodile farming
Central	15
North	4
North Eastern	3
Eastern	6
South	2
Total	30

Distribution of crocodile farms in Thailand is shown in FIGURE 6.

Crocodile farming area is about 2,000 Rai(626 Rai= 1 sq.KM) which is equal to 3.2 Sq.Km. or 0.00058 percent of country area.

The value of only crocodiles is more than 1,200 million Baht or around 50 million U.S. Dollars.

Among the strong current of conservation all over the world, crocodile conservation is one of the most important and highlight programme in Thailand. Gathering of people who have the same interest from many fields such as crocodile farmer, researcher, scientist, conservationist and government officers, then a core body for conservation and management of crocodile both in the wild and in captivity was formed. Crocodile Management Association of Thailand (CMAT) was formerly established in early 1991.

CMAT plays an important role in crocodile conservation and management in Thailand for examples; CMAT conducted preliminary scientific survey on wild crocodilians in Thailand, survey on crocodile farming status in Cambodia, training and seminar on crocodile farming for Thai crocodile farmers and etc.

Since 1990 crocodile farming in Thailand is growing very fast. Now there are 5 new farms those recognized by CITES as registered captive breeding operation;

1. Sriracha crocodile farm
2. Nong Yai crocodile farm
3. Samphran crocodile farm
4. Wasan crocodile farm

5. Pattaya crocodile farm

Including Samutprakarn crocodile farm, 6 CITES registered crocodile farms are in Thailand.

Regulation of Trade

In the past, consumption of crocodile products with in Thailand has no regulation to control this business. Crocodile skin, products and hatchlings can be sold freely.

After the implementation of Wildlife Reservation and Protection Act B.E. 2535, all crocodilian farming and their products must be registered and under controlled by government authorities following the regulations which are now in correcting processes at the law department. These regulations supposed to inoculate soon.

International trade as well as internal trade must be strictly controlled under the same regulations and rules which corresponse and serve CITES regulations.

All captive crocodiles and farmings must registered their animals; number, source, history and identification to government authorities to apply for farming permission. When ever they are permited, their farms can be checked the stock anytime the authorized officer needed and they also have to report on current status of crocodiles in their farms periodically.

Any movement of crocodilians from place to place must be informed to government authority.

CMAT assist government authority by producing standard record keeping system to crocodile farmers and use their data base to store and back up informations to government authority. Identification and tagging are also provided to the farmers through CMAT. For example plastic skin tags are available and all records will be kept in CMAT and transfered to government authority via computer network. Then inventory and stock of live crocodiles including skins and their products in each registered farm could be cross checked. Recording formats are shown in Appendix I.

Imports & Manufacturing

Thailand imported live crocodiles, C.siamensis from Cambodia around 3,000-5,000 hatchlings a year. Those hatchlings came from small captive breeding farms and big farms through Thai-Cambodian border which is too long (803 Km.) for government officers to control illegal trade.

By this year, 1993, due to political situation in Cambodia and decrease of world crocodilians price, demanding of Cambodian crocodiles is quite low then number of animals came to Thailand is lesser than before.

Most of the crocodile farmers recognized that illegal crocodiles are prohibited, they can not registered to government authority because these crocodiles have no documents and origin. This is due to "Public Relation Activities" of CMAT that frequently informed the farmers through mass media; television newspaper lecture and seminar to concern and avoiding of those illegal animals which can destroy crocodile industry in Thailand.

Crocodile skin consumption in Thailand came from local skin, mostly C.siamensis that died in the farms, a few obtained from slaughtering. Majority of crocodile skins were Caiman skin which were both legal and illegal imported into Thailand. These skins were old stocks before implementation of "Wildlife Reservation and Protection Act B.E. 2535". By this law, those skin must be consumed only in Thailand, They can not be re-exported.

In the future, tanneries and leather factories should be inspected and controlled by government authority for crocodilian skins and products. All products made of captive bred C.siamensis skin should be labelled as:-

Product made from captive breeding Siamese crocodile in Thailand.

And accompany with tag numbers corresponsed to export permit number and document issued by CITES management authority.

Research

Research on crocodiles in Thailand has been done in a few years ago by many instutes. We can divided those reseaches into 2 fields. The first one is to research on captive management of crocodile for example; diseases, nutrition, incubation and etc. The second one is to research on wild crocodile which emphasized on conservation for example; wild crocodilian survey, habitat selection for restocking and etc.

Those researches are carried out in cooperation among scientists from various instutes such as :-

1) Wildlife research Laboratory, Faculty of Science, Kasetsart University.
2) Center for Aquatic Animal Medicine, Faculty of Veterinary Science, Chulalongkorn University.
3) Inland Fishery Division, Fishery Department, Ministry of Agriculture and Cooperatives.
4) Technical Section, Wildlife Conservation Division, Royal Forestry Department, Ministry of Agriculture and Cooperatives.
5) CMAT

CMAT has appointed their members in order to set up many varieties of collaborative research centers and facilities with universities.

Four projects are setting up as follow:-

A. National Crocodile Research Center at Sriracha Crocodile Farm.

b. Crocodile Farming Extension Service Center, North-Central Region at Wasan Crocodile Farm.

C. False Gavial Conservation and Propagation Project at Samphran Crocodile Farm.

D. Freshwater Siamese Crocodile Conservation and Propagation Project at Nong Yai Crocodile Farm.

CMAT do hope that these projects will give more advance researches for the benefit of crocodile conservation and farming in Thailand and our neighboring countries.

Some scientific papers and articles are summarized in Appendix II.

Conservation, Management and farming of Crocodiles in Thailand are setting up and starting according to assistanceship from Australian scientist Dr.Grahame Webb Mr.Robert Jenkins and Mr.Charlie Manolis. Under closed supervision these activities can grow very fast and more effective than before.

Protected Areas

Protected areas which are correlated to historical distribution of crocodilians in Thailand are listed below :-

1) Bung borapet, a water reservior in Nakornsawan province which is an important habitat for C. siamensis in the past. At this moment this reservior is controlled by Fishery department and they plan to set up crocodile breeding facilities including education center at Bung borapet. Reintroduction of crocodile into this area is quite hard because fishermen and farmers are all around and invade through the reservoir. Most of suitable ecosystem for example vegetations and nesting sites were destroyed in the process of cleaning and clearing of reservoir for fishery purpose.

2) Yod dome, Wildlife sanctuaries, which has an incidence of C.siamensis ever occured. But this area is closed to Thai-Cambodian border surrounded by active mines field then no one can enter this place.

3) Pang seda, this national park is in the eastern part of Thailand. There are many creeks in the park and C.siamensis are found for the last 2-3 years ago. Pang seda has a good patroling system so it is proposed to be one of restocking site. This need to be surveyed and more scientific work should be conducted to obtain enough informations for decision making.

4) Taru Tao Island, this is also a national park which is an island in Andaman Sea. C.porosus ever found in the river and swamp area in the middle zone of island. Restocking of C.porosus in Taru Tao island is discussed between CMAT and National Park Divison, Royal Forestry Department.

5) Pa pru, non hunting area in Narathiwat province is situated in the southern part of Thailand. It was reported that C.porosus and T.schlegelii were found in this area. Survey should be carried out soon.

So far, many protected areas that have history of crocodiles are reported but few of them have to be proved. Further study will be done to confirm the informations. Then we can asked for government authorities to support in strickly and strongly protection of our wild creatures, crocodiles.

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Discussion

Crocodilian conservation in Thailand is now in a good progress. Many institutes get together in order to support the conservation of crocodilans by protection of their habitat, restocking and educational programme. Meanwhile management of crocodilian farming is also going to be changed. Technology in reproduction and nursery are transferred to many farms to increase production and reduce mortality. However the crocodile farmers still aware of conservation of crocodiles then excellent cooperation is strengthen among conservationist, farmers, researcher and government officers by CMAT who is the coordinator. We believe that in the future crocodile will return to the wild in Thailand as well as succeeded in crocodile farming and related businesses.

Further more, Thailand hoped to be the coordinator and supporter for crocodile conservation management and farming in this region of the world.

FIGURE 1

HISTORICAL DISTRIBUTION OF *CROCODYLUS SIAMENSIS* IN THAILAND

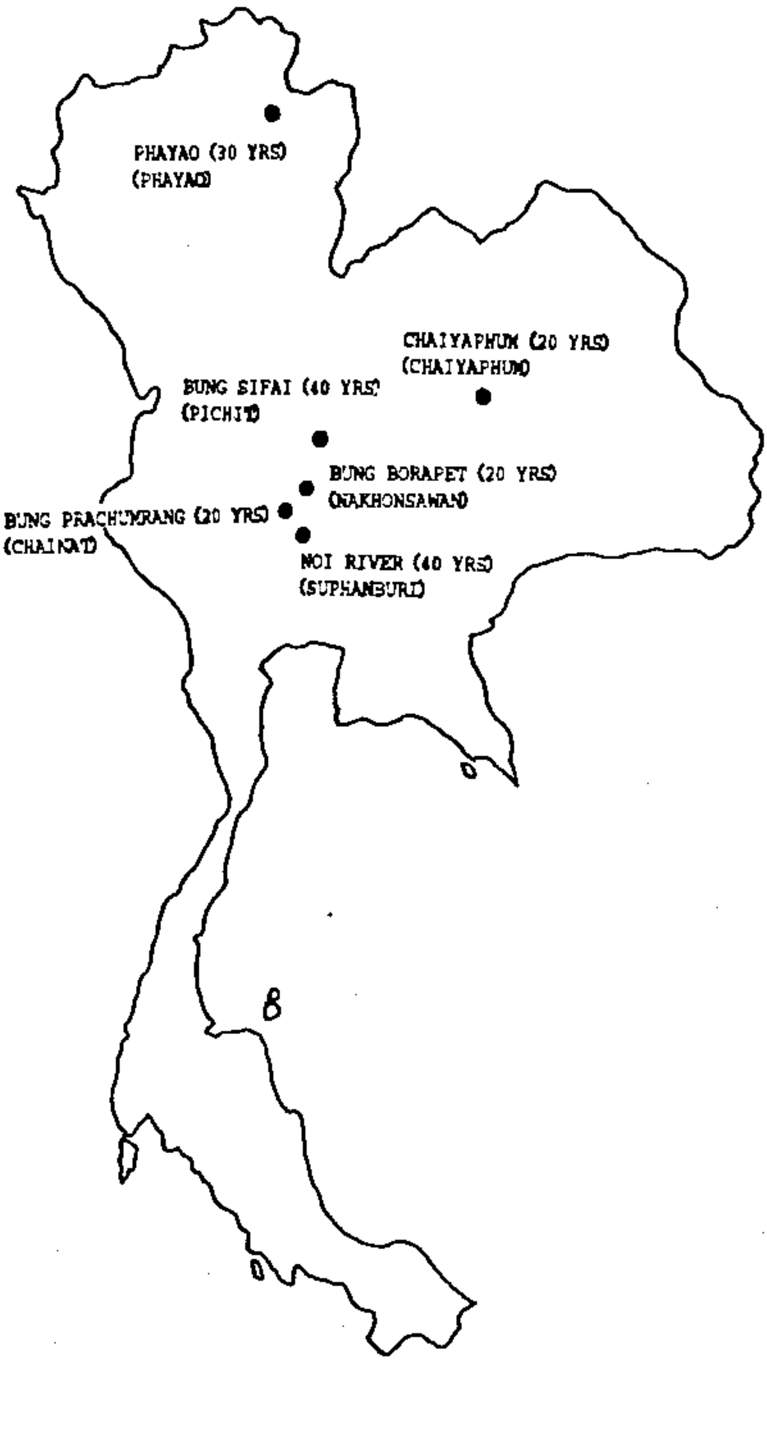


FIGURE 2

DISTRIBUTION OF *CROCODYLUS SIAMENSIS* IN THAILAND

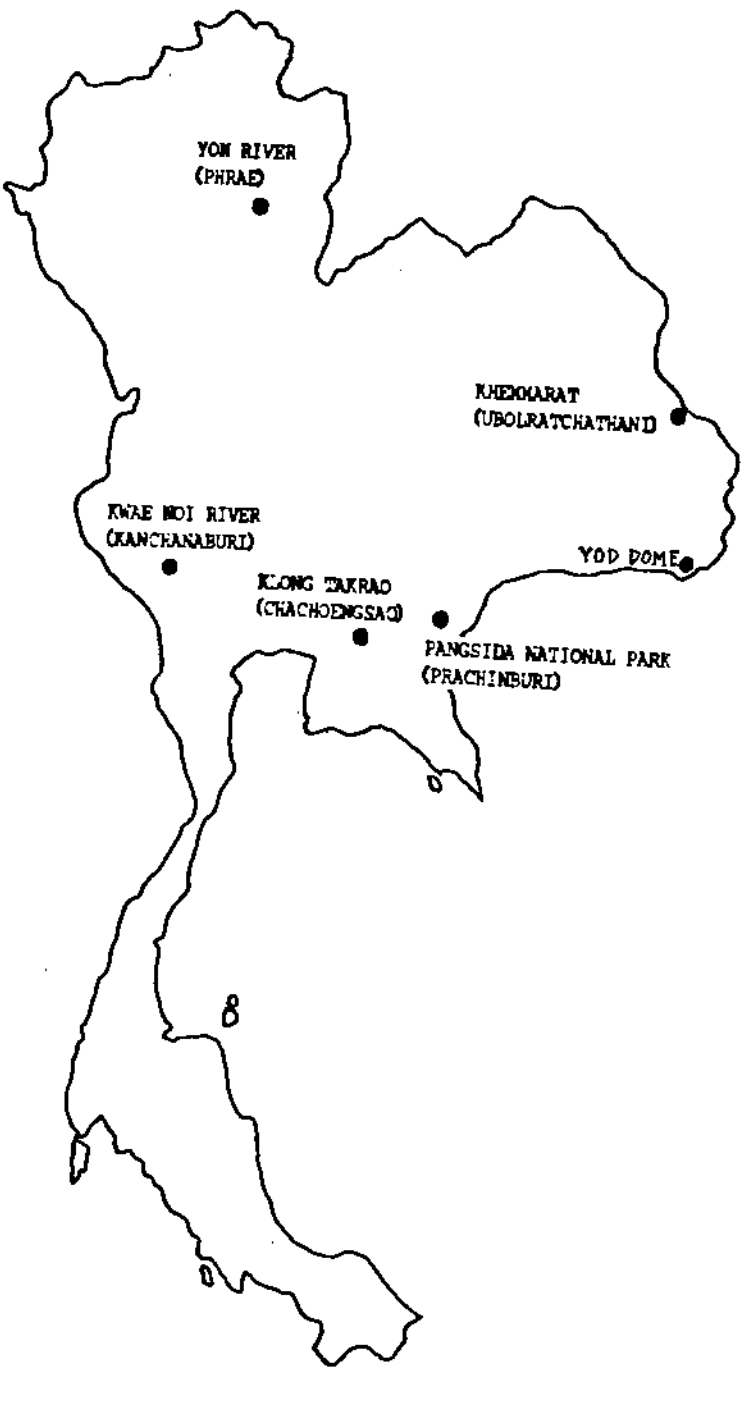


FIGURE 3

HISTORICAL DISTRIBUTION OF *CROCODYLUS POROSUS* IN THAILAND

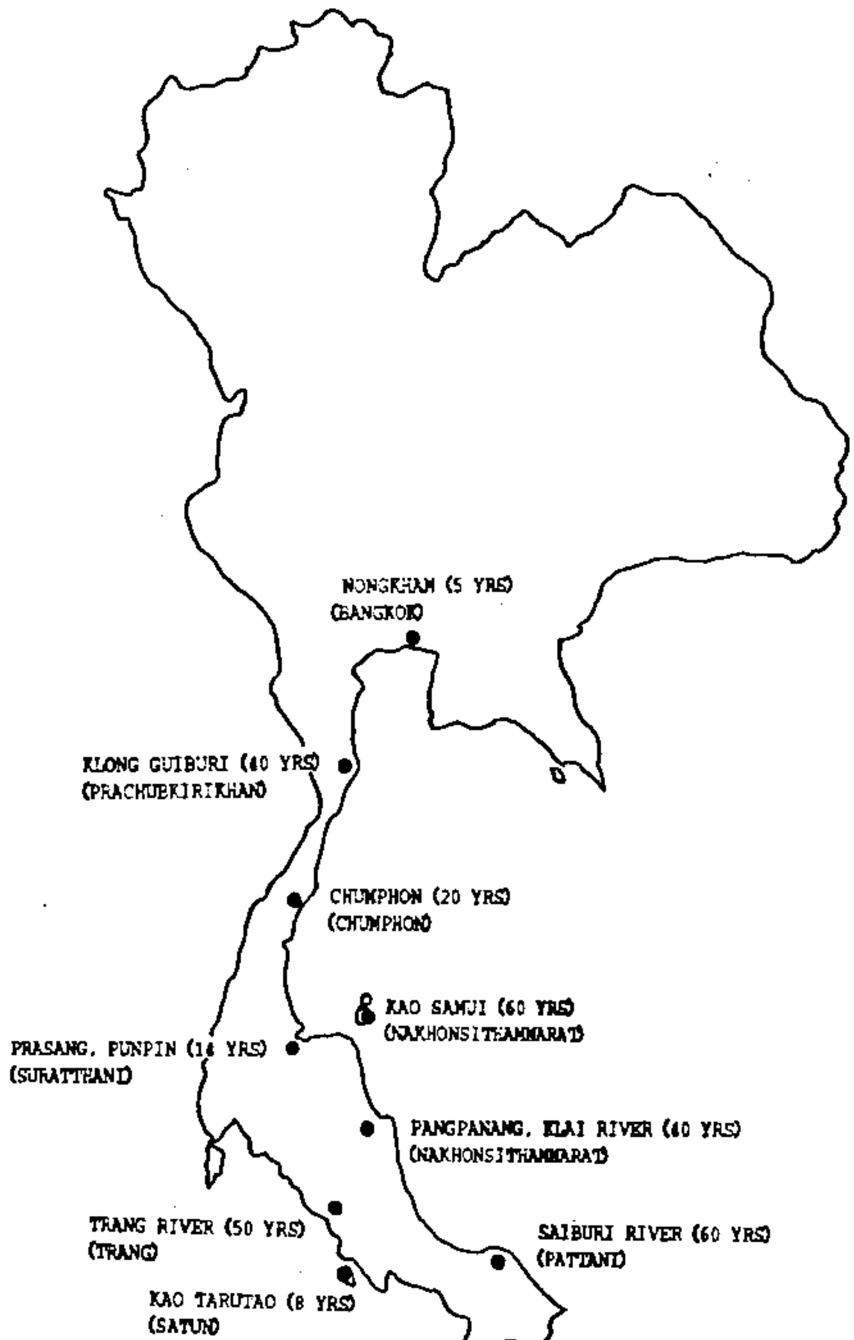


FIGURE 4

DISTRIBUTION OF *CROCODYLUS POROSUS* IN THAILAND

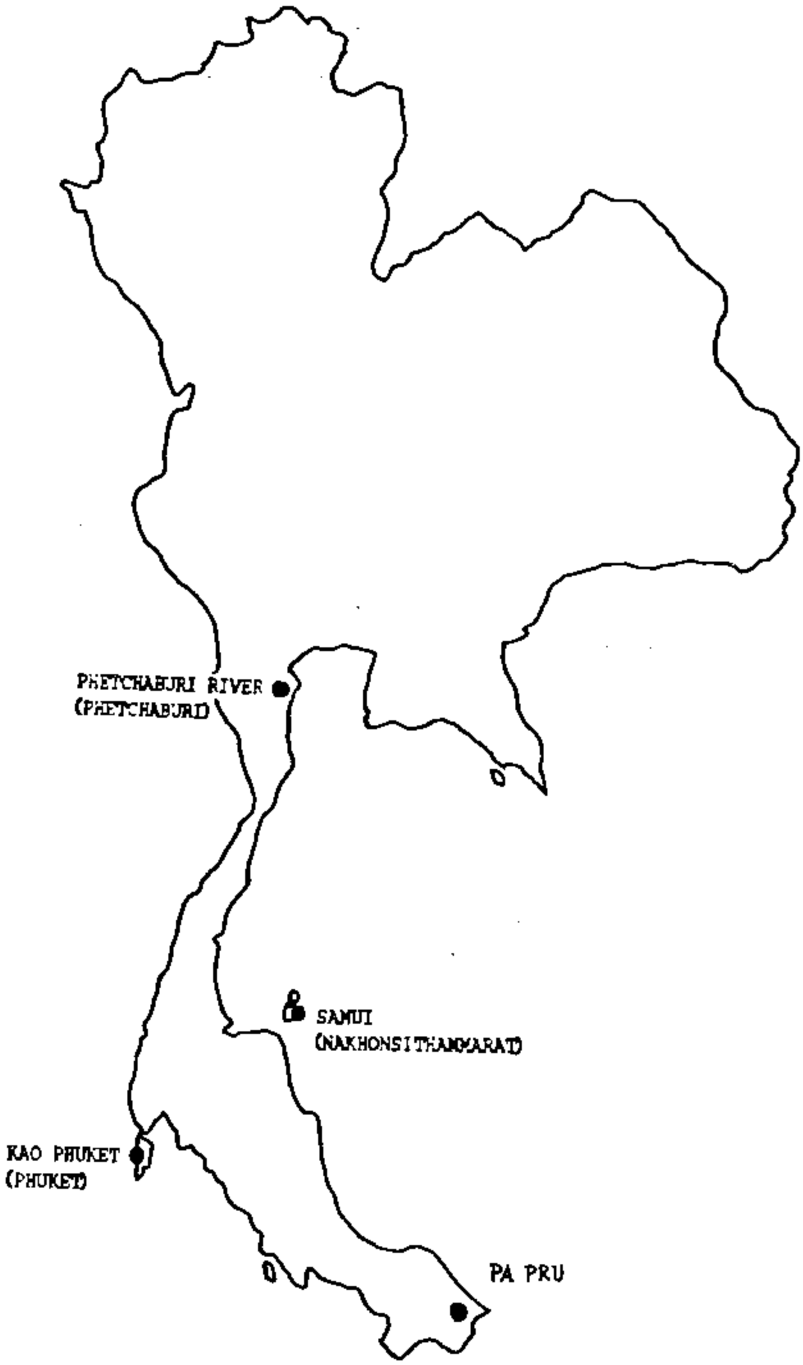


FIGURE 5

DISTRIBUTION OF *TOMISTOMA SCHLEGELLI* IN THAILAND

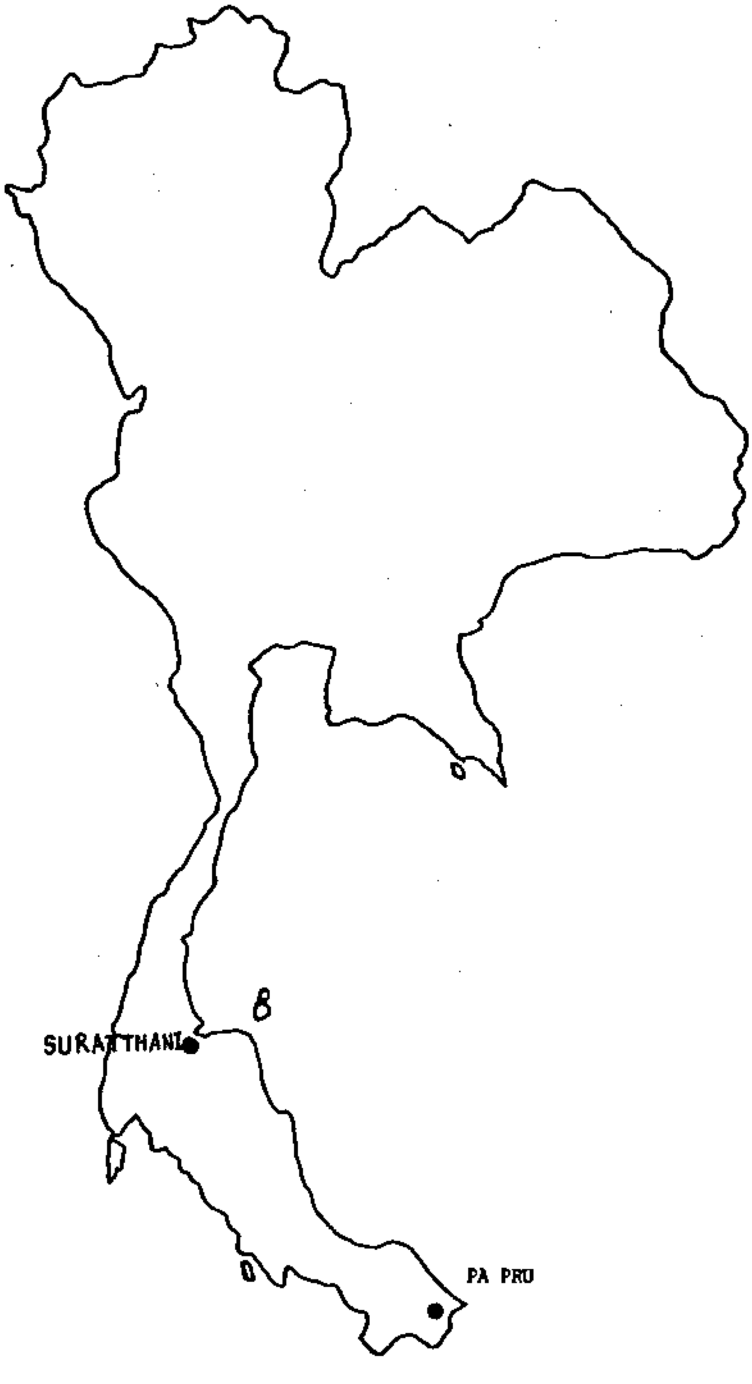
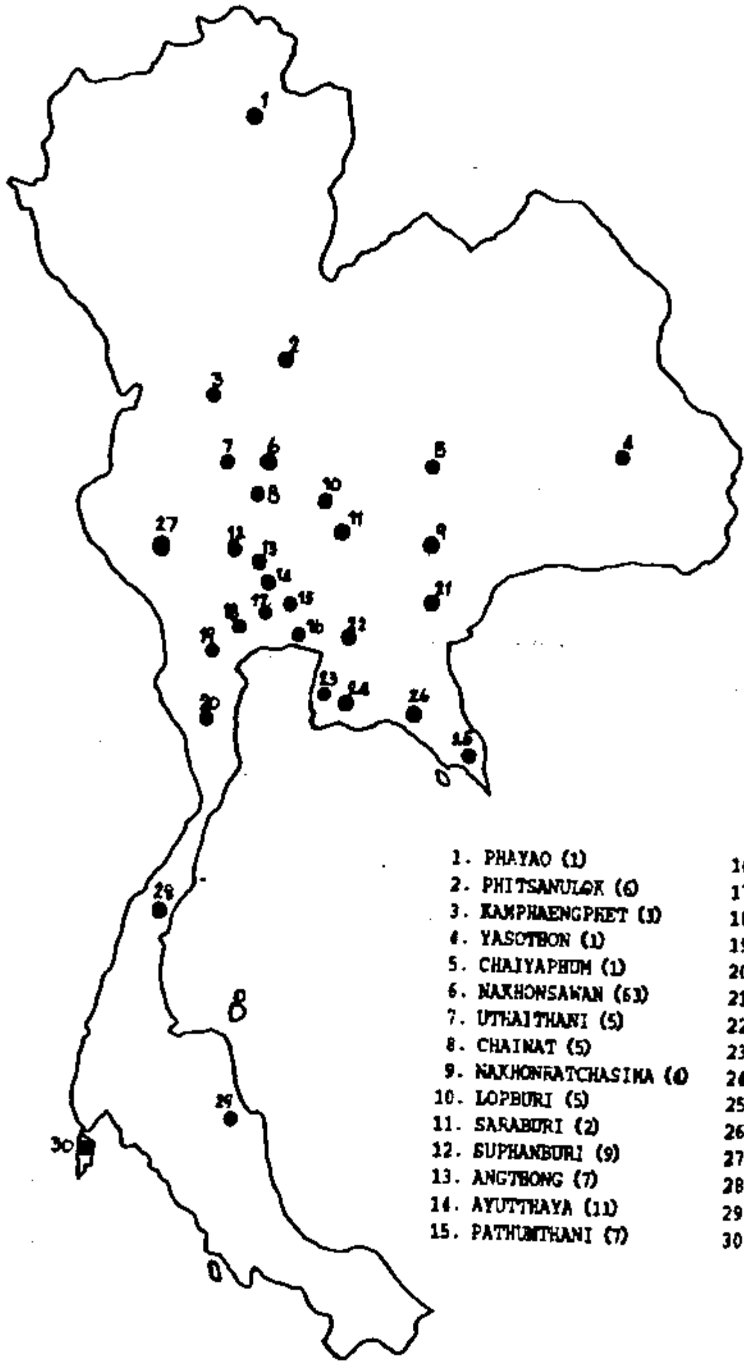


FIGURE 6

CROCODILE FARMS IN THAILAND



1. PHAYAO (1)
2. PHITSANULOK (6)
3. KAMPHAENGPHET (1)
4. YASOTHON (1)
5. CHAIYAPHUM (1)
6. NAKHONSAWAN (63)
7. UTHAITHANI (5)
8. CHAINAT (5)
9. NAKHONRATCHASIMA (4)
10. LOPBURI (5)
11. SARABURI (2)
12. SUPHANBURI (9)
13. ANGTHONG (7)
14. AYUTTHAYA (11)
15. PATHUMTHANI (7)
16. SAMUTPRAKAN (1)
17. NONTHABURI (1)
18. NAKHONPATHOM (5)
19. RATCHABURI (2)
20. PHETCHABURI (1)
21. PRACHINBURI (9)
22. CHACHOENGSAO (6)
23. CHONBURI (10)
24. RAYONG (2)
25. TRAT (12)
26. CHANTHABURI (2)
27. KANCHANABURI (2)
28. CHUMPHON (1)
29. NAKHONSITHAMMARAT (1)
30. PHUKET (2)

Appendix I

MONTHLY REPORTS

Month ____________________________ year ______________________________

Farm (name) ____

Species of crocodile (___________)	number in previous month	increase		decrease				TOTAL
		egg hatch	other	dead	sale	error 1)	other 2)	
hatchling 0-1 Y								
juvenile (subadult)								
adult								
Total								

1. details :- ____

____

2. details :- ____

____

CROCODILE SKIN EXPEORT FORMS

Exporter (name) ____________________ Signature ____________________

Customer (name) ____________________ address ____________________

____

____

date of shipping ____________________ via ____________________

Total number of C. siamensis ______________________________ pieces

C. porosus ______________________________ pieces

ID number Skin Tag Code	ID number Animal microchip or Scute cutting	species	width x length (cms.)	remarks
<---------------- can be the same	------------------> number on tag			

CROCODILE SKIN RECORDS

TANNERY ____

date	spp.	ID number	widthx length (cms.)	signature (reciever)	destination (customer)	date (export)	signature (exporter)

TRANSLOCATION OF CROCODILE RECORDS

Name of farm ______________________ Date of inspection ______________

ID number	Signature (owner)	date	spp.	width x length (cms.)	dead/alive culling	destination (place) CUSTOMER	signature (receiver)

Egg laying and incubation record

Farm ______________________________ Year ______________________

Pond No.	DAM No.	SIRE No.	Lay date	No. Egg	Incubate date	No. Egg	Hatch date	No. Hatch	No. Survive*

* Survive more than 30 days after hatch.

Individual record of crocodile

Farm ______________________ **Species** ______________________

Pond No.	I.D.NO.		Sex		Age	Purchasing data					Record date
	Scute	Implant	M	F	Y/M	Birth date	DAM No.	SIRE No.	Purchase date	From	

Appendix II

Some scientific papers and article carried out on Thailand.

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RESOURCE MANAGEMENT & ECOLOGY UNIT
RP-JAPAN CROCODILE FARMING INSTITUTE

DISTRIBUTION AND STATUS OF CROCODILES IN PALAWAN PROVINCE

BY

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NOVEMBER 1992

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ABSTRACT

Two crocodile species, the Saltwater Crocodile (*Crocodylus porosus*) and the endemic Philippine freshwater crocodile (*Crocodylus mindorensis*) have been recorded from Palawan province.

The current distribution and status of these two species in Palawan province has been well studied until the RP-Japan Crocodile Farming Institute (CFI) conducted surveys of crocodile habitat trying to determine their current distribution and status. Additional insights were obtained from acquisition records, CFI sightings and interviews of trappers provide further insight on the status of crocodiles in the wild.

This study has confirmed the existence of wild *C. porosus* on Palawan, Balabac, Dumaran, Bugsuk, Ramos, and Pandanan islands. The continued occurrence of *C. mindorensis* on Busuanga Island was discovered. Remnant crocodilian populations occur in areas with less human population density and remaining pristine wetland vegetation.

Some crocodiles of both species remain in private possessions, collected as pets, for show or possibly simply for rearing.

INTRODUCTION

Palawan province is located between 8° 30' to 12° 10' latitude and 114° 8' to 121° 45' longitude. It is bounded on the west by the South China Sea and on the east by the Sulu Sea. It lies between Mindoro island and North Borneo (see Fig. 1).

The province has a total land area of 14,897 sq km and stretches 650 kilometers in a north-south direction. It is composed of 1,769 islands and islets; Busuanga Island in the north, the Cuyo group of islands in the northwest, Cagayancillo and Spratley Islands in the west, and the southernmost tip of Balabac, at Mangsee Island, in the south.

Palawan Province is considered as the "last frontier" of the Philippines as its remaining forest resources, diverse flora and fauna, and relative size (1,489, 655 ha) make it attractive to immigrants from more densely settled areas in the central and northern Philippines. Palawan's 1,959 km of irregular coastline afford excellent harbors (PPDO 1991). The human population in the province was 397,261 in 1990 (density [1] = 35) and the immigration rate is 3.58 (National Statistics Office or NSO 1990).

There are two pronounced seasons in Palawan Province, Type I when it is dry from November to April and wet during the remainder of the year; and Type II when the seasons are not as pronounced, but still relatively dry from November to April and wet during the rest of the year (Fig. 2). For the past three years (1988-90), the average annual rainfall in Type I climate is 2,539.8 mm, much higher than CFI recorded average annual rainfall of 1,805.4 mm during the same period. CFI project site lies on the second climatic type. At sea level throughout the islands, the temperature averages about 27 °C (Encyclopedia Americana 1990).

The main island, Palawan, is 425 km long and 40 km wide at its narrowest part in Bahile, Puerto Princesa City. The total length of shoreline of the main island is approximately 1,400 km. The island is shaped like a *kris*[2] . Tall mountain ranges run through the entire central length of the province into 2 areas - the east and the west coasts (PPDO 1991). A mountainous spine rising to over 2,000 m runs almost the entire length of the island although in the north the mountains give way to low rolling hills. As a consequence, river courses are generally short, steep and fast-flowing (Davies and Green 1990). There are more than 229 rivers, mostly draining to the eastern coast. River ranges 1-5 km (n=76), 5-10 km (n=82), 10-20 km (n=45), to 20-30 km (26). The majority of rivers are fringed with mangroves from the mouth to a few kilometers inland. Generally, the dominant mangroves in the island's rivers are of *Rhizophora spp.* and *Bruguiera spp.* Stands of *Xylocarpus spp.*, *Sonneratia alba*, *Avicennia marina*, *Heritiera littoralis*, *Ceriops sp.*, *Aegiceras floridum* and *Lumnitzera littorea* are also found occasionally mixed with the dominant stands. Further upstream, where salinities are lower, *Nypa fruticans* and *Excoecaria agallocha* are common. In less inundated areas, *Acanthus ilicifolius*, *Acrostichum spp.*, *Hibiscus tiliaceus* and *Terminalia cattapa* occur.

Northeast of Palawan Island, the island of Busuanga could be found. It is located at 12° 01' latitude and 120° 12' longitude (Fig. 1). It is accessible by a 1.5 hour plane trip or about 20 hours by boat. Its total land area is 392.9 sq. km. It has a shoreline length of around 241 km. Its topography is generally hilly with few plains. Busuanga island is divided into two municipalities, Coron and Busuanga, with human population of 33,252 and 11,011 (density = 27) (NSO 1990) respectively. Busuanga municipality is richer in natural vegetation than the municipality of Coron. Adjoining Busuanga Island are the islands of Culion,

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[1] individuals/sq. km.

[2] a type of Moslem dagger with undulated shape.

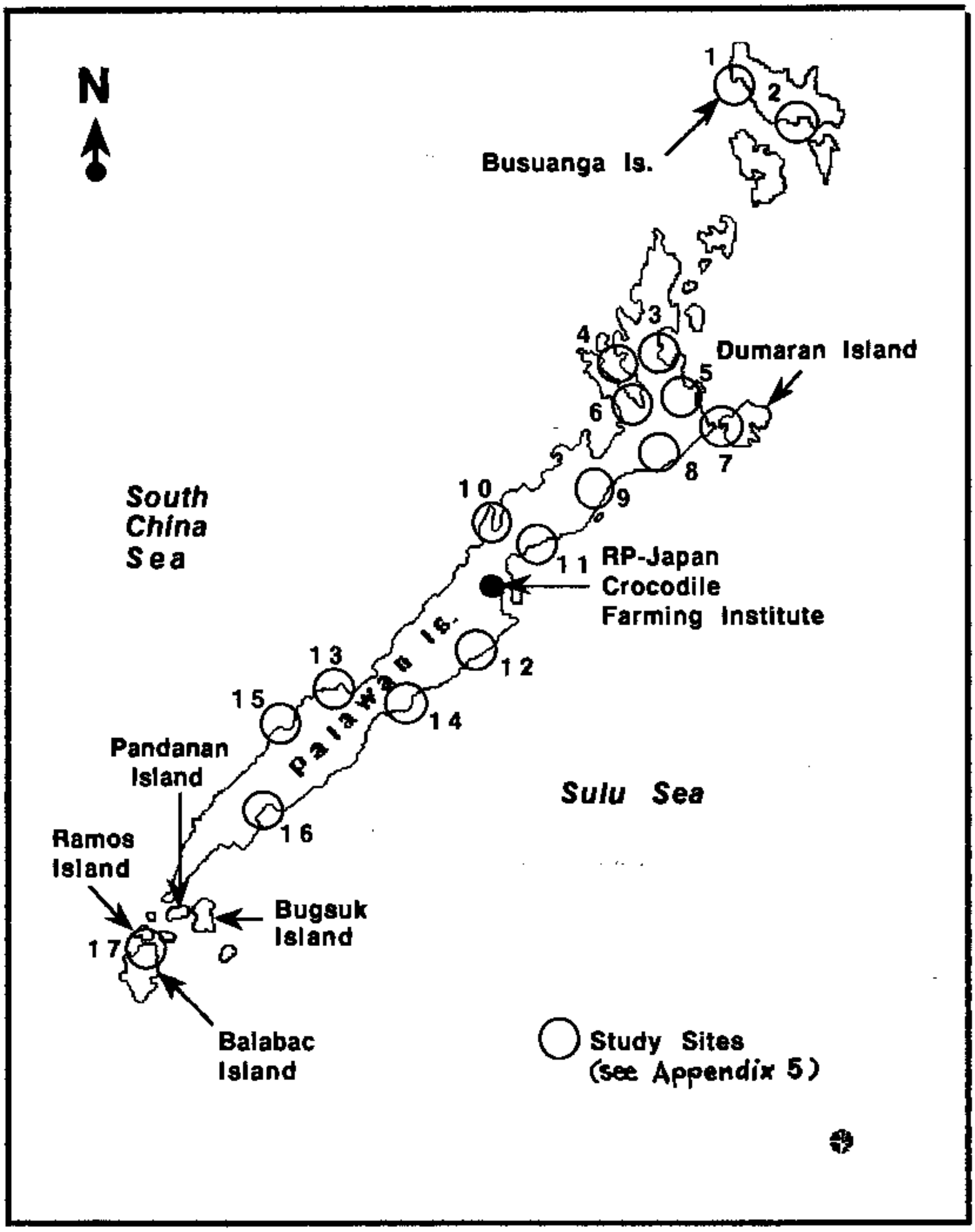

Fig. 1. Location of study areas in Palawan Province.

Linapacan, and Coron. These small islands are collectively known as the Calamianes Islands. Although they are closer to and have established trade connections with nearby Mindoro Island and Manila, the islands are under the jurisdiction of Palawan. Busuanga has hilly topography and few plains. Growth of tall grasses (*Saccharum sp.* or local "talahib") on the hills and sparse stands of forests suggest low soil fertility, which was confirmed by a resident; the soils are evidently acidic and generally rocky. The specific study sites on Busuanga Island are the Dipuyai and Busuanga Rivers. The Busuanga River extends farther inland than the Dipuyai and has a large water inlet at the south side of its mouth. Dominant mangrove stands

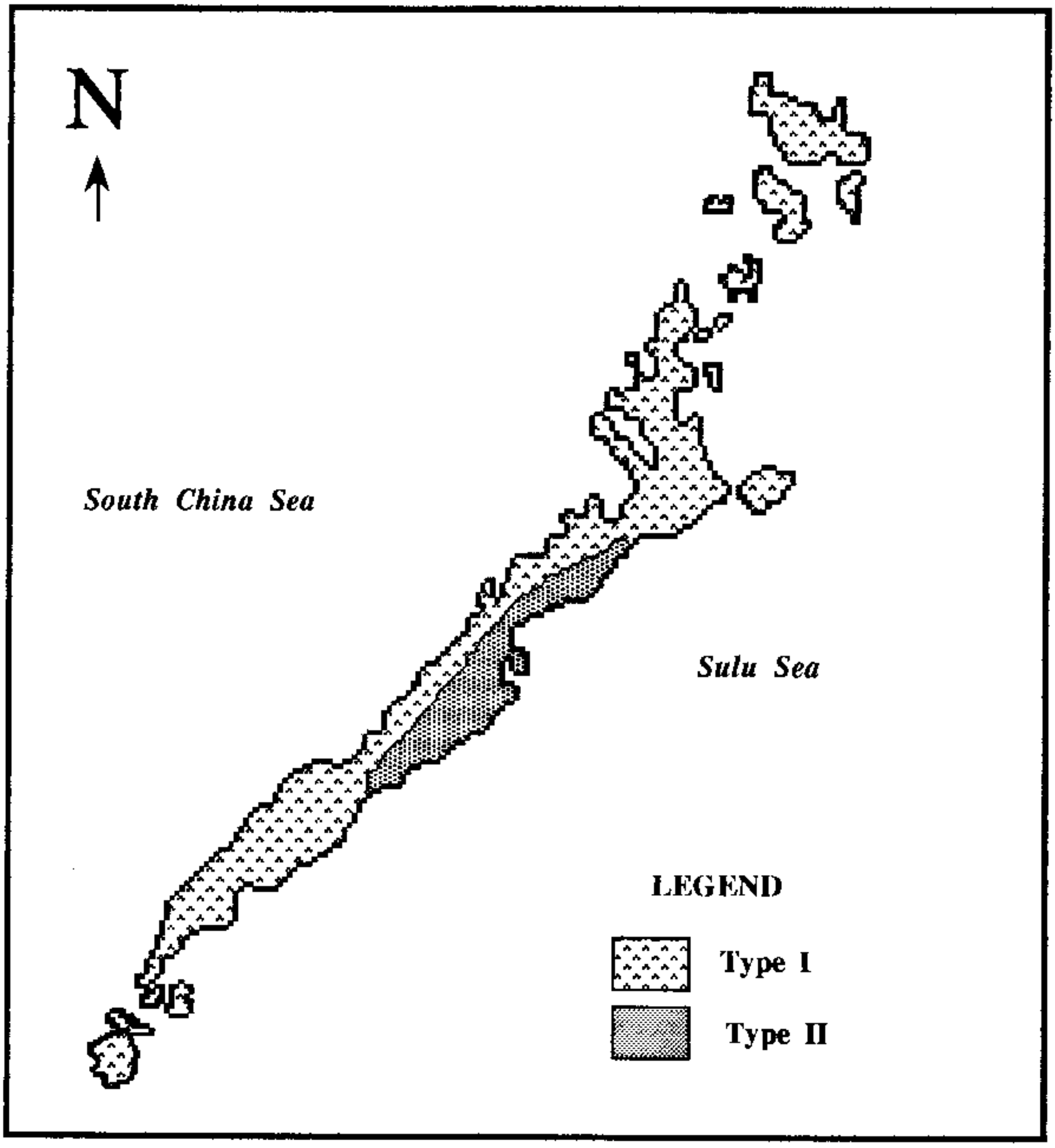

Fig. 2. Types of Climate in Palawan Province (based on PAG-ASA 1976).

occupying the shores of the river are *Sonneratia alba*, followed by *Rhizophora apiculata* and *R. mucronata*. Inland, thick and tall stands of *Nypa sp.* were observed. Other mangroves noted and identified were *Excoecaria agallocha*, *Lumnitzera sp.*, *Osbornia octodonta*, *Calophyllum inophyllum* and *Heritiera littoralis*. *Pandanus sp.* are fairly common along the seaward shores. Aerial observation of mangrove areas reveal a more or less pristine forest condition. Reportedly, this is partly due to private ownership of mangal areas.

Balabac Island falls under the political jurisdiction of the southernmost municipality of Palawan Province, Balabac (Fig. 1). The municipality's capital town is located on the island at approximately 7° 59' 02" latitude and 117° 03' 42" longitude. The island has an approximate area of 58,160 hectares and has a hilly terrain. The municipality has a total human population of 20,027 (density = 34) (National Statistics Office or NSO 1990). The shoreline of Balabac Island is approximately 183.6 kilometers, approximately 134.5 km of which are fringed with mangrove. Mangrove stands are dominated by dense growths of *Rhizophora spp.* and *Bruguiera spp.* Tall stands of *Avicennia spp.* have been observed but no *Nypa fruticans* noted. The municipality's total mangrove area is approximately 4,690 hectares which represent roughly 13% of the total land area. There are 13 bays and 19 rivers identified in the island. Of particular interest to the present study are the three small rivers of Kalibunan, Karunutan and Rampang in northern part of the island. During the wet season, salinity in Kalibunan ranges from 33 to 34 ppt, at Karunutan 5 to 34 ppt and at Rampang, 17 to 19 ppt. (measurements were from the upstream limit to the mouth). Dense clusters of sea grasses are present at the mouths of Karunutan and Rampang Rivers. Kalibunan is characterized by extensive coral growths, however, many of these are dead, probably as a result of dynamite fishing practiced by fishermen in the area.

Dumaran Island is located around 49 kilometers southeast of the town of Roxas in northern Palawan (Fig. 1). It is accessible by a 3-hour trip by boat. It has a land area of 43,500 + ha and a shoreline length of around 132.7 km. Its topography is plain to rolling hills. The municipality of Dumaran where Dumaran Island is a component is 21,332 or a density of 39. It has 5 rivers, majority of which are fringed with *Rhizophora* and *Bruguiera spp.*

Bugsuk Island lies approximately 25 kilometers northeast of Balabac Island (Fig. 1) and has only one significant river, Bugsuk. Half of this river, which transects the island, is fringed with mangrove. The total shoreline length of Bugsuk is around 64 km, the majority of which is sandy in nature. The total land area is 8,903 hectares and the total human population is 1,508 (NSO 1990).

Ramos Island is to the immediate north of Balabac (Fig. 1) and is under the political jurisdiction of the municipality of Balabac. Land area is 3,300 hectares. It has a total shoreline length about 31 km mostly made up of corals. Around 24 km of this, mainly on the southern side, is fringed with *Rhizophora spp.* and *Bruguiera spp.*Its total human population is 1,159 (NSO, 1990). The island is flanked by grasslands at its northern and southern portions and has 6 low hills (12 to 78 m). It has only one river, Kalukog, in which salinity ranged from 31 to 34 ppt during the wet season. Corals can be found in the characteristically wider interior portion of Kalukog.

Pandanan Island located north of Balabac and west of nearby Bugsuk has an area as big as Ramos Island (Fig. 1). It has a shoreline length of ca. 36 km.

METHODS

Spotlighting method was employed during night surveys on navigable portions of rivers. Spotlighting, however, was not totally relied upon in surveying crocodilian populations in Palawan Province owing to the relatively short nature of the rivers which are almost totally closed over by canopy. Moreover, the upper portions of the rivers are shallow and non-navigable by boat. A significant portion of crocodiles caught on Palawan Island were trapped in the portions of river inaccessible to boats. Day surveys on boat and on foot were conducted on some river habitats and mangrove flora were noted.

To complement the limited surveys, CFI used historical accounts from personal interviews, acquisition records, travel reports of the Resource Management & Ecology Unit (RMEU) and the Acquisition Sub-unit of the CFI from March 1987 to October 1992 in mainland Palawan and in five adjacent large islands; Balabac, Ramos, Bugsuk, Pandanan, Dumaran and Busuanga. The other two large islands, Culion and Linapacan, were not visited.

Survey reports were reviewed and analyzed, CFI acquisitions plotted on maps and entered in tables together with sightings. CFI interviews were tape recorded. Reports before 1987 were considered as former distribution and 1988 to 1992, current distribution. A degree of subjective judgment was used to identify unbelievable or grossly exaggerated accounts, which were subsequently omitted.

The majority of interviewees were fishermen and farmers, who in many cases caught crocodiles by rope snare (c. 50%) and accidentally (c. 40%) in fishnets, fish corrals, by hook and line, etc. Farmers usually trap during March to June when they are free from farm work and waiting for the rainy season.

RESULTS AND DISCUSSION

Former Distribution in Palawan Province

Retired colonel Gonzalo Barcia, a famous Philippine crocodile hunter, hunted crocodiles in Malampaya Sound and adjacent areas in Taytay, a northern municipality on Palawan island during the 1950's. He alleged that he could kill an average of four crocodiles per night around Malampaya Sound, Abongan River channel. At Lake Manguao, a nearby lake, he reportedly killed ca. 200 crocodiles. His estimated total haul from Malampaya was around 2,000 mostly sub-adult and adult crocodiles. Smaller crocodiles were allegedly not hunted because their skins do not fetch high value.

Reese (1915) figured a nest containing eggs discovered "on the edge of a small lake on the island of Palawan, Philippine Islands." He believed the eggs belong to *C. porosus*. Earlier, Schultze (1914) described a crocodile nest at Lake Manguao and identified the species as *C. palustris*. However, he gave no criteria for his identification and may have used habitat as the basis. Auffenberg (ca. 1977) states that the lake harbors "respectable populations of crocodiles that at this date are relatively undisturbed" and suggests that these crocodiles are *C. mindorensis* (in Ross 1982). However, no specimens were examined and no descriptions of nests or eggs were given by Auffenberg to verify the identity of these crocodiles. Later investigations in the lake (Ross 1982) could not resolve the issue of crocodile identity because no crocodiles were seen. However, according to a Tagbanua native, Percillano Llanorit, a crocodile nest containing around 50 eggs was found in the 1960's on an islet, east of Lake Manguao, amongst tall grasses. This site was visited by CFI and Percillano was asked to describe the dimensions of the nest. According to his estimate, the nest has a height of c. 1 meter. The number of eggs and the supposed large size of the nest suggest it may have been constructed by a *C. porosus*. The acquisition of a skull fragment from the lake in 1989 by the CFI may resolve the issue.

Barcia's reported take near Malampaya may sound exaggerated but Ruperto Iquibal, a former companion of Barcia during his hunting on Palawan confirms that they hunted for around one year in Malampaya Sound and vicinity during 1951 to 1952, caught 3 to 4 crocodiles per day but at times, 5 as maximum and 2 as minimum. They also collected hatchlings from the area, which was contrary to Barcia's claim. He added that the biggest crocodile caught was around 3 meters in total length. After skinning the animals, they used to salt the skins on an island near Old Guinlo and bury the remains. He also noted that the crocodiles in Lake Manguao, are generally smaller and relatively longer and more pointed snouts, further confusing the identity of the population at Lake Manguao.

Relationship between crocodile densities and fish densities was also described by Iquibal. In places and at times when he spotted many crocodiles in some places in the sound, he and other fishermen would encircle the area with nets and catch a lot of fish. Whenever crocodiles were observed, a lot of fish could be caught in the same areas. At times when crocodiles were numerous in the sound, such that their eyes looked like Christmas lights, tons of fish could be caught by the fishermen. Ross (1982) had sightings in Malampaya during his investigation.

According to a long-time resident of Puerto Princesa, a foreigner named Jack Vermont, hunted in Puerto Princesa Bay, Iwahig and Barbacan areas from 1947 to 1955. He reportedly collected around 7 to 10 crocodiles a week using headlamp and a rifle. Sometimes he would catch the crocodile alive using a small but sturdy piece of wood, within a bait, tied to a cable. If the bait was taken, the ingested piece of wood would anchor in the crocodile's stomach such that the crocodile could then be pulled or winched onto a boat or tied to a tree. The skins were reportedly sent to Manila for sale. His activity continued for approximately 15 years and suddenly stopped, probably because wild populations in the area had been depleted to such an extent that it was no longer profitable.

Ross (1982) reported *C. porosus* in the municipalities of Narra and Brookes' Point in Palawan Island where he examined a live juvenile, skin, and photograph, in 1980-81. He also mentions the occurrence of *C. porosus* on Bugsuk Island.

In Busuanga Island, local hunters in the 1950's appear to have concentrated their efforts in the lengthy Busuanga River. According to a local informant, in one night, they could catch 4 to 5 individuals, 2 to 3 m long. Allegedly, more than 100 crocodiles were caught from this river by these hunters. Over the past 20 years or so, the informant remarked that three crocodile nests were found near the mouth of the river. The eggs were either smashed or thrown away. Two young women have reportedly been preyed upon by crocodiles near the port of Old Busuanga.

Present Distribution

In the period March 1987 to October 1992, 140 *C. porosus* caught in the wild from Palawan Province were acquired by CFI (Fig. 3). As of October 1992, *C. porosus* are definitely known from forty-four rivers on Palawan Province. The frequency of crocodile acquisitions and sightings on the rivers of the province is in Table 1.

Table 1. Frequency of crocodile acquisitions and sightings on the rivers of Palawan Province.

	Year Acquired [Sighted]						
	1987	1988	1989	1990	1991	1992	Total
Ramos				1			1
Pandanan				1			1
Bugsuk		1					1
Dumaran		[2]	1	2			3 [2]
Balabac		2 [3]		3 [6]	1 [3]		6 [12]
Palawan	8 [1]	7 [22]	19 [8]	15 [4]	11 [3]	2 [3]	62 [41]
Total	8 [1]	10 [27]	20 [8]	22 [10]	12 [6]	2 [3]	74 [55]

Reliable crocodile reports and sightings made by CFI staff indicate their presence in a further 31 locations (See Appendix 1-4 for more details on acquisitions and sightings). Crocodile acquisitions, nesting and habitat status on the component islands of Palawan Province is further discussed below.

On Palawan island, most of the crocodiles acquired by CFI came from the town of Quezon (n=38), Bataraza (27), and Narra (25). Other captures were from Rizal (n=8), Puerto Princesa City (n=4), Roxas (n=3), Taytay and Aborlan (n=1)(Fig. 3). These municipalities may have a few remaining crocodiles. Capture sites ranged from heavily populated (92,147) to

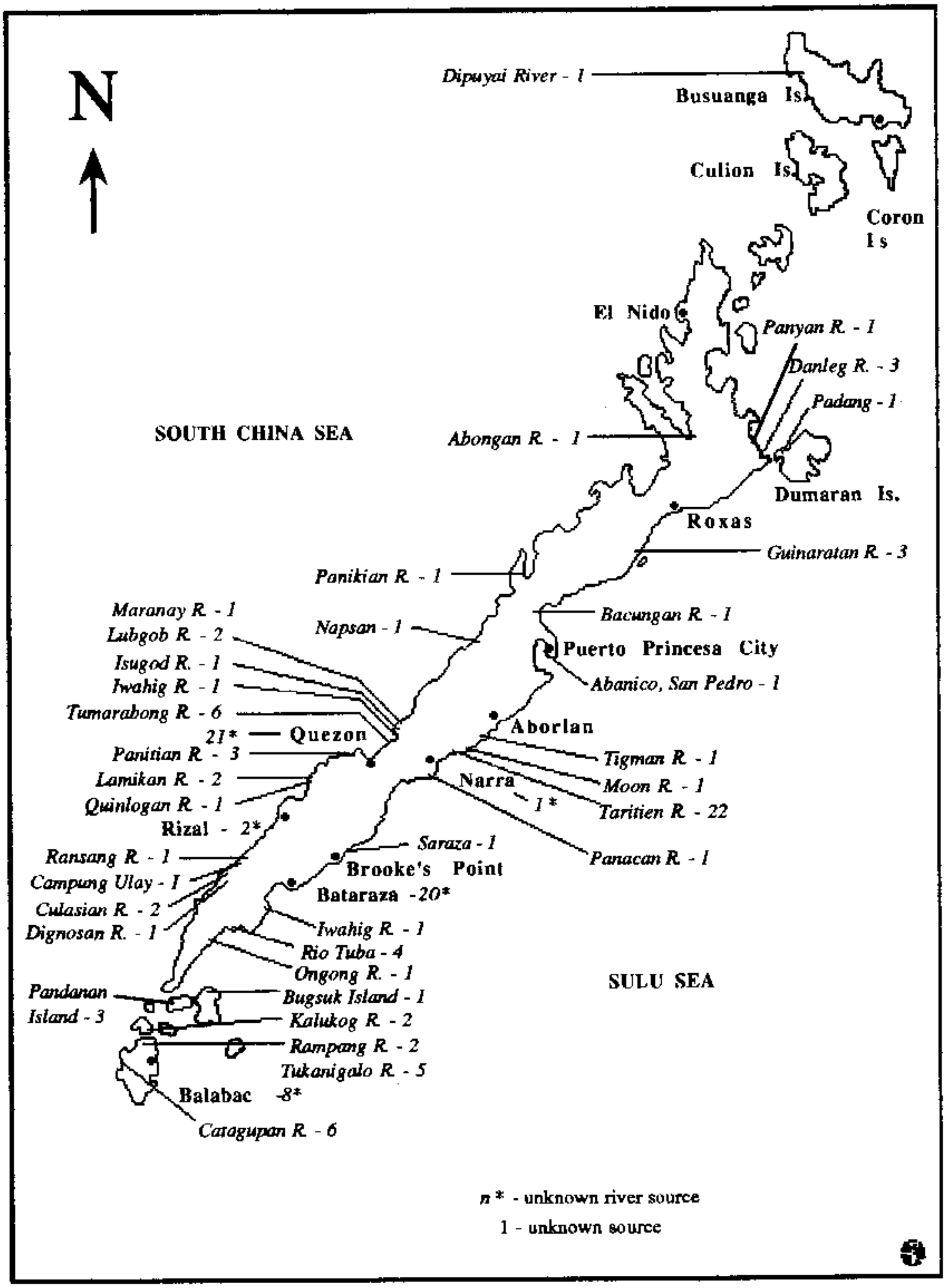

Fig. 3. Source of crocodiles acquired by CFI from Palawan Province as of October 1992.

wilderness areas (18,751). The case of a crocodile captured in Puerto Princesa City and another caught in a shallow pond 2 km from the seashore at Saraza, Brooke's Point, signify movement from permanent water sites, perhaps because of human disturbance. A crocodile was spotlighted in Bacungan River, Puerto Princesa City, around 2 km from the river mouth

(February 20, 1992) although its size could not be determined due to wariness. Some six rats were seen at the site, and presumably may represent part of the crocodile's diet. No further captures nor sightings from this river have occurred. In 1990, a crocodile took the bait from a trap without getting caught; it was thought to be a juvenile that evaded capture in a trap designed for large crocodiles. In Panyan River, Siangal, municipality of Dumaran, a farmer, Romeo Felizarte reported a crocodile caught on a hook baited and left out of the water (1 m above it; 21 December '90). The crocodile died of stomach injury, and upon dissection, contained 7 large developing eggs and numbers of smaller ones. The river is around a fathom deep and 20 m wide at the capture site, with both sides cleared for planting. It was never suspected that crocodiles exist in the river, as many children bath there and no previous crocodile sighting has been reported. Only the skeletal remains were brought to the CFI. Based on skull length, the total length of the crocodile was around 2.5 m. Earlier, a 2.07 m female was caught in the same river (May 26, 1990) by Loreto Servano and companions, when it became entangled in a gill net. In Guinaratan River, Roxas, on February 17, 1992, a hatchling crocodile was sighted during the day around 5 km upstream from the river mouth (salinity in the area = 27 ppt). The hatchling was spotted around 10 meters from the boat beside *Nypa fruticans*, and dived suddenly. This sighting indicates that some breeding may still occur in the river, which was confirmed by a nearby resident who said that around a week ago, a large crocodile was spotted in the river. Crocodiles also occur at nearby Barangay Tagumpay, where it is alleged some pigs were eaten. In Barbacan, municipality of Roxas, crocodile remains (skeleton) were exhumed by CFI survey team in 1989. Allegedly, the crocodile was poisoned by local inhabitants on July 26, 1988. Its estimated length was 14 feet, indicating that it was probably a male. A skull fragment was acquired from Lake Manguao on April 5, 1989. The fragment was allegedly a remnant of a crocodile shot by a local resident while it was at its nest in 1987. The total length (TL) was estimated at about 3 m. This crocodile is probably a *C. porosus*, but the identity cannot be confirmed from the fragment.

On Busuanga Island, two rivers, Dipuyai and Busuanga, still contain crocodiles. One *C. mindorensis* was caught in Dipuyai River, in the island municipality of Busuanga, and several *C. mindorensis* have been observed by local residents. Ross (1984) (later cited by Groombridge 1987) indicated the island of Busuanga was within the range of *C. mindorensis* and the recent records confirm that it continues to exist there. Clearly, it also confirms that both species occur in the Palawan Province. Some small crocodiles were reported by local informant farther upstream in Busuanga river. Two crocodiles were also observed near Old Busuanga port (1989) although these have not been caught. The upper Busuanga river dries up into isolated water pools during the summer and according to a resident of Old Busuanga, Abel Sucro, crocodiles congregate in the deep, wide pools located inland. In Barangay[3] Santo Nino, where Dipuyai river mouth is located, a *C. mindorensis* was caught in 1989 by Eddie Cabanero. This crocodile was sold to the mayor of Salvacion, a nearby barangay but it escaped. It was estimated to be around 2 to 3 m in total length and has an amputated digit at the forelimb. The *Crocodylus mindorensis* caught and brought to CFI on May 30, 1991 was from an area called Bogtong. Reportedly, this crocodile was bought by an American who released it opposite the island of Calumboyan, where the American resides. The crocodile was caught by the crew of a fishing boat which happened to pass between Laho Island and the Dipuyai river. Local inhabitants do not generally hunt crocodiles, unless livestock or their own lives are at risk, and thus the remaining crocodile populations may have been given a chance to recover. However, the good condition of the habitat may help the remnant population recover in the wild. Though the inhabitants of Busuanga dislike crocodiles, the maintenance of its habitat serves as saving grace for them since availability of food for whatever crocodile populations that were left are well sustained. At the eastern portion of the island which is under the municipality of Coron, crocodiles were reportedly depleted by hunters in 1956 but there are still sightings in Labangan River, near Tulbuan airport during the recent years.

[3] the second smallest political unit of the Philippines

On Balabac Island, south of Palawan Island, saltwater crocodiles occur. According to interviews, crocodiles were sometimes seen lying on logs, mudflats and sandbanks. A number of fishermen fishing with kerosene lamps have also seen the reflections of crocodile's eyes at night. A crocodile nesting site was visited on the island. The site is about 2.5 km from the shore of Sitio[4] Turong. It is near the foot of a hill. The habitat is in mangroves dominated by *Saccharum sp.*, hagonoy, *Acrostichum spp.* and other unidentified ferns. *Acanthus ilicifolius*, anibong (*Oncosperma sp.*) and several bushes invaded with vines were at the site. The substrate was moist soil and mudcrabs and numerous wild pigs (abundant spoors) occurred in the area. Two nests were discovered. One was presumably older than the other, as it had collapsed. Measurements of the newer nest are in Fig. 4. It was made of *Saccharum sp.* and other unidentifiable grasses, ferns, *Acanthus sp.* and *Oncosperma sp.* leaves, pebbles and moist soil; all materials present in the immediate nest area. A small stream or canal with shallow water at the time of survey, almost surrounded the nest. The nest contained 18 eggs and 16 of these were collected by CFI personnel on July 1990. They were incubated artificially at the institute, and produced 5 hatchlings. According to other sources, the older nest had also contained eggs, but these were either eaten or destroyed by local villagers. The total number of eggs was reported to have been 48, many contained live embryos. It is possible that the female *C. porosus* caught in Rampang River on October 1990 was the one who constructed the nests, as the stream surrounding the nest drains to the Rampang River. The capture site of the crocodile was about 2.2 km from the nest site. In addition to the crocodile obtained from the Rampang River (October 1, 1990), 4 crocodiles were acquired by CFI from the island. Subsequent trappings on October 5-7 yielded nothing although a trap was allegedly touched hy a crocodile at Karunutan River, where a hatchling was also sighted. A crocodile was allegedly shot and killed a few years ago on the island, but the location remains unknown. According to local informants, two crocodiles were caught in a fish corral in the area (April or May of 1990) and was taken to a fishing company in nearby Candaraman Island. They were sold for P100.00 per animal to George Watt, a resident of the island who took care of the animals. At least two persons (a young boy and an old man) were reported to have been killed and eaten by crocodiles in the area over the last few years.

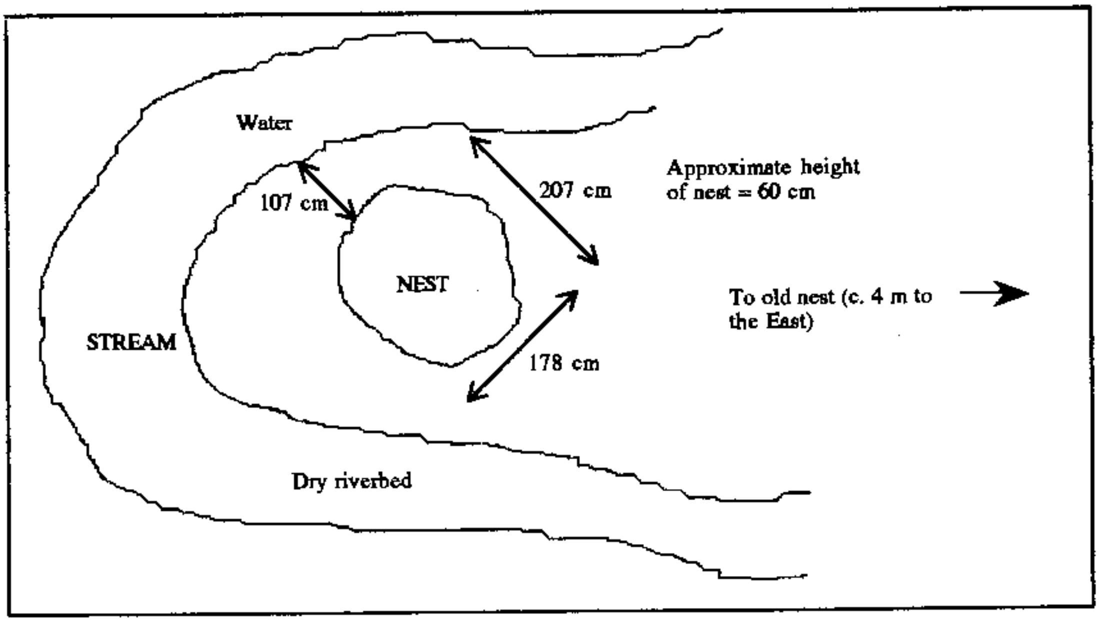

Fig. 4. Sketch map of relative crocodile nest location and dimensions in upperstream of Rampang River.

[4] the smallest political unit of the Philippines

On Dumaran Island crocodiles had been acquired by CFI. A female (TL = 2.72 m) was acquired from Sitio Padang on August 2, 1989. Later, a nest with eggs was discovered by a local resident, which was visited by CFI researchers on August 15, 1989. The nest was fenced with "boho" and mangrove sticks by its discoverer, probably to ward off intruders and/or predators that may destroy it. The substrate at the nest site was mud. The nest was 3.1 m from the water. Chamber temperature before opening was 30°C, whereas ambient temperature is 29°C and water temperature in a nearby stream, 26.4°C. Salinity of the surrounding water was 6.8 ppt (see Fig. 5). Nest dimension are on Fig. 6. The nest was constructed of mud, fibrous material from a vine, tree roots, and leaves of *Nypa fruticans*, *Pandanus sp.*, mangroves, and fern. Earthworms and insect larva were also in the nest material. Three groups of eggs were found in the nest, containing 9,6 and 8 eggs respectively from top. Two eggs at the bottom were cracked. Five of the eggs were previously brought to CFI while one was cooked and eaten by the discoverer. The total number of eggs laid, therefore, was 29. Twenty three of these eggs were artificially incubated at CFI; four hatched on October 11, 1989. It is likely that the discoverer opened and counted the eggs prior to our visit which may have affected embryo survival. Twenty-five meters from the current nest site, what appears to be the previous year's (1988) nest was located. A few years ago, a sighting of a hatchling and a breeding sized animal was reported 15 m from the present nest site, although a trap had been set there to no avail.

From Bugsuk Island, northeast of Balabac, a male *C. porosus* (TL = 2.8 m) was caught by snare trap and delivered to CFI on July 17, 1988. According to a reliable source, there are three other crocodiles caught and are held captive on the island to the present time but CFI could not gain access to the island because it is prohibited from outsiders. There is no data on these animals other than that two are "large" individuals, probably mature.

On Pandanan Island, two female *C. porosus* (TL = 56.2 and 52.2 cm) were caught accidentally in gill nets set for fish on May 8 and 9, 1990. These may be juveniles from a female *C. porosus* (TL = 2.63 m) caught from the island on October 10, 1992 and brought to the CFI.

On Ramos Island, CFI conducted trapping activities. In Kalukog River, two crocodiles, a male (TL = 2.31 m) and a female (TL = 2.63), were caught on September 29, 1990. Follow-up trapping on October 5-7 with 7 traps set, yielded nothing. CFI traps were designed to catch sub-adult and/or adult individuals, and the individuals caught may have been remnants in the area.

General Discussion

There is little doubt that other crocodiles exist within the 229 rivers on Palawan and more than 42 rivers in the islands of Busuanga (13+), Balabac (19), Dumaran (5), Bugsuk (1), Ramos (1), and Pandanan (3), even though none have been acquired or sighted. Some are very remote and difficult to access. However, it seems likely that very low densities will be the rule rather than the exception. Most of the CFI acquisitions were from southern Palawan suggesting this is perhaps the best area for remaining crocodiles, although such a distribution could also reflect a number of biases.

The results generally indicate that the *C. porosus* population in Palawan is widespread especially on the southern part of the island, but is at best a surviving remnant with little long-term future. The rivers are short, although numerous, and may simply not provide the habitat needed for a large population. It may be that some crocodiles migrate between adjacent rivers, if food is limiting or disturbances great. The extensive shoreline of Palawan offers numerous possible refuges for *C. porosus*, although it is not generally acceptable habitat for the species.

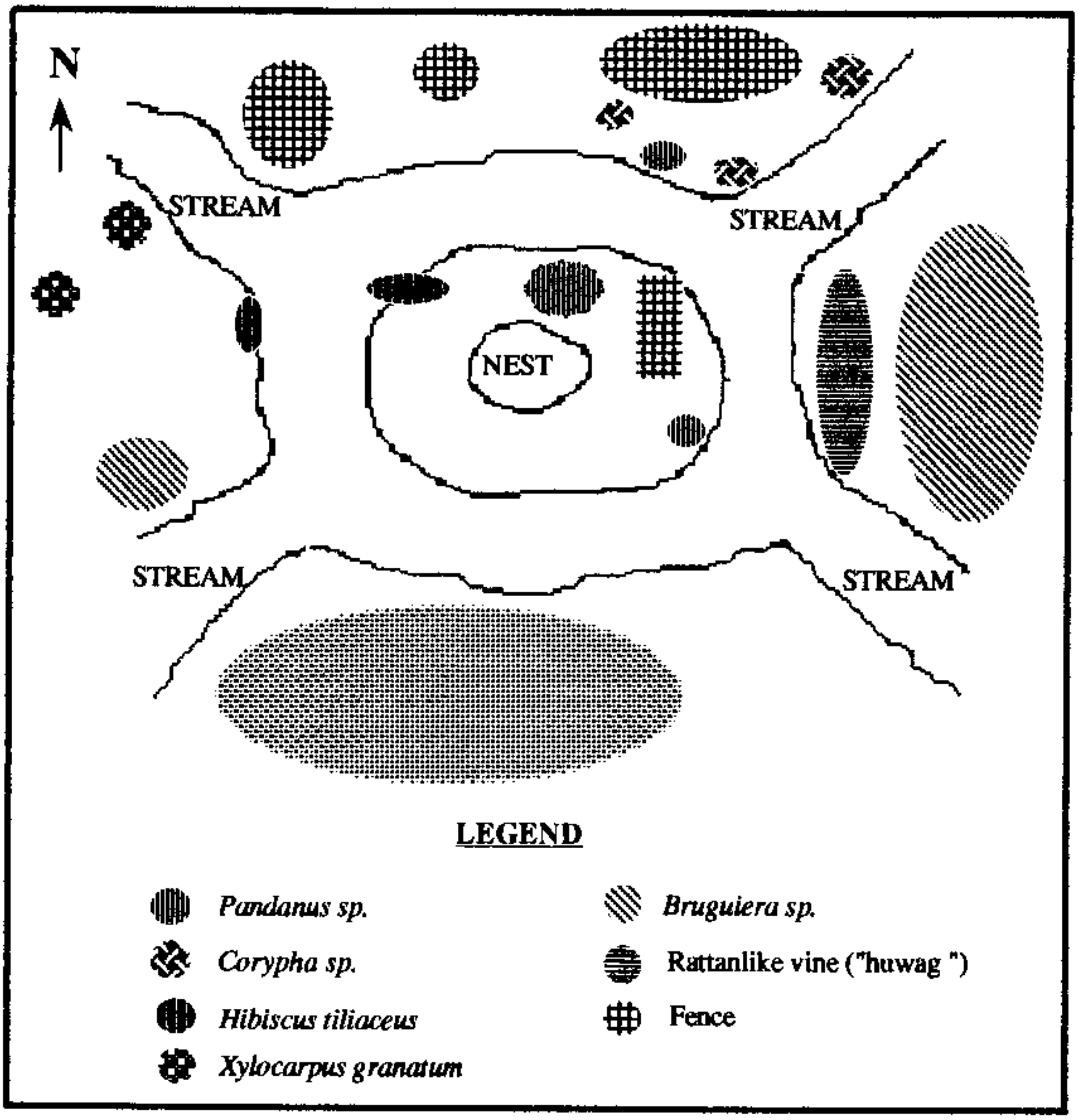

Fig. 5. Sketch map of the relative location of *C. porosus* nest in Padang, Dumaran including the surrounding flora.

Fewer acquisitions and sightings in later years of the study imply that the crocodile population in the wild was both small and was decreased significantly by the acquisition program. It must be stressed however, that the crocodiles in the Philippines are considered in immediate danger of extinction and that in the interests of conservation, their capture and relocation to the CFI, where they could be cared for and induced to breed, was a deliberate strategy employed. It was considered a desperate conservation situation requiring a bold initiative. The acquisition programme justifies further the extreme nature of the conservation problem at hand.

Crocodiles are considered vermin, and the local population are not willing to tolerate large wild populations. The compromise through catching animals alive for the CFI, gave direct economic benefit and has significantly increased the chances of survival of the remaining populations. There is no doubt that the attitude of people has become more favorable to crocodiles as a consequence of a commercial value being placed upon them, and as breeding

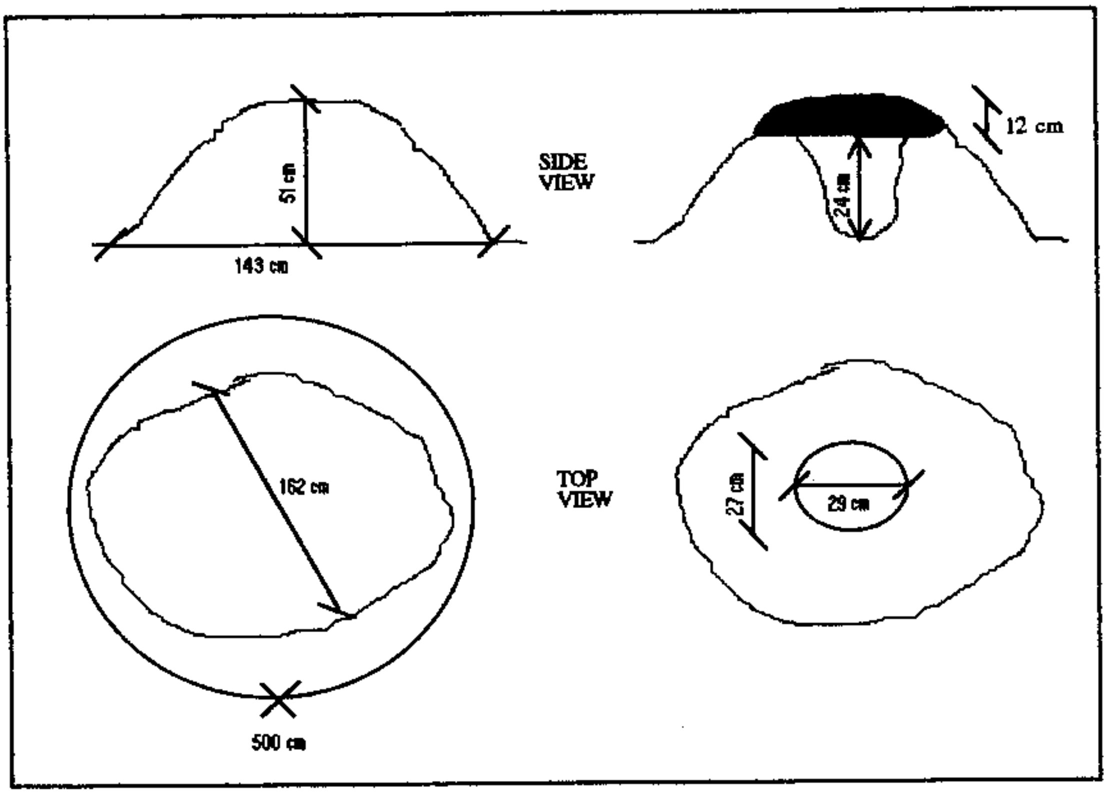

Fig. 6. Nest dimensions of nest in Padang, Dumaran Island.

continues at the CFI, numerous options may arise for re-establishing wild populations in an atmosphere of public acceptance, due to their potential for use as a natural, renewable resource.

The present hatchling production trend at the CFI signify a significant step towards realization of a self-sustaining crocodile conservation programme in the Philippines. Currently (September 30, 1992), CFI produced from wild caught breeders a considerable number of hatchlings ($n_{C.\ mindorensis} = 349$; $n_{C.\ porosus} = 805$). Commercial utilization of farm-produced crocodiles are at present being considered and may be realized in the near future.

CONCLUSION AND RECOMMENDATIONS

Based on our findings, we conclude therefore that:

1. *C. porosus* population is widespread on Palawan Island and the adjoining islands of Balabac, Ramos, Bugsuk, Pandanan and Dumaran. Results show however, that there are few breeding individuals in the wild, and the population as a whole is severely depleted. The increasing human population and steady loss of wetland habitats will be the main reason for the crocodiles' eventual extinction in the wild. Sighting or acquisition of crocodiles in supposedly unnatural habitats apparently indicate that crocodiles are highly mobile, perhaps attempting to find favorable habitats where they are not disturbed.

2. A small *C. mindorensis* population still occurs on the island of Busuanga.

3. Balabac previously have viable crocodile population but continuous destruction of its habitat and uncontrolled hunting will eventually lead to local extinction. The island appears to be the main crocodile habitat (nesting areas) at the southern portion of Palawan Province. The adjacent and proximate islands of Bugsuk, Ramos and Pandanan serve as feeding areas of crocodiles.

4. Crocodiles acquired from Dumaran may be the last remnants of a formerly viable population.

Based on the above conclusions and insights on results, we recommend that:

1. The remaining crocodile populations in the wild will undoubtedly become extinct in the not so distant future. Efforts made to gather the remaining animals, especially *C. mindorensis*, and breed them in captivity, offers the only practical approach to conservation. When local inhabitants approve their reintroduction into the wild, or into wildlife sanctuaries, the stock will be available to do it (see Messel *et al.* 1992).

2. Undertaking another 5-year study of wild crocodiles in the province of Palawan will further clarify the situation and status of crocodiles in the province.

3. Effective conservation of crocodiles in the province of Palawan, and probably applicable to the whole Philippine archipelago, will only be possible if economic benefits can be derived from the crocodiles.

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To all CFI personnel wbo have assisted us in one way or the other so that we may be able to realize this present work, our heartfelt thanks and indebtedness.

THE AUTHORS

Appendix 1. Crocodiles acquired from and reported sightings on the southern part of Palawan.

LOCATION	Year Acquired						Reported Sightings					
	1987	1988	1989	1990	1991	1992	1987	1988	1989	1990	1991	1992
NARRA												
Taritien River	*	*	*	*	*		+	+	+	+	+	
Malatgao River	*											
Panacan River		*										
QUEZON												
Panitian River			*	*				+				
Agurang River			*					+				
Irasol River, Aramaywan	*		*					+				
Irasol River, Balintang	*											
Lubgob River, Balintang	*											
Maranay River, Balintang	*				*							
Balintang River		*	*	*								
Tumarbong River			*	*	*	*		+			+	
Quinlogan River			*	*					+			
Isugod River			*	*								
Tabon River			*									
Iwahig River			*									
Maasin River				*								
Lamikan River				*								
Quezon		*			*	*						
BATARAZA												
Ocayan River			*						+			
Puring River									+			
Rio Tuba River				*	*							
Pinunglo River			*									
Sumbiling River			*									
Palihi River			*									
Bagusay River			*									
Taisay River			*									
Iwahig River			*									
Sarong River				*								
Ongong River				*								
Bataraza River	*				*							
BROOKE'S POINT												
Taghalogo River								+				
Brgy. Saraza				*						+		
ABORLAN												
Maasin River	*											
Isaub River									+			+
Kamuning River									+			
May-iligan River											+	+
RIZAL												
Isugod River			*									
Ransang River				*								
Campung Ulay				*								
Culasian River					*							
Dignosan River					*							
Rizal					*							
PTO. PRINCESA												
Abanico, San Pedro					*							
Alimbugas, Napsan					*							

Appendix 2. Crocodiles acquired from and reported sightings on the northern part of Palawan.

LOCATION	Year Acquired						Reported Sightings					
	1987	1988	1989	1990	1991	1992	1987	1988	1989	1990	1991	1992
ROXAS												
Barbacan River									+			
Ilian River								+				
Calabucay River								+				
Malico River		*										
Irrigation Dam								+				
Brgy. Sandoval								+				
San Jose		*										
Caruray , San Vicente								+				
Port Barton								+				
Boayan River								+				
Tarapiton River								+				
New Agutaya								+				
TAYTAY												
Abongan River		*						+		+		
Kawayakan River								+				
Alacalian River								+				
Pinagupitan River								+				
Lipid River								+				
Ibay River								+				
PTO. PRINCESA												
Sabang Bay								+				
Bacungan River			*						+	+		+
Panikian River				*								

Appendix 3. Crocodiles acquired from and reported on Balabac Island.

LOCATION	Year Acquired				Year Reported			
	1988	1989	1990	1991	1988	1989	1990	1991
Palisan River					+			
Tukanigalo River	*			*	+		+	+
Bucana River					+			
Rampang River			*				+	
Kalibuman River								+
Pananaan River							+	
Karitan River							+	
Kalukog River			*				+	
Karunutan River			*				+	+
Balabac	*							

Appendix 4. Crocodiles acquired from the islands of Ramos, Pandanan and Bugsul

LOCATION	Year Acquired		
	1988	1989	1990
Ramos			*
Pandanan			*
Bugsuk	*		

Appendix 5

Areas Visited by CFI Personnel

1. Dipuyai and Busuanga Rivers, Busuanga
2. Coron
3. Taytay
4. Bato and Ayacayan Rivers, Old Guinlo, Taytay
5. Abongan River, Taytay
6. Lake Manguao, Calauag areas, Taytay
7. Panyan, Siangal, Dumaran
8. Guinaratan River, Roxas
9. Barbacan River, Roxas
10. Panikian River, Ulugan, Puerto Princesa City
11. Bacungan River, Puerto Princesa City
12. Isaub River, Aborlan
13. Moon and Taritien Rivers, Narra
14. Tumarabong and Isugod Rivers, Birong, Quezon
15. Lamikan and Quinlogan Rivers, Quezon
16. Rio Tuba, Bataraza
17. Kalukog, Rampang, Karunutan and Kalibunan Rivers, Balabac

TITLE: Crocodile husbandry research and effective experimental design.

Gregor Riese, Crocodile Farms N.T. Pty Ltd., P.O. Box 37866, WINNELLIE, N.T., AUSTRALIA.

I've been employed by Crocodile Farms N.T. Pty Ltd (CFNT), a large commercially operated farm located just out of Darwin, since October 1990. One of my functions there has been to study the captive husbandry of *Crocodylus porosus* looking at ways of improving growth of this species in captivity in association with the University of Queensland. This has involved carrying out my own experimental trials on hatchling *C.porosus* as well as reviewing literature on other research.

I've titled this presentation "crocodile husbandry research and effective experimental design" because of the apparent need to look more closely at the way in which husbandry research is carried out on crocodilians as well as the way in which the results are interpreted. The point that I wish to make in this paper is that when planning husbandry research on crocodilians, too little attention is placed on experimental design. I'll be providing some examples to illustrate this point from my own data and some published works.

The literature on crocodile husbandry is fairly scarce and widely dispersed in various journals and publications. The most valuable information produced to date with some notable exceptions is largely fbo f—_< +Bn$_ô(rather than quantitative. Of the quantitative studies, experimental results may not agree with actual experience. I've listed a few examples here.

Summary of some crocodile husbandry research results.

Paper	Treatment	Species	Result	
Zilber et al	Density	C.niloticus	"no adverse effects of high density" (15/m2)	(1992)
Garnett et al	Density	C.porosus	Insignificant/ Disordinal response	(1986)
Garnett et al	Handling frequency	C.porosus	Insignificant/ Disordinal response	(1986)
Zilber et al	Light/ temperature	C.niloticus	High temperature & direct sunlight improves growth	(1992)
CFNT Data	Shelter	C.porosus	Non-significant effect	
Garnett et al	Diet	C.porosus	Clutch-specific effect	(1986)
Manolis et al				(1989)

Obviously, if a crocodile farmer actually went to the effort to read some of this published material, he or she may feel somewhat at a loss in deciding under what principles to manage their stock let alone how to respond to any production problems which may occur. From these results it would appear that density, diet, shelter, thermal environment - have an ambiguous influence upon crocodilian growth. There is obviously some contradiction between these results and actual experience.

I've summarized the caused of some common experimental failings under four headings:

SOME COMMON EXPERIMENTAL DESIGN FAILINGS

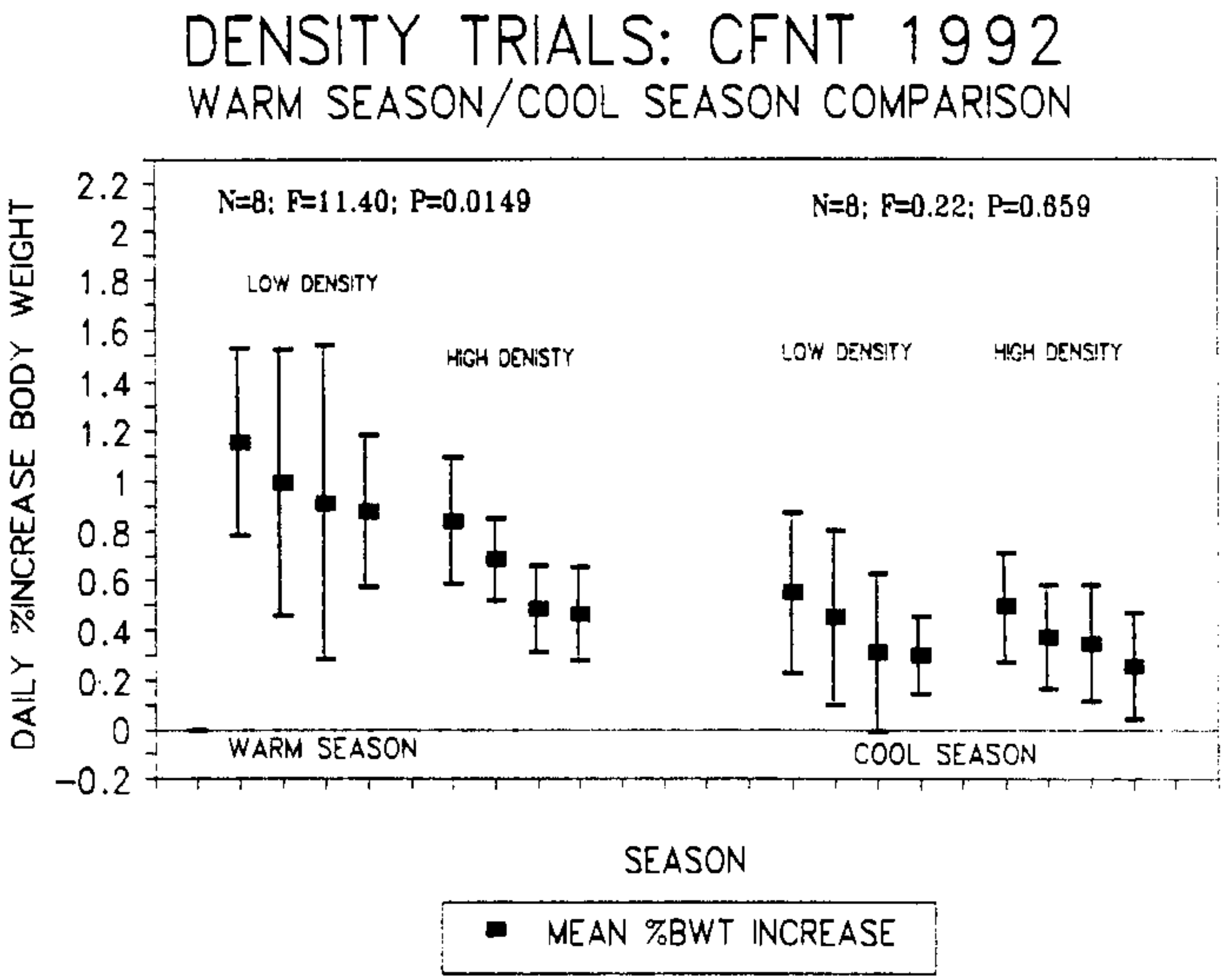
1) Treatment effects disguised by clutch specific growth patterns
These can be minimized through the randomization of clutches throughout treatments.

2) Inadequate replication (pseudoreplication): either in terms of inadequate sample size, non-conformity in treatments applied, treating individual hatchlings as a statistical degree of freedom.

3) Non-treatment: the treatment being applied is invalid or is not what you think it is.
eg: CFNT experiment testing varying degrees shelter provided to hatchlings. My perception of an increase or decrease in shelter being provided to trial animals was not a perception shared by those animals. The spatial arrangement of hatchlings was identical in all treatments, usually piled up in corners. They really didn't care very much for the shelter I provided and the result was an insignificant treatment effect.

eg: Zilber et al in their sunlight/temperature experiment concluded that both the provision of sunlight and high temperatures had a positive effect upon growth, however their design did not isolate these two factors. Obviously sunlight provides the possibility of higher body temperatures to those animals with access to it which is deprived those non-sunlight treatments.

FIG. 1.



DENSITY TRIALS: CFNT 1992
WARM SEASON/COOL SEASON COMPARISON
N=8; F=11.40; P=0.0149
N=8; F=0.22; P=0.659
LOW DENSITY
HIGH DENISTY
LOW DENSITY
HIGH DENSITY
WARM SEASON
COOL SEASON
DAILY %INCREASE BODY WEIGHT
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
−0.2
SEASON
MEAN %BWT INCREASE

4) Disguising of treatment effects: growth inhibiting factors override the treatment effects. This is best illustrated by dietary trials where a host of factors will influence the timing and quantity of food intake by an animal under experimental conditions before the dietary treatment can take effect. If one can imagine a dietary trial being established under sub-optimal thermal conditions for the species in question there would be little stimulus to initiate feeding in the first place.

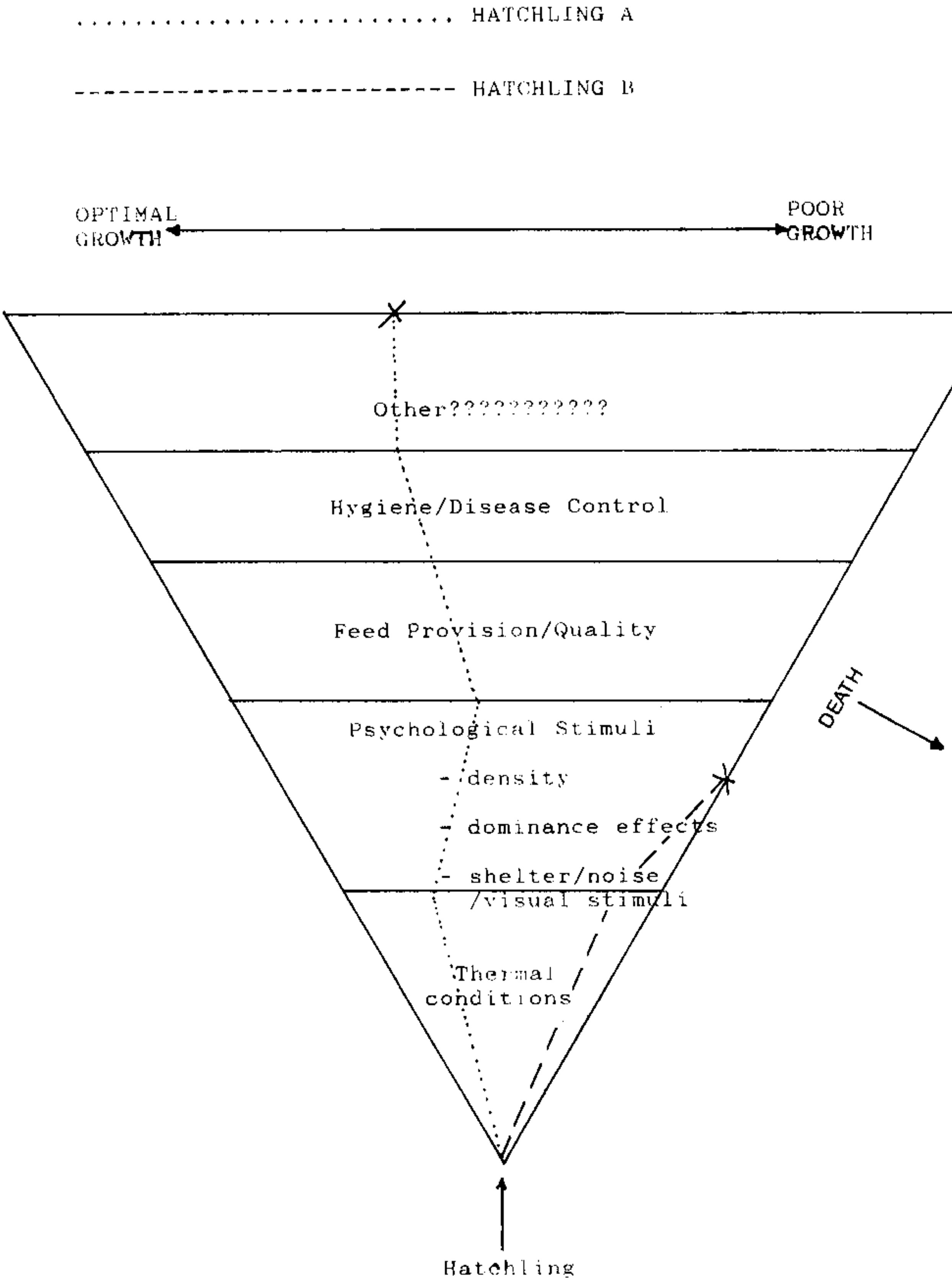
To provide you with some real data to illustrate this point this is an example of a trial carried out at CFNT testing the effects of density on C.porosus.

FIG. 1

The experiment was repeated once in the warm season and once in the cool season. The results show significant effects for density in the warm season during the high growth period and no significant effect for density when the experiment was repeated in the cool season. The drop in growth rates is also apparent.

FIG. 2.

GROWTH DETERMINATION MODEL



This suggests the need for a model which ranks growth-influencing factors in levels of priority allowing researchers and managers assess where growth-inhibiting factors may lie.

FIG. 2

I've based this model largely on Dr Hutton's paper (1989) "Science and the principles behind successful Alligator and Crocodile production", Dr Lang's (1987) papers on crocodilian thermoregulation and behaviour. The model attempts to rank growth influencing factors on crocodilians. It is a considerably simplification of the real situation as it ignores genetic (clutch specific) influences upon growth.

The ideas put forward in the model actually tie in nicely with Dr Hutton's idea's on the basic principles to crocodile farming.

These are: 1) Good incubation and neonatal treatment

2) Maintenance of a high metabolic rate'

3) Elimination of stress

4) Adequate nutrition

The model suggests that it would be unwise to test for density effects in a poor thermal environment. Likewise it would be inappropriate to carry out dietary trial within a poor thermal environment or at excessively high densities, and so on. Experimental results in crocodilian husbandry should be interpreted with a close eye on the experimental design.

To conclude, I suggest that it is very easy to obtain a non-significant result when testing growth influencing factors in crocodilians, for reasons which have just been discused. A lot more thought needs to go into planning husbandry experimentation with crocodilians which should lead to more meaningful results being generated from husbandry research.

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THE CROCODILIANS OF MALAYSIA
« A REVIEW »

by

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CROCODILIANS OF MALAYSIA - A REVIEW

MALAYSIA

Malaysia geographically comprises the Malay Peninsula (south-southeastern tip of the Asian Continent), Sabah and Sarawak (on the island of Borneo).

Peninsular Malaysia extends from latitude 1°20'N to 6°40'N and longitude 99°35'E to 104°20'E. It is bounded to the east by the South China Sea and to the west by the Straits of Malacca sharing a common boundary with Thailand to the north and separated from the island of Singapore in the south by the narrow Straits of Johor. Peninsular Malaysia stretches for 736 km with a maximum width of 322 km and has 1,930 km of coastline. There are eleven states and the Federal Territory of Kuala Lumpur, covering a land area of 131,600 sq.km.

Sabah lies between 4°10'N and 7°40'N, 115°10'E and 119°20'E and is the northernmost state. It has a land area of 73,700 sq.km. with mountains dominating much of its interior. The Crocker Range runs northwest to a granite massif, Mount Kinabalu (4,101 m), the highest peak in southeast Asia between the Himalaya and New Guinea.

The northeast monsoon (Dec-Mar) and the southwest monsoon (Jun-Nov) form two distinct seasons. The northeast monsoon brings heavy rains to the interior leaving the west coast dry but receiving heavy rains during the southwest monsoon. Average temperatures vary little between maximums of 30°C during the day and 25°C at night.

Sarawak lies in northwestern Borneo between 0°50'N, 5°00'N and 109°30'E, 115°40'E. It has a single coastline length of 1,050 km along the South China Sea. The coastal lowlands are intersected by numerous rivers forming deltas and wetlands in which mangrove and nipa forests (1.4% of total land area) and peat swamps (11.9%) dominate. These wetlands constitute roughly 1,640,000 ha or 13.3% of the state and represent some of the best wetlands and the largest tract of peat swamp forest in the country.

TABLE I - DISTRIBUTION AND EXTENT OF MAJOR FOREST TYPES IN MALAYSIA (million ha)

REGION	LAND AREA	DIPTEROCARP	SWAMP	MANGROVE	TOTAL FOREST	% TOTAL OF FORESTED LAND
Peninsular	13.16	5.62	0.46	0.11	6.19	47.0
Sabah	7.37	3.98	0.19	0.32	4.49	60.9
Sarawak	12.33	7.78	1.47	0.17	9.42	76.4
Malaysia	32.86	17.38	2.12	0.60	20.10	61.2

Source : Forestry in Malaysia

In summary, Malaysia has a total land area of 32,860,000 ha, with 2,720,000 ha (8.28%) of wetlands. The east coast of Sabah has the largest area of mangrove forest in the country, comprising some 320,000 ha or 53.3% of Malaysia's mangrove forest. Swamp forests constitute two different types, freshwater swamp forest and peat swamp forest. Freshwater swamps are the most seriously threatened wetland habitat in the country. Peninsular Malaysia has borne the bulk of development, presently supporting about 83% of the country's population.

DESCRIPTION OF WETLAND HABITAT TYPES

Mangrove Forests

600,000 ha of mangroves remain in Malaysia, restricted mainly to Sabah with 53.3% and Sarawak with 28.3% (accounting for 81.6%). In Peninsular Malaysia (18.3%), mangroves occur primarily along the west coast in the states of Perak, Selangor and Johor. Mangroves represent a rich and diverse ecosystem with many specialized and endemic species of flora and fauna. The intertidal mudflats associated with mangrove ecosystems also support rich benthic fauna and provide vital feeding, stop-over and wintering areas for migratory waders. Heavy pressure from development along the coasts has threatened these feeding grounds and are threatening the wintering populations of waders throughout the country.

Typical mangrove specialists include Mangrove Pitta *Pitta megarhyncha*, Mangrove Blue Flycatcher *Cyornis rufigastra*, Milky Stork *Mycteria cinerea*, Silvered Leaf-monkey *Trachypithecus cristatus* and the Bornean endemic, the Proboscis Monkey *Nasalis larvatus*.

Nipa swamps

Nipa swamps are tidal, monospecific tracts of the Nipa Palm *Nypa fruticans* which occur in association with mangroves and the brackish tidal reaches of rivers. Many of the deltas of Sarawak and Sabah have huge areas of nipa swamps, providing habitat for Proboscis Monkeys and waterbirds. The fronds of the Nipa palm are harvested by local villagers and used for making thatched roofs and also as cigarettes.

Freshwater Swamp Forest

This forest occurs in seasonally and permanently inundated areas along rivers and freshwater lakes. A species rich and diverse habitat, freshwater swamp forests provide support many endangered species of wildlife such as the Storm's Stork *Ciconia stormi*, Otter Civet *Cyanogale bennettii* and the highly endangered Sumatran Rhinoceros *Dicerorhinus sumatrensis*.

Extensive conversion to agriculture has made this habitat the most threatened wetland type in Malaysia and today is restricted to small isolated areas in Johor, Sabah and Sarawak.

Peat Swamp Forest

This forest occurs on peaty soils with high acid-sulphate content. Tannin released into the water from decaying leaves gives the water its characteristic tea-colour (known as blackwater). Peat swamp forests occur in alluvial basins with lagoonal profiles and present a species-rich wetland habitat. Recent draining of peat swamps in southeast Asia has resulted in a potentially catastrophic situation, the burning of dried out peat soils. Dry peat is highly susceptible to spontaneous combustion and smouldering peat can burn underground for years, erupting above ground during extended dry periods. Recent years have seen smoke from peat fires in eastern Kalimantan (Indonesian Borneo) spreading over the entire region and causing throat, lung and eye infections and reduced visibility, affecting aircraft movements.

Peat swamps support faunal and floral communities similar to freshwater swamp forests. Swamp forests in general serve as aquifers and play vital roles in flood mitigation and ground-water recharge. The complex hydrology of swamp forests pose management problems, especially where fragmentation has occurred, to the long-term preservation of viable tracts of this wetland habitat.

Freshwater Lakes

Large natural lakes do not feature prominently in this country. Tasek Bera and Tasek Chini in Pahang in the peninsula and Loagan Bunut in Sarawak (an ox-bow lake) are the most significant. Many large reservoirs have been formed over the past two decades from the building of dams. Lakes provide habitat for endangered species such as terrapins, and some species of fish.

The lower reaches of the major rivers in East Malaysia (the Baram and Limbang in Sarawak and the Kinabatangan, Sugut and Segama in Sabah) have numerous ox-bow lakes. These lakes, especially those in the remote upper reaches, are often fringed by thick floating vegetation mats and support rich fish populations.

The advent of tin-mining in the 1840s, which paved the way for the development of the Malay peninsula, inadvertently created a new wetland habitat, the mining pools. These pools have today become some of the richest artificial wetlands in the country. Surface mining creates extensive lakes of varying depths which gradually get colonized by aquatic plants and *Phragmites* reed-beds and support many waterbirds.

River Systems

Malaysia boasts some 100 river systems with the Rajang, Pahang, Kinabatangan and Baram as the largest, covering huge catchment areas (the catchment of the Rajang itself is 51,000 sq.km.). The numerous tributaries and the terrain create individually distinct riverine habitats, with six distinct types of rivers recognized in Malaysia.

This habitat is home to a diverse fish fauna such as the elusive freshwater Stingray in the Pahang river (Joan Cramphorn, pers. comm.) and endangered animals such as the Hairy-nosed Otter *Lutra sumatrana*, rediscovered in 1992 in Malaysia after 25 years (Sebastian, in prep.).

Marshes

Typical open marshland is not a naturally occurring habitat in this country. The few marsh habitats all occur in Sabah. Marsh habitats have not been studied in this country and need some attention in the near future to assess the values of these wetlands.

Figures 1 and 2 show the distribution of wetlands in Malaysia.

Figure 1 Wetlands of Peninsular Malaysia

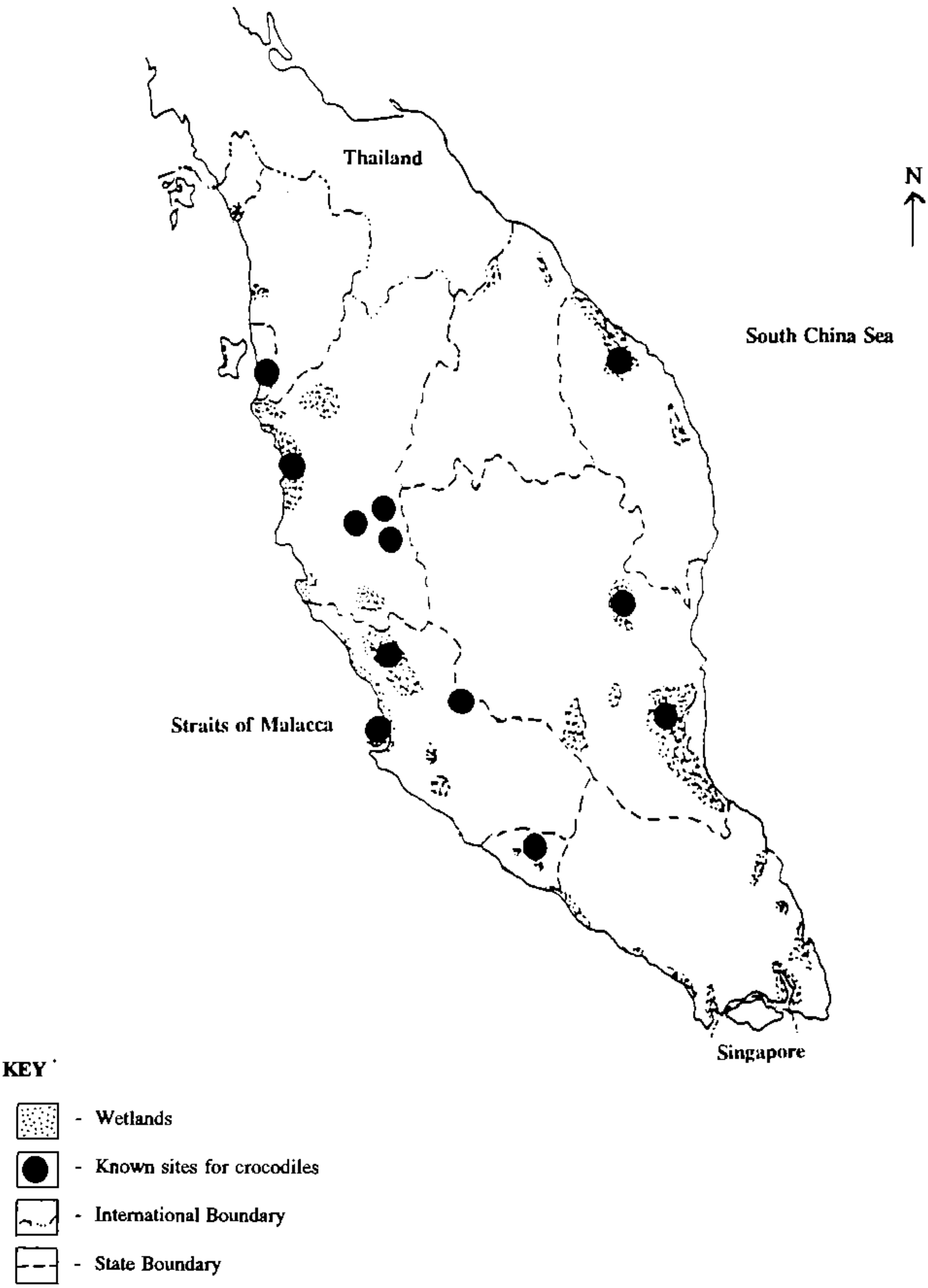
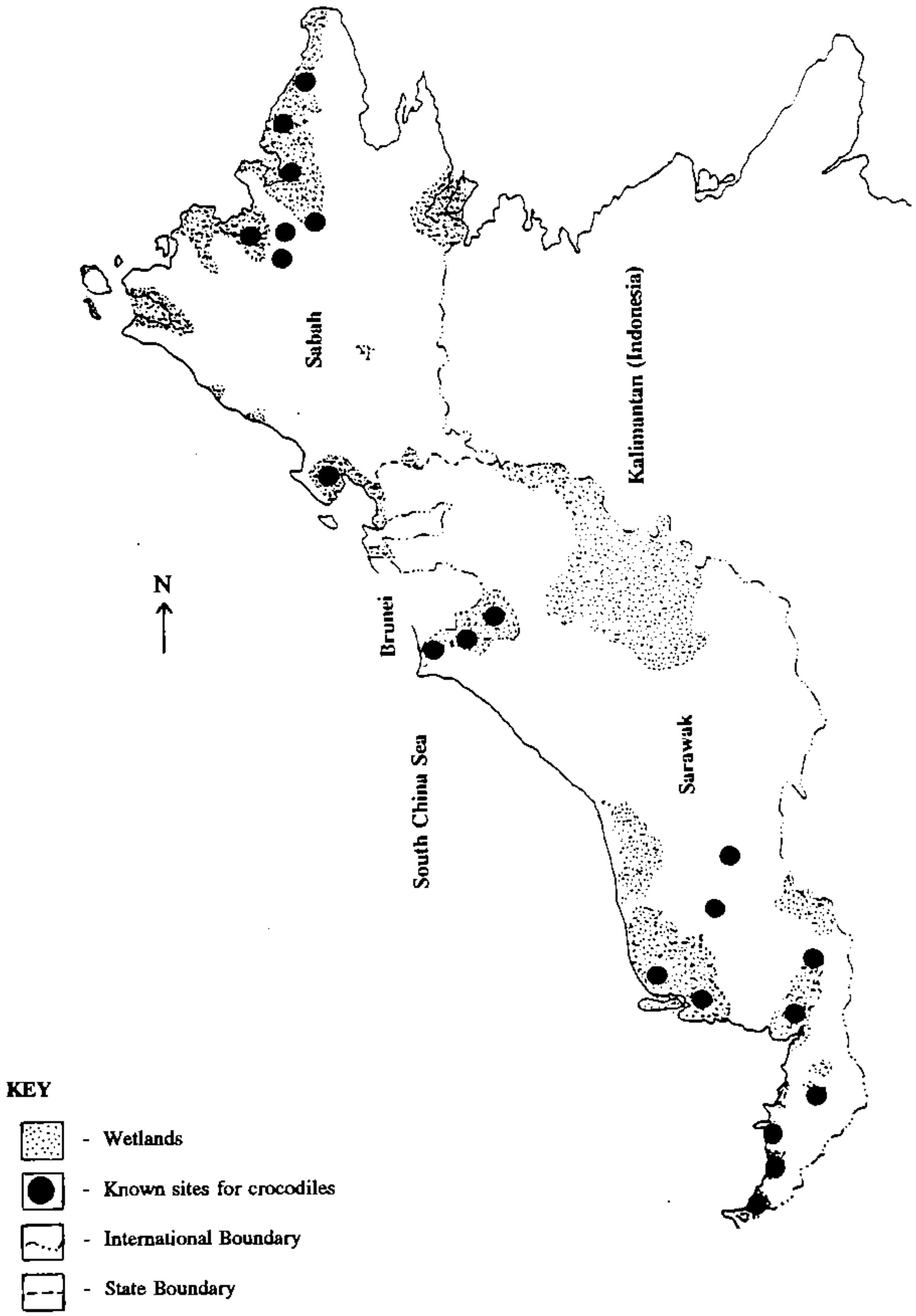


Figure 2 Wetlands of East Malaysia (Sabah and Sarawak)



HISTORICAL STATUS OF CROCODILIANS

Peninsular Malaysia

Historically, only two species of crocodile have been known to occur, the Estuarine Crocodile *Crocodylus porosus* and the Malayan False Gharial or Tomistoma *Tomistoma schlegelii*. Although *T.schlegelii* never occurred in high densities, *C. porosus* was probably once common in estuaries and rivers and the large tract of swampforest along the alluvial lowlands of the west coast. The sixties and seventies witnessed an ever increasing export of crocodile skins from the region and undoubtedly played a part in the decline of *C. porosus* in the peninsula. The mining pools were probably colonized extensively by *C. porosus* in the early years. The past twenty years have seen the rehabilitation of these 'wastelands' for industry and housing. Most of the crocodiles were caught and sent to farms (Mohd. Tajuddin, PERHILITAN, pers.comm.).

T. schlegelii has been poorly recorded in literature and this lack of information may be consistent with the theory that this species naturally occurs in low densities. Two records from the immediate vicinity of the North Selangor Peat Swamp Forest, one caught close to the Bernam River in the seventies (Marsh, 1982) and a crocodile caught in the Tengi river (which flows out of this swampforest) fitting the description of a Tomistoma in 1988 (Mohd. Rosli, pers.comm.) suggest the continued presence of this species in the state of Selangor.

The Siamese Crocodile *C. siamensis* has never been recorded in Peninsular Malaysia though historical records show it existed just north of the Malaysian-Thailand border (Groombridge, 1982).

There has been no records of a crocodile survey done in Peninsular Malaysia to date.

Sabah

Historically, three species of crocodilian are known to occur in Borneo although only one has ever been recorded in Sabah, the northeastern part of the island. The Siamese Crocodile *Crocodylus siamensis* has never been recorded though it may have in the past. *T. schlegelii* is thought to have never spread to the northeastern side of the island (Whitaker, 1984). The Siamese Crocodile *Crocodylus siamensis* has been recorded in the Indonesian archipelago from Borneo, Sumatra, Bangka and Sulawesi (Ross, 1986) but the presence and distribution of this species in Borneo has never been studied. Frazier and Maturbongs (1990) have recently confirmed the presence of *C. siamensis* in Kalimantan Borneo (Indonesia). There have been suggestions to revive the taxonomy of an endemic species of crocodile to Borneo, *Crocodylus raninus* (Ross, 1990). Investigations should be made to confirm the existence of a new distinct species or the presence of a race of *C. siamensis* in Borneo.

A survey of crocodiles was conducted in 1984.

Sarawak

The presence of *C. porosus*, *C. siamensis* and *T. schlegelii* is historical although within the last ten years, only *C. porosus* and *T. schlegelii* have been confirmed. *C. porosus* was present in most of the larger rivers and inland waterbodies and the sight of crocodiles basking on river banks was common in the mid-sixties (Jacob Sebastian, pers.comm.). Regular reports of crocodile attacks in the interior have long been attributed to this species. Tomistoma was largely unknown with relatively few records, again undoubtedly due to the dense haunts of this species. *C. siamensis* has never been recorded in Sarawak to date. However, while the Tomistoma differs considerably from *C. porosus* and is easily distinguished from the latter by locals, *C. siamensis* does not differ very much from *C. porosus* to the casual observer and reports of crocodiles from locals cannot be safely regarded as *C. porosus* without expert observation or examination.

The most recent survey of crocodilians in Sarawak was in 1985.

CURRENT STATUS OF CROCODILIANS IN MALAYSIA

Estuarine Crocodile

The Estuarine Crocodile has been recorded in most wetland habitats in Malaysia, from mangroves to the remote reaches of rivers and inland freshwater lakes. East and West Malaysia are treated separately below.

Peninsular Malaysia

In Peninsular Malaysia, this species is now considered rare in the wild. The innate fear of these large reptiles have lead to their 'removal' whenever sighted or known to occur in an area close to human habitation. The National Parks and Wildlife Department (PERHILITAN) has a crocodile-catching squad to attend to any crocodiles sighted. Captured animals are sent to zoos or croc farms.

The last stronghold in the peninsula might be the Setiu-Chalok-Bari basin, an area of swampforest and *Melaleuca* forest fed by three rivers. This basin is situated on the east coast of Peninsular Malaysia in the state of Trengganu, 40km north of Kuala Trengganu, the state capital. These three rivers eventually join to flow into the Setiu lagoon, a 22 km long shallow brackish lagoon formed by long-shore drift action, a characteristic feature of many rivers along the east coast of the peninsula. Local entrepreneurs conduct organized tours up the river to watch crocodiles. Although no surveys have been conducted specifically for crocodiles, recent bird and vegetation surveys in the basin (Asian Wetland Bureau, 1992) indicated ideal habitat for crocodiles. This area is presently under threat from a planned flood mitigation scheme which would cause drainage of this basin during the dry season (Sebastian and Davies, 1992).

In Peninsular Malaysia, the Estuarine Crocodile is listed as *Totally Protected Species* under the Protection of Wildlife Act 1980 (amended in 1983).

Sabah

In Sabah (East Malaysia), the situation is more encouraging. *C. porosus* still occurs in many areas, and is reported to be common in the Kinabatangan River, its numerous oxbow lakes and associated floodplain. The distribution of this species appears to be mainly restricted to the eastern part of the state with only one confirmed record of *C. porosus* from the west coast, the swampforests of the Klias Peninsula.

Sarawak

Crocodiles still occur in most of the major rivers in Sarawak though probably in low densities. The infamous Bujang Senang "Easy Bachelor" till today remains at large, having terrorized villagers and eluded numerous intensive hunts for over ten years. Reputed to be 20ft in length, this Estuarine Crocodile has claimed over 12 lives along the Batang Lupar in Sarawak. Cox and Gombek (1985) recorded *C. porosus* in most of the inland lakes and river systems they surveyed in Sabah and Sarawak.

The Estuarine Crocodile is listed as a *Protected Species* in Sarawak. This category (as opposed to the *Totally Protected Species*) allows native rural residents of traditional lifestyle, who legitimately need to hunt these animals for their own consumption, to hunt this species without a licence (Wild Life Protection Ordinance 1958).

Tomistoma

Peninsular Malaysia

This reptile remains largely unknown in Peninsular Malaysia. The North Selangor Peat Swamp Forest may still have a small population of Tomistomas. In December 1992, there was an unconfirmed record of a Tomistoma from an unidentified river in the Ayer Hitam - Bukit Mertajam area in the state of Penang (mainland Penang). Surveys of the fish fauna of the Pahang river by the Asian Wetland Bureau in February-March 1993 reported numerous sightings from local fishermen of two species of crocodiles in the Jemur river, a tributary of the Pahang river. One net put up by the survey team was found missing, suspectedly taken by a crocodile (Patrick Lee, pers.comm.). Siltation at the confluence of the Jemur and the Pahang river has created numerous deep pools along this slow flowing eutrophic river. This site should be given priority for crocodile surveys in the future.

The Tomistoma is likely to be restricted to pristine riverine habitats which today remain mostly along waterways in swampforests. The presence of Tomistoma in Tasek Bera was described in the early seventies but no records of any crocodiles have been received in the past ten years. This could be due to a combination of the destruction of natural swamp forest habitat surrounding the lake system in recent years and hunting pressure.

The Tomistoma is a *Totally Protected Species* in Peninsular Malaysia.

Sabah

The Tomistoma has never been recorded in Sabah.

Sarawak

Cox and Gombek (1985) recorded Tomistoma in only one river system, the Ensengai Baki in the First Division in Sarawak. They believe that the species may also occur in the more interior of the state, in areas not covered by their surveys. If this is true, Sarawak will be the last stronghold for this species in Malaysia as the more developed and heavily populated peninsula has very little remaining natural habitat capable of supporting viable populations of such a large predator. The most recent population estimates for Sarawak were between 500-1000 wild animals (Whitaker & Whitaker, 1989).

The Tomistoma is also listed as a *Protected Species* in Sarawak

Siamese Crocodile

The Siamese Crocodile has never been recorded from Malaysia. Recent evidence of its presence in eastern Kalimantan on the island of Borneo suggests the possibility of this species occurring in East Malaysia.

Table II at the back of this document provides a list of wetland sites in Malaysia where records of crocodilians have been received or have been confirmed from surveys or from existing literature.

THREATS

The following have been identified as threats directly and indirectly affecting crocodiles in Malaysia. Some attempt has been made to list them in order of seriousness but this remains indefinitive.

Habitat Loss

The loss of suitable habitat has invariably contributed significantly to the decline of crocodilians in the country and today remains the most significant contributing factor to their continued decline. An ever increasing demand for space, especially on the coast, has resulted in a 30% loss of wetlands in Peninsular Malaysia since 1987, a period of only five years. The mangrove habitat, backed by extensive swampforests, which once covered the entire west coast of the peninsula today totals 110,000 ha of which 41,000 ha constitutes the Matang Forest Reserve in Perak and 23,000 ha the Klang Islands in Selangor, these two sites accounting for more than half of the total mangrove forest area of the peninsula (Malaysian Wetland Directory, 1987). The only significant remaining area of swamp forest on the west coast is the North Selangor Peat Swamp Forest (30,000 ha) and recent evidence suggesting the continued presence of crocodilians in this forest confirms that both these habitats provided excellent habitat for crocodilians in the past.

Fishing Activity

Intensive fishing activity along entire stretches of all the major rivers have severely depleted fish stocks. Fishing methods have increased in efficiency which lead to the banning of the use of drift-nets in Malaysia as a method having serious effects on both marine and freshwater fish populations. The use of poisons, both traditional root-extracts and insecticides/weedicides predominantly along the upper reaches and tributaries have effectively wiped out fish populations along some the smaller rivers. Another more recent technique, electro-fishing, is posing an increasingly serious threat to freshwater fish populations.

The loss of food supplies are believed to have also contributed to the decline of crocodilians, particularly the exclusively fish-eating Tomistomas. The effect of the use of long-lines (baited hooks) to catch larger fish and terrapins on crocodiles, particularly juveniles and hatchlings is unknown.

Human Persecution

This is also a significant factor threatening crocodiles in Malaysia. Crocodiles are invariably killed or trapped on sight, mainly from fear and bad media publicity (see Appendix I). In 1992, three incidents were covered in the local newspapers where crocodiles were spotted in lakes and mining pools, close to recreational areas causing widespread panic and public avoidance of these areas. These animals were all caught and removed to safer areas, namely crocodile farms.

The capture of hatchlings for sale to crocodile farms continues but at unquantifiable levels.

Pollution

The densely populated west coast of the peninsula has resulted in many of the rivers becoming polluted. Again, the effect of pollution of crocodiles is unknown.

SURVEYS

The bulk of information of crocodilians in Peninsular Malaysia comes from incidental sightings and reports from locals. The significant lack of recent survey presents a major obstacle to the formulation of any conservation plans. In response to this urgent need for survey data on crocodilians in Malaysia, the Asian Wetland Bureau, a non-government organization based in Kuala Lumpur, has initiated preliminary survey work. These surveys however, have been on an *ad hoc* basis, and only in wetlands where other survey work is currently being conducted and when personnel are available.

It must be emphasized that to date, no comprehensive survey of crocodilians has been carried out in Peninsular Malaysia. The situation is similar in East Malaysia where the last crocodile survey was done in 1985 and was preliminary. Survey work in Sarawak is a logistically difficult task due to the remoteness of the interior and limited access.

CONCLUSIONS

The status of crocodilians in Malaysia is definitely of concern. In Peninsular Malaysia, both species bave reacbed seriously low population levels and are in danger of becoming extinct, the Tomistoma in particular. In East Malaysia, *C. porosus* survives and though in low densities, is not in immediate danger of extinction with viable populations in certain areas. The Tomistoma occurs in much lower densities and is more specific in its habitat requirements. The lack of information on this species is probably more from a lack of comprehensive surveys than an actual absence. Also, the Tomistoma is believed to naturally occur in low densities, even in ideal habitats.

PROPOSAL FOR CONSERVATION WORK ON CROCODILIANS IN MALAYSIA

Justification

In recognition of the urgent need for efforts to conserve the remaining populations of these highly endangered reptiles, a series of proposals have been identified to address this issue. It is proposed that a national action plan be drawn up incorporating all these proposals and to identify relevant actions for the conservation of crocodiles in Malaysia. This action plan will be tailored in line with the national policies of the country with the ultimate aim of establishing a *National Crocodilian Conservation Strategy*. Due to the political and legislative differences between East and West Malaysia, this plan may require separate treatment for the Peninsular and Sabah/Sarawak.

Priority should be given to the establishment of a sanctuary for crocodilians, covering sufficient areas of pristine natural habitat required to support a viable crocodile population. The urgency in identifying potential sites cannot be over-emphasized.

National Crocodilian Conservation Strategy

It is proposed that a conservation strategy be formulated for the protection and preservation of crocodilians in Malaysia. A detailed project proposal is yet to be drawn up but its mention here is to give an overview of the situation and the proposed scope of the project. The objectives of this strategy are listed below.

i. To record and map out the distribution of crocodilians in the country.

ii. To identify habitat types which support viable populations of crocodilians and to identify viable populations occurring within existing protected areas.

iii. To propose the gazetting of areas identified as supporting viable breeding crocodile populations as wildlife sanctuaries to protect the species from exploitation.

iv. To identify threats to crocodilians in the wild and propose mitigating measures.

v. To formulate a monitoring strategy for farming operations in the country.

vi. To initiate research on the ecology and breeding biology of the Malayan False Gharial and identify research organizations to undertake this work.

vii. Alternatively, to establish a Crocodile Research Centre in Malaysia with facilities for ecologieal studies on crocodilians, particularly the False Gharial. A captive breeding programme could be incorporated to maintain a gene pool and to aid in reintroduction programmes.

The estimated duration of this project is three years. The initiation of this project would require a national conceptual workshop on crocodiles enabling an action plan to be drawn up, identifying priority sites for survey work and collaborating agencies to be involved in the project. In recognition of the fact that no previous comprehensive study of crocodilians has been undertaken, it is proposed that this study be done in two phases. The respective phases are described briefly below.

Phase I *National Crocodile Surveys*

This phase aims to conduct comprehensive baseline data collection on occurrence, distribution and habitat preferences of crocodilians in Malaysia. Peninsular Malaysia will be treated separately from East Malaysia (Sabah and Sarawak).

Projected Time Frame : One year.

Phase II *National Action Plan for Crocodile Conservation*

This phase aims to formulate an action plan for conserving crocodilians in Malaysia. This plan will address all relevant issues related to crocodilian conservation as well as identifying the roles to be played by the various government & non-government agencies, institutions and crocodile farms within the country. The formulation of such a strategy is seen as a natural follow-up phase of the *National Crocodile Surveys*.

Projected Time Frame : Two years (one year each for West and East Malaysia).

Implementing Agencies

A task of this proportion would require the setting up of a task force to coordinate and oversee the running of the project. This task force should ideally comprise of representatives from the various agencies with relevant expertise in this field. A list of Malaysian agencies and institutions is included below.

a. PERHILITAN, the Department of Wildlife and National Parks, in Peninsular Malaysia.

b. State Forestry Departments for the respective states.

c. The National Parks and Wildlife Office (NPWO), under the Department of Forestry, in the State of Sarawak.

d. Sabah Parks and Sabah Forest Department in the State of Sabah.

e. State Fishery Departments.

f. Malayan Nature Society

g. Asian Wetland Bureau

h. World Wildlife Fund Malaysia

i. Local Universities

j. Representatives from crocodile farms.

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TABLE II - DISTRIBUTION OF CROCODILIANS IN MALAYSIA

NO	SITE	STATE	HABITAT	*C. porosus*	*T. schlegelii*
1	Tumpat Lagoon and the Setiu-Chalok-Bari River Basin ✓	Trengganu	Tidal lagoon, swampforest	+	
2	Pahang River System ✓	Pahang	riverine	+?	+?
3	Ulu Lepar Lake System ≈	Pahang	lakes	+	
4	Tasek Bera Forest Reserve ≈	Pahang	lake, swampforest	+	+
5	Southeast Pahang Swamp Forest ?	Pahang	Swampforest	+?	+?
6	Jemaluang Swamp Forest ?	Johor	Swampforest		+?
7	Malacca River System ✓	Melaka	Riverine	+	
8	Segambut Mining Pools ✓	Selangor	Mining Pools	+	
9	Klang Islands ≈	Selangor	Mangroves	+?	
10	Kapar Forest Reserve ?	Selangor	Mangroves	+?	
11	North Selangor Peat Swampforest ✓	Selangor	Swampforest	+	+
12	Taiping Mining Pools ✓	Perak	Mining Pools	+	
13	Kinta Mining Pools ✓	Perak	Mining Pools	+	
14	Batu Gajah Mining Pools ✓	Perak	Mining Pools	+	
15	Matang Forest Reserve ?	Perak	Mangroves	+	
16	Beriah Swamp Forest ?	Perak	lake, Swampforest	+?	+?
17	Ayer Hitam-Bukit Mertajam ✓	Penang	riverine	+	
18	Kulamba Wildlife Reserve ✓	Sabah	marsh, swampforest	+	
19	Segama River Basin ✓	Sabah	oxbows, swampforest	+	
20	Kinabatangan Floodplain ✓	Sabah	oxbows	+	
21	Temengang Oxbow lakes ✓	Sabah	oxbows, swampforest	+	
22	Danau Labaung ✓	Sabah	Lake	+	
23	Labuk-Sugut Deltas ≈	Sabah	Mangroves	+	
24	Sugut River ✓	Sabah	oxbows, swampforest	+	

TABLE II - DISTRIBUTION OF CROCODILIANS IN MALAYSIA [cont'd]

NO	SITE	STATE	HABITAT	*C. porosus*	*T. schlegelii*
25	Unggong Swamps ✓	Sabah	Mangroves	+	
26	Likas Swamp ≈	Sabah	Mangroves, swampforest	+	
27	Klias Peninsula ✓	Sabah	Swampforest	+	
28	Marintaman Mengalong ≈	Sabah	Swampforest	+	
29	Trusan-Sundar Mangroves ✓	Sarawak	Mangroves	+	
30	Limbang Mangroves ✓	Sarawak	Mangroves	+	
31	Sungai Karap ✓	Sarawak	vegetated river	+	
32	Loagan Ungar ✓	Sarawak	lagoon	+	
33	Loagan Bunut ✓	Sarawak	lake	+	+
34	Rajang Delta ✓	Sarawak	Mangroves, nipa forest	+	
35	Maludam Swamp Forest Reserve ✓	Sarawak	Swampforest	+	+
36	Batang Lupar River ✓	Sarawak	Mangroves, swampforest	+	+
37	Samarahan-Sadong Mangroves ✓	Sarawak	Mangroves	+	
38	Sarawak Mangrove Forest Reserve ✓	Sarawak	Mangroves	+	
39	Samunsam Wildlife Sanctuary ✓	Sarawak	Mangroves, riverine	+	
40	Sungai Ensengai Baki ✓	Sarawak	Swampforest	+	+

KEY

✓ - Confirmed sites for either species of Crocodilian

≈ - Historical records of Crocodilians

? - Suspected presence of Crocodilians

THE TOMISTOMA OR FALSE GHARIAL *Tomistoma schlegelii*
THE NEED FOR ITS CONSERVATION IN SOUTH EAST ASIA

WORKING PAPER

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INTRODUCTION

The False Gharial or Tomistoma *Tomistoma schlegelii* is one of the least known and most endangered crocodilians in South-east Asia. Placed in a genus of its own, the Tomistoma was formerly thought to be more closely related to the true crocodiles rather than the Indian Gharial *Gavialis gangeticus* (Tarsitano et al. 1989). Recent evidence, however, seems to suggest closer ties to this ancient *Gavialis* genus, Family Gavialidae (Densmore & Owen 1989).

Gharials are primitive reptiles, dating back to the Eocene of Africa and Asia. They have poorly developed limbs making them less mobile on land than most other crocodilians. They are easily distinguished from true crocodiles by their long slender snouts. Adult male Gharials develop a bulbous growth at the end of the snout. Adult male Tomistomas do not develop the bulbous nose and are distinctly marked with dark bands on the tail and snout. They can attain lengths of over 4 meters and are thought to feed primarily on fish.

Like all the other crocodilians, the Tomistoma is an elusive reptile, occurring in slow-flowing waters along the upper reaches of small rivers, freshwater swamps and lakes. These areas are often overgrown with aquatic and riverine vegetation, usually species such as *Pandanus*, *Baringtomia* and *Hanguana*. This species is thought to naturally occur in low densities and therefore can often be inadvertently overlooked in survey records of an area.

The Tomistoma is a mould nester and requires extensive areas of undisturbed riverine habitat to breed. The extensive conversion of wetlands to agriculture and urban development in recent years has resulted in a huge loss of Tomistoma habitat. The subsequent isolation of populations has also resulted in the loss of their viability and breeding success.

Tomistomas have been kept in captivity at crocodile farms throughout the region and have recently been the focus of attention as stock for reintroduction programs and also as genetic pools. However, all attempts to breed Tomistomas in captivity have been unsuccessful to date. It is increasingly clear that more information on the nesting habits in the wild is necessary to be able to breed this species successfully in captivity.

Formerly known to range from south-eastern China, west to Burma and throughout south east Asia and Indonesia, this species has now been confirmed only in Malaysia, and Indonesia (Sumatra, Kalimantan). The Tomistoma is probably extinct in Thailand. The species may also occur in Sulawesi. This restricted range is emphasized further by the limited availability of suitable habitat.

STATUS

The Tomistoma today probably occurs in the wild in only three countries; Thailand, Malaysia and Indonesia. Confirmed populations are known only from Malaysia and Indonesia with the Thai population possibly extirpated over the last decade. These three countries are dealt with separately below, describing the status of Tomistomas as known from existing literature.

Thailand

No recent information exists on the status of populations in the wild. Last records of Tomistomas were in the 70's from southern Thailand (Taylor, 1970) and the species may have already gone extinct. The species exists in captivity at Samutprakarn Crocodile Farm but claims that successful breeding bas taken place are doubtful. Bain and Humphrey (1980) state that if surviving, the Thai population probably numbers fewer than 20 individuals.

Malaysia

No recent information exists on the status of this species in West Malaysia. Formerly known to occur in the Pahang river basin, Tasek Bera in Pahang and the North Selangor Peat Swamp Forest, no recent surveys have been conducted to confirm the presence of this species. There have been recent unconfirmed records of a crocodilian fitting the description of a Tomistoma from the North Selangor Peat Swamp Forest. A Tomistoma was caught here in the late 70's close to the Bernam river (Marsh, 1982). The Setiu river basin, Trengganu, also provides an ideal habitat for crocodiles and regular Crocodile Safaris are conducted for tourists. The identity of the crocodilian here is unknown. Although most probably *C. porosus* along the lower reaches, the possibility of Tomistoma occurring in the dense riverine forests of the upper reaches is high.

In 1983, a survey done in Sarawak (East Malaysia, Borneo) recorded Tomistoma in almost all the inland river systems and freshwater swamps (Whitaker, 1984). A subsequent survey in 1985 in Sarawak recorded the Tomistoma only once; two adults and one juvenile in the Upper Ensengai Baki River in western Sarawak (Cox & Gombek, 1985). Further surveys are required in Sarawak to determine the current status of this species. The species is kept at Johnson Jong's Crocodile Farm, Kuching. Although numbering over 100 individuals, all attempts to breed have been unsuccessful.

The species has never been recorded in Sabah, north-east Borneo (Whitaker & Whitaker, 1989) and is probably excluded from this corner of Borneo due to geographic topography.

Indonesia

Thought to be the last stronghold of this species, recent surveys were conducted in 1990 by FAO-PHPA in Sumatra and Kalimantan. Significant populations were recorded in nine river systems. The species was confirmed in the Berbak National Park, east Sumatra, the Lalan, Kuran and Bahar rivers in south Sumatra and the swamps along the Medak and Merang rivers. The Beran river and Tanjung Puting National Park in Kalimantan have both been confirmed to support populations of Tomistomas (IUCN, 1992). Frazier and Martubongs (1990) provides a complete listing for Kalimantan.

The Tomistoma has been reported from Sulawesi (report from Marisa river, north Sulawesi) but is not confirmed (IUCN, 1992). If confirmed, this would be the furthest east its range extends.

THE NEED FOR CONSERVATION

Of the seven species of crocodilians identified as deserving the highest priority in the CSG Action Plan, five are Asian. With substantial progress made in initiating conservation of the Gharial *Gavialis gangeticus*, the Chinese Alligator *Alligator sinensis* and the Philippine Crocodile *Crocodylus mindorensis*, two species remain unaddressed, the Siamese Crocodile *Crocodylus siamensis* and the Tomistoma. This species is now becoming an urgent priority (CSG Steering Committee, 1992). The Tomistoma is listed as Endangered in the IUCN Red List 1990 and is an Appendix I species under CITES.

Natural wild populations are thought to have been reduced to dangerously low levels, mainly due to habitat loss. Restricted to slow-flowing rivers with dense riverine vegetation, freshwater swamp forests and lakes, the natural habitat of the Tomistoma is undergoing conversion at an increasingly rapid rate. It is crucial to locate viable populations of Tomistomas now, so as to be able to justify and acquire legal protection for the habitats.

The fragility of these freshwater wetlands used by this species requires protection and management of entire ecosystems and not representative parts of the habitat. The level of effort and cost required to maintain an area as a sanctuary for Tomistomas is likely to be higher the smaller the area is. It is therefore important to identify areas of suitable habitat of sufficient size to be gazetted as a sanctuary for Tomistomas.

In the event that no viable populations are located in Thailand or West Malaysia, the option of captive breeding centers with the purpose of scientific studies and reintroduction programs must be examined.

Surveys should be conducted in West Malaysia, especially in the Pahang River basin, concentrating on the freshwater lake systems of Tasek Bera, Tasek Chini and Ulu Lepar, to establish the presence of this species and identify potential habitats.

Indonesia still retains vast areas of freshwater swamp forests in Sumatra and Kalimantan. The presence of Tomistomas within protected areas has recently been confirmed. These are probably the only areas supporting such populations of the Tomistoma in the world and present good opportunities for detailed ecological studies of the species in the wild.

The urgency for the design of proposals and the allocation of funds for the conservation of this species cannot be emphasized. Efforts should be made now to save this ancient reptile from extinction.

KNOWN SITES FOR THE FALSE GHARIAL *Tomistoma schlegelii* IN SOUTH EAST ASIA

SITE	COUNTRY	AREA/ha	STATUS	HABITAT
Pa Phru ■	Narathiwat, Thailand	34,636	National Reserve Forest	Peat Swamp Forest - 9,684 ha., Melaleuca Forest - 14,600 ha. Grassland - 9,800 ha.
Tasek Bera ■	Pahang, Malaysia	26,500	Wildlife Reserve	Lakes & Swamp Forest - 6,150 ha.
North Selangor Peat Swamp Forest ■	Selangor, Malaysia	74,823	Forest Reserve	Peat Swamp Forest
Lower Reaches of Sg. Baram	Sarawak, Malaysia	300,000	Forest Reserve	Freshwater Swamp forest - middle reaches Sg. Karap - 60 km of river
Loagan Bunut	Sarawak, Malaysia	19,000	National Park	Freshwater lake
Maludam Swamp Forest	Sarawak, Malaysia	125,000	Forest Reserve	Peat Swamp Forest
Sg. Ensengai Baki	**Sarawak, Malaysia**	**1,400**	**Forest Reserve**	**Freshwater Swamp Forest 30 km of river**
Way Kambas	**Sumatra, Indonesia**	**123,500**	**National Park**	**Freshwater Swamp Forest**
Danau Tanjung Padang	Sumatra, Indonesia	3,000	Proposed Wildlife Reserve	Peat Swamp Forest - 3,000 ha.
Buaya Bukit Batu	**Sumatra, Indonesia**	**18,000**	**Proposed Nature Reserve**	**Peat Swamp Forest & waterways**
Sg. Lalan	**Sumatra, Indonesia**	**586,417**	**None**	**Freshwater & Peat Swamp Forest - 80,000 ha. Mangroves**
Berbak National Park	**Sumatra, Indonesia**	**175,000**	**National Park RAMSAR Site**	**Peat Swamp Forest - 110,000 ha. Freshwater Swamp Forest - 60,000 ha.**
Danau Bawah & Pulau Besar	Sumatra, Indonesia	23,750	Nature Reserve	Peat Swamp Forest & two lakes
Danau Belat, Basar Sekak & Sarang Burung	Sumatra, Indonesia	10,000	Wildlife Reserve	Peat Swamp Forest and lakes
Siak Kecil	**Sumatra, Indonesia**	**100,000**	**Proposed Hunting Reserve**	**Peat Swamp Forest - 30,000 ha.; Freshwater Swamp Forest - 2,000 ha.; Small Freshwater lakes**
Kutai National Park	Kalimantan, Indonesia	320,000	National Park	area of wetlands less than 200,000 ha. Mangroves & freshwater swampforest
Gunung Palung and surrounding swamps	Kalimantan, Indonesia	130,000	National Park	Mangrove forest - 7,000 ha.; Freshwater Swamp Forest - 20,000 ha.; Peat Swamp Forest - 30,000 ha.
Tanjung Puting National Park	**Kalimantan, Indonesia**	**300,040**	**National Park**	**Mangroves, Nypa, Kerangas, *Hanguana/Pandanus* & Peat Swamp Forest.**
Danau Sentarum	Kalimantan, Indonesia	80,000	Wildlife Reserve	Freshwater & Peat Swamp Forest - 40,000 ha. Lakes - 40,000 ha.

■ - Historical records (not recorded within past 15 years)

Sources : Asian Wetland Directory, Indonesian Wetland Directory, Wetland Database, Rusila (pers. comm.), Giesen (pers. comm.), Frazier (pers. comm.), IUCN/SSC CSG.

POSSIBLE NEW SITES FOR FALSE GHARIAL *Tomistoma schlegelii* IN SOUTH EAST ASIA

SITE	COUNTRY	AREA/ha	STATUS	HABITAT
Kerumutan Baru	Sumatra, Indonesia	120,000	Nature Reserve	Peat Swamp Forest - 100,000 ha.
Tulang Rawang Backswamps	Sumatra, Indonesia	unknown	none	Freshwater swamps
Sg. Chalok / Sg. Bari Basin	Trengganu, Malaysia	unknown	Forest Reserve	Freshwater & Peat Swampforest, *Melaleuca* forest.
South East Pahang Peat Swamp Forest	Pahang, Malaysia	325,000	Forest Reserve (80,000 ha.)	Peat Swamp Forest - 90,000 ha.; Freshwater Swamp Forest
Tasek Chini	Pahang, Malaysia	3,800	Proposed Nature Reserve	Open Water - 202 ha.; Freshwater Swamp Forest - 700 ha.; Lowland Dry Forest.

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Serum Uric Acid Level in Siamese Crocodile *(Crocodylus siamensis)*. II. Feeding with Mixed Diet.

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Abstract

The study was conducted to evaluate serum uric acid in 60 Siamese crocodiles *(Crocodylus siamensis)*, 21 males and 39 females aged 5-6 years. They were fed with mixed diet composed of chicken carcass,pork,pig visceral organs,vitamins and minerals supplement. Mean ($\pm$SD) serum uric acid level was 3.94 ± 1.29 mg/dl. There were no different in levels between male and female crocodiles ($P>0.05$) which the average serum uric acid concentration were 4.22 ± 1.48 and 3.79 ± 1.17 mg/dl, respectively.

Introduction

In reptiles, the end product of purine and protein metabolism are uric acid.[1] The abnormality of these metabolisms that contribute to the crystallisation of uric acid and urate *in vivo* cause abnormal condition that know as "gout". So the measurement of uric acid in serum is an important investigation in both diagnosis and management of gout.[2,3,4] Uric acid in serum is depend on the daily diet especially for the high purine protein diet that usually found in visceral organs e.g.heart,liver,kidney etc. Crocodile is a carnivorous reptile which mainly fed on protein diet. In the present,there are several types of crocodile food, for example chicken carcass, fish, pork or mixed diet. The low quality and quantity of crocodile's diet is an important factor that cause gout, one of these diseases ~~caused the loss of value~~ which resulted in high mortality in crocodile farming.[5] The purpose of this research is to study ~~the~~ effect of mixed diet and level of serum uric acid in Siamese crocodiles *(C.siamensis)*.

Materials and Methods

Sixty healthy Siamese crocodiles (21 males, 39 females) aged 5-6 years were used in this study. These crocodiles were fed with mixed diet composed of chicken carcass, pork, pig visceral organs, vitamins and minerals supplement once a week for one year. Analysis of mixed diet are shown as: 1735.48 kcal of energy, 17.94% of protein, 8.03% of fat, 0.44% of fatty acid, 3.13% of calcium, 1.34% of phosphorus, 0.46 % of fibre, 52.19% of moisture, 8.89% of ash, and 0.21% of sediment.

Blood samples were obtained from the dorsal post-occipital sinuses. Serum uric acid level was determined by phosphotungstic acid method [2,3] using commercial kit (CLINAG ®,

Discussion

Serum uric acid level of *C.siamensis* in this study was higher than in *Alligator mississippiensis* that mean serum uric acid level was 2.55 mg/dl, (1-4 mg/dl).[6] This level was also higher than mean values reported in *C.siamensis* feeding with chicken carcass (3.17±1.28 mg/dl).[7] Elevation of serum uric acid level may due to high protein and purine nucleotide contents in pork and pig visceral organs which are major component of mixed diet. This predisposes to "gout" if they still intake mixed diet for a period of time because of serum uric acid level in crocodiles suffered from this metabolic disease was in the range of 10.7-59.6 mg/dl.[8] Then,for prevention of gout the other sources of protein should be tried.

This study confirmed that the composition of daily diet such as protein source is an important factor which effected the crocodiles's health. Concentration of uric acid in serum can be determined to evaluate the optimised food, and also useful for diagnosis and prevention of gout in crocodiles. Therefore, serum uric acid level affected by other diet should be studied in the future.

Acknowledgement

We thanks the Sriracha Crocodile farm, Co.Ltd. for their supporting of specimens and other necessary facilities.

Clinical diagnostics Inc., Bangkok 10300, Thailand). Phosphotungstic acid is reduced by urate in alkaline medium; a blue color ("tungsten blue") is ~~read~~ determined by spectrophotometry at wavelength of 700 nm. Mean values between male and female crocodiles were compared with t-test.

Results

Serum uric acid levels of male and female Siamese crocodiles are presented in Table 1. Using t-test, no difference ($p>0.05$) was found between male and female means for serum uric acid values.

Table 1 : Serum uric acid level in male and female Siamese crocodiles *(C.siamensis)* feeding with mixed diet.

	Crocodylus siamensis (n=60)	
	Male (n=21)	Female (n=39)
Serum uric acid (mg/dl)	4.22 ± 1.48[a] (2.3 - 7.5)[b]	3.79 ± 1.17 (1.8 - 7.5)
Total	3.94 ± 1.29 (1.8 - 7.5)	

[a] $\bar{x} \pm SD$

[b] (range)

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Conservation, Management and Farming of Crocodiles in Sabah

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I. Introduction

Sabah is the most eastern state in the Federation of Malaysia, located between 3º 42' - 7º 2' N. latitude and 115º 25' - 119º17' E. longitude, contiguous with Sarawak and the Indonesian State of Kalimantan. Occupying an area of approximately 80,290 km^2, Sabah is inhabited by about 1.5 million people, with a population growth rate of nearly 3.5%, one of the highest in Asia . The State has experienced a boom in human population growth since the 1950's (Jones, 1992) which has been augmented by an influx of several hundred thousand immigrants.

Until about 30 years ago, about two-thirds of Sabah consisted of lowland dipterocarp forests. Approximately 50% of the State is still under some kind of natural vegetation, principally secondary forests of both mangroves and tropical hardwoods. The species composition of the latter habitat however, has been substantially modified as a result repeated cycles of logging. The rest of the landscape is divided into large agricultural plots of rubber, oil palm and cocoa, or traditional small holdings. Rubber cultivation was dominant until the 1960's, when oil palm plantings were introduced. Oil palm estates now cover broad areas of the lowlands of eastern Sabah, while rubber plantations are located principally in the West Coast Residency. Cocoa was a crop initiated in the 1980's mainly in the eastern lowlands. After a period of widespread planting activity, interest in this crop temporarily declined because of a slump in world prices .

Sabah's terrain is more undulating than that of the rest of Borneo. Geographically, the state is divided into two unequal portions by the Crocker Range, which is aligned in a roughly northeast-southwest direction, reaching its highest point at its northeastern end, the 4101 meter summit of Mount Kinabalu. About one-quarter of Sabah's land area lies west of the Crocker divide, forming a narrow coastal plain about 40 km wide. Rivers in this area are short, steep and rocky, with swift currents and clear, cool waters. Few of the latter are affected by tidal cycles for more than a ten kilometers of their length. In Sabah's southwest corner, the Padas River (which drains about 25% of Sabah's interior) escapes through a gorge to produce a sizeable alluvial peninsula where several rivers (Klias, Padas Damit, among others) meander through swamps under tidal influence.

The eastern coast of Sabab is geologically much younger than the western side of the state (Tongkul, 1990). Although possessing some hilly terrain in isolated areas, the eastern side of Sabah consists principally of areas of altitude less tban 300 meters above sea level. Rivers are generally much longer compared those of to the west coast, and carry much larger volumes of water (Figure 1). The longest is the Kinabatangan, flowing eastwards for at least 300 km, from the Maliau area near the Sarawak-Indonesian border to the Sulu Sea just east of Sandakan. The second largest river draining Sabah's interior is the Segama, meandering first southeast then eastwards, receiving tributaries from areas south of the Kinabatangan basin. Both these large rivers possess extensive, multichanneled deltas with mangrove-nipah associations, although the latter do not penetrate more than 30 km inland as a result of the enormous freshwater discharge. Other somewhat sborter river systems such as the Sugut, Labuk Kalumpang and Kalabakan Rivers have more extensive mangrove habitat.

Sabah's wetland areas, primarily in the form of mangroves, cover an area of approximately 4,000 km^2 (Whitaker, 1984). *Rhizophora* trees have been exploited for house pilings and charcoal, with large-scale harvesting mostly in areas around Darvel Bay near Sandakan, and in Tawau Bay. Other harvesting is done in a subsistence fashion, making the lessening overall impact considerably. All major rivers have associated mangroves and freshwater swamps, while certain ones, including the Padas, Sugut, Kinabatangan and Segama also possess numerous oxbow lakes (Whitaker, 1984). A series of extended droughts during the 1980's has accelerated the loss of swamp forests which are often are replaced by grassland and scrub.

The climate of Sabah is wet tropical, with an average temperature of about 26º C., with a range of approximately 22 - 32º C. Two distinct monsoon periods occur, bringing about 3000 mm of rain per year (Davis, 1962). Although rainfall is distributed throughout the year, the heaviest rains occur during November - January, or the Northeast monsoon. A second period of moderately heavy rain occurs in May - June, during the weaker Southwest monsoon. The west coast of Sabah can experience heavy rains in August, while the Sandakan - Lahad Datu area can have heavy rain even in February. Ordinarily there is a dry season from February through April during which no rain may fall for 4 - 8 weeks. This dry period can be extended to more than 16 weeks during long droughts such as the El Nino-Southern Ocillation phenomenon in 1983 and 1992. The west coast of Sabah is consistently drier than the eastern side of the State, and has experienced a rainfall deficit since 1987 (Sabah Meteorological Department, Unpublished data). Burning of forest and swamp vegetation by rural people is commonplace during prolonged droughts.

II. Species

Only one species of crocodilian, *Crocodylus porosus*, has ever been reported from Sabah (Whitaker, 1984). Although it was suspected that a freshwater species might been in the headwaters of the Padas River, no crocodiles besides *Crocodylus porosus* have ever been taken from there. There is no evidence that *Tomistoma schlegelii* has ever occurred in Sabah.

III. Status

There are numerous records of crocodile attacks on man, particularly the rivers on the East Coast of Sabah, from about 1900 to 1960. The *British North Borneo Herald* reported attacks resulting in casualties in the Paitan, Kinabatangan, Labuk - Sugut, Segama and Kalabakan Rivers during that period. These attacks presumably occurred because of the frequent use of rivers for domestic activities as well as for transportation. On the West Coast of Sabah, nuisance crocodiles also attacked villagers in the Padas and Papar Rivers . In 1957- 1958, a series of crocodile attacks occurred in the upper Padas River (near Tenom), following which a single 13 foot *C. porosus* was killed. There apparently have been no further crocodile attacks on man since the 1960' s.

Traditionally, hunters have used hooks spears or harpoons to hunt crocodiles at night, using kerosene lamps with biscuit tin reflectors to catch eyeglow. From early 1880s until World War II, the British Government issued rewards for the destruction of crocodiles and paid 15 cts per inch of head and 5 cts for each egg collected, as crocodiles were regarded as a threat to human safety. Over the next 10 years a total of 18, 167 inches of crocodile skulls from Kinabatangan, Labuk, Sugut and Padas River were collected (Whitaker, 1984). Newspaper articles from 1928 to 1929 reported that a total of 14, 962 inches of crocodiles skulls from 402 individuals was claimed by a single hunter in the three main rivers of the East Coast; Labuk. Sugut and Paitan. In the years of commercial exploitation before the 1930's, not less than 200 skins were taken monthly. After skin prices on the world market fell in 1935, a bounty was no longer offered for crocodiles.

Until about forty years ago, crocodiles were extremely abundant in Sabah. Crocodile hunting, as reflected in the number of skins exported, reached a peak in the mid 1960s, and declined thereafter (Whitaker, 1984). Newspaper reports from the period mention hundreds of animals slaughtered for their skins in the Labuk River, as well as attacks on humans in various locations. Crocodiles have declined since, undoubtedly because of hunting, but also because of the effects of habitat modification. In rivers flowing through agricultural areas, crocodiles apparently are few (Kusuadi, 1984). Currently the only gazetted area for wildlife protection in Sabah which includes crocodiles is the Kulamba Wildlife Reserve (118º 20' E, 5º 30' N), east of Sandakan , an area of 50,000 ha of mngrove forest (Sabah Wildlife Department, Unpublished data).

Whitaker (1984), in his 1983 survey traversed a total of 1146 km along seven rivers, and observed a total of 56 *C. porosus*. He reported sighting a single individual from the Klias area. Kusuadi (1984) surveyed five rivers on the west coast of Sabah (Padas, Klias, Binsuluk, Membakut and Inanam), but saw only two crocodiles (in the Klias). Crocodiles were reported from the Klias River by Wells *et al.* (1975). Beginning in 1987 - 88, a series of 9 surveys was conducted in the Klias River (about 12 km north of the town of Beaufort), revealing that a healthy breeding population of *Crocodylus porosus* existed. A follow-up project in 1991-92 confirmed that the Klias River was indeed an important breeding area for *C. porosus* (Stuebing and Shahrul, 1992) Following Whitaker's surveys in 1983 no comprehensive surveys were done in Sabah for ten years. However, a new series was done from December, 1992 - February, using the spotlight counts1993. The results of which are shown in

Table 1. Not surprisingly, the most crocodiles were seen in the Klias River, where familiarity with the area and repeated surveys allowed for efficient observations to be made.

It is likely that the complex of rivers (Padas Damit, Bentuka) and their connecting channels in the Klias Peninsula forms one of the largest breeding areas for *C. porosus* in Sabah. Nevertheless, though fewer crocodiles were seen in the Kinabatangan River, this area with its oxbow lakes, numerous isolated channels and generally undisturbed floodplain is likely to possess a large reservoir *C. porosus*. Substantial numbers would also be expected to exist in the lower Segama River.

Overall, spotlight counts results were disappointing, and probably do not reflect actual numbers of crocodiles. One persistent problem has been the large volume of river traffic, particularly on the larger rivers, while surveys were in progress. Illegal logging is still commons, and many illegal operators prefer to transport contraband log rafts at night. This was a serious hindrance in the Labuk River. Also December, the month in which the surveys were made, is the period of heaviest rainfall on Sabah's east coast. Storms interrupted at least two surveys (Kinabatangan and Labuk). In addition to spotlight counts (Shahrul, 1992), there were many firsthand accounts, or reliable anecdotal reports of crocodiles in 1992 (Table 2 below).

IV. Legislation

Local laws

Under the Sabah Fauna Conservation Ordinance, 1963 (1982 Amendment), hunting of *Crocodylus porosus* is totally prohibited. Under this Ordinance, no license may be issued to hunt the crocodiles except under special conditions such as for scientific research. Regulations concerning the rearing of wild animals, including, crocodiles, were amended in 1988. Under the terms of the new amendments, a license to keep crocodiles may be issued to private owners by the Wildlife Department at a rate of RM 10.00 or about A$ 5.60, per head per year. There is also a fee of RM 10.00 for certificate of ownership, charged in the first year only.

The Fauna Conservation Ordinance is enforced hy the Sabah Wildlife Department. The Ordinance is revised or amended from time to time, and the latest amendements (1988) provide for a mandatory jail sentence of minimum of one month and a maximum of five years upon conviction for offenses involving the hunting of totally protected species, including *C. porosus*.

The Sabah Government is currently in the process of revising the Ordinance. Apart from revisions such as a provision for heavier penalties for offences committed, the revision is also aimed at full adoption of CITES regulations.

V. Farming

There are currently three crocodile farms in Sabah, two still in early stages of development. The two most recent ventures are by Undersea Research Pte. Ltd. and Andrassy Farming and Research. The latter was established in 1989, and began with 84 crocodiles obtained as breeding stock from the Chai Farm. In 1990, the Andrassy farm produced 173 hatchlings from a total of 30 nests. This farm is not yet allowed by the Wildlife Department to export crocodile products until it produces its own breeding stock.

Farming of crocodiles in Sabah was pioneered by the Chai Crocodile Farm in Sandakan, which was established in the early 1960s. Initially the Chai Farm obtained breeding stock from the wild, before the 1982 legislation was enacted, a total of 450 animals from 1 - 9 years old. As of December, 1992, the farm possessed a total of 2,160 crocodiles, and produces its own breeder animals from this captive population. A record of the development of its production efforts is given in Table 3.

Its captive bred crocodiles are reared for skin export and for reintroduction into the wild. The farm has also provided breeding stock for the other two farms recently set up in Sabah.

The Chai Crocodile Farm is the only such farm in Sabah that is registered with the CITES World Conservation Monitoring Centre for Crocodile Farming Operation. The farm currently exports small consignments of skins to Singapore and Japan.

VI. Regulation of Trade

1. Exports and trading partners

Figures for export of crododile skins exported from Sabah from 1985 - 1992 are given in Table 4. A total of 10,599 kg was exported at a value over eight years of RM 1,131,733 ($US 443,817), at an average unit price per kilo of RM 106.77 ($US 41.90), with an average export earning of RM 141,467 ($US55,477) annually. The principal destination for crocodile hides was Japan (RM 810,504 = $US 317,845), followed by Singapore (RM 321,229 = $US 128,492). Most exports were in the form of raw skins , which were shipped to Japan, while all pre-tanned hides were shipped to Singapore.

As a part of the Federation of Malaysia, Sabah is a member State under the CITES agreement. Trade and export of wildlife species included in the CITES list such as crocodiles and crocodile products is to be regulated in accordance with the provisions of the Convention's articles. Commercial trade and export of crocodiles and crocodile products which is an Appendix I species is to be restricted to animals bred in captivity.

VII. Imports and Manufacturing

Currently, there is no significant product manufacture. Record on imports of crocodile skins and exports of their products are nil.

VIII. Research

Research on crocodiles in Sabah began with a series of surveys done by Whitaker (1984) in seven major rivers. Subsequently, several small research projects were carried out by the students from the Sabah Campus of the Universiti Kebangsaan Malaysia, including Kusuadi (1984), Ling (1988) and Shahrul (1992) in the Klias River. Among the published papers hased on these surveys are Stuebing, *et al.* (1985), and Stuebing and Shahrul (1992). The individual studies Klias were intensive, e.g., repeated a minimum of seven times along the same stretch of river for a period of eight months.

Apects of biology of *Crocodylus porosus* studied were seasonal and spatial distribution and abundance of various age classes, movement and growth of crocodiles (< 0.5 m SV length). Diet of juveniles was also investigated. A mark recapture study of juvenile *Crocodylus porosus* conducted from January, 1992 until February, 1993 is in preparation for submission to the *Malayan Nature Journal* (Stuebing and Shahrul, manuscript in prep).

A finding relevant to the present inquiry into the status of *C. porosus*, derived from observations in the Klias area is that short-term assessments of crocodile densities (in Sabah) are usually unreliable. Relative densities of various size classes in the same river may fluctuate during the year , as has been reported by Jenkins and Forbes (1985). The wariness of older crocodiles (more frequently encountered March - May and August - December) will result in misleadingly low estimates during those periods, while surveys from January - February and June - July, may give estimates biased in favour of juveniles. Furthermore, the probability of sightings is at a maximum during slack water at low tide. In the Klias, crocodiles (particularly young juveniles) are less visible while the tide is receding, perhaps because of strong currents. Bank vegetation, particularly in upstream areas (as pointed out by Bayliss *et al.*, 1986) also affects visibility. In Sabah, surveys in areas above tidal influence have consistently yielded poor results, probably because of poor "sightability". Thus, no proper assessment of density is possible without consideration of season, tidal conditions, vegetation type, as well as information on the structure of the population surveyed.

Two projects in the Klias were funded directly by the Universiti Kebangsaan, while the third was made possible through a grant to the University from the the John D. and Catherine T. MacArthur Foundation of Chicago, Illinois (USA). In 1990, at the International Conference on Forest Biology and Ecology in Borneo, World Wide Fund for Nature (Malaysia) was approached for assistance, but no positive feedback was received. The current grant from the MacArthur Foundation (which has supported the production of this paper), will end by December of this year. No further research on crocodiles is anticipated unless new funding is obtained. Mr. Shahrul Anuar Mohd. Sah, as a trainee lecturer at the Science University of Malaysia is applying to pursue further studies, and if the opportunity arises wishes to do ecological work on crocodiles for his dissertation. Mr. Shahrul is presently the only Malaysian with research experience in crocodile biology.

X. Discussion

The present abundance and distribution of *Crocodylus porosus* in Sabah is difficult to assess. There is little doubt that present densities in most Sabah rivers are but a fraction of their original values. Whitaker (1984) surveyed approximately 1,146 km in seven rivers in sabah, sighting a total of 56 crocodiles for an overall density of 0.049 km^{-1} This figure is probably incorrect, the result of too little time spent on each river surveyed. The only density figures which are known with any certainty, based on repeated surveys in the Klias River, are many times higher than reported by Whitaker. In the Klias, calculated density (Messel *et al.*, 1981) ranged from 0.9 - 1.6 km^{-1} (Based on survey data, 4/2/93). Though this figure is well below that of rivers in the Northern Territory of Australia, "sightability" of crocodiles in Sabah is likely to be lower, as well. Whitaker's 55.4% "EO" (Eyes Only) sightings for Sabah, is large compared to that of Australia, said to average about 10% (Shahrul, 1992). Interestingly, during brief crocodile surveys in 1992-93 along many of the same rivers Whitaker surveyed, the EO percentages were nearly 100% for the few sightings made.

Overall, crocodiles are apparently holding their own in the short term, despite reported illegal hunting, and collection of juveniles. Regular sightings in rivers all over Sabah indicate that where natural, relatively undisturbed habitat exists, the species has adapted well to human presence. Estimating density however remains more art than science. Local conditions usually influence the visibility of crocodiles. Factors which will reduce the number of animals seen include time of year, weather, tidal conditions, river stage and current and river traffic, to name the most important ones.

Based on land use, currently existing crocodile populations in most major rivers in Sabah should remain stable for the foreseeable future, *e.g.*, about ten years. The most successful populations will be found where riverbank vegetation has remained relatively intact, such as in the Klias, Kinabatangan and Segama Rivers. In contrast, from admittedly limited observation (Kusuadi, 1984; present surveys) rivers of relatively high disturbance from various kinds of agricultural activities, such as the (lower) Padas and Kalumpang, seem to have few or no crocodiles. Another aspect worth noting, and perhaps an artifact of the survey method, is that a majority of crocodiles have been observed in brackish water areas, and relatively fewer reported from upstream, or from freshwater swamps (with the exception of the Kinabatangan River). Nevertheless, the potential of freshwater swamps as breeding habitats should not be underestimated (Webb, *et al.* 1983 Whitaker, 1984).

The trade in crocodile skins in Sabah was at a high level for the past seven years (comparable to the levels of the 1960's) until 1992. The three crocodile farms in existence apparently no longer acquire local crocodiles (in significant numbers, at least) but may occasionally import animals from Kalimantan (Indonesia) via Sebatik Island near Tawau. Skin exported from crocodile farm accounted for about 50% of the total quantity exported in 1989 (the latest years for which figures are available). By 1992 export of hides appear to be falling. It is yet unclear whether this drop reflects a serious loss from wild populations via reduced availability.

A strictly enforced ban on illegal hunting, leading to an increase in the numbers of large *C. porosus* in Sabah could initially have a negative impact. Public attitudes towards crocodiles have not changed, and *C. porosus* is widely feared and still regarded as a menace despite the death of attacks over the last thirty years. Deaths or injury will not be tolerated, and as has been the case in Sarawak, following an attack there would be a public outcry calling for an extermination campaign. Any conservation program would have to emphasize protection in areas where human-crocodile interactions are likely to be few, and perhaps even devise methods to ensure that adult *C. porosus* do not become what in Australia are referred to as "nuisance" animals. Education and awareness campaigns might in the long term change public perceptions, but for the present any conservation program achieving strictly enforced protection could founder on public opinion after a single incident. Education on economic value of crocodiles through Department Wildlife of Sabah Museum would help to create a more positive atmosphere.

XI. Acknowledgements

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Table 1. Observed *C. porosus* densities in Sabah rivers, December, 1992 - February, 1993.

Dates	River (Fig. 1)	Sightings per km. and (%EO)	Remarks
15.01.93	Binsuluk	0 (0)	Bank habitat severely damaged by flood control project
05.01.93	Kalabakan	0. 05 (100)	Heavy river traffic (logging, oil palm transport & commercial fishing)
07.01.93	Kalumpang	0.0 (0)	Bank habitat converted to oil palm estate; heavy river traffic (logging, oil palm transport & commercial fishing)
07- 08.12.92	Kinabatangan	0.06 (100)	Good habitat, river in flood, moderate river traffic
04.2.93	Klias	0.78 (10.3)	Excellent breeding habitat; little disturbance
02.01.93	Labuk	0.0 (0)	Heavy rain; heavy river traffic: logging & village transport. Upstream habitat oil palm estate.
16.02.93	Padas (Upper)	0.0 (0)	Shallow, banks disturbed by agriculture (cocoa), heavy subsistence fishing.
06.01.93	Serudong	0.0 (0)	Disturbed by logging and commercial fishing.
July, 1992	Sugut	0.03 (100)	Wildlife Dept. survey; Disturbed by logging and commercial fishing.
17.12.92	Tuaran	0.07 (100)	Banks disturbed by agriculture, buffalo. Heavy subsistence fishing, dense human population.

Table 2. Firsthand accounts or other reliable records of crocodile sightings in Sabah for 1992

Date	River / District	Size of Crocodile (m)	Type of Observation
March, 92	Tambalang / Tuaran	1.5	Sighting
October, 92	Kalumpang / Tawau	3.0	Sighting
October, 92	Silimpopon / Tawau	1.8	Sighting
November, 92	Tuaran / Tuaran	2.0	Sighting
November, 92	Likas* / Kota Kinabalu	0.5	Sighting
November, 92	Padas / Tenom	3-4**	Sighting
November, 92	Serudong / Tawau	3.0	Sighting
December, 92	Sabahan / Semporna	5.0	Captured
December, 92	Kinabatangan /		
January, 93	Bukit Garam - Kuamut	"large" (eight individuals)	Sighting
January, 93	Dent Peninsula	3.1	Captured
February 8, 93	Likas* / Kota Kinabalu	1.3	Captured
November, 92	Padas River / Tenom**	6 "large" individuals	Sighting

* In large monsoon drain connected to the sea.

** Sighted on sandbank

Table 3. Production of skins and captive-bred animals at Chai Crocodile Farm, Sandakan (Sabah) 1980 - 1989.

Year	No. hatchlings	Breeder stock	Total	Skins exported	Mortality	Total stock
1980	-	450*	450	-	40	410
1981	-	410	410	-	32	378
1982**	-	378 (89)***	467	-	5	462
1983	115	462 (82)	659	-	-	659
1984	128	659 (112)	899	-	-	899
1985	198	899 (196)	1,293	-	5	1,288
1986	137	1,288 (58)	1,483	250	17	1,216
1987	186	1,216 (73)	1,475	234	21	1,220
1988	198	1,220 (41)	1,459	125	26	1,308
1989	189	1,308 (98)	1,595	280	31	1,284

Note:

* Stock since 1960's

** The pilot project commenced operation in 1982

( )*** Acquired from pet owners and from the wild before the crocodile became a protected species in 1982.

Table 4. Quantity, value, and major destinations of crocodile hide exports from Sabah, 1985 - 1992.*

Year	Quantity (kg)	Value (RM2.55 = $US1.00)	Unit price (RM)	Destination
1985	1,223	87,369	71.40	Japan
"	564	13,740	24.40	Singapore
1986	1,550	77,338	49.90	Japan
"	110	8,560	77.80	Singapore
1987	936	70,358	75.20	Japan
"	471	25,313	53.70	Singapore
1988	500	58,896	117.80	Japan
"	860	51,237	59.60	Singapore
1989	535	189,562	354.30	Japan
"	670	65,475	97.70	Singapore
1990	972	159,363	164.00	Japan
"	1,091.5	115,075	105.40	Singapore
1991	716	167,618	234.10	Japan
"	411	29,181	71.00	Singapore
1992	40	12,648	316.20	Singapore

* Source: Statistics Department of Malaysia, Sabah Branch, February, 1993

Table 5. Quantity and major destination of crocodile hide exports from Chai Crocodile Farm, Sandakan, 1988 - 1992.

Year	Quantity	Description	Destination
1988	100	Whole skin	Japan
1989	55	Whole skin	Singapore
"	405	Dorsal ridge skin	Singapore
1990	None		
1991	57	Belly skin	Singapore
"	200	Dorsal ridge skin	Singapore
"	200	Belly skin	Japan
1992	50	Belly skin	Singapore
"	49	Dorsal ridge skin	

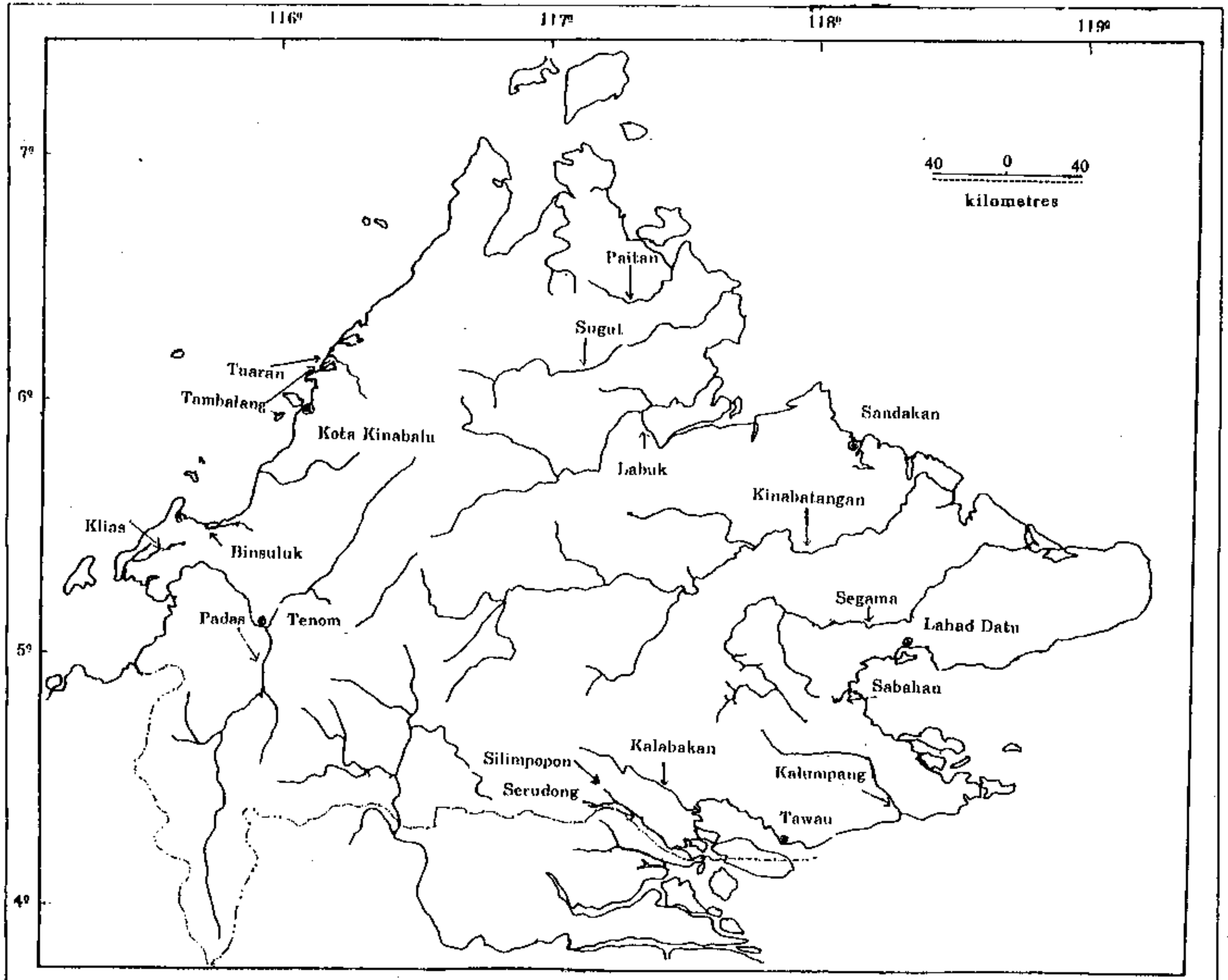

Figure 1. A map of Sabah and its major Rivers

Crocodylus johnstoni in the Lynd River, Queensland: continuation of a long term field study

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Demographic processes are seldom examined critically for populations of large long-lived vertebrates. Economic and logistical reasons are often identified as reasons for the difficulty in establishing viable long-term studies. Funding priorities shift from year to year and the uncertainty of an established patron can result in lapses of continuity in population coverage, particularly if the study animal exists far from the researcher, is expensive to sample, or difficult to process (Likens 1989). Large animals with slow rates of maturity are also problematic to study since research may be marginally productive for many years as a necessary database accumulates to undertake a thorough demographic analysis. Such has been the case for most crocodilian populations.

A literature review indicates that most studies of crocodilian demography have followed three main patterns, each having an inherent limitation: (1) empirical studies of short duration (Smith and Webb 1985, Webb et al. 1983) do not allow direct estimation of interannual variability, (2) repetitive surveys (Bayliss 1987, Messel and Vorlicek 1986, Messel et al. 1979-1984) to develop relative density indices but which provide no information on actual age structure, and (3) population simulations based upon sustainable harvest regimes (Nichols et al. 1976, Taylor and Neal 1984) that are largely unproven in applicability for Australian species (Nichols 1987). For all published studies to date, the data seldom incorporate both long-term study with information from known-aged individuals. This study integrates both aspects to derive and provide comparisons among alternative demographic models to select an accurate simulation of the population processes occurring in wild population of freshwater crocodiles, Crocodylus johnstoni.

Population models derived for vertebrates are traditionally based upon discrete age intervals or Leslie matrices (Leslie 1945) despite the recognition that size-based categorizations or staged-based grouping may be a more appropriate approach (Sauer and Slade 1987, Taylor and Neal 1984). More recent attention has focussed on Lefkovitch matrices for organisms that can be functionally grouped by stages as the functional unit of classification (Caswell 1989, Lefkovitch 1965, Manly, 1990). Stage-based models provide an ecologically relevant method of grouping animals ontogenetically if characteristics such as survival or fecundity are scaled to the size or mass of an organism. Phenotypic plasticity also has particular relevance to populations which exhibit delayed maturity (Caswell 1983) for in these animals, maturity may be related to specific size (or range of sizes) rather than a mean age of maturity.

Wild populations of the endemic freshwater crocodiles, C. johnstoni, have not been described in any detail for Queensland. The population has been intensively tagged and meticulously measured since 1976 to monitor the population recovery following full protection in Queensland in 1974. A strength of the study is the marking of hatchlings by tail notching so that subsequent recaptures of the animals provide population parameters for animals of known age. Growth intervals are thus calculated on the basis of actual age rather than the more common use of size classes (e.g. a two foot croc is a two year old).

A key component of this study is the aging of animals with long recapture histories but of unknown age by skeletochronological analysis of the cervical osteoderms or scutes (Griffiths 1962, Hutton 1987, Suzuki 1963 Cooper-Preston 1992). Preliminary assessments using thin section analysis from cervical osteoderms of known-aged crocodiles provide a close correspondence between the number of lamellar bone layers and age. The high number of known-aged individuals in the study population provides a unique opportunity to validate the technique for unaged animals at this site. Independent verification would also be accomplished though the incorporation of oxytetracycline markers within osteocytes (Steendijk 1963, Zug 1990). The removal of a cervical scute is a simple nondestructive sample that requires only a pocket knife. Scute specimens are processed with standard lapidary equipment, histological staining procedures, and compared under transmitted, reflected, and polarized light microscopy and epiflourescence. Forensic methods that use incident interference microscopy coupled with computer enhanced imaging have provided excellent delineation and will likely provide a preferred method for age determination, particularly for the high resolution needed to delineate small growth annuli in older animals.

The population of C. johnstoni near Mt. Surprise offers a unique opportunity for both age and stage-based models to be developed from the same database. The study requires an accurate estimation of the population parameters to provide a reasonable comparison among analytic methodologies. The data from known-age animals permits the variability associated with age estimates to be minimized, thereby substantially improving the models' predictability, and the sensitivity analysis of the models' parameters. The study provides acomparative demographic analysis of the population but also has an applied nature for wildlife management.

Parameters that define demographic models (survivorship, migration, fecundity, growth rates, and age structure) must be estimated before well-informed management of captive populations can proceed. Otherwise wildlife managers are in the uncomfortable position of prescribing harvest quotas based on growth rates derived from captive-reared crocodilians (Abercrombie 1987). Ranching or farming operations that derive stock from the wild are not closed operations; ranches function as demographic sinks with an emigration of eggs, juveniles, or adults as a drain from wild population sources. Unless the demographic parameters are known for wild populations of freshwater crocodiles, the cumulative impact on those stocks remains, at best, a guess. Population models developed from both age and stage-based cohorts provide an effective means of gauging long term impacts on crocodiles.

Methods

The study site encompasses ~20 km of the Lynd River and its tributary, Fossilbrook Creek in north central Queensland (near 17° 50' S., 144°20'W) at the upper altitudinal distribution for the species. Although the Lynd dries incompletely during most dry seasons (April - October), one of its tributaries, Fossilbrook Creek, remains everflowing. The drainage is constrained during the dry season to a set of longer, deeper pools connected by riffles. This time of year provides the most efficient sampling opportunity as crocodiles are confined to discrete pools that can be efficiently sampled (Webb et al. 1982).

Animals are captured by a combination of methods including seining, snaring, set netting, and nocturnal hand collecting (Webb and Messel 1977) and are transported in wet cloth sacks to quiet them and minimize stress. Captured animals are doubly marked using a standard tail-notch and a metal tag through the webbing of the hind foot. Standard measurements of length, mass, and morphometrics are recorded for all crocodiles. A single cervical scute is removed with a pocket knife and animals selected for age validation are injected with oxytetracycline intraperitoneally. Since 1984, laparoscopies have been conduccted to determine reproductive status of all animals nearing maturity (Limpus 1984). Animals are returned within 24 h to the original capture site. Annual field trips and subsequent scute removals will document growth rates and verify rate of annulli deposition for both known and unknown-aged crocodiles.

Thin sectioning of scutes, staining, and examination are undertaken after returning to the University of Queensland. Scutes will be thin sectioned by two methods for comparative analysis. Scutes are decalcified with dilute hydrochloric acid, 10 micron sections cut with a microtome, and sections overstained using Ehrlich's hematoxylin. Sections are viewed with transmitted light microscopy. A second method of specimen preparation is the use of diamond saws to obtain sections 80 microns thick and fine polish both surfaces on diamond lapidary wheels. Specimens are examined by incident interference microscopy resulting from Komarski condensers and image analysis software used to enhance the degree of contrast marked by lines of arrested growth. This approach is currently the method of choice among forensic scientists who study dental odontochronology to age humans by counting dental annuli. Limited comparisons by the latter method have provided superior resolution to that obtained with transmitted light microscopy.

Specimens that can be aged using skeletochronology will augment the capture-recapture field program to provide the necessary data to analyze appropriate age and stage-based models. Population viability and age and stage-based models will be analyzed using program VORTEX and programs RAMAS-age and RAMAS-stage. Year to year measurements provide estimates of growth rates. Population abundance and long-term fluctuations will be calculated from the trends shown over >17 years using open population (JOLLY-SEBER) and closed population (SCHNABEL) estimates. The data generated from the study will constitute one of the few long term studies of crocodiles that spans a generation and will provide significant insight concerning the function of recruitment in a wild population.

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PRELIMINARY REPORT ON STRESS IN FARMED *CROCODYLUS POROSUS* HATCHLINGS

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Mortality of farmed crocodilians in the first year of life is one of the major constraints in the industry worldwide. Hatchlings dying are often runts, and necropsies frequently reveal little other than maladaptation. Ocasionally lesions such as hepatitis, bacteraemia or mycotic dermatitis are observed. The organisms cultured in such cases are generally opportunistic pathogens. These organisms are usually environmental ones, which the animal can normally co-exist with, but which result in problems when the animal is immunosuppressed. There are few primary pathogens of crocodiles, particularly in the increasingly hygienic intensive farms.

"Stress" has frequently been cited as a factor contributing to maladaptation, disease and mortality in reptiles, as well as poor growth and feed conversion and reproductive failure. The causes of stress are varied and include such husbandry factors as overcrowding, inadequate environmental temperature, excessive handling, inadequate grading resulting in dominance hierarchies, and noise. Low temperature appears to be particularly important, and high mortalities are frequently observed in the colder months of the year.

Crocodilians have been shown to develop increased plasma corticosterone levels in response to stressors, and changes in the immune system have been observed in stressed crocodilians.

The aim of this study was to determine whether water temperature, which is related to increased morbidity and mortality in farmed crocodilians, does in fact result in stress, alter immune function, and so lead to increased disease susceptibility.

The trial was conducted at Grahame Webb Pty Ltd's Crocodile Research Centre in Berrimah from March to July 1992. 1992 *Crocodylus porosus* hatchlings were allocated to 5 different temperature regimes after 10 weeks at 32^0 C. The temperature regimes were as follows:

1. 32^0 C

2. 32^0 C, increasing to 36^0 C at 10 weeks of age and maintaining at 36^0 C until the conclusion of the trial

3. 32^0 C, increasing to 36^0 C at 10 weeks of age, maintaining at 36^0 C for 10 days, and returning to 32^0 C for the remainder of the trial

4. 32^0 C, decreasing to 28^0 C at 10 weeks of age, and maintaining at 28^0 C until the conclusion of the trial

5. 32^0 C, decreasing to 28^0 C at 10 weeks of age, maintaining at 28^0 C for 10 days, and returning to 32^0 C for the remainder of the trial

Parameters tested were body weight, body length, food consumption and conversion, plasma corticosterone levels (to assess stress), plasma immunoglobulin levels and total and differential white cell counts (to assess immune function). Baseline levels were taken before the temperture change, followed by samplings after the first and second temperature changes. The aim of having the 5 different water temperatures was to determine whether both high and low temperatures can result in stress, and whether recovery can occur if the temperature is subsequently readjusted to the optimal 32^0C.

The trial results are currently being analysed and will by published subsequently.

THE ECONOMICS OF CROCODILE FARMING

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ABSTRACT - The crocodile farming industry attracted many investors when skin prices were high in 1985-89. Prices are now lower but many farms still have technical problems to solve and new investors continue to enter the industry. The economic parameters of crocodile farming are discussed, based on experience with a large ranching operation which rears two species of crocodiles in Papua New Guinea. The impact of the main features of farm construction and pen design are considered, with a summary of the suggested relative importance of factors affecting the cost of production.

INTRODUCTION

Crocodile farming is a relatively young commercial venture compared with many other livestock industries. Farms vary from intensive controlled-environment buildings to simple outdoor earthen ponds. The appropriate choice of farming system is affected by many factors, only some of which are under management control. There are places that have crocodiles in the wild but, because of other factors, are not able to operate a farm economically.

Farms located near a suitable tourist centre may earn a major part of their income from tourism. However, many locations with crocodile resources are in more remote locations where tourism is limited.

Skins are the main product and they are usually sold to tanneries in Japan, France, Italy or Singapore. Meat is typically a by-product, and may be eaten in the country of production or exported, particularly into South-East Asia. There are purported to be markets for other by-products, but in Mainland Holdings experience these are small.

Animals for farming may be obtained by collecting wild juveniles or eggs (ranching), or by captive breeding. However it is essential before any farm is built, that the Management Authority of the country has international approval, under CITIES, for harvesting from the wild. If ever breeders for a farm are obtained from the wild, without consideration of the effect of that harvest on the wild population, then registration of the farm under CITIES may be refused. It should be noted that "closed" systems, relying on captive breeding are NOT preferred under CITIES. Harvest of wild eggs or juveniles links commercial viability of farms to the wild resource and it's habitats.

The size of a farm will depend on many factors, including the availability of animals and the food to feed them. Mainland Holdings' operation in Lae, on the north coast of Papua New Guinea, has been built steadily, over many years, with much experimentation. The farm has approximately 35,000 animals, held in a variety of pen and pond designs, including many small heated tanks for hatchlings. It also includes a breeding section with over 200 mature females, but most of the 8000 to 10000 skins produced each year are from eggs or juveniles, harvested from the wild.

Apart from sales of some skulls and feet to tourists, there are supposed to be markets for dried meat, gall bladders, penises and crocodile oil. Mainland Holdings has found that the market for each is very small and the price falls substantially if you produce the product in any quantity.

In summary, investors must carefully research the customers requirements. Ensure that the species to be farmed has a saleable skin. Investigate price trends for meat and skins, and the wide range of regulations that will apply in both exporting and importing countries. The value of the skins typically far exceeds the profit on meat. There is a risk that chasing sales of meat and other products will distract management from the most important objective - ensuring the highest possible percentage of grade 1 skins.

PLANNING A FARM

A small farm can produce skins that are 90% grade one. It will make more profit than one that is 3 or 4 times bigger, which has lost control of its animal husbandry and produces low grade skins. Bigger is NOT better. Money MUST be spent on good pen designs that are appropriate for the species being farmed. Some species will tolerate high densities and large group sizes better than others, but generally best results are obtained from small groups; less than 300 and preferably less than 150. Design features for the pens include water depth, layout of feeding space, ratio of land to water, total pen size, and the number of animals of different sizes.

Essential farm requirements are sufficient land, food, water, labour, communications, power supply, finance, refrigeration (for food and saleable crocodile meat), and heating fuel.

A reliable food supply must be near the farm. It is cheaper to carry the crocodiles once, to the food, than to carry the food every day to a farm in a remote area. Investors must be able to guarantee an adequate food supply for many years. If it is seasonal or variable, the cost of freezing some food must be considered.

There must be sufficient space available in the pens for feeding. This may mean spreading the food out in a long line close to the water. As a rule, consider the width of the animals head. For example, one hundred animals with heads 5cm wide need the food spread out in a line at least 500cm long, so they can all feed together. Lack of food or reduced feeding space causes fighting, and bite-marks will downgrade skins. Some animals will be shy but it must not be hard for them to feed. Good access to the food should not encourage animals to drag it into the water. The texture of the feed may be critical. If it is too dry, with some species food intake will be reduced; long thin pieces (eg. chicken guts) encourage fighting for food, and "sticky" food can get stuck in the mouth of hatchlings. If changes of diet are needed, the new food should be mixed to give a gradual change, especially for young animals. Animals in outdoor pens will eat more on sunny days and almost nothing on cold rainy days (see table 2). This reduces annual growth rates and increases the time to reach killing weights. Heated pens have the advantage of higher food intake, more regular feeding patterns, and a better food conversion ratio (FCR) or kilos of food eaten for every kilo of crocodile weight gain. Food conversions (FCR) in the early 1980's at Mainland Holdings were 6:1 with no heated pens and using outdoor ponds. Figures of 3:1 and 2.5:1 can now be obtained with good management, mainly due to heating, but also helped by better feed formulation and reduced feed wastage. Figures of 2.5:1 are also reported by Joanen & McNease (1987) for American alligators in heated pens.

Nutritional information on almost all crocodilian species, is limited, and needs much further research. Mainland Holdings feeds minced chicken offal (heads, feet and guts), mixed with a vitamin and mineral premix and some high protein ingredients (eg.meat meal, fish meal). Experimentation is needed to formulate a diet with the best physical characteristics, at the lowest cost, for different sized animals. Professional nutritional advice is essential for every farm. Computer formulation can be successfully used to examine the composition of proposed mixes. Some farms have recorded poor growth rates by using diets that were clearly inadequate. Unbalanced diets can cause deaths and reduce the animal's resistance to diseases, so money spent on diets is a good investment. Some figures published by Staton & Vernon (1991) are reproduced in Table 3.

Several feed manufacturers in the USA are successfully producing extruded compounded feeds, which can be either fed alone or mixed with wet abbatoir offal or other protein source. Although expensive high density diets are of little use in developing countries with access to cheap abbatoir offal, a supplement of vitamins and minerals will usually be important, especially for animals under one year of age. Sources of offal include abbatoirs that are killing chicken, pigs, cattle etc. Alternatives are trash fish, if it is economical to bring it to shore and freeze it, and meat from culling operations (eg. wild pigs and buffalo in Australia and excess game meat in Zimbabwe). Fish diets can be deficient in Vitamin E and the fat goes rancid very easily; vitamin supplements and good freezing may be essential. Some food has a high percentage of water (see table 4), so the cost of the protein content must be calculated, when comparing alternative food sources.

Heating for young animals is essential. The metabolic rate of a 750 gram alligator doubles when its temperature is raised from 20 °C to 28 °C (Coulson & Hernandez,1983), and when the animals are warmer,they are more resistant to disease. Further, if they expect a warm day tomorrow, they will feed even in the cool of the evening (Lang,1987). At Mainland Holdings, heating reduced the average time for hatchlings to reach 500 grams from 300 days to 210 days. By contrast, alligators can reach that weight in 60 days and achieve killing weight in 18 months compared to 2.5 or 3 years for C. porosus and *C. novaeguineae*. A reliable heating system is essential, and usually involves heated water recirculating in underfloor pipes. There can be problems with deposits inside underfloor heating pipes from the minerals in the water, and water pressure changes causing uneven heat transfer to different pens. A target temperature of 30-31 °C, and a minimum of 20-25 °C at night, is essential for good growth in animals under 6 months of age. Rapid changes in temperature appear very stressful, especially if the animal cannot select its preferred temperature; 35 °C may be lethal in young animals. Overall, heating ensures good healthy animals, which use food efficiently. Keeping animals in controlled environment buildings for their whole life is ideal, but may also be uneconomic in the tropics. Every location and species is different, and technology must be adapted to suit.

In Papua New Guinea (PNG) there is estimated to be 60,000 square kilometres of swamp and river systems suitable for crocodiles, and in most of this area the human population is sparse. There are two species of crocodiles of PNG, the saltwater crocodile (*Crocodylus porosus*) and the New Guinea Freshwater crocodile (*Crocodylus novaeguineae*). They have never been under serious threat of extinction because of the remoteness of much of the vast habitat. Both species are listed under Appendix II of CITIES, which allows harvesting of eggs and live animals. The Management Authority of PNG has strict licencing laws, requiring regular reporting, so that the extent of the trade can be monitored closely. It is essential for the long term future of a commercial crocodile farming industry in any country, that the Management Authority demonstrates a high standard of wildlife management expertise and has the authority to control any harvest from the wild.

Potential investors in a crocodile farm must ensure the proposed method of farming is acceptable to the country's Management Authority. They should also consider that the Management Authority may have additional laws that extend controls beyond those required by CITIES. Investors must research other laws controlling both export and the proposed importer, and the market for meat and skins. They should also consider that permission to export farm products under CITIES may be lost if wildlife trading laws are broken. It is a business with long-term profits, but with only short-term licences!

SOURCES OF INCOME

The principal income will typically be from skins, with meat earning less than one quarter of farm revenue (excluding tourist income); see table 1. Only in Taiwan is this situation apparently reversed, where a number of farms concentrate on raising *Caiman crocodylus* for meat. Producing quality skins is the commercial object of most farms. A small cut in the belly skin causes a substantial drop in the value of the whole skin. Skinners need a comfortable working environment and plenty of time. Even small errors in the preparation and shipping of skins may cause a 25% drop in their value or even a total loss. In today's market, there is little demand for skins that are not grade 1, and the standard required by the tanners for a grade 1 skin is high.

All crocodile skins are NOT the same. Commercially there are two broad classes, Caiman skins from South America and "Classic" skins. Classic species are Nile crocodile (*C.niloticus*), American alligator (*A.mississippiensis*), New Guinea Freshwater (*C.novaeguineae*) and the Saltwater crocodile (*C.porosus*). The highest price is paid for saltwater crocodile skins. Others are of lesser value depending on their suitability for tanning and the appearance of the final tanned skin.

Meat can be another source of income. It must be hygienically packed and well presented. Calculations on meat processing yields were published in Staton et al (1990; see table 1). If the meat is to be exported ,it will need to satisfy quarantine, health, veterinary, wildlife, customs and CITIES rules of both the exporting and importing country ! Meat prices have varied from USD 0.70 per kilo in Venezuela, to the equivalent of USD 20 per kilo in Australia (G.GOUDIE, 1989a). Small amounts of meat can be sold at high prices, but a well run farm needs customers who will purchase all the production, on a regular basis.

The density of animals and choice of building is an economic consideration. Generally, lower densities give better growth and high quality skins. Based on early work with American alligators, by Joanen & McNease, Mainland Holdings have used the following densities for open pens and ponds:

SQUARE METRES PER ANIMAL

HATCHLINGS	0.1
4KG BODYWEIGHT	0.3
16KG BODYWEIGHT	0.6
21KG BODYWEIGHT	1.0

Elsey et al(1990) recommended 0.2 sq m per animal for 7 month old alligators (727+/-189 grams). This research was based on small groups but similar stocking rates have been recommended for young Nile crocodiles (Blake,1974) and *C.johnstoni* (Webb et *al.* 1983). Recently these figures have been reviewed at Mainland Holdings. Several trials in 1990, on groups of 100 to 300 *C. porosus* indicated that 0.2 sq m per animal is adequate up to 1.5kg bodyweight. In 1992, the Louisiana Dept. of Wildlife and Fisheries was recommending for alligators in controlled environment pens:

1 sq ft (0.1 sq.m) up to 24" long (say 6oo grams)
3 sq ft (0.3 sq.m) from 25" to 48" long (say 6oo grams to 8kg)
1 extra sq ft (0.1sq.m) for each 6" over 24" long

This gives very generous space to 700 gram animals because of their rapid growth rate. However the species, type of building, group size and pen design, all affect the relationship between space and optimal growth.

A reliable source for eggs or young animals must be secured. If the farm is to purchase live juveniles from the wild, or from other farms, then the disease status and feeding history of the new arrivals may be unknown, and will certainly be variable. This means that quarantine controls within a farm, are needed both to prevent the introduction of disease and to ensure all new arrivals are eating. It may take 3 to 6 weeks for stressed arrivals to adjust to new pens and food.

If harvesting eggs or juveniles from the wild, there may be significant annual changes in availability due to natural variations in the wild population. Depending on the country and Management Authority, harvesting may be subject to annual limits. International pressure, may also influence harvest limits, so there is no certain way to plan the farm intake. In PNG there are always plenty of crocodiles in the swamp, but they may become impossible to harvest in some years, when river water levels are high. Flooding may also destroy many nests and create a temporary shortage of juveniles. There is no such thing as a reliable wild source.

Breeding farms are a very long term investment. Captive *C. porosus* breeders start laying at 5 to 7 years. Young females lay 25-30 eggs with up to 65 larger eggs from mature females. Reasonable hatch rates can be obtained with efficient incubator equipment (see table 5). Housing one male with one female gives the best control, but using colony pens reduces the number of males that need to be fed and housed. Fighting occurs between males and females in some species and it is essential to fence the pens securely, to keep the animals in as well as tourists out. Artificial hatching of eggs harvested from the wild, or bred in captivity, gives more control over the health and early feeding of the animals. Eggs should never be incubated "naturally"; the expense of an incubator is well justified by more and healthier hatchlings.

Stress is a major factor in reduced performance (G.S.GOUDIE,1989b). Animals will not eat and small ones will go into shock and die. While American alligators and Nile crocodiles are very placid, the stressed saltwater crocodile will refuse to eat for months. Even healthy animals may pile up and die in pen corners, if seriously stressed by noise or other unusual activity. Regular noise patterns (or music), stable temperatures and reduced lighting all seem beneficial. Crocodiles have not yet been selected genetically, like other farmed species, so there is enormous variation in individual growth rates. If the smaller ones are not removed and sorted into groups of their own size, they will stop growing, until they are given a less competitive environment. Larger animals attack the small ones and bite marks downgrade their skins. All crocodile farms need to sort penned animals at regular intervals, usually 6 months or less for animals under 1 year. Pens must be designed for easy access by staff for sorting, cleaning, and feeding.

Water needs to be clean but most species prefer "cloudy" water so they can easily hide by submerging. Regular water changing must include removal of faeces and food in the water, preferably with some disinfection or chlorination. If the water is heated, then water used for washing down and refilling should be at the same temperature to avoid thermal shock. Design of the pens will affect the volume of water used. At Mainland Holdings we used 1500 cu metres of water per day in 1989 but this could have been cut to one third with better pen design. However most pens are built in concrete, so its hard to correct a poor design! Investors must ensure there is adequate water supply and the necessary licences, plus power to pump it and gentle slopes on the land for drainage. Apart from the cost of pumps and electricity, a large water volume can create a major effluent problem. The water depth required varies with the animal size, but most of the water area can be gently sloping shallows. This creates small variations in water temperature in most pens, and allows the animals a choice. When in pens, most species of crocodilians make only limited use of the land area, so 70 to 90% of indoor pen area can be water. Outside pens with no heated water require a significant area for basking on sunny days. At Mainland Holdings, early pens were built with a land to water ratio of 50:50 but now many outdoor pens are 20:80, and indoor pens with heated water have only the minimum space of land needed for feeding. Some Nile crocodile farmers even flood the feeding area when all food is removed.

Diseases can be a problem but healthy stock, properly maintained, at reasonable density, will have few disease problems. Pen design should not run water from one large pond to another. Sick animals must be sorted out and medicated in separate pens. Problems have occurred with coccidia, bacteria, fungii, eye infections, worms and other parasites. Apart from mortality and reduced growth rates, diseases also reduce the food conversion ratio of the farm, and so significantly increase the quantity of food required.

ECONOMIC FACTORS

To demonstrate the relative importance of various factors, a theoretical model of two farms is presented. Both farms purchase 2000 hatchlings per year to be sold for skins of 40cm bellywidth at approx. 17 kg liveweight. One farm uses EXTENSIVE rearing, with unheated ponds for all ages. The INTENSIVE farm uses heated pens for all animals. The performance results and costs suggested, will vary with species, local management methods, and many other factors. Suggested figures are US dollars.

COSTS

-----	EXTENSIVE $$	INTENSIVE $$
COST OF CONSTRUCTION OF FARM		
(a) services(roads,fences etc.)	150,000	250,000
(b) buildings -cost per animal	10	40
AGE AT KILLING	3 YEARS	2 YEARS
number of animals held	6000	4000
total building cost	60,000	160,000
TOTAL CONSTRUCTION COST (a+b)	210,000	410,000
OVERHEAD COSTS		
depreciate buildings and services over 10 years.	21,000	41,000
repairs and maintenance	7,000	15,000
administration (see below)	30,000	60,000
skinning building(annual cost)	5,000	5,000
water,electricity,heating	5,000	20,000
salaries	50,000	50,000
TOTAL OVERHEADS FOR 2000 PER YEAR	118,000	191,000

MAJOR VARIABLES

COST OF ANIMALS		
assume hatchlings at $10 each	20,000	20,000
COST OF FOOD		
delivered mixed to farm	50cents/Kg	50cents/Kg
FCR	6:1(for 3yrs)	3:1(for 2yrs)
food eaten per croc(to 17Kg live)	102 Kg	51 Kg
food cost per croc	51.00	25.50
TOTAL FOOD COST per 2000 animals	102,000	51,000
WAGES		
No. of employees(farm and skinning)	8	4
Avg. annual wage(skilled and not)	5,000	12,000
TOTAL WAGES COST	40,000	48,000
GRAND TOTAL COST ESTIMATE (overhead,animals,food,wages)	280,000	310,000

REVENUE (Selling 40 cm skins)

mortality (hatch to kill)	15%	5%
animals to sell yearly	1700	1900
centimetres of skin to sell	68,000 cm	76,000 cm
skin sell price grade 1	$ 5.00/cm	$ 5.00/cm
grade 2 (25% less)	$ 3.75/cm	$ 3.75/cm
skin grades ratio first:second	60:40	90:10
resulting avg. sell price	$ 4.50	$ 4.875
SKIN REVENUE FROM 2000 ANIMALS	S$ 306,000	S$ 370,500
NET PROFIT	S$ 26,000	S$ 60,500

Administration includes insurance, vehicles, medication, cleaning chemicals, security, staff amenities, permits and licences.

EFFECT OF SOME VARIABLES

(1) If food was virtually free, a waste by-product, and delivered to the farm for 5 cents per kilo then Net Profits would be:
Extensive S$111,800 and Intensive S$127,400.

(2) If the Extensive farm improves one or all of the following
(i) cut mortality to 9%
(ii) improve FCR to 4:1
(iii) improve grading from 60:40 to 80:20
then profits, with food at 50 cents per kilo would be:

Net profit above	$ 20,000	
Extra 6% skins at 80:20 grades	$ 22,800	(4800cm*4.75)
Improving FCR to 4:1	$ 34,000	(2000*17*2*.5)
All skins improve grades to 80:20	$ 17,000	(40*2000*{4.75-4.5})
NEW TOTAL PROFIT	$ 93,800	

This suggests that on most farms the additional expenditure on heating pens can be quickly repaid from extra profits.

SKIN PRICES

Very little data is available on the selling prices of skins for different species. Prices for the American alligator are published in annual reports, and Table 6 summarises data from Louisiana for the period 1972-1991. Crocodile skins are a luxury item and prices have been hard hit by the world recession. In general terms, prices have fallen 30-50% from the peaks of 1989-90. Price drops for the non-classic skins have been greater. The requirements for a grade 1 skin have increased and markets are much harder to find for grade 2 and 3 skins. A grade 2 skin is worth 25% less than a grade 1, and grade 3 is worth only 50%, so the loss of revenue from cuts and bites is severe. There have also been erratic changes in the market that affect the relative price of large and small skins. Some years there is a good demand for small skins, but in recent years skins under 25cm bellywidth have received poor prices. It is also noticeable, for example, that with the September cull of large wild American alligators, the price of large skins of other crocodilians drops from July to October. Since farm growout takes 1.5 to 3 years, these relative price changes have a serious impact on planned revenues. The situation in future will not change and past price trends are NOT a guide to the future.

If caiman skins can be produced in large numbers without osteoderms, this should seriously affect the market , especially for the easier to produce small skins. The only solution is to develop good contacts in the industry and to exchange information in the same way that the buyers do. Investors must appreciate that there is a limited market. Since the buyers know how many animals are harvested, bred and hatched each year, they can predict how many farmed skins will be offered for sale next year.

SUMMARY

The substantial rise in skin prices up to 1989/90 attracted many investors to crocodile farming. Only the efficient operators and those in developing countries with very low costs of production, will survive the present recession. Investors must ensure the farm has a legal, reliable source of young animals, and that the necessary CITIES export and import permits can be obtained. A reliable source of food close to the farm must be secured and every effort made to ensure that the maximum possible percentage of grade 1 skins is produced.

Research may be needed on the requirements of a particular species; pen design, diets, food texture, temperatures, group size, etc. There is a lot of natural variability in the animals and careful records and good husbandry are essential to be able to identify which methods give the best results.

The objective is to make the best possible use of the wildlife resource on a sustainable basis. Active support for crocodilian conservation makes good commercial sense, including assisting on wild crocodilian population surveys, promoting the breeding of endangered crocodilians and protecting wildlife habitats. Responsible farming on a sustainable basis will ensure the farm continues to receive international and CSG support for continued trading under CITIES.

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TABLE 1. ANALYSIS OF REVENUE FROM 9 KILOGRAM LIVEWEIGHT CROCODILE

ref:crcmeat

TOTAL LIVEWEIGHT	9.64	Kg
LIVE BELLY WIDTH (CM)	33	cm
EVISCERATED CARCASS WEIGHT		
LEGS	0.67	
UPPER BODY	3.62	
TAIL	2.05	
TOTAL	6.34	Kg
DEBONED & DEFATTED MEAT		
BODY MEAT	1.74	
LEG MEAT	0.52	
TAIL MEAT	1.33	
TOTAL	3.59	Kg
FINAL SALTED SKIN BELLY WIDTH	30	cm

REVENUE

MEAT : 3.59 Kg AT USD 8 /Kg = = USD 28.72 PER CROC

SKINS: 30cm WIDTH AND 80% GRADE 1 AT USD 9 /CM
AND THE 20% GRADE 2 AT 25% LESS = USD 256.50 PER CROC (average)

After Table 3 & 4 of Staton et al 1990
& internal records of Mainland Holdings.

TABLE 2. AVERAGE DRY MATTER FOOD CONSUMPTION

grams/crocodile/day in warm & cool weather

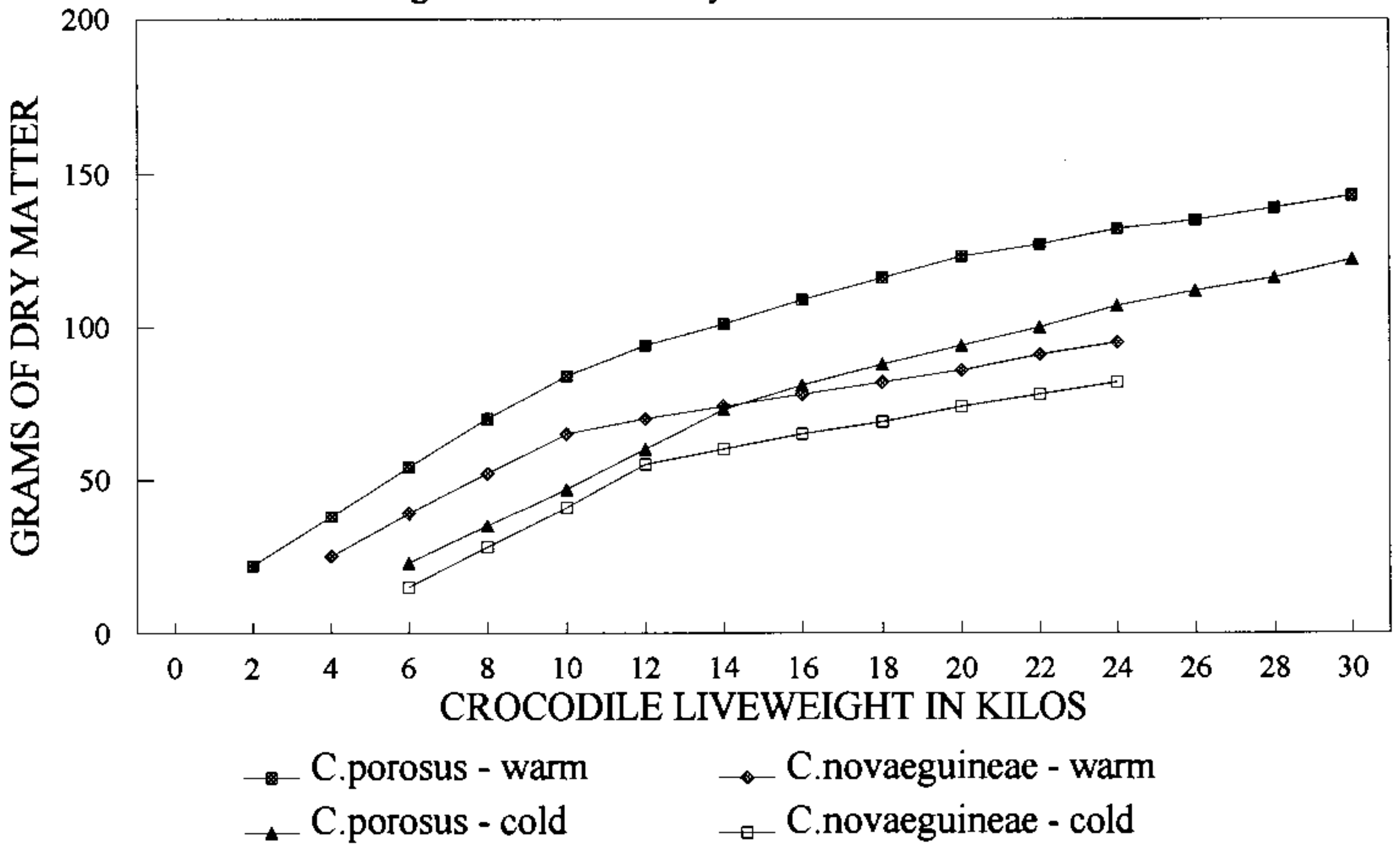

TABLE 3. SUGGESTED DIETARY ALLOWANCES FOR FAST-GROWING CROCODILES UP TO 25 KILOGRAMS WEIGHT

ref:crcons

NUTRIENT		AMOUNT	% or per kg diet dry matter
Digestible Protein	(minimum)	45 plus	%
Digestible Energy		4500	kcal
Fat		10-16	%
Fibre		< 4	%
Calcium		1-2	%
Phosphorus		0.5-1	%
Potassium		0.7	%
Sodium		0.3	%
Chloride		0.3	%
Magnesium		0.05	%
Iron		90	mg
Copper		8	mg
Maganese		80	mg
Zinc		80	mg
Iodine		1.5	mg
Selenium		0.5	mg
Colbalt		0.2	mg
Molybdenum		1.2	mg
Vitamin A		12000	IU
Vitamin D		1200	IU
Vitamin E		120	IU
Vitamin K		7	mg
Thiamine		8	mg
Riboflavin		12	mg
Niacin		70	mg
Pantothenic Acid		25	mg
Pyridoxine		15	mg
Vitamin B-12		0.03	mg
Folic Acid		3	mg
Biotin		0.5	mg
Ascorbic Acid		450	mg
Choline		1000	mg
Linoleic Acid		1.0	%
Arachidonic Acid		0.5-0.1	%
	(----- % OF DIETARY PROTEIN ------)		
Arginine		5.5	%
Glycine + Serine		6.5	%
Histidine		1.8	%
Isoleucine		3.2	%
Leucine		5.9	%
Lysine		5.3	%
Methionine		2.1	%
Methionine + Cystine		3.6	%
Phenylalanine + Tyrosine		5.8	%
Theronine		3.6	%
Tryptophane		1.0	%
Valine		3.6	%

From Staton & Vernon (1991).

TABLE 4. PROTEIN & MOISTURE OF FEED INGREDIENTS

ref:crcfeed

	% MOISTURE	PROTEIN % WET BASIS	PROTEIN % DRY BASIS	INDEX OF RELATIVE PROTEIN CONTENT WET BASIS	INDEX OF RELATIVE PROTEIN CONTENT DRY BASIS
WHOLE CHICKEN	66.4	16.2	48.2	144.6	123.9
CHICKEN HEADS	73.1	13.3	49.5	89.9	127.2
CHICKEN FEET	55.3	22.8	51.1	154.1	149.4
BONELESS RED MEAT	62.0	14.8	38.9	100	100
PRAWN TAILS IN SHELLS	77.5	18.6	82.6	21.5	90.2
ISOLATED SOY PROTEIN	5.5	86.4	91.5	100	100
WET BLOOD	85.0	14.0	93.3	16.6	98.8
BLOOD MEAL	11.0	84.0	94.4	100	100
TRASH FISH	68.0	23.0	71.8	34.3	96.6
FISH MEAL	10.0	67.0	74.3	100	100.0

TABLE 5. NESTING BY C.POROSUS CAPTIVE BREEDERS AT MAINLAND HOLDINGS.

NESTING YEAR	87/88	88/89	89/90	90/91	91/92
FEMALES	133	130	121	118	207
MALES	67	67	67	66	90
NESTS					
TOTAL	44	73	98	50	71
PER FEMALE	0.33	0.81	0.81	0.42	0.34
EGGS					
TOTAL LAID	1599	2895	4368	2271	2988
PER NEST	36.3	39.7	44.6	45.4	42.1
PER FEMALE	12.0	22.3	36.1	19.2	14.4
INFERTILES					
TOTAL	360	1039	994	1102	927
%	22.5	35.9	22.8	48.5	31.0
DISCARDS	0	100	901	27	105
SET	1239	1646	2489	1142	1956
HATCHLINGS					
TOTAL	496	1150	2013	1000	1397
PER FEMALE	3.7	8.8	16.6	8.5	6.7
PER BREEDER	2.5	5.8	10.7	5.4	4.7
PER NEST	11.3	15.8	20.5	20.0	19.7
HATCHABILITY					
OF TOTAL LAID	31.0	40.6	46.8	44.7	46.8
OF FERTILE	40.0	63.3	60.6	86.8	67.8
OF SET	40.0	71.3	82.2	88.9	71.4

NOTE: 91/92 season includes FEMALES laying for first time.
Data from internal records of Mainland Holdings.

TABLE 6. LOUISIANA ALLIGATOR HARVEST 1972-91

YEAR	WILD NUMBER of hunters	WILD ANIMALS HUNTED FOR SKINS NUMBER of crocs.	T.L. (A)	VALUE PER FOOT(B)	TOTAL USD VALUE
1972	59	1,350	211	K8.10	K75,505
1973	107	2,921	213	K13.13	K268,994
1975	191	4,420	229	K7.88	K258,791
1976	198	4,389	216	K16.55	K512,240
1977	236	5,474	224	K12.23	K488,499
1979	708	16,300	211	K15.00	K1,711,500
1980	796	17,692	201	K13.00	K1,609,972
1981	913	14,870	211	K17.50	K1,821,575
1982	1,184	17,142	208	K13.50	K1,621,633
1983	945	16,154	211	K13.00	K1,452,568
1984	1,104	17,389	213	K21.00	K2,556,183
1985	1,076	16,691	216	K21.00	K2,482,619
1986	1,207	22,429	211	K23.00	K3,611,000
1987	1,370	23,892	216	K40.00	K6,689,760
1988	1,545	23,526	221	K48.00	K7,905,024
1989	1,769	24,846	221	K50.00	K9,006,675
1990	1,921	25,575	221	K57.00	K10,568,869
1991	1,996	24,036	226	K32.00	K5,704,307

FARMED ANIMALS

YEAR	NUMBER OF FARMS	No. SKINS SOLD	T.L. (A)	VALUE PER FOOT(B)	TOTAL FARMED SKINS USD VALUE
1972	8	35	152.4	K8.10	K1,417
1973	8	103	193.0	K13.13	K8,560
1975	8	83	167.6	K7.88	K3,597
1976	8	360	175.3	K16.55	K34,258
1977	8	376	160.0	K12.23	K24,142
1979	-	-	-	-	-
1980	8	191	142.2	K13.00	K11,595
1981	8	360	142.2	K17.50	K29,421
1982	8	113	121.9	K13.50	K6,102
1983	14	1,449	139.7	K13.00	K86,273
1984	12	2,836	129.5	K21.00	K253,113
1985	15	4,430	129.5	K21.00	K395,377
1986	22	5,925	137.2	K23.00	K613,237
1987	30	10,670	134.6	K24.00	K1,131,873
1988	47	27,749	129.5	K36.00	K4,245,597
1989	83	61,968	121.9	K32.00	K7,931,904
1990	123	88,500	123.0	K24.00	K8,496,000
1991	134	105,000	127.0	K17.00	K7,416,700

(A) T.L. is total length of average skinned animal in cm.
(B) is average selling price per foot length (30.5 cm).

THE LINK BETWEEN CONSERVATION AND THE SUSTAINABLE USE OF WILDLIFE

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The long-term destiny of wildlife is intimately linked to its ability to compete successfully for the land and water it needs to survive. It is continually at risk from agriculture, aquaculture and other forms of resource use required for human needs. Needs that are increasing exponentially with human population growth.

The concept of "conservation through sustainable use" (CSU), as applied to wildlife today, is based on the economic reality of the competition for resources. It is a concept of "value-driven" conservation. By "using" wildlife to generate economic benefits, economic incentives to conserve wildlife and their habitats can be created. If the rates of use are within the capacity of species to renew themselves, the use and thus the incentive to conserve can theoretically continue indefinitely.

Proponents of CSU programs come largely from the ranks of wildlife managers: the people charged with finding practical solutions to wildlife conservation problems. Opponents come largely from animal rights and welfare circles. Two of their main points of contention with the CSU concept (Rawlinson 1988; Fox 1992) are:

- the morality of linking wildlife conservation to instrumental (use-values to humans) rather than to intrinsic values: a rejection of human-centred programs, regardless of whether they achieve conservation for underlying intrinsic reasons; and,

- the rights of humans to use wildlife consumptively. Specifically, to kill other living organisms or remove them from their habitats.

This paper addresses what is essentially a conflict between two groups of people, each of which considers themselves to be conservationists. I argue that CSU should *not* be abandoned as a management tool simply because consumptive use, in particular, offends the morality of some individuals, in some countries. The basis for this position is the compelling evidence that links effective conservation with "use". Blanket opposition to instrumental values and consumptive use is not a conservation strategy, but rather the projection of dogma with little practical relevance to conservation.

THE PROBLEM AND ITS CONSEQUENCES

The concept of CSU is by no means a new one, despite its resurgence in today's conservation literature (Thomsen 1992). The earliest wildlife conservation programs, implemented hundreds of years ago, in a number of different countries, were motivated by the desire for sustainable, consumptive use - to conserve wildlife so that hunting could continue indefinitely (Graham 1973; Gilbert and Dodds 1987).

Theodore Roosevelt and Aldo Leopold, two Americans often considered the founders of modern conservation, both supported consumptive use of wildlife, while being critically aware of the need to limit harvests to the capacity of species to renew themselves (Leopold 1933; Beard 1988). Roosevelt's pragmatic doctrine of "conservation through wise-use", which is synonymous with CSU, reversed the collapsing US wildlife stocks of the early 1900's (Gilbert and Dodds 1987). In more recent times, CSU has been important, if not fundamental to, the "World Conservation Strategy" (IUCN/UNEP/WWF 1980) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

With such eminent credentials, one may well pose the question: "why don't CSU proponents ignore opponents and get on with business of applying CSU?" After all, everyone seems to agree that "time is of the essence" with wildlife conservation. Unfortunately, it is not so simple. Today's animal rights and welfare groups are a powerful political force in many developed countries. Through spirited opposition and astute "biopolitics", they can and do render CSU programs unworkable (Lapointe 1993). The fate of Zimbabwe's elephant and rhinoceros proposals at the 1992 CITES meeting in Kyoto, Japan (Hemley 1992; Broad et al. 1992) provides an excellent example. As a large share of all public and Government funding for conservation goes to groups with strong animal rights and welfare constituencies, it is ironic that the resources are often used to hinder programs considered by experienced wildlife managers to be effective in solving conservation problems (King 1988; Lapointe 1993).

There is also a humanitarian dimension to the problem. In many parts of Africa, Asia, South America and Central America, the consumptive use of wildlife provides primary sources of protein and income for people - often poor rural people (Brundtland *et al.* 1987; Webb and Jenkins 1991; Barbier 1992a; Murphree 1992). The consequences of stopping that "use", because CSU programs do not satisfy distant people in distant lands, is a moral issue in its own right. It prompted the African Resources Trust (ART) to convene a workshop (London, November 1992) to review the situation.

Attended by a range of people with credentials in international conservation and wildlife management, the workshop concluded that public opposition to CSU programs in developed nations was often based on misinformation and ignorance about the links between conservation and sustainable use.

THE LINKS

Much of the recent literature on CSU, like that on biodiversity, is dominated by economic and development arguments (Aylward 1992; Barbier 1992b). We hear more and more about unique and economically valuable genetic resources, property rights for natural living organisms, the questionable rights of developed nations to utilise the natural resource capital of developing nations, the need to encourage all people to live off the interest rather that erode their natural capital base, and so on.

All these issues are important, and debate about them is legitimate. But they are not concepts to which the public can relate easily, let alone become emotionally involved with. Most people have a rudimentary understanding of economics and few could even consider living off the interest from their savings (capital)! The connection between these analogies and wildlife conservation will be lost on many people. The central problem with CSU education, is that the public tends to see "consumptive use" and "conservation" as contradictory (ART 1993), despite a simple and fundamental connection between them.

Conservation. We have been conserving a great variety of items, both animate and inanimate, for centuries. We thus have a long experience with conservation per se, although it is often ignored when discussing the relatively recent concerns about wildlife conservation. Independent of wildlife, conservation can be defined as:

> *the sum total of actions taken to preserve and maintain items to which we attribute a positive value.*

The critical elements of this definition are the attribution of a positive value, the implication that without attention the items will deteriorate or be lost, and the link between *preserve* and *value.* The need to preserve those characteristics of an item that are responsible for its positive value. Conservation clearly contains preservation goals, but as discussed below, drawing a distinction between preservation and conservation has utility.

Value. Values are inherently changeable. What we consider highly valuable today may have no value tomorrow. An item with little market value, that is valued by no substantial part of the community, may be greatly prized and valued by an individual for reasons that are intangible. However, we would not normally expect the community as a whole to expend resources conserving items that few consider have value or potential value. In contrast, we often expend considerable resources trying to eliminate, remove or eradicate items that have no value in the eyes of the community.

The problem of course is that *one man's honey is another man's poison.* An item with a positive value to one group of people, may have a negative value to another. Yet typically, only one of them is in a position to conserve or destroy it. What are the implications for the conservation of any item if the group with ownership has only a negative value?

Use. Use is intimately linked to value and hence to conservation. All use is associated with a reward, a value, which can be positive or negative. Things that have no use are termed "useless", and the garbage industry is based upon the daily disposal of millions of tonnes of useless items. Yet such items may well have value to future generations as antiques or archaeological treasures. Some people may value positively a unique geological structure, because when they sit and ponder it (use it), it gives them pleasure (reward). Alternatively, others may not value the same unique geological structure, because it contains no fertile soils, has no value for farming and threatens their village with landslides.

Use and value, and thus the incentive to conserve, will vary greatly at local, national and international levels. It will involve both consumptive and non-consumptive forms of use. Cultural, religious and socio-economic diversity ensures that no single set of use-values will ever be applied to all items, wildlife included, by all people.

Sustainability. To use any item in perpetuity is to use it sustainably, regardless of the form of use. Accordingly, there is much substance to the statement that *conservation is sustainable use*. However, there are a number of aspects of sustainability, as it relates to wildlife conservation and the achievement of sustainable use, that are confused:

- There can never be a guarantee that any use will be sustainable in the long-term, because it is impossible to know what tomorrow may bring, despite predictions. There can only ever be a probability of sustainable use.

- Sustainability can only be demonstrated if use is occurring. For this reason, monitoring and flexible management are important because they allow adjustments to counteract unpredicted responses.

- It is impossible to predict with certainty the way in which a population will respond to being used consumptively or non-consumptively. Experimental use - management by experiment - is the most accurate and cost-effective way of fast-tracking CSU programs (Walters 1986).

In summary, if plants and animals have no use, they have no value - they become useless or valueless. People will rarely expend resources conserving them in the face of competing economic reasons to use wildlife environments for other purposes. This is especially so in developing countries, where poverty is widespread. Sustainable use can never be guaranteed in advance, so CSU programs must be based on a commitment to monitoring and must involve feedback channels which allow management to be continually refined.

INSTRUMENTAL AND INTRINSIC VALUES

What about species with no recognised value or use? If the CSU concept is based entirely on instrumental or human-centred values, do we ignore species with no value? These are valid questions (Rawlinson 1988; Fox 1992), but such doubts do not constitute a logical case for opposing CSU programs.

The relationship between humans and the natural world varies greatly. There is not necessarily a right relationship, nor a wrong one. There is no one set of ideas or philosophies that can or should be expected to suit all peoples, nor be imposed on all. However, humans are united in having *evolutionary rights* to survive. Humans evolved as part of the natural world with an evolutionary obligation to use plants and animals. They did not evolve as guardians or protectors. That most societies and cultures adopt that role to varying degrees is understandable. Their survival, to varying degrees, is dependent upon it.

Of prime importance, there is no universal obligation to conserve things for their intrinsic value per se. In fact it can be argued that the whole issue of intrinsic value makes no biological nor evolutionary sense. It could never be selected for in human populations, because by definition, if any benefits were derived, the motivation becomes instrumental.

That instrumental values rather than intrinsic values are more effective in generating public support for conservation issues is well exemplified by today's efforts to encourage public support for biodiversity. The mainstay of most arguments is the *potential* "uses" of living organisms to people. There would appear to be no living organisms whose conservation could not be justified on real or potential instrumental values.

Nevertheless, proponents of intrinsic value should not see attempts to ascribe an economic value to wildlife as threatening their concept of intrinsic values. The central conservation goal of CSU programs is to increase the proportion of the community that attributes a positive value to wildlife. It does this through linking the benefits of conservation to the day to day exchange of currency that dominates value systems in all our lives; whether we acknowledge it or not. To adopt the approach that no conservation efforts should be undertaken unless they are based on a purely intrinsic motivation, is to abandon wildlife conservation efforts throughout most of the world.

THE RIGHTS TO USE

Humans, like all living organisms, affect their environment and use other forms of life consumptively. If humans and most other living animals do not use other living materials they die. It is an issue of basic survival, and hence the right of humans and of all species to use other living organisms is unequivocal.

Over and above this fundamental right, which links all peoples, most societies have established rules and controls, typically for instrumental reasons, to govern the extent of resource use by individuals. These vary greatly in form and in their ability to ensure sustainable use. Within any one society rules may be established that take away "rights" of use from all or part of its people. But this in no way constitutes resolution of the moral issues on a global scale; it does not provide justification for opposing CSU programs that operate in countries where society has different values, perceptions, needs and rules.

PRESERVATION AND CONSERVATION

Drawing a distinction between preservation and conservation probably has utility in the public arena, despite the fact that preservation is and always has been a central goal of conservation. At the risk of generalising, preservationists emphasise intrinsic values and take the view that wildlife should he left to manage itself. They tend to oppose human intervention and the use of wildlife, regardless of sustainability. Conservationists may have more instrumental goals and are prepared to intervene as necessary to achieve them. This apparently subtle distinction may lead to extreme divergence in outcomes: culling elephant populations so that the carrying capacity of the habitat is maintained (conservation), versus watching elephants destroy habitats through overpopulation and then lamenting the images of them starving to death (preservation).

DISCUSSION

It is not difficult to understand why many people oppose wildlife use. The *unsustainable* use of a great variety of wild species was one of the main problems that led to the establishment of the international conservation/preservation movement. However, during the exponential growth phase of the movement, conservation became increasingly linked to animal rights and welfare issues. Stopping all killing and use of wildlife became a central goal of large and vocal elements of the conservation movement. The fundamental assumption, which is wrong, was that this action alone would prevent the extinction of wild species.

On the surface, the problem was simply defined (species were going extinct) and the potential solution was easy for the public to understand and accept (stop killing and using them). Add the power of television, the attractive images of wildlife, the added attraction of "bad" news - an issue shrouded in negatives - and a campaign with the potential to strongly influence public attitudes was created. With news and current affairs programs disseminating the information for nothing, the "message" spread rapidly. The conservation movement literally swept through developed nations, catching the imagination and support of tens of millions of people. It made wildlife conservation a political reality, on a global scale, and the public continues to provide tens of millions of dollars annually to sustain it's activities.

In any overview, wildlife has benefited greatly from the conservation movement. But for a variety of cultural and socio-economic reasons, many developing countries are unable to implement the types of wildlife conservation programs ("preservation only") that people mostly living in the cities of developed nations want.

Programs aimed at conserving wildlife should not be restricted to a narrow range of options, based on a narrow range of philosophies. It makes much more sense to tailor programs to the circumstances in which they are expected to operate (Webb et al. 1987). Accepting socio-economic and cultural situations for what they are, and designing pragmatic conservation programs around them. Goal-oriented rather than method-oriented conservation, which does not require fundamental changes in culture. It makes no sense to close off options for solving conservation, at a time when serious conservation problems are being identified at an alarming rate.

That we should be concentrating on conservation strategies that will work today, within the local environment, has a firm foundation in elementary science. The time scale of any solution to a problem must be aligned with the time scale at which the problem is occurring. The status of habitats and wildlife species is declining rapidly throughout the world, despite the role of the conservation movement. Our immediate need is for workable solutions to those problems - pragmatism and innovation - rather than attempts at changing ingrained social and cultural values as a prerequisite to implementing a narrow range of conservation options. This is not a short-term undertaking, not to mention the moral issues involved. Judging from the work of religious missionaries in distant corners of the globe, it may well prove impossible to meet the prerequisites in many countries.

Wildlife conservation is clearly a complex area of endeavour, requiring compassion, understanding, tolerance and respect for other peoples, cultures and religions. Yet this reality does not seem to be generally understood by the public. As pointed out by Gorzula (1987) overzealous attempts to win public support for conservation generally, has left the public with a series of ecological myths and legends that have little basis in fact. Similar myths and spurious assumptions are associated with opposition to the CSU issue. For example:

- the concept that all wildlife conservation problems have simple causes and can be solved with simple solutions - usually not the case.

- the concept that wildlife conservation can be advanced generally by adopting a philosophical position against killing and use - usually not the case.

- the concept that wildlife conservation can be advanced by not buying wildlife products, regardless of whether or not they were produced through approved management programs - rarely the case.

- the concept that wildlife conservation could work without the ground-roots support of landowners and custodians - rarely the case.

- the concept that all wildlife populations are fragile entities driven closer to extinction by any human use - usually not the case.

None of these insights is new. In the US alone there has long been unequivocal evidence that conservation goals can be achieved through management programs designed to provide animals for hunters to kill (Gilbert and Dodds 1987; McCullough 1992; McCullough and Barrett 1992). However, they are not simple messages and nor are they easily packaged to be attractive to the public.

In the meantime, opposition to CSU and consumptive use continues (Thomsen 1992). The philosophy adopted to guide the solving of wildlife conservation problems ("preservation") and win public support for such efforts, has become dogma. Protecting the dogma has become more important than solving the problems that spawned it.

CONCLUSIONS

The obvious question for all conservationists, is what to do about this conflict? There are no easy solutions, and the issue is complicated by the fact that many conservation organisations are now so big that they have become totally dependent on the massive amounts of money (Spencer et al. 1991) generated by the public on the basis of unrealistic expectations. Accurately and comprehensively informing the public will sometimes conflict with attracting the greatest sums of money.

But if the case for CSU is both theoretically and practically sound, then it should not be abandoned because it creates problems for the conservation establishment. CSU programs should continue to be tested and their worth judged on their ability to achieve tangible conservation benefits.

In any overview, we are at an important crossroad in the development of responsible and effective wildlife conservation. No single philosophical position can solve all problems, and thus it is important that we continue to test new and innovative strategies. To abandon any option without good cause is simply irresponsible. CSU is essentially a conservation strategy with good potential in some circumstances. Public support for CSU programs will require a good deal of public education. For many years the public has been subjected to misinformation and half-truths, a bias which is in danger of becoming institutionalised in order to *preserve and maintain* what has become the preservationist establishment, rather than to promote the best interests of the world's wildlife.

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Optimising artificial incubation regimes for crocodilian eggs: assigning priorities.

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Introduction

Reptilian embryos are affected profoundly by their incubation environment, and those effects linger long after their transition to an independent existence, marked by successful hatching. In addition to determining such basic reproductive parameters as the proportion of eggs that hatch (e.g. Webb and Cooper-Preston 1989), incubation regimes exert long-term influences over juvenile survival, sexual differentiation, growth rates and hence adult size, and associated aspects of behaviour (Deeming & Ferguson 1991; Lang 1987; Webb & Cooper-Preston 1989).

Clearly natural selection will act strongly to influence maternal choice of nests sites. As a consequence, it has been argued that measurements of physical parameters in nests will reveal incubation conditions that are optimal for a particular species or broader taxon (e.g. Ackerman 1977). This argument has been extended even to the nest microbiota, which Ferguson (1982) has suggested perform a vital role in breaking down eggshells to facilitate hatching of full-term embryos.

But under natural conditions, the optimal achievable incubation environment remains far from physiologically perfect, because nest site selection is constrained by factors unrelated to embryonic needs. Biological factors acting independently of embryonic physiology, but influencing maternal choice, include: accessibility of the nest to predators, vulnerability of the adult to predation during laying and nest-guarding, availability of nest materials or appropriate substrate, the physical capacity of the parent to travel to an optimal site, or to excavate or otherwise build a suitable structure.

Interactions among these and other constraints on adult nesting behaviour will not necessarily converge to also select for a physical nest environment that optimally balances those abiotic factors likely to influence patterns of embryonic development. The rapidly fluctuating climatic conditions that characterise many crocodilian habitats (e.g. Taylor and Tulloch 1985) further conflict with achievement of optimality (Whitehead 1987b). No crocodilian appears to have evolved the complex integrated behaviours employed, for example, by megapode birds (Seymour & Bradford 1992) to manipulate their nest mounds to compensate for short term environmental change.

Recognition that the evolutionary solution to incubation needs must involve compromises, dictated by a complex mix of features of the past and present natural environment, should also inform the design of artificial incubation regimes. While observations of natural nests provide a convenient starting point for understanding the forces that led to the current "design" of crocodilian nests and eggs, criteria satisfied by evolutionary processes in wild populations are unlikely to satisfy all of the divergent needs of crocodile farms.

This obvious, but sometimes overlooked, notion provides the theme for my discussion of appropriate incubation regimes for the eggs of crocodiles. I consider the level of control required over each of the factors temperature, moisture and gaseous conditions in terms not only of their biological effects, but the commercial and operational feasibility of achieving fine control.

The Crocodilian Egg and its Nest Environment

Eggs of crocodilians vary much less among species in their structure, appearance and function than do the eggs of other reptiles such as turtles. All species produce eggs with hard external shells of calcite (calcium carbonate) attached to a thick underlying fibrous membrane (Ferguson 1985) that in turn contains the embryo, the large yolk and a substantial volume of albumen. The brittle shell is penetrated by pores of varying shape and size (Packard & DeMarco 1991) which, in combination with the gaps in the fibrous membrane, permit the diffusion-driven movement of gases to and from the living interior of the egg. This exchange with the environment allows the embryo to "breath" and so generate the energy used to drive the basic physiological processes that maintain life and drive development and growth. Crocodilian embryos deprived of this exchange die quickly (Joanen *et al.* 1977).

Egg design is matched to the way in which crocodiles attempt to regulate the environment experienced by their clutches. They construct nests which buffer developing embryos against conditions that might otherwise compromise survival and development. These nests can be divided into two broad categories: mounds and holes. Materials incorporated in mounds and overlying soils of hole nests insulate the clutch, slowing the movement of heat into the eggs during the hotter parts of the day and reducing heat loss at night. Extremes of heat or cold experienced near the soil surface, that would often be capable of killing embryos, are are thereby avoided. The depth at which the clutch is placed within the mound or beneath the soil surface influence both the mean nest temperature and its variability: deeper nests tend to be cooler and to fluctuate less in temperature (e.g. Webb *et al.* 1977; 1983).

Mounds built above the substrate surface predominate among species that breed during rainy seasons on sites where soils are likely to be saturated with water, or the water table may rise to or above the soil surface. Hole nesters breed at sites less susceptible to flooding, such as elevated slopes of river banks (Campbell 1972), and most often in the drier part of the year.

Nesting habits that avoid saturation with water, and so reduce risks of entirely blocking respiratory gas exchange, expose eggs to a different risk - dehydration. Nest material helps to reduce water loss, as humidity within holes or mounds is often very high (Seymour *et al.* 1987), but elevated humidity is insufficient to entirely eliminate the potential for severe dehydration (Ackerman *et al.* 1985; Ackerman & Seagrave 1987). The brittle eggshell is a further adaptation to reduce that threat. It inhibits water vapour loss (Deeming & Thompson 1991) but, like mound material and soil, impedes access to atmospheric oxygen and the excretion of carbon dioxide (Whitehead 1987b).

The Important Factors

Crocodilian nesting strategies have been strongly influenced by the need to avoid extremes of both temperature and moisture saturation. Tradeoffs have involved (i) an increased risk of dehydration, which has in turn influenced eggshell structure to reduce rates of water vapour loss from the egg; and (ii) impedence of gas exchange between embryo and environment by nest material, added to by the heavily calcified eggshell. The evolutionary precedence given to avoidance of extremes of temperature and moisture implies that other factors, including the potential for significant water loss and partial inhibition of gas exchange, are in general capable of assimilation by the homeostatic mechanisms available to the embryo in its egg. Thus as a first approximation, artificial incubation regimes should concentrate on those factors most clearly targeted by maternal behaviour and for which mechanisms of intrinsic compensation are inadequate: temperature and avoidance of moisture saturation.

Incubation Temperature

Incubation temperature has a marked effect on the development of crocodilian embryos. Under artificial constant-temperature incubation, differences of a few degrees celsius from the mean temperatures measured in natural nests may greatly increase rates of embryonic mortality or abnormality (Webb and Cooper-Preston 1989). Within the temperature range that produces high hatch rates and chiefly normal hatchlings, other effects include variation in (i) embryonic sex ratios (ii) growth rates, (iii) metabolic rates and energy budgets, (iv) the proportion of egg solids and water incorporated in embryonic tissue, and (v) the total duration of incubation (Ferguson & Joanen 1982; Webb & Smith 1984; Webb *et al.* 1987; Whitehead & Seymour 1990; Whitehead *et al.* 1990, Whitehead *et al.* 1992).

Given such a range of temperature effects on fundamental developmental processes, it is not surprising that impacts should extend well beyond emergence from the egg to influence the longer term, post-hatch performance of the young crocodilian. Experimental evidence indicates that the influence of temperature on growth rate may linger for at least two years, a substantial proportion of the production schedule in crocodile farms (Webb and Cooper-Preston 1989). In general, animals incubated at constant temperatures near the centre of the span that achieves apparently normal development survive and grow substantially better than their clutch-mates incubated at other temperatures (Joanen *et al.* 1987; Webb and Cooper-Preston 1989). [Although some evidence suggests that *C. niloticus* does best at temperatures near the upper end of its tolerance (Hutton 1987)]. Clearly temperature is an incubation parameter that requires close attention.

Natural mound or cavity nests do not produce a fixed thermal environment for embryos. Marked diel and seasonal variations are ubiquitous, although the excursions are much reduced compared to temperature variation in ambient air or substrate surfaces (Webb 1977, 1983; Georges 1992). Linkage of the clutch to the thermal inertia provided by a large inorganic mass buffers the clutch against much of this environmental variation.

It remains an open question whether fluctuation about a mean temperature produces a different result, in terms of hatching rates or post-hatch performance, than constant temperature incubation at that same mean. The chemical and physiological mechanisms available to an ectothermic embryo to maintain high rates of metabolic activity and biosynthesis in a fluctuating thermal regime are unclear, but may include maintenance of variants of key enzymes that function optimally at different temperatures (Hochachka & Somero 1973). On emergence the hatchling must cope with a diverse thermal environment, and a physiological or chemical "memory" of variable incubation temperature may "pre-adapt" it to cope with sub-optimal thermal conditions. Thus a search for a single "best" constant incubation temperature may be futile, unless post-hatch conditions of matched stability can also be offered.

Indeed, some data can be interpreted to suggest that a gradual rise in incubation temperatures during the incubation period may produce superior results. Escalating temperatures in 1°C increments at intervals throughout incubation produces many more male *C. johnstoni* hatchlings than are produced at any constant temperature (Webb *et al.* in press). Given that males often grow more rapidly (Joanen *et al.* 1987), temperature rises that mimic seasonal increase may offer some production advantages.

But on balance, the safest commercial strategy at present is probably to maintain incubator temperatures near the median of the known span of embryonic tolerance, which for most crocodilians is around 32°C, and to limit daily or seasonal variation as far as possible.

Water Relations
Embryonic development is dependent on the maintenance of a favourable hydric environment inside the egg (New 1956). Reptiles developing in parchment-shelled eggs may be adapted to take up water from their incubation environment to achieve optimal development (Packard 1991). Among crocodilians, however, the available evidence indicates that their hard-shelled eggs have evolved to constrain evaporative water loss to the environment rather than to facilitate water uptake: they carry a substantial water "buffer" at oviposition (Fig. 1), and develop apparently normally despite substantial water loss (Grigg 1987; Whitehead 1987a).

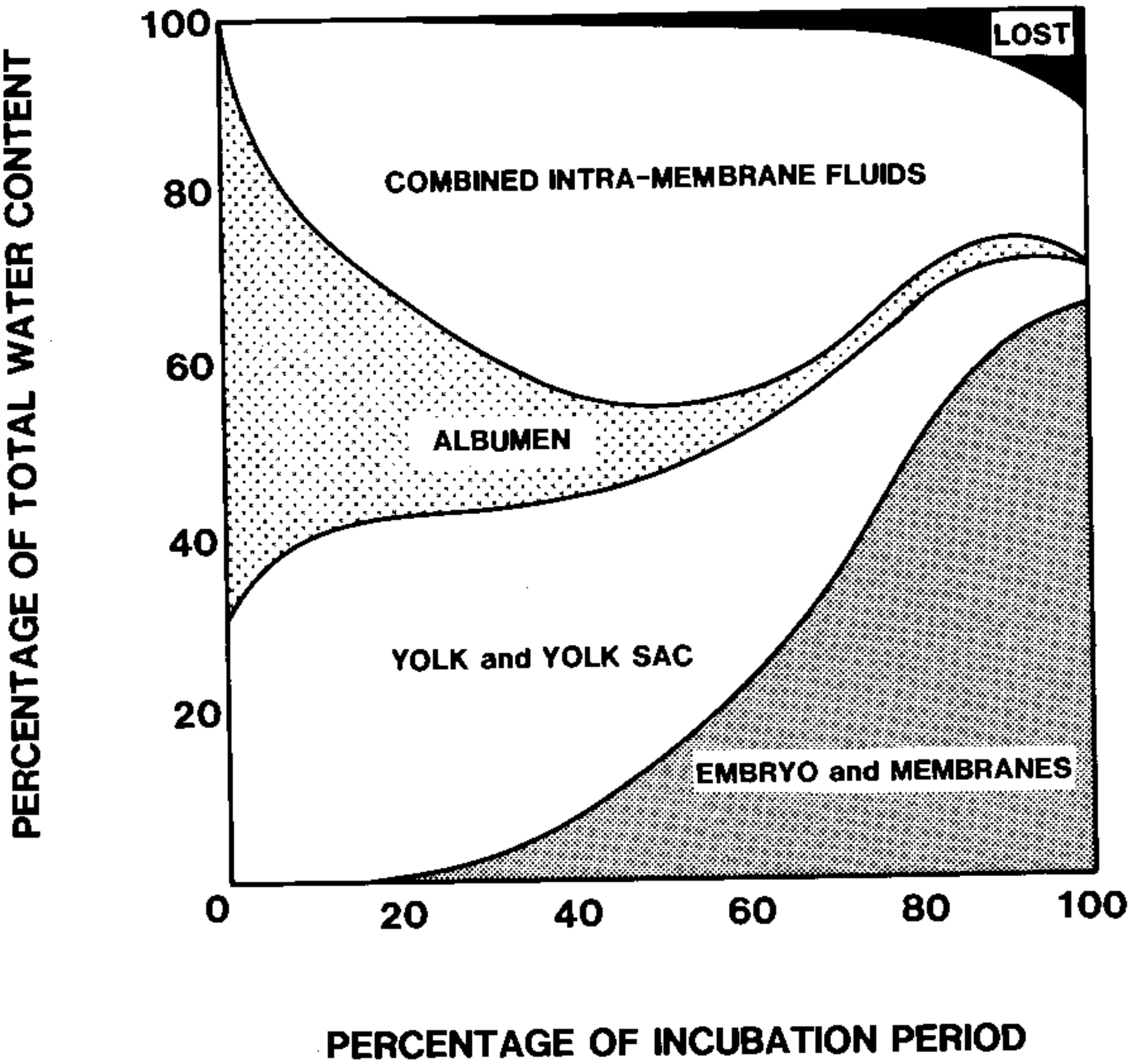

Figure 1: The water budget of *Crocodylus johnstoni* eggs incubated at a constant temperature of 29°C and losing a mean 10% of their initial water content prior to hatching.

Lutz and Dunbar-Cooper (1984) recorded egg weight losses of up to 30% in successful natural nests of *C. acutus* without apparent impact on hatchling size. Embryonic survival rates were significantly better in natural nests of *C. johnstoni* that showed moderate rates of water loss (Whitehead 1987b). At hatching, artificially incubated *C. johnstoni* eggs that lost up to 17% of their original water to evaporation shed a further 25% in residual fluids that drained from the egg, suggesting that the evaporative losses were well within the capacity of the buffer (Whitehead 1987a).

Post-hatch effects of moderate water loss during incubation have not been rigorously determined in crocodilians, but given the absence of obvious effects on hatch rates and hatchling sizes, they appear likely to be minor (Webb and Cooper-Preston 1989). In combination, the available data indicate that incubation regimes that cause crocodilian eggs to lose between 1 and 15% of fresh egg weight will produce good results. Extremely wet conditions that cause eggs to either take up water (increase in weight) or lose no weight during incubation are likely to be just as threatening as very severe water loss (Grigg 1987).

Respiratory Gas Concentrations

Gas exchange between a crocodilian egg and its environment is mediated almost entirely by diffusion. Embryos possess no ventilatory pump to generate absolute pressure differences between the egg and the nest. Thus movement of oxygen (O_2) into the egg requires that its concentration (partial pressure=P_{O2}) be lower inside the eggshell than outside it. Maintaining high rates of exchange may therefore require that oxygen tensions to which the embryo is exposed be substantially lower than atmospheric. Similar limitations may cause some elevation of carbon dioxide tensions, although the movement of CO_2 through the hydrated cell membrane is enhanced by its greater solubility in water relative to O_2 (Whitehead 1987b).

The relationship between embryonic survival or growth and gaseous conditions in the incubation environment of reptiles remains poorly understood, although some trends are beginning to emerge. Ackerman (1981) found that incubation of marine turtle eggs under conditions that restricted gas exchange compromised growth and survival, but he did not report the gas tensions resulting from his treatments. In more detailed experiments with eggs of freshwater turtles *Trachemys scripta*, Etchberger *et al.* (1992a) found that oxygen concentrations at 8% or lower (approximately 60 torr or less than 40% of the O_2 concentrations in air at sea level) significantly reduced survival and may have compromised embryonic growth. However, these oxygen tensions are substantially lower than would be experienced in the relatively shallow nests of this species of turtle. *Crocodylus johnstoni* embryos appear to tolerate significantly depressed oxygen tensions in natural nests (to 120 torr) without measurable effect on embryonic weight and survival, although at extremes (<80 torr) both may be compromised (Whitehead 1987b). There are no data on the effects of low P_{O2} on the post-hatch survival and growth of crocodilians and other reptiles.

Effects of elevated CO_2 are less clear, because most experiments or field measurements have involved elevation of P_{CO2} in tandem with declining P_{O2}, so that the individual effects of the different gases are difficult to separate (e.g. Ackerman 1981; Whitehead 1987b). In contrast, Etchenberger's (1992a) results with *T. scripta* were obtained under artificial gaseous environments with high turnover rates and so tested the effects of reduced P_{O2} in the absence of elevated P_{CO2}. Other experiments with the same species holding P_{O2} constant while elevating P_{CO2} have shown that incubation times are increased markedly at higher P_{CO2}, while the proportion of egg contents converted to hatchling tissue is reduced. Hatching rates and post-hatch survival (to 45 days) were also compromised at high P_{CO2} (Etchberger *et al.* 1992b). But the study employed a range of CO_2 concentrations extending well above those ever measured in any natural nest of a reptile, and even the least severe treatment (5% or around 40 torr) exceeds levels most often encountered in natural nests and artificial incubators. At 5%, the biologically most relevant concentration, effects were insignificant.

Less extreme variation in gaseous conditions may have important effects that do not involve a gross alteration of whole-incubation growth and development patterns. For example, depressed P_{O2} may stimulate hatching of some turtle eggs (Ewert 1991; Webb *et al.* 1986), and has been suggested as a cause of premature hatching of *C. johnstoni* under artificial incubation conditions (Whitehead 1987b). However, the threshold P_{O2} below which hatching is stimulated is known for no species.

Taken as a whole, the limited available data suggest that shifts in ambient concentrations of O_2 and CO_2 from atmospheric conditions present a significant threat to normal development only at levels which can be avoided in most artificial incubation regimes, subject to a few simple precautions (see below).

Symptoms of Unfavourable Incubation

Some of the signs indicating unfavourable incubation conditions are summarised in Table 1. In most cases these symptoms appear after adverse processes are complete or irreversible. If repetitions of incubation failure are to be avoided and methods refined over time, it is essential that accurate, detailed records be kept of all significant changes in operating practice and measurements throughout the incubation period, together with clear descriptions of the nature and extent of the problem. In this way events can be re-constructed, causes of failure inferred, and corrections made in the future. Pencil and paper are two of the most important pieces of incubation technology available, regardless of the other more expensive items of equipment used. The responses to incubation problems suggested in Table 1 assume that record-keeping allows the operator to identify probable sources of difficulty and to implement appropriate corrections.

Table 1: Common symptoms of incubation problems with eggs of crocodilians. The list is not comprehensive, being intended to illustrate the broad range of potential difficulties and the importance of record-keeping to determine effective responses.

Symptom	Likely cause	Suggested Response
Egg Appearance		
- Opaque band absent after 2 days	Infertility or early embryonic death	Remove eggs, candle and open. Identify female producing eggs and check collection protocol or timing
- Opaque band slow to develop	Excess moisture or embryonic abnormality	Reduce moisture levels and monitor affected eggs for further change
- Opaque band patchy or uneven	Excess moisture or embryonic abnormality	Reduce moisture levels and monitor affected eggs for further change
- Opaque band development incomplete after 10 days	Embryonic death	Monitor egg for further 3 days and open to determine age of embryonic death
- Egg discoloured, usually accompanied by some odour	Embryonic death and decay of egg contents	Open egg to determine age of death and relate to records of collection or incubation conditions
- Generalised cracking of eggshell, often accompanied by swelling of egg	Excess moisture	Reduce moisture levels and monitor egg
- Air spaces in egg formed by membrane detaching from shell	Insufficient moisture	Increase moisture levels
- Localised cracking of eggshell near anticipated hatching date but delay in pipping	Hatching problems	Open egg to remove hatching after anticipated hatching date
- Egg pipped but embryo dead	Abnormal development or occassionally dehydration	Open egg and examine embryo. Relate to any signs of dehydration in this or other eggs in same incubator.
Hatchlings		
- Hatchlings deformed	Unfavourable temperatures before or after collection	Relate to timing of collection, transport and conditions recorded at nest or during early incubation
- Oedema (water retention) in hatchling tissues	Unfavourable temperatures - perhaps too low	Relate to timing of collection, transport and conditions recorded at nest or during early incubation
- Yolk not entirely enclosed	Premature hatching associated with unfavourable incubation conditions. - low P_{O_2}/ high P_{CO_2} - mechanical stimulation	Check timing of hatching against expected incubation time Relate incubator volume and hence gas capacity to number and development stage of eggs. Check recent movements of eggs or prolonged presence of active hatchlings in incubator. Monitor frequently near earliest anticipated hatching date and remove all hatchlings.
- Small hatchlings with very large enclosed yolk and distended abdomen	Incubation temperature too high	Re-examine inenbation records and adjust temperature as necessary
- Large hatchlings with unusually small yolk volume	Incubation temperature too low	Re-examine incubation records and adjust temperature as necessary

Designing Optimal Incubation Regimes and Correcting Faults

Just as the natural nest environment is the product of compromise between conflicting pressures, so too will be the incubation arrangement chosen for commercial or conservation operations. Judgements are made that balance the value of the resource, the cost of providing preferred arrangements, and the returns realised from efforts to closely regulate incubation conditions.

Temperature Control

Once thermal problems are identified by their effects on eggs or embryos, it will often be too late to take corrective action. Development will have been irreversibly compromised (Webb and Cooper-Preston 1989). Thus the most appropriate response to evidence of temperature problems will most often require the modification of the incubation system or operating methods for future use. However, if temperature problems are detected promptly by routine measurements showing a relatively brief excursion into unfavourable regions, then corrective adjustments should be made immediately.

Electric Incubators: Close control of temperature is the single greatest benefit accruing from artificial incubation. The best currently available method of achieving the desirable level of control is to use electrically operated incubators controlled by an electronic or mechanical thermostat, which is capable of maintaining egg temperatures within a few tenths of a degree celsius of the required mark. This approach assumes the continuous availability of a reliable source of electrical power for the duration of incubation. Moreover, in many of the regions inhabited by crocodiles, it will require either (i) that the incubator be housed in an airconditioned building if the outside temperature around the incubator(s) is not to exceed the desired internal target of about 32°C; or (ii) that the incubator also be equipped with refrigeration facilities capable of cooling the air inside the incubator. Where such colling facilities are unavailable, ambient air temperature outside the incubator should be several degrees lower than the incubation target, if the thermostat is to operate efficiently. Many thermostats become erratic when the thermal gradient between the exterior environment and the incubator interior becomes too narrow.

Naturally Heated Artificial Nests: In situations where electrical facilities are unavailable, methods that take advantage of natural insolation or high ambient shaded temperatures are often employed (G.J.W. Webb, pers. comm.). In these cases attempts are made to mimic the thermal insulation and inertia provided by natural nests. Given the wide range of methods employed, including beds of sand and straw or cement cylinders filled with sand, and the various climatic conditions under which they operate, it is difficult to make robust recommendations regarding optimal management of such systems. Nonetheless it is possible to make tentative suggestions regarding potential enhancements of existing practice.

The basic thermal problem to be overcome by both natural and artificial nests is to reduce the tendency for the clutch to track external ambient temperatures into unfavourably hot or cool realms. In part this is accomplished by surrounding the clutch with a large volume of material with good insulating properties and high thermal inertia. Once such systems have accumulated heat, their temperature responds slowly to further external change. Such effects are illustrated by the long lag time between the attainment of maximum surface temperatures and resultant maxima in the egg mass in the relatively shallow nests of *C. johnstoni* (Webb *et al.* 1983). An unfortunate byproduct of such high thermal inertia is that if unfavourable temperatures develop, they may persist for a considerable time. While embryos are able to cope with short exposure to temperature extremes, extended exposure is invariably fatal or severely compromises development (Webb and Cooper-Preston 1989).

At present, operators of artificial nests may attempt to control elevated temperatures by wetting the medium above the eggs to provide evaporative cooling, but in unseasonably cool conditions few options are available to raise clutch temperature. Prolonged use of water for cooling also might lead to unfavourably moist conditions and create other problems (Table 1).

Alternative methods to accelerate rates of heat exchange in a controllable way require improved thermal access closer to the centre of the incubating egg mass. This could, for example, be accomplished by installing a large galvanised metal tube (say 15 cm diameter) to pass vertically through the centre of the "incubator" substrate and the egg mass. Heating, cooling or thermal stabilisation could be achieved by adding or removing materials with appropriate heat exchange characteristics. For example, if rapid cooling was required then wetted porous material with a large effective surface area might be introduced to enhance rates of evaporative heat loss.

Development of such modifications would require some preliminary work to examine thermal behaviour under a range of conditions, before use with living eggs. Many permutations are available, including control of insolation of artificial nests by use of removable panels in surrounding structures, or regulation of air movement around the artificial nests. In essence these possibilities involve control of thermal inputs to the system and alteration of thermal inertia to achieve a desired rate and extent of directed temperature variations.

Moisture Levels

Control of moisture levels should be directed at prevention of excessive dehydration. In most cases this is a relatively straight-forward process as the physical properties that allow an incubator to trap heat also tend to trap moisture. High humidities (>99%) are easily maintained in well-sealed electric incubators. In artificial nests, layers of soils or similar substrates maintain high humidity even when their moisture content is relatively low. However, contact between an egg and a surrounding substrate may create complex patterns of water exchange because the water potential of the substrate relative to the eggs (which determines whether water moves into or out of the egg) can alter dramatically with quite subtle shifts in soil moisture content (Ackerman 1991).

The simplest method of reliably maintaining favourable moisture conditions is to incubate crocodilian eggs on open racks where they are exposed to an atmosphere either saturated with water vapour (100% relative humidity) or very nearly so. Eggs under these conditions will still lose water by evaporation when the ambient vapour pressure drops temporarily after the incubator is opened. Moreover, late in incubation, the metabolic activity of the embryo generates heat that creates a vapour pressure gradient between egg and atmosphere even if that atmosphere is saturated with water vapour. This creates a pattern of water loss from the egg (Fig. 2) that probably approximates that from hard-shelled eggs of birds and reptiles in natural mound, hole, or open nests (Ackerman & Seagrave 1987; Ar 1991). Easy access to eggs provided by incubation on open racks allows visual inspection of eggs to detect adverse change, or perhaps the weighing of a sub-sample to monitor rates of weight loss, which will closely approximate water loss.

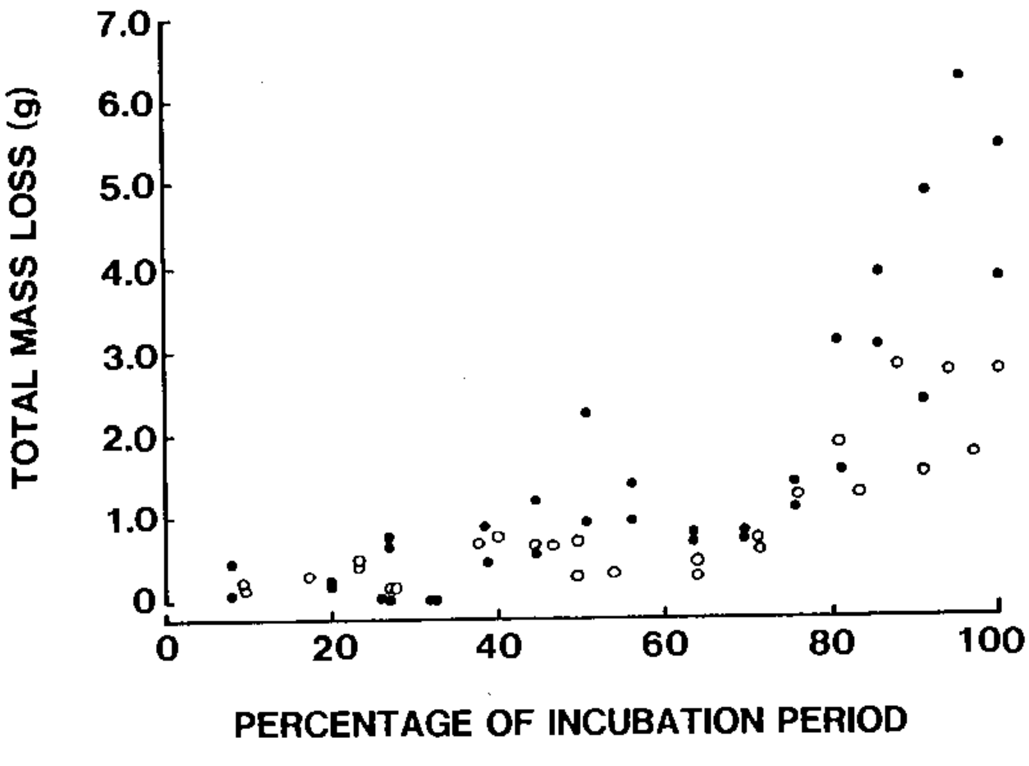

Figure 2: Patterns of water loss from artificially-incubated eggs of *C. johnstoni* that achieved high rates of hatching success. Closed symbols are for eggs incubated at 29°C and open for eggs at 31°C. Lower temperature eggs lose more water because they incubate longer.

Under less closely controlled conditions where the thermal insulation and inertia of a substrate is required to maintain favourable temperatures, simultaneous optimisation of both thermal and moisture regimes may prove difficult, particularly if water is used to control unfavourably high temperatures. Wetting of substrate with large quantities of water late in incubation may stimulate premature hatching by inhibiting gas exchange. Given that eggs will not be easily monitored, it will be particularly important that rates and quantities of water supplements be carefully recorded, so that the possible interactive effect of water use and temperature can be examined and methods refined over time.

Gaseous Conditions

There exists a basic conflict between attempts to trap heat and moisture while fostering free exchange of respiratory gases. Both heat and moisture will be exchanged with the atmosphere through any openings capable of exchanging respiratory gases by diffusion or convection. This is one of the most obvious tradeoffs in natural nests, and one which cannot be entirely avoided under artificial incubation, except when operating on a small scale or using the most sophisticated (and expensive) environment chambers.

Yet adverse impacts of impaired respiratory gas exchange on embryonic development are rarely reported. This is in part because tolerances of variation are wide (above), but also because the impacts are unrecognised or attributed to other causes. The inert appearance of eggs belies the fact that for part of the incubation period they are respiring at a rate higher than the hatchlings that will eventually emerge from them (Fig. 3; Whitehead 1990). Whilst one might think twice about the advisability of enclosing 1000 hatchlings in a sealed box for 3 months, superficially the respiratory needs of 500 eggs appear less pressing.

In well-sealed incubators constructed of impervious materials (like most electric incubators), the risk of adverse conditions developing depends on an interaction among the size of the incubator, the number of eggs, the developmental stage, and the frequency with which doors are opened to inspect the eggs. Crocodilian embryos show a peaked pattern of O_2 consumption, with maximum demands occurring about 90% of the way through the incubation period at all incubation temperatures (Whitehead 1987b; Thompson 1989). The mean peak rate of O_2 consumption is approximately 2.8 $ml.g^{-1}.d^{-1}$ (Whitehead 1987b). Thus the peak O_2 demand of 50 kg of crocodilian eggs (approximately 450 *C. porosus* or *C. niloticus* eggs; 700 *C. johnstoni* or *Caiman crocodylus* eggs) is 140 $litres.d^{-1}$. Placed in a large incubator, these numbers of eggs near the peak of embryonic growth would consume the entire O_2 content of a large electric incubator (300 litre) in 11 hours, and depress P_{O2} below the level at which damaging effects may occur (80 torr) in around 5 hours. While the thresholds at which premature hatching may be stimulated are unknown, it is a likely reponse in such a situation where many eggs are at a similar late stage of development.

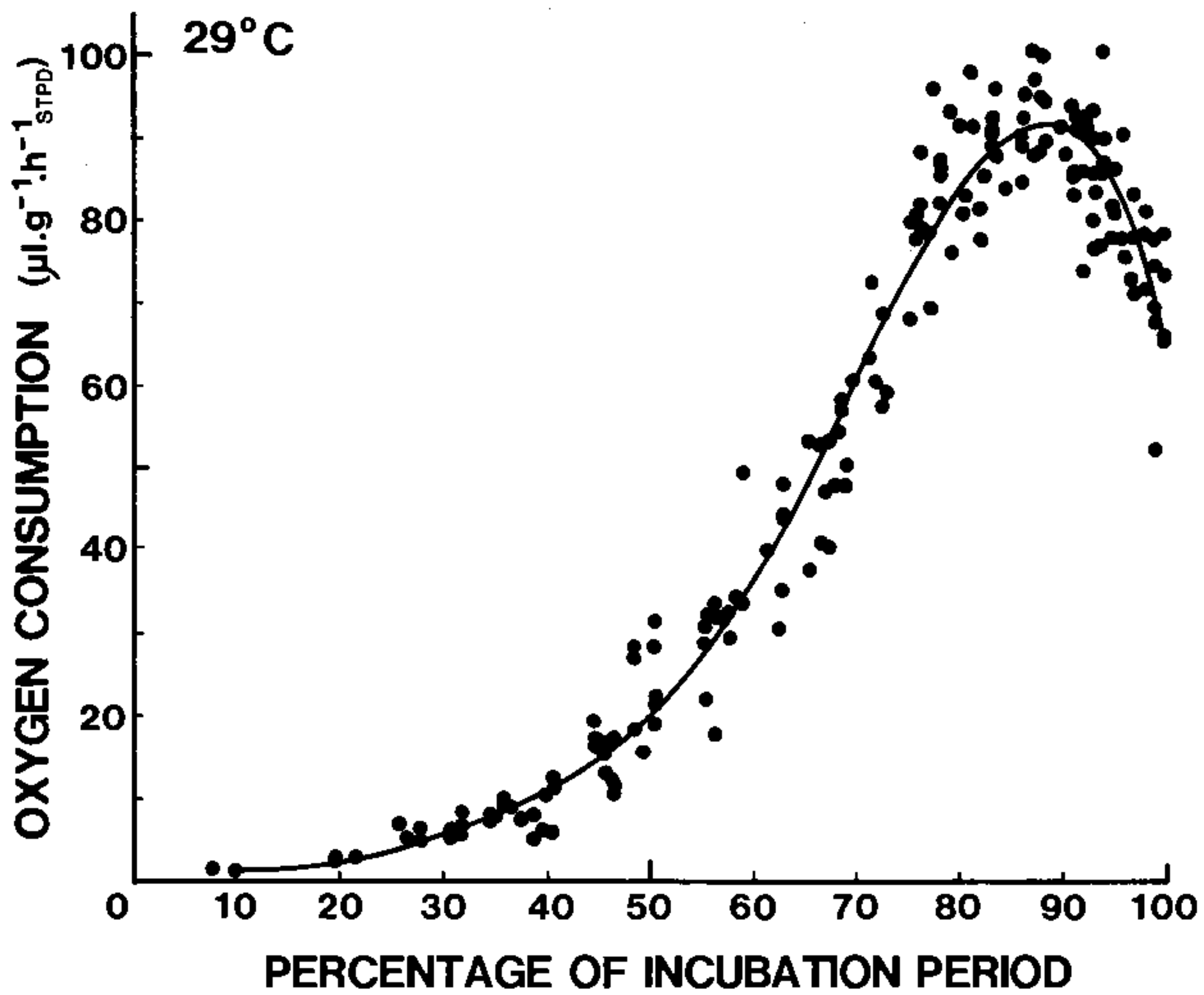

Figure 3: Pattern of oxygen consumption of *C. johnstoni* eggs incubated at 29°C. All crocodilians for which data are available show the same pattern, with a strong peak at about 90% incubation, just before yolk internalisation. Resting metabolic rates of unfed hatchlings continue the pre-hatch decline, averaging about half the peak embryonic rate.

To provide a good safety margin under such conditions, I suggest that it is necessary to replace the entire incubator air volume roughly 5 times per day. Just opening the incubator will replace gases with fresh air very rapidly, but frequent opening will also conflict with precise temperature control and will increase moisture losses. An alternative response by users of electric or other sealed incubators without systems of forced or convective ventilation could be to maintain ratios of egg to incubator air volume that keep daily consumption at all stages of incubation below half the O_2 initially present in the incubator, and then to inspect the eggs at least daily. This ratio is approximately 1 kg of eggs for each 12 litres of free incubator space (free space in litres can be calculated as the volume in m^2 x 1000 less the volume of eggs and other internal fittings). Adopting this response substantially constrains the number of eggs that can be placed in a large incubator - to about 200 *C. porosus* or *C. niloticus* eggs.

Thus as a general rule, users of electric incubators will wish to include vents or pumps to encourage some turnover of incubator air. The range of possibilities is too broad to be dealt with here in any prescriptive way, but the arrangements should clearly be tested to ensure that they do not excessively compromise maintenance of moisture levels or temperature, and in particular, do not create temperature gradients within incubators so that some eggs suffer suboptimal thermal conditions. Humidifying air by pumping through water and using a source of air at a temperature similar to the target incubation temperature can minimise these difficulties.

Where facilities are such that rapid turnover of air conflicts with adequate temperature control or cannot be arranged to avoid dehydration problems, the compromise adopted should favour temperature and moisture control, with regular inspections to avoid extreme depletion of O_2 or accumulation of CO_2. In general, a situation in which control of moisture loss is imperfect (free exchange of water vapour occurs) is unlikely to compromise exchange of respiratory gases.

It should also be noted that when adjustments to air flow through incubators are made, it will often also be necessary to adjust thermostats slightly. Although in theory a thermostat set at a particular temperature should compensate for changes, for example, in the volume of cooler air pumped into an incubator, in practice it often does not. The location of the thermostat relative to the air source or other fittings may deflect the anticipated response.

Users of artificial nests may influence respiratory gas exchange by choice of substrates. For example, coarse sand will cause few difficulties with depressed P_{O2} or elevated P_{CO2}, but care will be needed to avoid dehydration. Heavy clay soils should not be used as these are associated with low P_{O2} and high P_{CO2} and gas conductance can alter alarmingly when they are wet (Fig. 4). Some work with *Alligator mississipiensis* suggests that natural nesting medium should surround the eggs during incubation to facilitate breakdown of eggshells and hence aid hatching (Ferguson 1982), but these observations have not been confirmed by subsequent investigation (Moses and Chabreck 1990) and do not appear to apply to other crocodilians (Webb and Cooper-Preston 1989). In most cases the risks (bacterial infection, reduced P_{O2} / elevated P_{CO2}) and other disadvantages (inability to readily inspect condition of eggs, costs of collection and transport) associated with use of nesting media are likely to outweigh advantages. But if incubation facilities cannot be modified to offer adequate control over humidity, then a sterile medium such as vermiculite or clean medium-grained sand with at least partly understood water holding and exchange properties (Packard *et al.* 1987; Ackerman 1991) should be preferred to natural media (e.g. Hutton and Childs 1990).

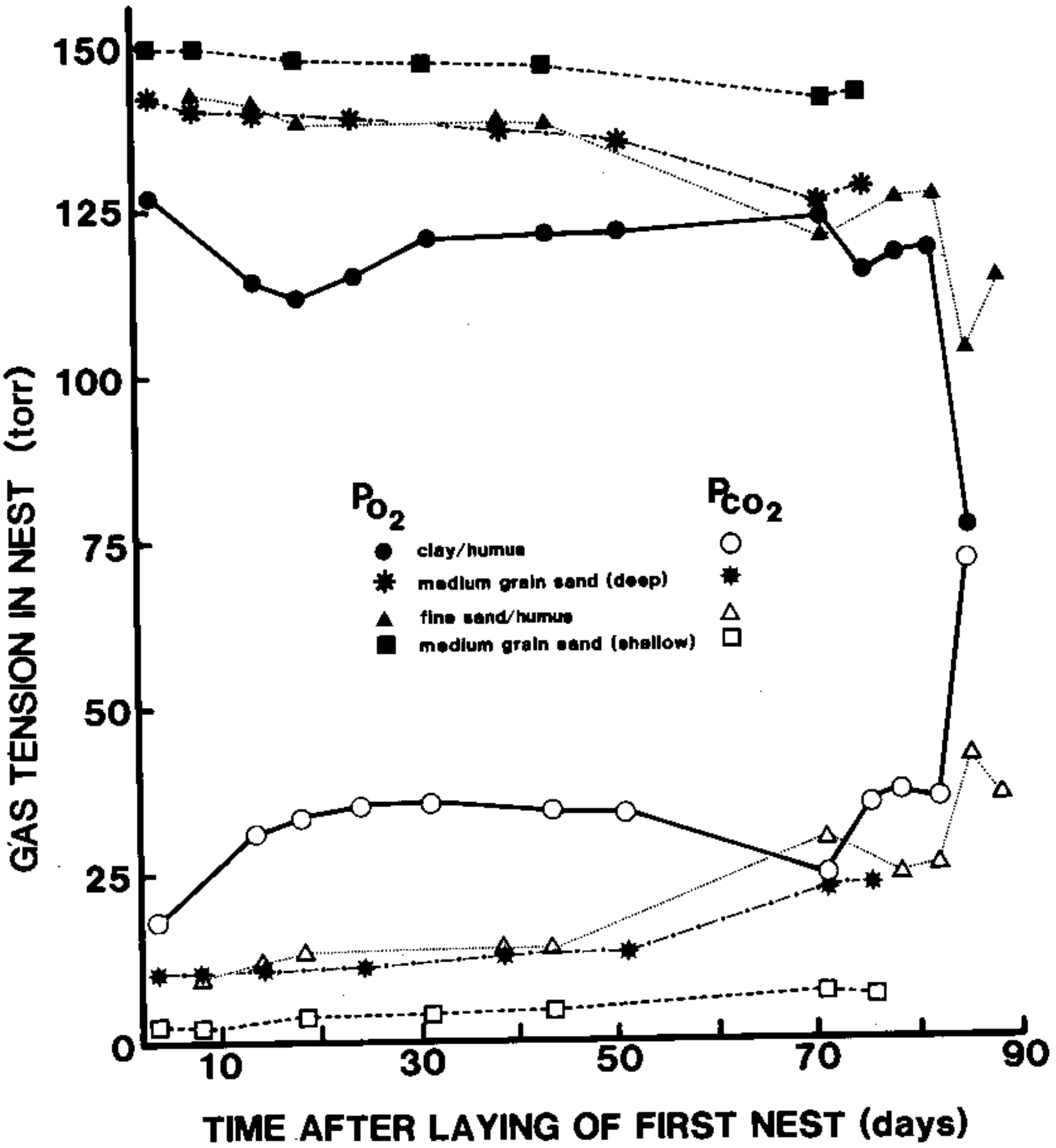

Figure 4: Gas tensions in natural nests of *C. johnstoni*. Effects of depressed P_{O2} and elevated P_{CO2} on embryonic development are confined to extreme conditions, such as those that follow rainfall (e.g. day 75). Gas tensions are most variable in nests constructed in clay soils, especially following wetting.

Wherever possible, the use of water to regulate temperature of artificial nests should be avoided, because continued reliance on this technique could, for example, during a period of unseasonably hot weather result in saturation of the substrate and so compromise development. Other methods of controlling temperature could be substituted (above).

Conclusions

The wide range of incubation facilities used in crocodile conservation and farming operations inhibit a prescriptive approach to optimisation of incubation regimes. All realistically achievable regimes suitable for application on a large scale involve tradeoffs among the various influences on hatching success and post-hatch performance. Interactions among these influences are complex, but they can be ranked in importance. Where embryonic tolerances are broad, the risk of error is reduced and the potential effects of errors on commercial and conservation programs are less damaging. On this basis, priority for control efforts can be assigned in the order temperature, moisture regime, and gaseous conditions.

There remains much scope to improve incubation performance. In many locations where reliable access to technologically advanced facilities is unlikely in the short term, the most significant immediately achievable advance is to implement comprehensive and detailed record-keeping. Records should cover all incubation management actions and measurements of responses. Both conservation and economic aims demand that all incubation systems continue to evolve towards optimal solutions applicable under the prevailing technical infrastructure. That process can be greatly accelerated if practitioners and their advisers have access to records that can be used to reconstruct events and their consequences.

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Optimising artificial incubation regimes for crocodilian eggs: assigning priorities.

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Introduction

Effects of the incubation environment on reptilian embryos are profound, and those effects linger long after the living individuals derived from that environment escape its constraints and take up independent existence. In addition to determining such basic reproductive parameters as the proportion of eggs that hatch (e.g. Webb and Cooper-Preston 1989), incubation regimes exert long-term influences over post-hatch survival, sexual differentiation, growth rates and hence adult size, and aspects of behaviour (Deeming & Ferguson 1991; Lang 1987; Webb & Cooper-Preston 1989). Clearly natural selection acts strongly to influence maternal choice of nests sites and as a consequence, it has been argued that measurements of physical parameters in nests will reflect incubation conditions that are optimal for a particular species or broader taxon (e.g. Ackerman 1977). This argument has been extended even to the nest microbiota, which Ferguson (1982) has suggested perform a vital role in breaking down eggshells to facilitate hatching of full-term embryos.

But under natural conditions, the optimal achievable incubation environment remains far from perfect. Even in stable and predictable settings, nest site selection will require tradeoffs. Biological factors acting independently of embryonic physiology, but constraining maternal choice of sites include: accessibility of the nest contents to predators, vulnerability of the adult to predation during laying and nest-guarding, availability of nest materials or appropriate substrate, the physical capacity of the parent to travel to an optimal site, or to excavate or otherwise build a suitable structure.

There is no *a priori* reason to assume that interactions among these and other constraints will converge to select for a nest environment that optimally balances those abiotic factors - temperature, moisture and concentrations of respiratory gases - that are thought to most strongly influence patterns of embryonic development. The rapidly fluctuating climatic conditions that characterise many crocodilian habitats (e.g. Taylor and Tulloch 1985) further conflict with achievement of optimality (Whitehead 1987b). No crocodilian appears to have evolved the complex integrated behaviours employed by megapode birds (Seymour & Bradford 1992) to manipulate their nest mounds to compensate for short term environmental change.

Recognition that the evolutionary solution to incubation needs may involve compromises, dictated by a complex mix of features of the past and present natural environment, should also inform the design of artificial incubation regimes. While observations of natural nests provide a convenient starting point for understanding the forces that led to the current "design" of crocodilian nests and eggs, criteria satisfied by evolutionary processes in wild populations are unlikely to satisfy all of the divergent needs driving the development of crocodile farms.

Simply transplanting a natural regime to a very different controlled environment invites a sub-optimal solution to the requirements of artificially incubated and captive-reared crocodiles. Ill-considered solutions may also compromise the commercial or conservation activity that is dependent on the pre- and post-hatch health of the animals.

This obvious, but sometimes overlooked, notion provides the theme for my discussion of appropriate incubation regimes for the eggs of crocodiles. I consider the level of control required over each of the factors temperature, moisture and gaseous conditions in terms not only of their biological effects, but the commercial and operational feasibility of achieving fine control.

The Crocodilian Egg and its Nest Environment

Eggs of crocodilians vary much less among species in their structure, appearance and function than do the eggs of other reptiles such as turtles. All species produce eggs with hard external shells of calcite (calcium carbonate) attached to a thick underlying fibrous membrane (Ferguson 1985) that in turn contains the embryo, the large yolk and a substantial volume of albumen. The brittle shell is penetrated by pores of varying shape and size (Packard & DeMarco 1991) which, in combination with the gaps in the fibrous membrane, permit the diffusion-driven movement of gases to and from the living interior of the egg. This exchange with the environment allows the embryo to "breath" and so generate the energy used to drive the basic physiological processes that maintain life, and drive development and growth. Crocodilian embryos deprived of this exchange quickly die (Joanen *et al.* 1977).

Egg design is matched to the way in which crocodiles attempt to regulate the environment experienced by their clutches. They construct nests which buffer developing embryos against conditions that might otherwise compromise survival and development. These nests can be divided into two broad categories: mounds and holes. Mound materials and overlying soils of hole nests insulate the clutch, slowing the movement of heat into the eggs during the hotter parts of the day and reducing heat loss at night. Extremes of heat or cold experienced near the soil surface, that would often be capable of killing embryos, are are thereby avoided. The depth at which the clutch is placed within the mound or beneath the soil surface influence both the mean nest temperature and its variability: deeper nests tend to be cooler and to fluctuate less in temperature (e.g. Webb *et al.* 1977; 1983).

Mounds built above the substrate surface predominate among species that breed during the rainy season on sites where soils are likely to be saturated with water, or the water table may rise to or above the soil surface. Hole nesters breed at sites less susceptible to flooding, such as elevated slopes of river banks (Campbell 1972), and then most often in the drier part of the year.

Nesting habits that avoid saturation with water and so reduce risks of entirely blocking respiratory gas exchange expose eggs to a different risk, that of dehydration. Nest material helps to reduce water loss, as humidity within holes or mounds is often very high (Seymour *et al.* 1987), but elevated humidity is insufficient to entirely eliminate the potential for severe dehydration (Ackerman *et al.* 1985; Ackerman & Seagrave 1987). The brittle eggshell is a further adaptation to reduce that threat. It inhibits water vapour loss (Deeming & Thompson 1991) but, like mound material and soil, impedes access to atmospheric oxygen and the excretion of carbon dioxide (Whitehead 1987b).

The Imporant Factors

Crocodilian nesting strategies have been strongly influenced by the need to the avoid extremes of both temperature and moisture saturation. Tradeoffs have involved (i) an increased risk of dehydration, which has in turn influenced eggshell structure to reduce rates of water vapour loss from the egg; and (ii) impedence of gas exchange between embryo and environment by nest material, added to by the heavily calcified eggshell. The evolutionary precedence given to avoidance of extremes of temperature and moisture implies that other factors, including the potential for significant water loss and partial inhibition of gas exchange, are capable of assimilation by the homeostatic mechanisms available to the embryo and its egg. Thus as a first approximation, artificial incubation regimes should concentrate on those factors most clearly targeted by maternal behaviour and for which mechanisms of intrinsic compensation are inadequate: temperature and avoidance of moisture saturation.

Incubation Temperature

Incubation temperature has a marked effect on the development of crocodilian embryos. Under artificial constant-temperature incubation, differences of a few degrees celsius from the mean temperatures measured in natural nests may greatly increase rates of embryonic mortality or abnormality (Webb and Cooper-Preston 1989). Within the temperature range that produces high hatch rates and chiefly normal hatchlings, other effects include variation in (i) embryonic sex ratios (ii) growth rates, (iii) metabolic rates and energy budgets, (iv) the proportion of egg solids and water incorporated in embryonic tissue, and (v) the total duration of incubation (Ferguson & Joanen 1982; Webb &

Smith 1984; Webb *et al.* 1987; Whitehead & Seymour 1990; Whitehead *et al.* 1990, Whitehead *et al.* 1992).

Given such a range of temperature effects on fundamental developmental processes, it is unsurprising that impacts should extend well beyond emergence from the egg to influence the longer term performance of the young crocodilian. Experimental evidence indicates that significant influences on commercially relevant parameters like growth rate may linger for at least two years, a substantial proportion of the production schedule in crocodile farms (Webb and Cooper-Preston 1989). In general, animals incubated at constant temperatures near the centre of the span that achieves apparently normal development survive and grow substantially better than their clutch-mates (Fig. 1) incubated at other temperatures (Joanen *et al.* 1987; Webb and Cooper-Preston 1989), although *C. niloticus* appear to do best at temperatures near the upper end of its tolerance (Hutton 1987). Clearly temperature is an incubation parameter that requires close attention.

Natural mound or cavity nests do not produce a fixed thermal environment for embryos. Marked diel and seasonal variations are ubiquitous, although the excursions are much reduced compared to temperature variation in ambient air or substrate surfaces (Webb 1977, 1983; Georges 1992). Linkage of the clutch to the thermal inertia provided by a large inorganic mass buffers the clutch against much of this environmental variation.

It remains an open question whether fluctuation about a mean temperature produces a different result, in terms of hatching rates or post-hatch performance, than constant temperature incubation at that same mean. The chemical and physiological mechanisms available to an ectothermic embryo to maintain high rates of metabolic activity and biosynthesis in a fluctuating thermal regime are unclear, but may include maintenance of variants of key enzymes that function optimally at different temperatures (Hochachka & Somero 1973). On emergence the hatchling must cope with a diverse thermal environment, and a physiological or chemical "memory" of variable incubation temperature may "pre-adapt" it to cope with sub-optimal thermal conditions. Thus a search for a single "best" constant incubation temperature may be futile, unless post-hatch conditions of matched stability can also be offered.

Indeed, some data can be interpreted to suggest that a gradual rise in incubation temperatures during the incubation period may produce superior results. Escalating temperatures in 1°C increments at intervals throughout incubation produces many more male *C. johnstoni* hatchlings than are produced at any constant temperature (G.J.W. Webb; unpublished data). Given that males often grow more rapidly (Joanen *et al.* 1987), temperature rises that mimic seasonal increase may offer some production advantages.

But on balance, the safest commercial strategy is to maintain incubator temperatures near the median of the known span of embryonic tolerance, which for most crocodilians is around 32°C, and to limit daily or seasonal excursions as far as possible.

Water Relations

Embryonic development is dependent on the maintenance of a favourable hydric environment inside the egg (New 1956). Reptiles developing in parchment-shelled eggs may be adapted to take up water from their incubation environment to achieve optimal development (Packard 1991). Among crocodilians, however, the available evidence indicates that their hard-shelled eggs have evolved to constrain evaporative water loss to the environment rather than to facilitate water uptake: they carry a substantial water "buffer" at oviposition (Fig. 2), and develop apparently normally despite substantial water loss (Grigg 1987; Whitehead 1987a). Lutz and Dunbar-Cooper (1984) recorded egg weight losses of up to 30% in successful natural nests of *C. acutus* without apparent impact on hatchling size. Embryonic survival rates were significantly better in natural nests of *C. johnstoni* that showed moderate rates of water loss (Whitehead 1987b). At hatching, artificially incubated *C.*

johnstoni eggs that lost up to 17% of their original water to evaporation shed a further 25% in residual fluids that drained from the egg, suggesting that the evaporative losses were well within the capacity of the buffer (Whitehead 1987a).

Post-hatch effects of moderate water loss during incubation have not been rigorously determined in crocodilians, but given the absence of obvious effects on hatch rates and hatchling size, appear likely to be minor (Webb and Cooper-Preston 1989). In combination, the available data indicate that incubation regimes that cause crocodilian eggs to lose between 1 and 15% of fresh egg weight will produce good results. Extremely wet conditions that cause eggs to either take up water (increase in weight) or lose no weight during incubation are likely to be just as threatening as very severe water loss (Grigg 1987).

Respiratory Gas Concentrations

Gas exchange between a crocodilian egg and its environment is mediated almost entirely by diffusion. Embryos possess no ventilatory pump to generate absolute pressure differences between the egg and the nest. Thus movement of oxygen (O_2) into the egg requires that its concentration (partial pressure=P_{O2}) be lower inside the eggshell than outside it. Maintaining high rates of exchange may therefore require that oxygen tensions to which the embryo is exposed be substantially lower than atmospheric (Figs. 3 and 4; Whitehead 1987b). Similar limitations may cause some elevation of carbon dioxide tensions, although the movement of CO_2 through the hydrated cell membrane is enhanced by its greater solubility in water (Whitehead 1987b).

The relationship between embryonic survival or growth and the gaseous conditions in the incubation environment of reptiles remains poorly understood, although some trends are beginning to emerge. Ackerman (1981) found that incubation of turtle eggs under conditions that restricted gas exchange compromised growth and survival, but he did not report the gas tensions resulting from his treatments. In more detailed experiments with eggs of freshwater turtles *Trachemys scripta*, Etchberger *et al.* (1992b) found that oxygen concentrations at 8% or lower (approximately 60 torr or less than 40% of the O_2 concentrations in air at sea level) significantly reduced survival and may have compromised embryonic growth. However, these oxygen tensions are substantially lower than would be experienced in the relatively shallow nests of this species of turtle. *Crocodylus johnstoni* embryos appear to tolerate significantly depressed oxygen tensions in natural nests (120 torr) without measurable effect on embryonic weight and survival, although at extremes (<80 torr) both may be compromised (Whitehead 1987b). There are no data on the effects of low P_{O2} on the post-hatch survival and growth of crocodilians and other reptiles.

Effects of elevated CO_2 are even less clear, because most experiments or field measurements have involved elevation of P_{CO2} in tandem with declining P_{O2}, so that the individual effects of the different gases are impossible to separate (e.g. Ackerman 1981; Whitehead 1987b). In contrast, Etchenberger's (1992) results with *T. scripta* were obtained under artificial gaseous environments with high turnover rates and so tested the effects of reduced P_{O2} in the absence of elevated P_{CO2}. Other experiments with the same species holding P_{O2} constant while elevating P_{CO2} have shown that incubation times are increased markedly at higher P_{CO2} while the proportion of egg contents converted to hatchling tissue is reduced. Hatching rates and post-hatch survival (to 45 days) were also compromised at high P_{CO2} (Etchberger *et al.* 1992a). But the study employed a range of CO_2 concentrations extending well above those ever measured in any natural nest of a reptile, and indeed even the lowest concentration treatment (5% or around 40 torr) exceeds levels most often encountered in natural nests and artificial incubators. At this biologically reasonable concentration effects were insignificant.

Less extreme variation in gaseous conditions may have important effects that do not involve a gross alteration of whole-incubation growth and development patterns. For example, depressed P_{O2} may stimulate hatching of some turtle eggs (Ewert 1991; Webb *et al.* 1986), and has been suggested as a cause of premature hatching of *C. johnstoni* under artificial incubation conditions (Whitehead 1987b). However, the threshold depression of P_{O2} needed to stimulate hatching is unknown for any species.

Taken as a whole, the limited available data suggest that shifts in ambient concentrations of O_2 and CO_2 from atmospheric present a significant threat to normal development only at levels which can be avoided in most artificial incubation regimes with a few, usually simple precautions (below).

Symptoms of Unfavourable Incubation

Some of the signs indicating unfavourable incubation conditions are summarised in Table 1. In most cases these symptoms appear after adverse processes are complete or irreversible. If repetitions of incubation failure are to be avoided and methods refined over time, it is essential that accurate, detailed records be kept of all significant changes in operating practice and measurements throughout the incubation period, together with clear descriptions of the nature and extent of the problem. In this way events can be re-constructed, causes of failure inferred, and corrections made in the future. Pencil and paper are two of the most important pieces of incubation technology available, regardless of the other more expensive items of equipment used. The responses to incubation problems suggested in Table 1 assume that record-keeping is sufficiently developed to allow the operator to identify the most probable source of difficulty and hence to implement appropriate corrections.

Designing Optimal Incubation Regimes and Correcting Faults

Just as the natural nest environment is the product of compromise between sometimes conflicting pressures, so too will be the incubation arrangement chosen for commercial or conservation operations. Judgements are made that balance the value of the resource, the cost of providing preferred arrangements, and the returns realised from efforts to closely regulate incubation conditions.

Temperature Control

Once thermal problems are identified by their effects on eggs or embryos, it will often be too late to take corrective action. Development will have been irreversibly compromised (Webb and Cooper-Preston 1989). Thus the most appropriate response to evidence of temperature problems will most often require the modification of the incubation system or operating methods for future use. However, if temperature problems are detected promptly by measurements showing a relatively brief excursion into unfavourable regions, then corrective action should be implemented immediately.

Electric Incubators: Close control of temperature is the single greatest benefit accruing from artificial incubation. The best currently available method of achieving the desirable level of control is to use electrically heated incubators controlled by an electronic or mechanical thermostat, which is capable of maintaining egg temperatures within a few tenths of a degree celsius of the required mark. This solution assumes the availability of a reliable source of power 24 hours a day for the duration of incubation. Moreover, in many of the regions inhabited by crocodiles, it will require either that the incubator be housed in an airconditioned building if the outside temperature around the incubator(s) is not to exceed the desired internal target of about 32°C. Indeed ambient air temperature outside the incubator should be several degrees lower than the target if the thermostat is to operate efficiently. Many thermostats become erratic when the thermal gradient between the exterior environment and the incubator interior becomes too narrow.

Naturally Heated Artificial Nests: In situations where electrical facilities are unavailable, methods that take advantage of natural insolation or high ambient shaded temperatures are often employed (G.J.W. Webb, pers. comm.). In these cases attempts are made to mimic the thermal insulation and inertia provided by natural nests. Given the wide range of methods employed, including beds of sand and straw or cement cylinders filled with sand, and the various climatic conditions under which they operate, it is difficult to make robust recommendations regarding optimal management of such systems. Nonetheless it is possible to suggest some enhancements of existing practice.

The basic thermal problem to be overcome by both natural and artificial nests is to reduce the tendency for the clutch to track external ambient temperatures into unfavourably hot or cool realms. In part this is accomplished by surrounding the clutch with a large volume of material with good insulating properties and high thermal inertia. Once such systems have accumulated heat, their temperature responds slowly to the influence of external change. This effect is illustrated by the long lag time between the attainment of maximum surface temperatures and resultant maxima in the egg mass in the relatively shallow nests of *C. johnstoni* (Webb *et al.* 1983). An unfortunate byproduct of high thermal inertia is that if unfavourable temperatures develop, they may persist for a considerable time. While embryos are able to cope with short exposure to temperature extremes, extended exposure is invariably fatal or severely compromises development (Webb and Cooper-Preston 1989).

At present, operators of such systems may attempt to control elevated temperatures by wetting the medium above the eggs to provide evaporative cooling, but in unseasonably cool conditions may have few options to raise clutch temperature. Prolonged use of water for cooling also might lead to unfavourably moist conditions and create other problems (Table 1).

An alternative method of accelerating rates of heat exchange in a controllable way might be achieved by improving thermal access closer to the centre of the incubating egg mass. This could, for example, be accomplished by installing a large galvanised metal tube (say 15 cm diameter) to pass vertically through the centre of the "incubator" substrate and the egg mass. Heating, cooling or thermal stabilisation could be achieved by adding or removing materials with appropriate heat exchange characteristics. For example, if rapid cooling was required then wetted porous material with a large effective surface area might be introduced to enhance rates of evaporative heat loss.

Development of such modifications would require some preliminary work to examine thermal behaviour under a range of conditions, before being used with living eggs. Many permutations are available, including control of insolation of artificial nests by use of removable panels in surrounding structures, or regulation of air movement around the artificial nests. In essence these involve control of thermal inputs to the system and alteration of thermal inertia to achieve a desired rate and extent of directed temperature variations.

Moisture Levels

Control of moisture levels should be directed at prevention of excessive dehydration. In most cases this is a relatively straight-forward process as the physical properties that allow an incubator to trap heat also tend to trap moisture. High humidities (>99%) are easily maintained in well-sealed electric incubators and in artificial nests, layers of soils or similar substrates maintain high humidity even when their moisture content is relatively low. However, contact between an egg and a surrounding subtrate may create complex patterns of water exchange because the water potential of the substrate relative to the eggs (which determines whether water moves into or out of the egg) can alter dramatically with quite subtle shifts in moisture content (Ackerman 1991).

The simplest method of reliably maintaining favourable moisture conditions is to incubate crocodilian eggs on open racks where they are exposed to an atmosphere either saturated with water vapour (100% relative humidity) or very nearly so. Eggs under these conditions will still lose water by evaporation when the ambient vapour pressure drops temporarily after the incubator is opened. Moreover, later in incubation, the metabolic rate of the embryo generates heat that creates a vapour pressure gradient between egg and atmosphere even if that atmosphere is saturated with water vapour. This creates a pattern of water loss from the egg (Fig. 5) that probably mimics that from hard-shelled eggs of birds and reptiles in natural mound, hole, or open nests (Ackerman & Seagrave 1987; Ar 1991). The ease of access to eggs provided by incubation on open racks allows visual inspection of eggs to detect adverse change, or perhaps the weighing of a sub-sample to monitor rates of weight loss, which will closely approximate water loss. These steps can provide early warnings that allow correction of moisture regimes before impacts become irreversible.

Under less closely controlled conditions where the thermal insulation and inertia of a substrate is required to maintain favourable temperatures, simultaneous optimisation of both thermal and moisture regimes may prove difficult, particularly if water is used to control unfavourably high temperatures. Wetting of substrate with large quantities of water late in incubation may stimulate premature hatching by inhibiting gas exchange. Given that eggs will not be easily monitored, it will be particularly important that rates and quantities of water supplements be carefully recorded, so that the possible interactive effect of water use and temperature can be examined and methods refined over time.

Gaseous Conditions

There exists a basic conflict between attempts to trap heat and moisture while fostering free exchange of respiratory gases. Both heat and moisture will be exchanged with the atmosphere through any openings capable of exchanging respiratory gases by diffusion or mass transport. This is one of the most obvious tradeoffs in natural nests, and one which cannot be entirely avoided under artificial incubation, except when operating on a small scale or using the most sophisticated (and expensive) environment chambers.

Yet adverse impacts of impaired respiratory gas exchange on embryonic development are rarely reported. This is in part because tolerances of variation are wide (above), but also because the impacts are unrecognised or attributed to other causes. The inert appearance of eggs belies the fact that for a large part of the incubation period they are respiring at a rate much higher than the hatchlings that will eventually emerge from them (Fig. 3). Whilst one might think twice about the advisability of enclosing 1000 hatchlings in a sealed box for 3 months, superficially the respiratory needs of 500 eggs appear to be less pressing.

In well-sealed incubators constructed of impervious materials (like most electric incubators), the risk of adverse conditions developing depends on an interaction among the size of the incubator, the number of eggs, the developmental stage, and the frequency with which doors are opened to inspect the eggs. Crocodilian embryos show a peaked pattern of O_2 consumption, with maximum demands occurring about 90% of the way through the incubation period at all incubation temperatures (Whitehead 1987b; Thompson 1989). The mean peak rate of O_2 consumption is approximately 2.8 $ml.g^{-1}.d^{-1}$ (Whitehead 1987b). Thus the peak O_2 demand of 50 kg of crocodilian eggs (approximately 450 *C. porosus* or *C. niloticus*; 700 *C. johnstoni* or *Caiman crocodylus* eggs) is 140 $litres.d^{-1}$. Placed in a large incubator, these numbers of eggs near the peak of embryonic growth would consume the entire O_2 content of a large electric incubator (300 litre) in 11 hours, and depress P_{O2} below the level at which damaging effects may occur (80 torr) in around 5 hours. While the thresholds at which premature hatching may be stimulated are unknown, it is a likely reponse in such a situation where many eggs are at a similar stage of development.

To provide a good safety margin under such conditions, I suggest that it would be necessary to replace the entire incubator air volume roughly 5 times per day. Just opening the incubator will replace gases with fresh air very rapidly, but frequent opening will also conflict with precise temperature control and increase loss of moisture. An alternative response by users of electric or other sealed incubators without systems of forced or convective ventilation could be to maintain ratios of egg to incubator air volume that keep daily consumption at all stages of incubation below half the O_2 initially present in the incubator, and then to inspect the eggs at least daily. This ratio is approximately 1 kg of eggs for each 12 litres of free incubator space (free space in litres can be calculated as the volume in m^2 x 1000 less the volume of eggs and other internal fittings). It can be seen that adopting this response substantially constrains the number of eggs that can be placed in a large incubator - to about 200 *C. porosus* or *C. niloticus* eggs.

Thus as a general rule, users of electric incubators will wish to include vents or pumps to encourage some turnover of incubator air. The range of possibilities is too broad to be dealt with here in any prescriptive way, but the arrangements should clearly be tested to ensure that they do not excessively compromise maintenance of moisture levels or temperature, and in particular, do not create temperature gradients within incubators so that some eggs suffer suboptimal thermal conditions. Humidifying air by pumping through water and using a source of air at a temperature similar to the target incubation temperature can minimise these difficulties.

Where facilities are such that rapid turnover of air conflicts with adequate temperature control or cannot be arranged to avoid dehydration problems, the compromise adopted should favour temperature and moisture control, with regular inspections to avoid extreme depletion of O_2 or accumulation of CO_2 and the attendant risks, especially premature hatching. In general, a situation in which control of moisture loss is imperfect (free exchange of water vapour occurs) is unlikely to compromise exchange of respiratory gases.

It should also be noted that when adjustments to air flow through incubators are made, it will often also be necessary to adjust thermostats. Although in theory a thermostat set at a particular temperature should compensate for changes, for example, in the volume of cooler air pumped into an incubator, in practice it often does not. The location of the thermostat relative to the air source or other fittings may deflect the anticipated response.

Users of artificial nests may influence respiratory gas exchange by choice of substrates. For example, coarse sand will cause few difficulties with depressed P_{O2} or elevated P_{CO2}, but care will be needed to avoid dehydration. Heavy clay soils should not be used as these are associated with low P_{O2} and high P_{CO2} and gas conductance can alter alarmingly when they are wet (Fig. 4). Some work with *Alligator mississipiensis* suggests that natural nesting medium should surround the eggs during incubation to facilitate breakdown of eggshells and hence aid hatching (Ferguson 1982), but these observations have not been confirmed by subsequent investigation (Moses and Chabreck 1990) and do not appear to apply to other crocodilians (Webb and Cooper-Preston 1989). In most cases the risks (bacterial infection, reduced P_{O2} / elevated P_{CO2}) and other disadvantages (inability to readily inspect condition of eggs, costs of collection and transport) associated with use of nesting media are likely to outweigh advantages. But if incubation facilities cannot be modified to offer adequate control over humidity, then a sterile medium such as vermiculite or clean medium-grained sand with at least partly understood water holding and exchange properties (Packard *et al.* 1987; Ackerman 1991) should be preferred to natural media (e.g. Hutton and Childs 1990).

Wherever possible, the use of water to regulate temperature of artificial nests should be avoided, because continued reliance on this technique could, for example, during a period of unseasonably hot weather, result in saturation of the substrate and so compromise development. Other methods of controlling temperature could be substituted (above).

Conclusions

The wide range of incubation facilities used in crocodile conservation and farming operations inhibit a prescriptive approach to optimisation of incubation regimes. All realistically achievable regimes suitable for application on a large scale involve tradeoffs among the various influences on hatching success and post-hatch performance. Interactions among these influences are complex, but they can be ranked in importance. Where embryonic tolerances are broad, the risk of error is reduced and the potential effects of errors on commercial and conservation programs are less damaging. On this basis, priority for control efforts can be assigned in the order temperature, moisture regime, and gaseous conditions.

There remains much scope to improve incubation performance. In many locations where reliable access to technologically advanced facilities is unlikely in the short term, the most significant immediately achievable advance is to implement comprehensive and detailed record-keeping. Records should cover all incubation management actions and measurements of responses. Both conservation and economic aims demand that all incubation systems continue to evolve towards optimal solutions applicable under the prevailing technical infrastructure. That process can be greatly accelerated if practitioners and their advisers have access to records that can be used to reconstruct events and their consequences.

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Table 1: Common symptoms of incubation problems with eggs of crocodilians.

Symptom	Likely cause	Suggested Response
Egg Appearance		
- Opaque band absent after 2 days	Infertility or early embryonic death	Remove eggs, candle and open. Identify female and check collection protocol or timing
- Opaque band slow to develop	Excess moisture or embryonic abnormality	Reduce moisture levels and monitor affected eggs for further change
- Opaque band patchy or uneven	Excess moisture or embryonic abnormality	Reduce moisture levels and monitor affected eggs for further change
- Opaque band development incomplete after 10 days	Embryonic death	Monitor egg for futher 3 days and open to determine age of embryonic death
- Egg discoloured, usually accompanied by some odour	Embryonic death and decay of egg contents	Open egg to determine age of death
- Generalised cracking of eggshell, often accompanied by swelling of egg	Excess moisture	Reduce moisture levels and monitor egg
- Air spaces in egg formed by membrane detaching from shell	Insufficient moisture	Increase moisture levels
- Localised cracking of eggshell near anticipated hatching date but delay in pipping	Hatching problems	Open egg to remove hatching after anticipated hatching date
- Egg pipped but embryo dead	Abnormal development or occassionally dehydration	Open egg and examine embryo. Relate to any signs of dehydration in this or other eggs in same incubator.

Hatchlings		
- Hatchlings deformed	Unfavourable temperatures before or after collection	Relate to timing of collection, transport and conditions recorded at nest or during early incubation
- Oedema (water retention) in hatchling tissues	Unfavourable temperatures - perhaps too low	Relate to timing of collection, transport and conditions recorded at nest or during early incubation
- Yolk not entirely enclosed	Premature hatching associated with unfavourable incubation conditions. - low P_{O2}/ high P_{CO2} - mechanical stimulation	Check timing of hatching against expected incubation time Relate incubator volume and hence gas capacity to number and development stage of eggs. Check recent movements of eggs or prolonged presence of active hatchlings in incubator. Monitor frequently near earliest anticipated hatching date and remove all hatchlings.
- Small hatchlings with very large enclosed yolk and distended abdomen	Incubation temperature too high	Re-examine incubation records and adjust temperature as necessary
- Large hatchlings with unusually small yolk volume	Incubation temperature too low	Re-examine incubation records and adjust temperature as necessary

Figure Legends

Figure 1: Variation in growth rates of *Crocodylus porosus* to 2 years of age subjected to incubation at a range of different constant temperatures (from Webb and Cooper-Preston 1989).

Figure 2: The water budget of *Crocodylus johnstoni* eggs incubated at a constant temperature of 29°C and losing a mean 10% of their initial water content prior to hatching.

Figure 3: Pattern of oxygen consumption of *C. johnstoni* eggs incubated at 29°C. All crocodilians for which data are available show the same pattern, with a strong peak demand at about 90% incubation, just before yolk internalisation is complete.

Figure 4: Gas tensions in natural nests of *C. johnstoni*. Effects of depressed P_{O2} and elevated P_{CO2} on embryonic development are confined to extreme conditions, such as those that follow rainfall (e.g. day 75).

Figure 5: Patterns of water loss from artificially-incubated eggs of *C. johnstoni* that achieved high rates of hatching success.

TABLE 1. *Mean hatchling size among 122* Crocodylus porosus *hatchlings was largely unaffected by incubation temperature.* *

Temp. (°C)	n	HL (cm)	SVL (m)	Weight (g)	% abundant yolk
29	15	4.2	13.3	63.8	53
30	17	4.3	13.5	68.4	6
31	51	4.2	13.4	66.3	47
32	15	4.3	13.6	67.9	73
33	24	4.3	13.5	69.6	50

* Measurements have been standardised to the mean egg weight for the sample (105.5 g). The increase in hatchling weight (hatchling − residual yolk) was significant, but reflects in part the weight of residual yolk. HL = head length, SVL = snout–vent length, weight = hatchling − residual yolk, % abundant yolk = the percentage of the sample which, on the basis of abdomen appearance, had abundant yolk.

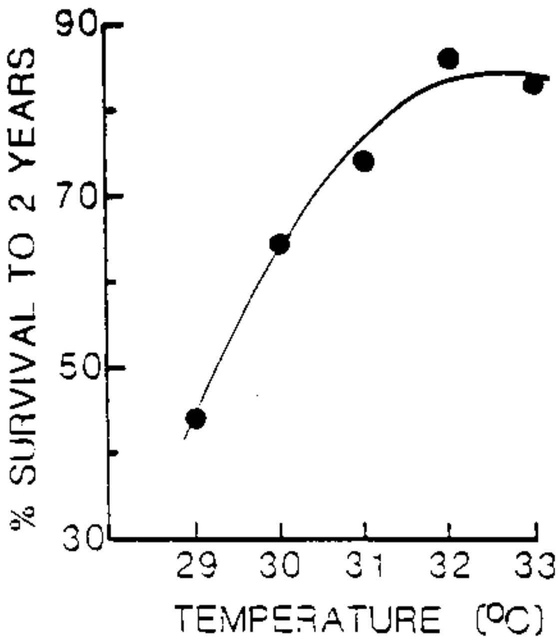


FIG. 9. The relationship between constant incubation temperature in the laboratory and survival to 2 yr of age for *Crocodylus porosus* hatchlings raised on a crocodile farm (hatching details are in Table 1). The line is a polynomial, least squares regression.

midway through development, must be consistent with the potential fitness of embryos coming from a nest at 34–35°C at the end of development where survival is compromised.

For the relationship between TSD and post-hatching performance to be correct, the "non-sexual" effects of temperature need to be induced prior to or concurrent with the allocation of sex: that is, during the first half of incubation (see also Bull [1987]). This is the period in which development rate is highly temperature dependent, and it is also the period in which incubation temperature exerts a major influence on total incubation time (Fig. 8).

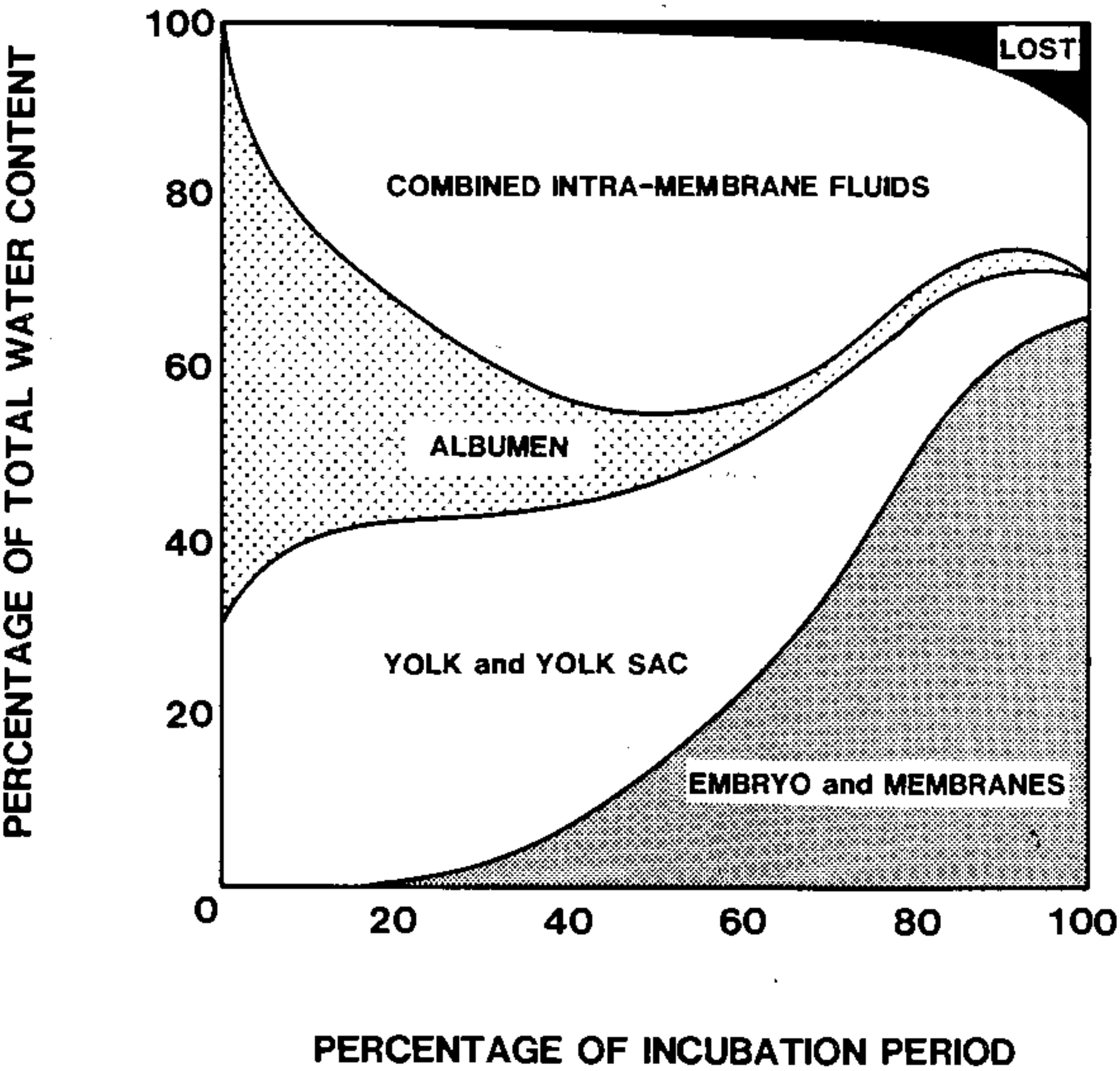
In summary, hatchling fitness varies profoundly with incubation temperature, independent of sex, and quite probably independent of the sex determining mechanism. TSD allows that variation to be exploited differently by the two sexes, giving advantages that would be unavailable with GSD. That these may be related to body size is suggested by the largest reptiles (crocodilians and sea turtles) having exclusively TSD. No extant crocodilians have sex chromosomes (Cohen and Gans, 1970), and the group as a whole may be committed to TSD (Ferguson, 1985); but this is not the case in chelonians (Bull, 1983). Given that GSD is widespread among the invertebrate and vertebrate ancestors of reptiles, TSD would seem to be a derived rather than a primitive trait in reptiles.

TEMPERATURE VERSUS MOISTURE EFFECTS

Successful development of any crocodilian embryo depends on there being an adequate moisture, temperature and gaseous environment for incubation. Many studies emphasise the effects of the moisture environment on hatchling fitness (for example see: Packard *et al.* [1981], Gutzke *et al.* [1987]), whereas we have clearly emphasised the temperature environment. Some believe that the moisture, temperature and gaseous environments act synergistically (Miller, 1985) such that no one parameter can be considered more important than any other. As explained below, we consider moisture and temperature to play equivalent roles in setting the survival limits within which most embryos will develop. However, within those limits effects of the moisture environment appear minor relative to those of the temperature environment.

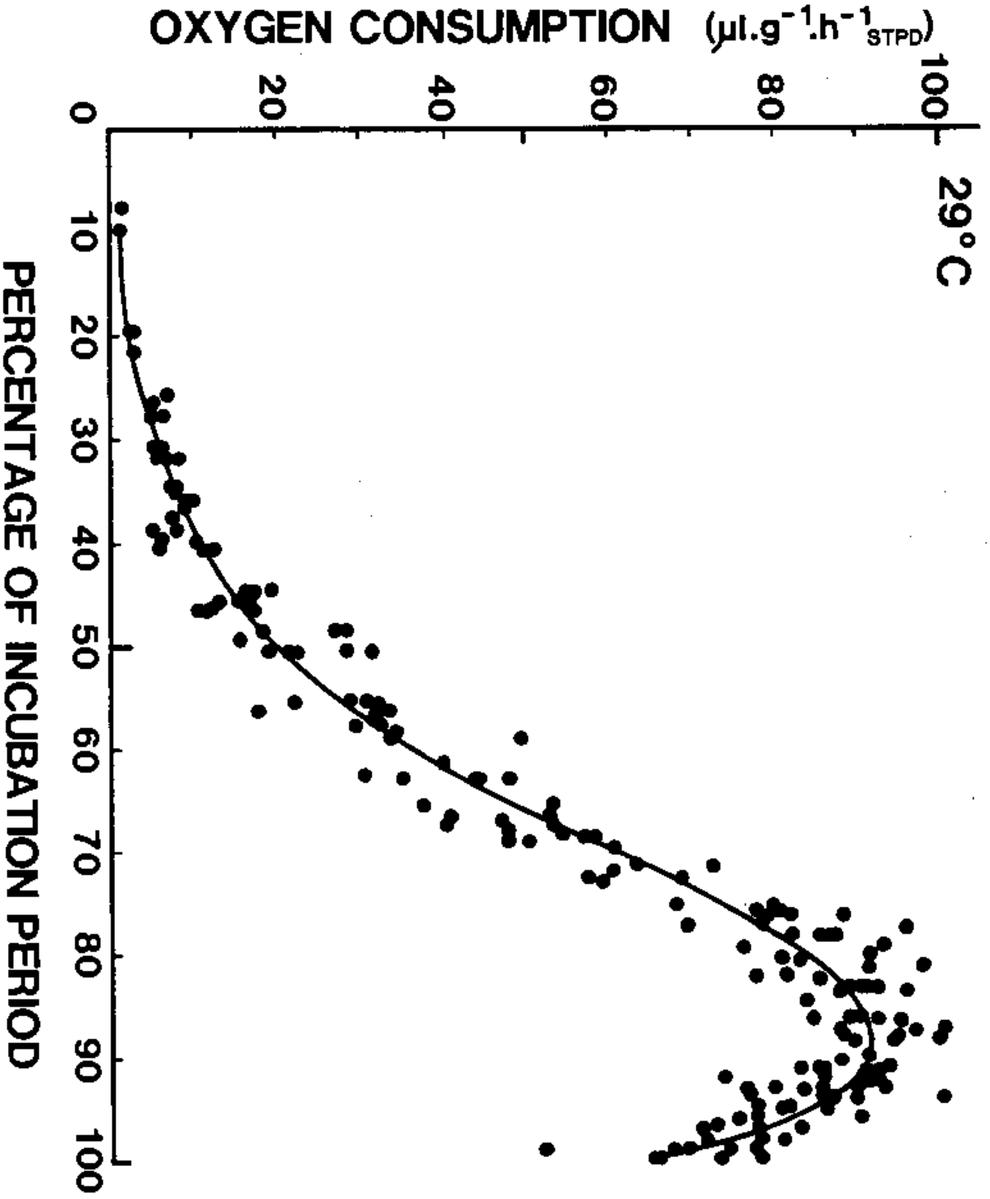
With *Crocodylus porosus* in Australia and Papua New Guinea (Cox, 1985), desiccation of eggs is rare and flooding is common,

Fig 2.



LOST
COMBINED INTRA-MEMBRANE FLUIDS
ALBUMEN
YOLK and YOLK SAC
EMBRYO and MEMBRANES
PERCENTAGE OF TOTAL WATER CONTENT
100
80
60
40
20
0
20
40
60
80
100
PERCENTAGE OF INCUBATION PERIOD

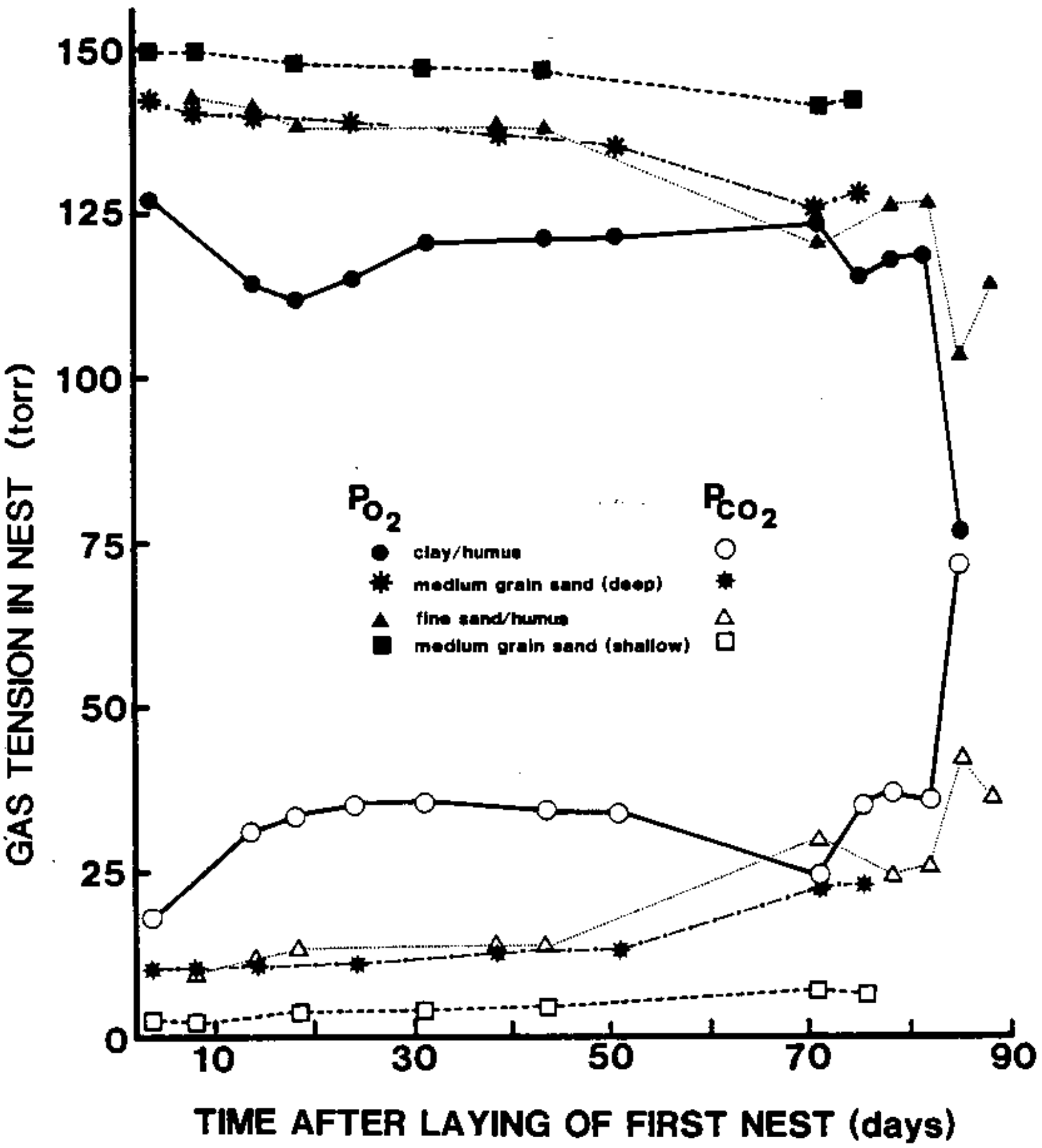
Fig 3.



OXYGEN CONSUMPTION (µl.g⁻¹.h⁻¹ STPD)
29°C
PERCENTAGE OF INCUBATION PERIOD
0
20
40
60
80
100
10
30
50
70
90

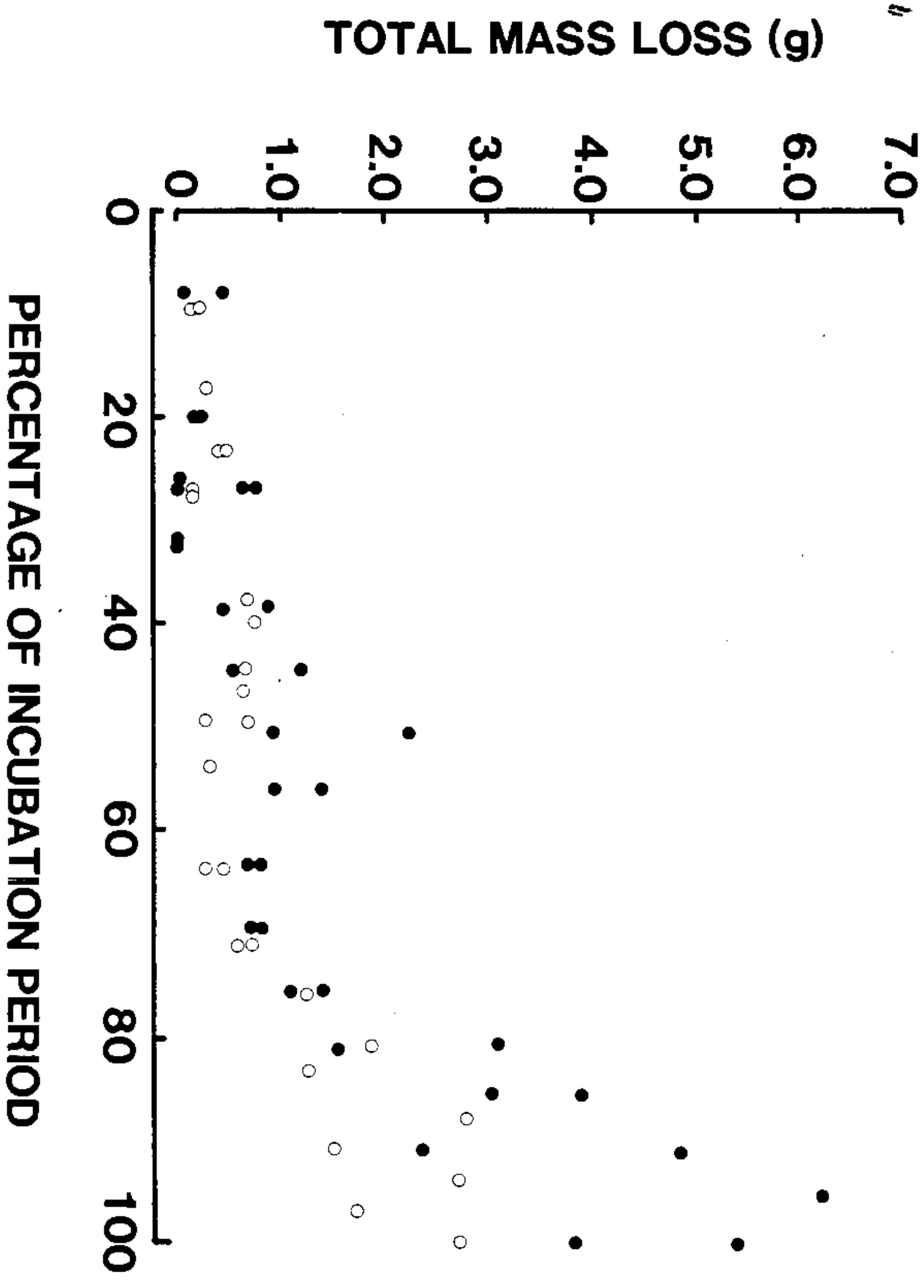
Fig 3

Fig 4.



GAS TENSION IN NEST (torr)
0
25
50
75
100
125
150
10
30
50
70
90
TIME AFTER LAYING OF FIRST NEST (days)
P_{O_2}
P_{CO_2}
clay/humus
medium grain sand (deep)
fine sand/humus
medium grain sand (shallow)

Fig 5.


TOTAL MASS LOSS (g)
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
0
20
40
60
80
100
PERCENTAGE OF INCUBATION PERIOD

THE RISE AND FALL OF CLASSIC CROCODILIAN SKIN PRICES:

WHERE DO WE GO FROM HERE?[1]

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The late 1980s were prosperous years for crocodilian skin producers. Prices rose (Fig. 1), utilization programs were expanded worldwide, farms proliferated (Luxmore 1992), production capacity expanded (Luxmore 1992), illegal skin trade was suppressed (Fitzgerald 1989), and developing countries saw an opportunity to legally utilize their natural resources with the blessing of the conservation community. Then came the 1990s. Hide prices have dropped by as much as 50% (Ross 1992), the financial viability of many propagation facilities has been compromised, and crocodilian utilization programs and their conservation-based rationale are threatened. What has happened? How bad is the damage? Are there remedies? Should we embark on a promotional campaign? Where do we go from here? Questions such as these are increasingly being posed to program managers and Crocodile Specialist Group (CSG) members. Yet, most of us have little formal background in economics. We will explore the above questions in this paper, attempt to apply basic economic theory to the crocodilian skin trade, and suggest several options for managing the problem of volatile skin prices.

Fluctuations in skin prices are not new. Accounts of the early (1860-1950) trade in American alligators (*Alligator mississippiensis*) describe cyclic price patterns in response to fashion trends, economic conditions, and supply instability (Smith 1891, Allen and Neill 1949, Kersey 1976). More recently, raw alligator skin prices rose from $1.87/cm in 1980 to $3.53/cm in early 1982 then dropped to $1.46 by late 1982 (Ashley and David 1987). During the early 1980s, approximately 90% of the international trade was comprised of wild skins. Although crocodilians still could be hunted profitably at such prices, a dip in the worldwide trade in skins in 1984 (Luxmore 1992, Fig. 2) suggested that harvest pressure declined with prices. Because hunters had very little capital investment in their businesses and usually had other sources of income to turn to, such downturns in prices had only

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moderate financial impact. A significant recovery of skin prices occurred within a year.

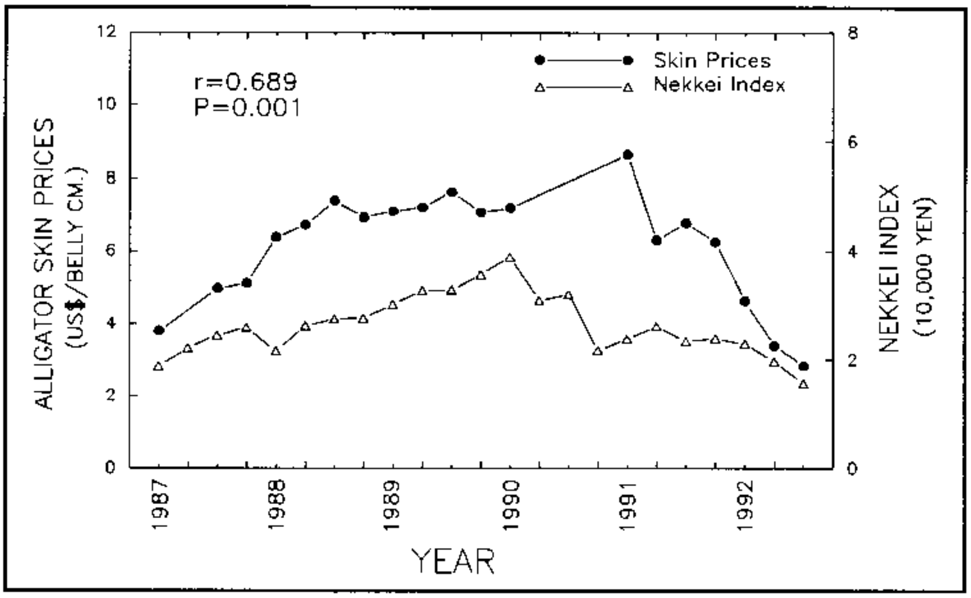

Figure 1. Prices (cm belly width) paid for alligator skins in Florida and price changes in the Japanese stock market (Nekkei Index) from 1987-92.

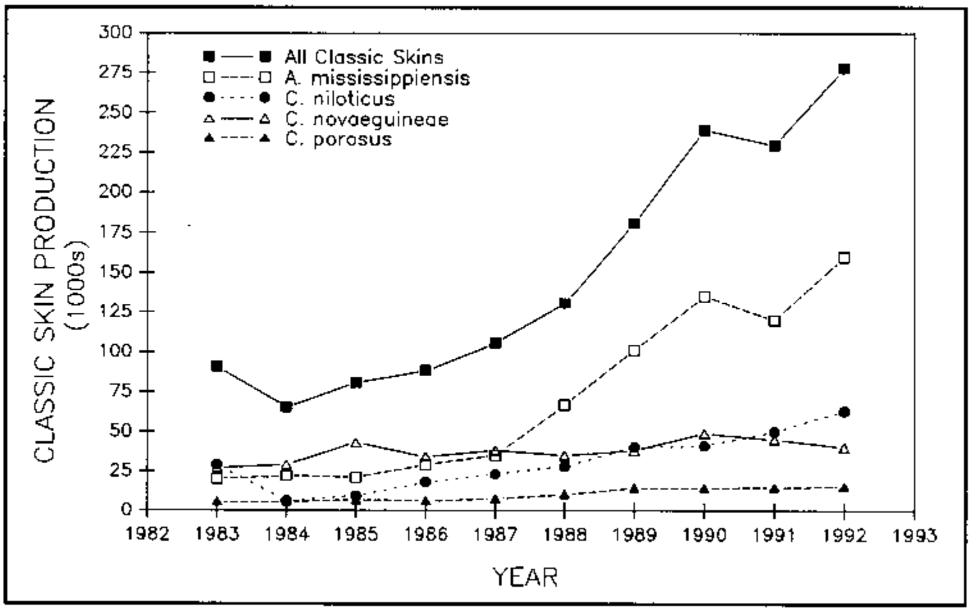

Figure 2. Classic crocodilian skin production trends during 1983-92.

The present price collapse has been different. Raw alligator skin prices dropped from \$8.66/cm for wild skins (\$6.00 for captive-raised) in 1990 to about \$3.00/cm in 1992. Prices of other crocodilian skins have decreased similarly (Ross 1992). Since 1990, over half of the worldwide trade has been composed of captive-produced skins (produced by ranching or farming). Worldwide capital investment in farm facilities exceeds \$100 million, and a substantial proportion of producers rely on the skin trade for their livelihood. Hence, it is not difficult to see why this recent plunge in raw skin prices has caused more anguish than past declines.

In August, 1992, a trade workshop was held during the 11th Working Meeting of the CSG in Victoria Falls, Zimbabwe, to address low skin prices (Ross 1992). A diverse panel of producers and industry representatives noted that the following factors contributed to depressed prices:

- Low demand for products in Japan
- Poor world economy
- Consumer resistance to wildlife products
- Paucity of manufacturing facilities worldwide
- Imbalance of production and consumption in the U.S.A
- Ban on wildlife trade with Italy

Van Jaarsveldt (1992) echoed some of the above points, further emphasizing the production/consumption imbalance in the U.S.A. Most importantly, he mentioned over-supply, which had been noticeably absent from discussions at the trade workshop. Is over-supply a major part of the equation and, if so, why was it ignored at the trade workshop? We will explore this question, and basic economic principles, in hopes of gaining a better understanding of factors affecting classic crocodilian skin prices.

SUPPLY AND DEMAND ANALYSIS

Economists use supply and demand curves as simple models to describe the relationships between supply, demand, and the price of goods or commodities (Baumol and Blinder 1982). The demand curve, *D* (Fig. 3) represents the association between the price of a good and the quantity demanded. Generally, as price increases (P_1 to P_2), customers will buy less of that good (Q_1 to Q_2) and vice versa. Shifts in the demand curve (Fig. 3) represent changes in the variables that influence demand, such as aggregate consumer income, consumer preferences, and prices of related goods. Thus, as aggregate income changes (more or fewer consumers are able to afford a good) or as styles change, the quantity demanded changes, as does the price. Under constant quantity demanded (Q_2), a positive shift in the demand curve ($D+$) will result in a shift of the equilibrium point from *b* to *c* and a consequent price increase from P_2 to P_3 (Fig. 3). Declining market conditions lead to a negative shift in the demand curve to *D-* with a new equilibrium point (*d*) and a lower price (P_1).

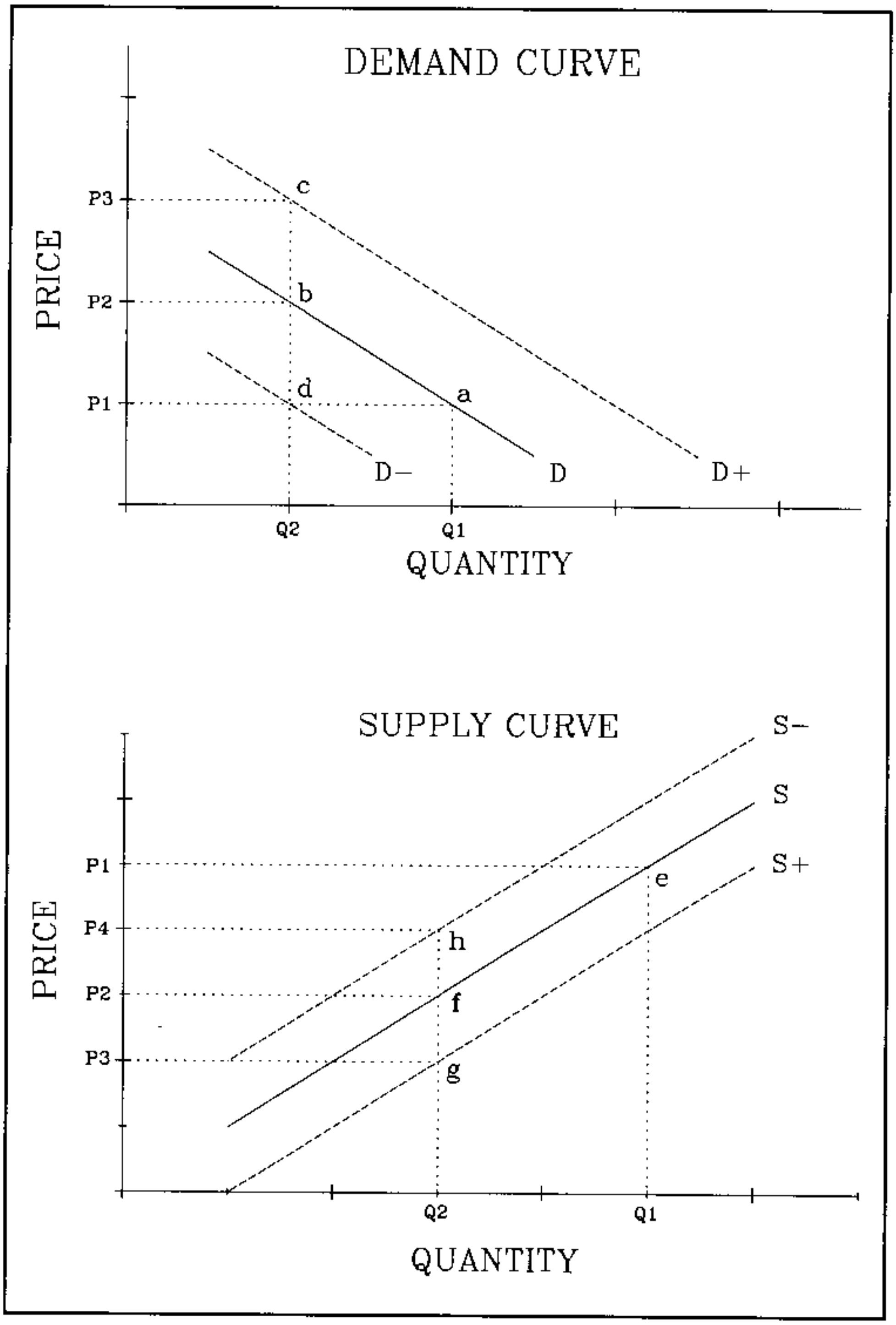

Figure 3. Hypothetical supply and demand curves.

The supply curve (Fig. 3) indicates how the quantity supplied varies with the price of a good. As price decreases from P_1 to P_2, quantity supplied decreases from Q_1 to Q_2, and vice versa (Fig. 3). Changes in the production capacity of the industry and changes in production costs result in shifts in the supply curve. Thus, as producers enter and leave an industry or the costs of labor and raw materials change, profits change. With changing profits, the quantity supplied changes, shifting the supply curve to the left or right. Assuming perfectly inelastic demand, if industry output declines, the supply curve shifts to the left (*S-*) and the equilibrium point shifts from *f* to *h*, resulting in an increase in prices from P_2 to P_4 (Fig. 3). Conversely, if industry output increases the supply curve shifts to *S+* with a resulting shift of the equilibrium points from *f* to *g* and a price drop from P_2 to P_3 (Fig. 3).

Supply and demand principles apply to most commodities, including crocodilian skins. Although crocodilian markets are influenced by unique market forces, a simple supply and demand analysis can allow us to evaluate price swings over the past several years. Supply and demand curves differ at various levels of the crocodilian skin industry (production, tanning, manufacturing, and retailing). For simplicity, we attempted to base our model on the production component. However, the influence of the retail markets frequently had to be considered.

Demand

As noted by the CSG trade panel (Ross 1992) and Van Jaarsveldt (1992), the worldwide economic recession has caused demand to stagnate or decrease. This is particularly apparent with the economic downturn experienced by Japan, consumer of 65-70% of finished classic crocodilian leather products (Ishii 1990, Ross 1992). Falling stock market and real estate values have plagued the Japanese economy since 1990 (Impaco 1993). In fact, since 1987, skin prices have been closely correlated ($r = 0.689$, $P = 0.001$) with prices of the Japanese stock market (Fig. 1). This phenomenon probably reflects investor attitudes that run from euphoria when stocks and real estate prices are spiraling to austerity during downturns. Moreover, it indicates that the demand for crocodilian leather products is affected by the general economy. In a recession, customers are likely to stop or delay purchases of exotic leathers or switch from classic crocodilian products to more affordable substitutes such as ostrich, lizard, snake, elephant, or caiman.

As shown in Fig. 4, as demand for crocodilian products increased during the late 1980s (*D-87* to *D-90*), so did prices of retail leather products and the price of legal raw skins (*P1 - P2*). It is likely that retail prices for most classic leather products exceeded the purchasing range of middle-income customers. Thus, the customer base for classic skin products was limited to the wealthy. During the recession, additional high income customers were lost, further reducing demand and adding to inventories at all industry levels. The ramifications of the latter problem may have lasting effects; retailers remember when they lose money on a product and subsequently, may be less inclined to purchase future crocodilian products. The net result was an excess inventory of skins at manufacturing, tanning, and trading companies. Thus, buyers purchased fewer raw skins, causing prices to fall dramatically. Only when prices reached extremely low levels did buyers measurably re-enter the market (Ross 1992).

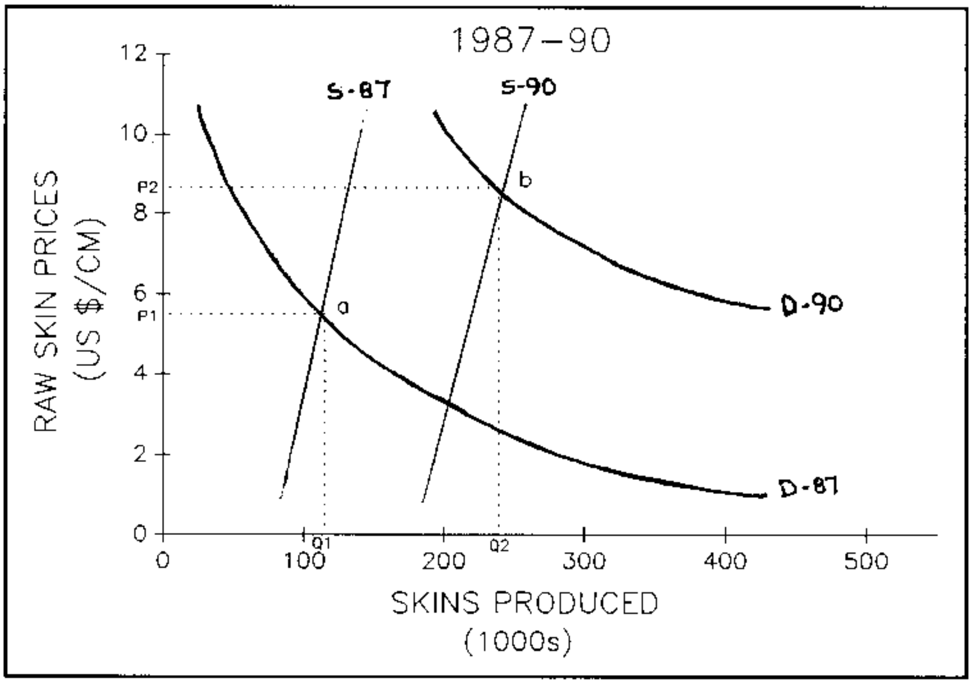

Figure 4. Hypothetical supply and demand analysis for raw classic crocodilian skins during 1987-90.

Demand for skins may have been affected by other factors such as subtle fashion shifts and increasing consumer resistance to wildlife products, but these components are difficult to quantify. Also, there is little evidence that they played a major role in the most recent price drop.

Shown graphically (Fig. 5), shrinking demand during 1990-92 shifted the demand curve to the left (*D-90* to *D-92*), which resulted in lower skin prices. Based on past history of customer attitudes about crocodilian products, we believe that the shape of the demand curve is not linear; as price drops and demand increases at an exponential rate, products become more affordable to an exponentially increasing customer base. This is typical of desirable products that are not necessities (i.e. jewelry). Conversely, as prices rise, fewer people can afford to buy products, resulting in an exponentially narrowing customer base. These important concepts will be addressed later.

Also important is the slope of the demand curve. Crocodilian leather products are not a necessity. Thus, a small change in price results in a disproportionally large change in quantity demanded. This is said to be an *elastic* demand curve and the resulting slope is more horizontal than vertical. However, demand is usually less elastic at the producer level.

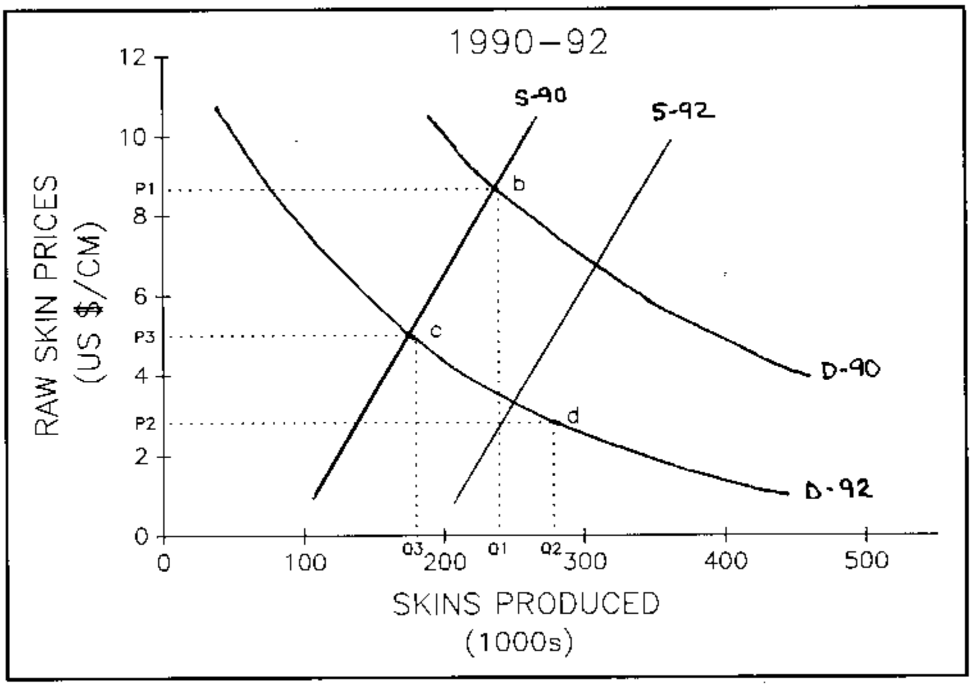

Figure 5. Hypothetical supply and demand analysis for raw classic crocodilian skins during 1990-92.

Another factor that undoubtedly affected skin prices was the substitution of caiman skins for classic skins. In the U.S.A., the influx of caiman products (Fitzgerald 1989) has been blamed for poor market conditions for alligator products. High raw alligator skin prices and associated prices for finished alligator products during the late 1980s excluded most middle income customers and created an open niche for moderately-priced caiman products. We note that American consumers are probably less knowledgeable about the differences in crocodilian products than are European or Asian consumers and may more readily substitute lower-priced caiman for classics. At some stores in the early 1990s, caiman products retailed for approximately the same price for which alligator products sold in late 1986 (A. Woodward, pers. comm.). Retail prices for alligator products in the U.S.A. more than doubled during 1987-92 while the general price level, as reflected by the Consumer Price Index increased by only 24% (U.S. Dept. of Labor, Bureau of Labor Statistics, 1992). The differential in prices between raw caiman skins and finished caiman products permitted greater profit potential at all levels of the caiman skin industry, thus, encouraging promotion of caiman over alligator by tanners, manufacturers, and retailers.

Supply

The worldwide supply of raw classic crocodilian skins is thought to have been 500,000 in the early 1960s and about 300,000 in the early 1970s (Ashley 1990, Luxmore 1990). Following a sharp decline during the late 1970s to a roughly estimated 75,000 skins resulting from closure of illegal markets, supplies began to increase again. Production increased steadily during the late 1980s, except for a dip in 1984 (Fig. 2). Trade specialists have generally accepted that 300,000-500,000 skins could be absorbed into the market at late 1980s prices (Ashley 1990).

Estimated worldwide production of classic skins jumped nearly 60% from 1989 to 1992 (Fig. 2), catalyzed by rising skin prices and associated profits. Increased captive production from Louisiana accounted for 85% of the worldwide rise (Ross 1992, Fig. 2). These skins were the end product of a massive expansion of Louisiana's ranching program from collection of approximately 70,000 eggs (about 67,500 hatchlings) in 1988 to 300,000 (245,500 hatchlings) in 1990 (Table 1). Production from other ranching programs throughout the world increased at a moderate pace over the same period (Ross 1992). Skin production in Florida increased from 11,000 in 1987 to 26,500 in 1991 (Joanen et al. 1990; GFC, unpubl. data). Most of this was attributable to an increase in hatchling production (from both farm and wild sources) from 7,685 in 1985 to 49,500 in 1990 (Joanen et al. 1990; Table 1). Nile crocodile skin production increased modestly during the 1989-92 period, and crocodile supplies from Papua New Guinea were relatively stable (Ross 1992).

The net result of increased hide production capacity has been a shift of the supply curve to the right (Figs. 4 and 5). Under stable demand this would account for a large portion of the drop in skin prices experienced between 1990 and 1992 (Fig. 5). Why couldn't the market absorb these skins, considering the volumes traded during the 1960s? Assuming that the rough estimates of skin trade in the 1960s are reasonably accurate, this can be partially answered by reduced manufacturing capacity and differences in consumer preferences as suggested by the CSG trade panel (Ross 1992). However, average skin size and, thus, useable leather, may be different from that of skins traded during the 1960s. Approximately 50% of the trade in alligators during the 1960s was 10-20 cm (2-4 linear ft.) skins (Hines 1979). These would yield less than half the leather of an average farm-raised alligator skin marketed today. Although this aspect warrants further analysis, we merely point out some of the pitfalls of using past trade volumes measured in number of skins to estimate current market potential. Furthermore, in the 1960s, all skins originated from cropping. Hunters could make a profit at considerably lower relative prices than can farmers today.

Despite poor market conditions, skin supply may continue to increase for at least another year due to intense egg collections during the late 1980s and continued worldwide implementation of new ranching and farming programs. Because of the costs of maintaining stock and the need for cash flow, farmers will be forced to slaughter and market skins in an already over-supplied market. Such supply increases will shift the supply curve further to the right, resulting in continued downward pressure on prices (Fig. 5). Even under moderately expanding demand, it is likely that little relief in prices can be achieved if supply expands. Any production decisions will take 2-3 years to take effect because of the average time it takes for hatchlings to reach market size. Thus, the industry is not able to immediately adjust supplies with price changes, resulting in an *inelastic* supply curve (more vertical slope).

Table 1. Inventories of American alligators (hatchlings and all sizes), and skin sales for alligator farms in Louisiana, Florida, and Texas during 1987-92.

	Hatchlings[1]				All alligators				Skins produced			
Year	La.	Fla.	Tex.	Total	La.	Fla.	Tex.	Total	La.	Fla.	Tex.	Total
1987	25,000	20,500	--	45,500	29,000	54,974	--	83,974	10,700	6,479	--	17,179
1988	67,500	30,500	--	98,000	84,000	75,175	--	159,175	27,500	7,592	--	35,092
1989	152,500	35,500	--	188,000	223,000	93,135	--	316,135	60,668	16,482	--	77,150
1990	245,500	49,500	6,000	301,000	360,863	115,793	12,592	489,248	88,500	20,007	348	108,855
1991	156,000	47,500	6,500	210,000	318,000	142,546	21,376	481,922	119,000	18,092	584	137,676
1992	136,000	31,500	3,500	171,000	292,000	129,143	23,038	444,181	150,000	31,874	4,723	186,597

[1]Estimates provided by T. Joanen (Louisiana), D. David (Florida), and B. Brownlee (Texas).

Increased supply was fueled by high prices and profitability during the late 1980s. Low prices can be expected to cause a temporary reductions in eggs collected, as has occurred in Florida and Louisiana since 1990 (Table 1). In fact, a 43% reduction in alligator hatchling production occurred between 1990 and 1992 (Table 1). Whether this is occurring throughout the rest of the world is uncertain. Some operations appear to be able to keep production costs below income and can operate profitably at existing prices. Other programs, subsidized by governments to provide jobs or foreign exchange, can operate profitably at prices below cost of production. Moreover, the allure of crocodilian farming and visions of vast profits will continue to attract additional interest in crocodilian production despite the balance sheets. Consequently, even at today's low prices, some production expansion can be expected.

Further expansion of supply is contingent upon unexploited wild reserves (nesting reserves and capacity for cropping) and the propagation potential of captive breeders. At higher prices, supply of alligators from the U.S.A. could easily expand by 10-20% (15,000-30,000 skins) (Ashley 1990b). Nile crocodile (*Crocodylus niloticus*) production could increase by 10,000-20,000 (Hutton 1990), crocodile (*C. novaeguineae* and *C. porosus*) production in Indonesia could increase by 10,000-20,000 (Cox 1990), and India, should it decide to enter into a ranching program, could produce a minimum of 10,000-15,000 *C. palustris* and *C. porosus* (Choudhury 1990). Expanding ranching programs in Latin America could increase the supply of American crocodile (*C. acutus*) skins by 5000-10,000. Other programs such as those in Australia and Thailand, could also contribute to increased supplies. Consequently, wild reserves could support the production of an additional 50,000-100,000 skins per year, or a worldwide total of 325,000-375,000 skins per year.

The capacity for increased skin production from cropping is limited. Although skin production from captive propagation can be expected to increase, particularly from Nile crocodiles, captive breeding of alligators has leveled off. Thus, ranching production represents the largest potential for expanded production.

FINANCIAL MANAGEMENT OBJECTIVES

It is important to examine the financial management objcetives of crocodilian programs. Maximization of *total profit* (total revenue less total cost) is the primary objective of most business owners, stockholders, and program managers, at least for the long-term.

Many businesses, however, look at profitability as a long-term goal and *market share* as a short-term objective in attaining that goal. Companies frequently increase market share by selling products at below-market prices to force competitors out of business and, thus, allow them to eventually dominate the market and exert more control over prices. A company's ability to accomplish such a goal is largely dependent on the depth of its financial resources. Diversified companies and government subsidized businesses generally have the best chances of being successful with such a strategy.

Current low raw skin prices provide an opportunity for such tactics. At the industry level, reducing crocodilian skin prices to below cost might attract customers from other exotic leathers or luxury items. Unfortunately, long-term low prices may lead to failures of sustained-use programs and negative conservation effects.

Because a certain amount of the costs of running a company are fixed (remain the same at different production levels), the cost of producing an additional unit will decline as output increases. Thus, *economies of scale* is used to increase profit margin (Baumol and Blinder 1982). However, at the industry level, increased output will put downward pressure on prices, thereby reducing profits. In hard economic times, "shake-outs" occur; unsuccessful businesses go bankrupt or sell to more financially sound businesses. This helps create a favorable economy of scale situation for surviving businesses that can produce a product at a lower cost (and can, therefore, sell to the consumer at a lower cost) without expanding industry-wide production (and exerting downward pressure on prices). This may be occurring to some extent in the crocodilian industry (Van Jaarsveldt 1992). Ironically, because of the enchantment of the crocodilian industry, new starts seem to out-pace business failures. Thus, any benefits from a shake-out may be short-lived.

Vertical integration (owning or controlling operations at all levels of the industry) may also increase profitability. Vertical integration can produce a less costly product, which should result in increased sales of skins at all levels of the industry.

Certainly, profitability is the objective of the crocodilian skin production industry. Profitability is also essential for the viability of sustained-use programs - the greater the profit, the more incentive to utilize wild crocodilians. It is common sense that 10,000 skins sold at a profit is preferable to selling 20,000 at a loss. Unfortunately, programs throughout the world, in their haste to garner greater wealth and conservation benefits from crocodilian utilization, have over-produced. The scenario of high prices, increased production, declining prices, and decreased production is common for most commodities because of the overwhelming and cyclic nature of market forces. Our challenge will be to will be to reduce the amplitude of such cycles.

SOLUTIONS

To summarize what we have covered so far: Classic skin prices have been depressed by a combination of factors including rapid increase in production and declining or stagnant demand. In the short and intermediate run, supply is inelastic - production changes slowly in response to changing price levels. However, demand is elastic - small changes in price cause disproportionally greater changes in quantity demanded. Low prices have reduced the profitability of many producers and threaten to compromise conservation programs in many countries. Continued surplus production capacity and prospects for a slow worldwide economic recovery threaten to keep downward pressure on prices. We will proceed with the premise that it would be in the best interest of classic crocodilian skin producers to increase profitability. How can this best be done?

For the well-being of the crocodilian production industry, profitability needs to increase soon. It is likely that demand will gradually increase as the world economy improves, a slow-down in skin production may occur, and prices may rise. Thus, markets could be allowed to recover naturally without intervention. However, this period may be protracted and, therefore, intervention may be a preferred option.

Economists suggest that profitability can be bolstered in three ways: (1) increasing demand; (2) decreasing supply; and (3) decreasing production costs. The conclusion of the CSG trade workshop in Victoria Falls was to increase demand for crocodilian products through promotional activities and education of consumers. Unfortunately, the other major part of the equations, supply and cost controls, were ignored. Why? Three reasons come to mind: (1) in a production oriented business, expansion is synonymous with progress; (2) a perception that nothing could be done about controlling supplies; and (3) a reluctance to interfere with free enterprise.

The problem with increasing demand with no control over supply is that supply will increase (we have already discussed the large surplus capacity or "reserves" available) as profitability increases. Furthermore, because of the inelasticity of supply, large cyclic price swings can be expected to continue. In the old days when little investment was involved at the producer level, this was acceptable. Now, the economic impacts of such swings may lead to business failures and negative ramifications for crocodilian utilization programs. Most producers would prefer to have stable but profitable markets. Although price goals have not been established, many producers have the lofty late 1980s prices ($8-9/cm) in the back of their minds. Those would be nice, but they would lead to a big profit margin and only stimulate more production, increase the costs of retail products, and again constrict the customer base. Such swings would expose producers to greater financial risk during inevitable recessions. Consequently, it may be preferable to target sustainable prices at the $5-6/cm level. Such prices will lower retail prices and exponentially increase the customer base. Profits may be smaller during times of rapid economic expansion but this will reduce incentives for increased production, and, thus, reduce the severity of price declines. This can only be accomplished through stabilization of supply.

Increase Demand

Demand can be enhanced through *promotion* (of which *advertising* is a component). However, to increase demand under fixed disposable income, consumers must shift their purchasing from other goods (usually other luxury items) to crocodile leather. Activities such as industry promotions, point-of-sale education, advertising, and educational programs were proposed during the CSG trade workshop to stimulate demand. Promotional activities can substantially increase overhead costs (and eventually retail prices), and there is always the risk that outlays for marketing will not be recovered by increased sales. Such activities may take years to take effect, their effectiveness will be hard to measure, they will be costly, and, due to the overwhelming power of the general economy and other market factors, they may be unsuccessful. For instance, a marketing program for alligator skin products was in place during the recent 50% price drop (Ashley 1990a). Supporters of the effort noted that the approximately $100,000 per year marketing effort was under-funded (D. Ashley and T. Joanen, pers. comm.). Indeed, marketers of branded luxury goods frequently spend 10% or more of total sales on advertising and other market development activities (Anon. 1992a, 1992b).

This does not mean that product promotion is too risky to pursue. On the contrary, continuing education of potential customers and promotion of products is necessary to maintain market share and should be a consideration. However, marketing alone will not provide a long-term solution to periodic unprofitable skin prices. Moreover, if a marketing approach is pursued, how much should be spent and to which marketing programs should funding go? Questions such as these can only be answered with a thorough market analysis. For example, consumer resistance to wildlife products (particularly species perceived as "endangered") has been frequently cited as a major contributing factor to depressed retail sales. Yet, no hard figures are available to support this contention or to chart trends in consumer attitudes.

Controlling Supply

The costs of stimulating a measurable increase in demand through product promotion can be enormous. However, limiting supplies can be accomplished at a fraction of the cost of marketing through stabilizing or reducing wild harvest quotas. This would create a controversial "cartel" situation and would generate many associated questions. Is a cartel approach an ethical and legal way of conducting business? Would production quotas infringe on the sovereign rights of nations or provinces? Could voluntary limitations on harvest quotas work in the international community? Would limiting expansion of production be unfair for some programs and a windfall for others?

Increasing wild egg collection quotas and expanding programs at this time is unwise for conservation and business. Although natural market forces may correct imbalances in supply and demand, rapid increases or decreases in skin supply will have a destabilizing effect on the market. Therefore, stabilization of supply growth should be considered as a component of any approach to improving skin prices. The immediate priority of a supply control approach would be to stabilize harvest quotas. This assumes that demand will increase gradually with the global economy. If demand does not improve over several years and prices remain low, reducing production may need to be considered. This could be accomplished by attrition; as farms go out of business, do not permit new ones. Under a voluntary system, these 2 strategies would involve the least pain to producers and sustained-use programs, and could be accomplished with minimum interference from regulatory bodies.

Cost Reduction

Assuming constant demand, profits can be improved through reduced production costs. In a competitive market such as the current skin market, reducing costs is essential. Reducing costs will allow profits at lower price levels, thus, increasing quantity demanded. Costs can be reduced through increased efficiency of production, by economies of scale, or by vertical integration. Most producers would benefit from an independent financial analysis to identify inefficiencies.

Some conservation risks may result from cost-cutting. Frequently, industry participants first request regulatory agencies to cut user fees. However, these fees constitute a relative minor portion of costs but are essential for the long term success of sustained-use programs.

CONCLUSION

The primary purpose of this paper is to provide a superficial evaluation of the crocodilian skin market so that program managers and CSG members can be better informed before making basic economic decisions about approaches to improving crocodilian skin prices. The crocodilian skin market is complicated. Most biologists, farmers, and program administrators have limited training in economics. Yet, they are required daily to make economic decisions that affect the conservation of crocodilians and the financial situation of private businesses. Furthermore, reliable trade and price data, with which to make decisions are not always readily available. Although many of us have traditionally thought that crocodilian skins will "sell themselves", price fluctuations over the past several years and the prognosis for the future have indicated otherwise.

We hope to have presented a case that stable and profitable skin markets are desirable not only from a business perspective but also for conservation of crocodilians. Marketing should be a component of any strategy to increasing profitability. Promotions may always be needed to maintain market share against other luxury goods that compete for the same customers. Moreover, education may be needed to counter consumer resistance to the use of wildlife products, which may erode demand for crocodilian skins over the long-term. However, marketing can be costly and 2 questions arise; who pays for it and how much is necessary to achieve price objectives? Therefore, we believe that supply control and cost containment should be considered as complimentary approaches.

The advantages of stabilizing supply is that it would produce results in a relatively short period of time (2 years) and at minimal cost. The drawback is government intervention. Although the idea of tampering with a free-enterprise system may be the biggest problem, we must also look at the alternatives to controlling supply; high costs associated with aggressive marketing programs, widely fluctuating prices, threatened conservation programs, and possible bankruptcies.

It is our assessment that, before taking any measures to increase demand or manipulate supply, an independent, impartial, and in-depth assessment of international crocodilian skin trade economics should be funded. This differs somewhat from a "marketing" study, which presumes that increasing demand is the best approach. The results would provide program managers with the tools for making decisions regarding demand enhancement or supply control and aid in planning sustained-yield harvest programs.

We would like to end this discussion with a thought. The CSG has embraced the concept that conservation of crocodilians can be enhanced through economic value. This is a subtle departure from the concept that the sustained-use of crocodilians can be justified by conservation benefits. In short, if crocodilian utilization programs are driven by the desire to develop industry rather than to enhance conservation, then they can be easily diverted from conservation goals by short-term industry objectives. Because of the interdependence of international skin markets, an industry-led program could threaten crocodilian utilization programs where conservation consequences are crucial. A free-market approach may be the best philosophy for business but may be less than satisfactory for conservation goals. This is where conservation organizations such as the CSG need to provide guidance to assure that conservation objectives are fully considered in any strategy.

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USE OF NIGHT COUNT DATA FOR ESTIMATION OF CROCODILIAN POPULATION TRENDS[1]

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Night spotlight counts (Woodward and Marion 1978, Messel et al. 1981) are used throughout the world as a basis for evaluating crocodilian population trends (Wood et al. 1985, Bayliss 1987, Webb et al. 1990). They are particularly effective in habitats that render aerial basking (Webb et al. 1990) and nest (McNease and Joanen 1978) surveys logistically impractical.

Night counts represent an *index* of the total population (Davis and Winstead 1980, Bayliss 1987). Although the exact relationship between a count and the total population (*sighting proportion*) may be unknown, for trend analysis, we either assume that this relationship remains constant over time or that we can account for factors affecting the sighting proportion. Thus, any change in counts should reflect a proportionate change in the total population.

The purpose of trend analysis is to estimate the direction and rate of change in a population. These results allow investigators to make inferences about the status of a population or the response of populations to influences such as harvest, protection, habitat management, or restocking. However, violation of the assumptions of trend analysis and improper analysis of data can result in erroneous conclusions.

Recent investigations (Woodward and Moore 1993) provided some insight into factors affecting trend analysis of American alligator (*Alligator mississippiensis*) populations, the importance of meeting assumptions of trend analysis, methods of analysis, and interpretation of findings. In this paper, we summarize those findings and discuss their application to general problems with population trend analysis of crocodilians.

DESIGN

Objectives

Trend analysis is applicable when inferences are to be made about the status of a

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population over time. In general, trend investigations are initiated as part of a *monitoring* effort, designed to evaluate the status of a population over time, or an *experiment*, the purpose of which is to measure the effects of certain treatments (e.g., harvests, protection, restocking) on populations. The objectives of an investigation determine the optimum design and need to be clearly identified early in the planning process.

Sampling

Night counts are normally conducted as systematic samples of an area and usually entail driving a boat parallel to the shoreline of a river, canal, or small lake. In most cases, systematic surveys can account for a major portion of the population. However, habitats such as large, shallow lakes, marshes, and swamps may require transect sampling.

Monitoring Surveys.--Crocodilian population densities may affect population growth rates (Webb et al. 1990). Densities may vary by quality of habitat (McNease and Joanen 1978, Wood et al. 1985, Webb et al. 1990), water salinity (Messel and Vorlicek 1986), and trophic state (Wood et al. 1985). Therefore, sampling should generally be stratified by density-affecting elements (Eberhardt 1978). Within strata, areas of suitable habitat should be sampled at random. Although random selection of areas is preferable, frequently it is not possible because of accessibility or cost. In those cases, systematic sampling over a reasonable geographic range would be a practical but more biased approach (Eberhardt 1978).

Experiment Surveys.--If testing of the effects of a *treatment* is the objective, then *control* (no treatment) areas must be included in the sample to enable attribution of any changes to the treatment. Treatment and control areas should be replicated at random within strata so that standard statistical tests (see ANALYSIS) can be applied to the results.

Replication

Replication increases the *power* (the probability of detecting a real effect) of statistical tests (Eberhardt 1978, Gerrodette 1987) and can reduce the time necessary to detect population trends (Harris 1986, Gerrodette 1987). True replicate counts represent independent measures of the population; this will be discussed later. Replication of counts for monitoring can occur at 2 levels; within-year on individual areas and within strata (habitat, salinity, trophic level, etc.). Within year replication enhances the detectability of trends on individual areas (Harris 1986, Gerrodette 1987). If inferences are to be made about a regional population, then replication of areas at the expense of within-year replication on individual areas will provide the optimum allocation of resources (Gerrodette 1987). Funds for surveys are usually limited. Thus, investigators will have to determine the best application of replication based on the objectives of their study. For a more detailed discussion of the replication necessary to detect trends see Eberhardt (1978), Harris (1986), Gerrodette (1987) or Link and Hatfield (1990).

VARIATION

Power of statistical tests increases with sample size but decreases with variation in counts (Eberhardt 1978, Gerrodette 1987). Variation in counts of crocodilians can be caused by *detectability* or *availability* differences. Detectability varies due to the ability of the observer to discern a crocodilian or due to the efficiency of the equipment. The probability that an animal can be seen is dependent upon its availability in the survey area. Thus, those animals that are submersed or are in inaccessible areas are not available for counting. Seasonal or environmental influences may affect availability. Precision of counts can be increased by standardizing methodology and accounting for sources of variations (Eberhardt 1978, Gerrodette 1987).

Observer and Equipment

Observer experience can affect detection rates of crocodilians. In most cases, the ability of observers to detect crocodilians increases quickly with experience then stabilizes. Thus, it is important that observers be thoroughly trained before contributing observations to trend analyses. Size estimates of crocodilians can vary considerably among observers. To reduce this source of bias, we recommend observers catch a sample of alligators from representative size classes after first judging their sizes.

Equipment and its patterns of use can affect counts. Woodward and Marion (1978) reported that boat speed and light intensity affected counts. Therefore, standardization of equipment and operating procedures will reduce variability in detection rates.

Seasons

Seasonally, crocodilians may move in or out of a survey area to breed, feed, or seek shelter, thus changing their availability. Annual surveys should be conducted during a single season to minimize such variation. The more expensive alternative is to calibrate seasonal differences by conducting sufficient counts during other seasons.

Environment

Water Level.--Water level changes, caused by rainfall or tide, have a profound effect on the availability of crocodilians in wetlands with associated inaccessible marsh or swamp (Woodward and Marion 1978, Messel et al. 1981, Messel and Vorlicek 1986, Webb et al. 1990). In general, as water levels rise, a net emigration of crocodilians occurs from the survey area to surrounding swamps and marshes. During periods of low water, animals tend to concentrate in remaining deep water, usually the survey area. Water level should be measured on all survey areas and used in analyses (see ANALYSIS) to isolate the water level effect (Fig. 1). Water levels in marshes and swamps associated with the primary wetland tend to be less stable than those in deeper water and may have a greater influence on crocodilian availability (Woodward and Moore 1993).

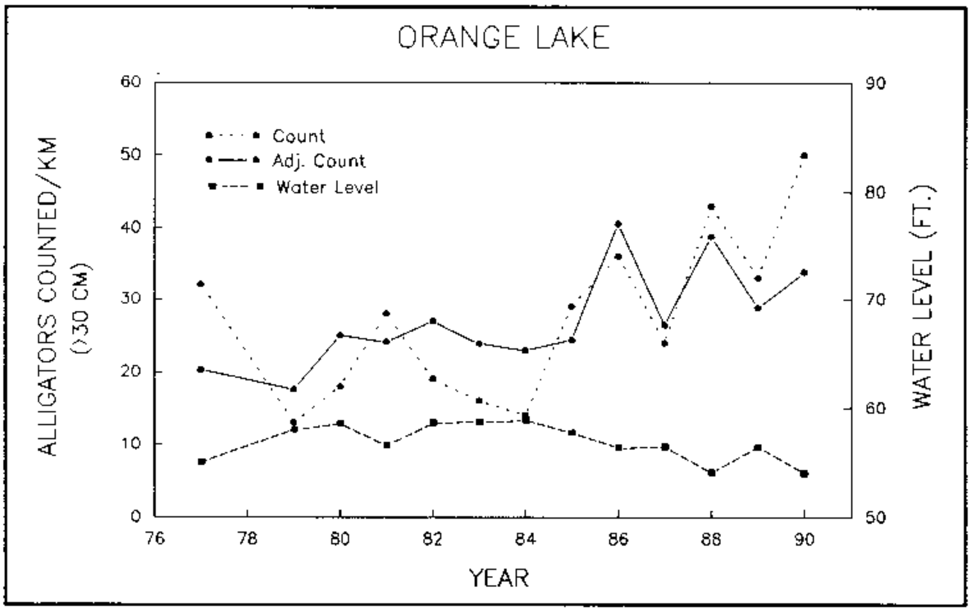

Fig. 1. The influence of water level on counts of non-hatchling alligators on Orange Lake, Florida. Original counts have been adjusted for mean water level (adj. counts).

Water Temperature.--Crocodilians tend to become less active under cooler conditions and apparently spend more time under water (Smith 1979), thus reducing the probability of being counted (Woodward and Marion 1978, Hutton and Woolhouse 1989). For some crocodilians (e.g., alligators) in cooler regions, counts are closely correlated with water temperatures at lower temperatures, but, at higher temperatures, the correlation fades (Woodward and Marion 1978, Brandt 1989). Thus, for alligators, counts conducted during warm water conditions would be most stable from year to year. The alternate, more expensive approach would be to conduct a series of counts over a variety of water temperature conditions to account for water level effects.

Vegetation.--Changes in floating and emergent vegetation can affect the detectability of crocodilians. Thus, vegetational changes should be quantified and measured. The availability of alligators can be influenced by the submerged plant, *Hydrilla verticillata*, that apparently provides added support for animals at the surface and encourages surface activity (Woodward and Moore 1993).

Other Variables.--Other variables, such as salinity (Messel and Vorlicek 1986), air and water temperature differentials (Hutton and Woolhouse 1989), and waves (Woodward and Marion 1978), may influence counts and should be accounted for if suspected as influencing counts.

ANALYSIS

Assumptions

Sampling.--To make unqualified inferences from statistical test results, the sampling scheme should be random and representative of the population on which inferences are to be made (see DESIGN).

Size Estimation.--When evaluating trends of specific size classes, unknown-size alligators must be distributed into size classes (unless the proportion and size distribution of unknowns is constant over years). This requires a systematic approach to allocation of unknowns into broad size classes. Allocating unknowns based on the known-size distribution was used for evaluating Florida alligator population trends (Woodward and Moore 1993), but this had some shortcomings. For instance, most unknowns were observed in habitat that was used by all size classes. Because wariness tends to increase with size in crocodilians (Webb and Messel 1979; A. R. Woodward et al., Final Alligator Rep., Fla. Game and Fresh Water Fish Comm., Tallahassee, 1992), it is likely that unknowns were disproportionately allocated into smaller size classes. However, if the same methodology is applied every year, inferences about trends would be minimally affected. Despite its weakness, we consider this approach to be superior to ignoring unknowns in analyses of different size classes or choosing not to analyze by size class.

Changes over years in observers and changes in observer skill of judging size can influence the size distribution of counts. Requiring observers to catch and measure several alligators after making size judgements will help calibrate their estimates (accuracy), increase precision, and minimize long-term biases. Woodward and Moore (1993) found that the biggest apparent problem was inconsistency among observers in placing deep water observations of alligator eye reflections into size classes. Larger, warier alligators tended to submerge before allowing observers to approach close enough to obtain a confident size estimate. However, certain characteristics, such as habitat type, water depth, water swirls, mud trails, wakes, and, occasionally, intensity of the eye reflection, can provide valuable clues to the size of an alligator. To minimize proportional allocation of unknowns, personnel were instructed to assign general size categories to eye reflections at the most precise level allowed by such qualitative information.

Assumptions of Trend Analysis.--Harris (1986) listed 4 important assumptions that need to be met when conducting trend analysis: (1) the population increases or decreases exponentially (the proportional change in population size is constant); (2) counts are lognormally distributed; (3) counts are independent; and (4) the mean percentage of the population counted is constant at all population levels. Closely related to assumption 4 is the general assumption that: (5) a constant proportion of the population is observed over time or that factors affecting this proportion can be isolated. Violation of any of these assumptions can lead to bias in trend estimates, erroneous conclusions concerning significance of trends, or both. The following is an assessment of the consequences of failing to meet these assumptions for determining trends on individual areas:

(1) Exponential population growth.--Exponential growth (positive or negative) is a suitable growth form for many animal populations that are well below carrying capacity. Most animal populations tend to increase or decrease in a multiplicative rather than additive fashion (Eberhardt 1978). The model will never predict a population size below zero, as can be the case with linear growth. Conversely, linear growth is appropriate for populations observed over short periods of time relative to the life span of the animal. Unfortunately, neither growth form is suitable for populations observed near carrying capacity as both models can predict sustained population growth above that level. Woodward and Moore (1993) saw no clear advantage in one growth form over the other for alligator count data. Therefore, the exponential model was ultimately chosen. As populations are monitored longer, more counts are collected, and count variability is decreased, either model may become unsatisfactory for describing alligator population growth in lieu of more complex finite-growth models.

(2) Lognormal distribution.--The assumption of a lognormal distribution of errors goes hand-in-hand with the assumption of exponential growth. Under this assumption, errors due to unobservable effects multiply, rather than add together. Woodward and Moore (1993) found no consistent tendency for errors of log-transformed counts to increase in magnitude with either time or density, so, they assumed lognormally distributed errors. As before, with more data, this assumption may prove untenable.

(3) Independence of counts.--Regression analysis requires that each observation error or, in this case, count error, be independent. In crocodilian populations a random "mixing" of the population between counts generally would insure this condition. Insufficient mixing of the population increases the chances that variation among counts under similar conditions will be less than the overall variance for the population monitored over a variety of conditions. This phenomenon could introduce downward bias in variance estimates of growth parameters and lead to too-frequent conclusions of trend (increase in Type I error). Insufficient mixing may be an important consideration, as adult crocodilians tend to be territorial, and juveniles of some species remain in the vicinity of their nest site for several years. Movements may only occur during major environmental or seasonal changes, during breeding season, when certain sizes are attained, or possibly when densities become excessive after water level changes. Woodward and Moore (1993) postulated that a long interval between counts or a substantial water level change over a short time interval could induce mixing of alligator populations. Their findings indicate that under stable water levels, the minimum period to achieve independence was 40 days. However, such an interval between surveys may overlap seasonal movements that alter the sighting proportion. For alligators, the resulting time interval to achieve independence would be 1-40 days,

depending on water level changes (Woodward and Moore 1993).

(4) Equal sightability at different population densities.--When counts are used as an index of population abundance, unequal sightability of animals available for counting at varying population densities can bias the trend estimate in either direction (Harris 1986). As population densities of some species change, so does their probability of detection, presumably because population pressures elicit changes in efficiency of detection relative to habitat use (Bart and Schoultz 1984, Harris 1986). This phenomenon may occur with crocodilians but would be very difficult to measure. Therefore, investigators may have to assume equal sightability under varying population levels in the absence of contrary evidence.

(5) Constant Proportion Observed.--The probability of detecting an animal on a survey route is a function of: (1) the ability of the observer to detect it; and (2) the position of the animal in the survey area. As mentioned earlier, standardizing observer skill levels over years can reduce observer variation. Variation in detection rates caused by vegetational changes can be isolated by including that variable as an independent variable in regression analyses. Accounting for water level changes can explain some of this variation in availability (Fig. 1) and scheduling annual surveys during the same season can minimize behavior-related distributional differences.

Transformation of Count Data

Count data rarely conform to the normal distribution and usually must be transformed for use in parametric statistics. Applying the natural logarithim ($\log_n$) to count data usually yields values with a stable variance (Eberhardt 1978).

Hypothesis Testing

Hypothesis.--Trend analysis is usually concerned with determining the direction and rate (slope) of population changes. Therefore, we are interested in testing the null hypothesis of no change in the population.

Power.--The power or sensitivity of the test and declaration of significance are important considerations in trend analysis (Eberhardt 1978, Gerrodette 1987). Few observations and high variation reduce the ability to detection of trends. Conventionally, Type I error (declaring a difference, or trend, when one does not occur) is considered less desirable than Type II error (declaring no trend when one occurred). In monitoring wildlife populations, the opposite is usually true, especially when management influences potentially decrease the population (Eberhardt 1978). In the case of crocodilian population trends, a 1-sided test, or relaxing the alpha level to $P = 0.1 - 0.2$ (or higher in cases where detecting declines are most critical) for declaring significance in a 2-sided test, will increase power for enhanced detections of population declines in exchange for a greater possibility of mistaken declaration of declines.

Tests for Individual Areas.--Because we are interested in determining rates of increase, count data are best analyzed with regression techniques. By using linear regression of $\log_n$-transformed counts, we would model population growth exponentially. Variables such as water level, vegetation changes, temperatures, and other factors that affect detection rates or availability can be included in the overall model as covariates to isolate their effects. Regression analysis of the model:

$$\log_n(\text{COUNT}) = \text{YEAR COVARIATES} \ldots \text{ERROR}$$

will yield the rate (regression coefficient) and the direction (+ or -) of change, and the test statistic will provide a probability level for rejecting the null hypothesis.

Tests for Multiple Areas.--If the objective is to make inferences about regional population trends from a sample of areas, then further analyses may be conducted on the covariate-adjusted trend estimates (slopes). Either one-sample or multi-sample tests may be performed to test the slope mean(s) for equality to 0 or for homogeneity. For example, the effects of habitat type, density signature (Webb et al. 1990), or other variables may be examined by ANOVA. For slopes that do not meet normal distribution criteria, a non-parametric test may be appropriate (Woodward and Moore 1993). If sampled areas differ with respect to size and population densities, weighting of estimated slopes by these factors prior to analysis may be appropriate (Collins 1990, Geissler and Sauer 1990).

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SECOND REGIONAL MEETING OF THE CROCODILE SPECIALIST GROUP
WORKSHOP ON ASIAN PRIORITIES
Conservation of crocodilians in Eastern Asia, Oceania and Australasia.

17 March 1993
Workshop summary.

James Perran Ross
Executive Officer CSG

Chairman- Dr. Parntep Ratanakorn
Workshop coordinator- Dr. James Perran Ross

The workshop was presented as a hands on working session that collected and collated recent information and presented a short list of gaps in our information and priorities for action. This task was accomplished by small working groups set up to discuss each species in the region. Individual comments and information was recorded on an "Input sheet" and the working group conclusions summarised on a fact sheet and presented for dicussion. The Input sheets, fact sheet summaries and individual working group reports appear below.

Workshop goals.

1) Identify needs, gaps and priorities for crocodilian conservation.

2) Promote regional coordination.

Schedule

8.30 am	Introduction P. Ratanakorn Work shop goals G. Webb Workshop structure P. Ross.
8.45	Break up into species working groups for discussion.
10.45	Re-convene for presentation of needs and priorities by working group leaders.
10.50	C. siamensis [P. Ratanakorn, Chea Peng Cnheang]
11.00	C. mindorensis [G. Ortega, F.W. King]
11.10	Tomistoma [A.Sebastian, Y.Raharajo]
11.20	C. sinensis [Jinzhong Fu, A. Woodward]
11.30	C. novaeguineaea [J.Genolagani, B. Vernon,W. Ramono]
11.40	C. porosus [C.Manolis, G. Miller]
11.50	C. johnsoni [H. Cooper-Preston, A. Tucker]

From the individual working group summaries presented the following general points were extracted.

Three of the seven species occurring in the region are seriously depleted in the wild (C. mindorensis, C. siamensis and Alligator sinensis). However each of these has substantial breeding populations in captivity.

Three species (C. porosus, C. novaeguineae and C. johnsoni) remain widely distributed and abundant in the wild although they may be subject to local depletion in some areas, (for example C. porosus in the Philippines).

One species (Tomistoma) is insufficiently known to judge its status although there are indications that it has specialised habitat requirements and occurs naturally in low densities.

It is of significance that no species in the region is currently endangered by trade, although, again, in some areas local depletion has been caused, usually by harvest for illegal trade.

In contrast the working groups for every species cited habitat loss and habitat degradation as a major problem for the future survival of every species. Examples were cited of draining of wetlands in Thailand for agriculture, road building causing erosion and siltation of habitat in Palau, gold mining degrading habitat in PNG, extensive settlement and clearing for agriculture in the Philippines, China and Indonesia, introduction of exotic species of fish and aquatic plants in PNG, overfishing (depleting Tomistoma food resources) in Malaysia and increased net fishing throughout the region.. The recognition of the severity and widespread effect of habitat degradation on crocodilians is an important result of the workshop.

Some common themes emerge upon inspection of the gaps in information, critical needs and priorities cites in the working group reports. All groups agreed that the distribution and natural variation of most species in the region remains insufficiently known.

The need for quantitative survey work to identify distribution and status of crocodiles in the wild was cited as a priority or an urgent need for every species. In the case of greatly depleted species that are being maintained in captivity we need to identify and protect any remaining relict populations. These are a valuable repository of genetic variability and their presence identifies suitable habitat that may be available for re-stocking in the future. For the more abundant species, particularly those in trade, the need is for continued monitoring of populations to assure that harvest and management actions are not detrimental to these species.
We are not confident that we are correctly assigning the crocodiles in this region into species or where those species are distributed. Increased work on distribution, morphology, and genetics was cited as a priority for C. porosus, C. novaeguineae, C. siamensis and C. mindorensis.

Several species require coordinated action between adjacent countries to ensure their survival. Examples are C. novaeguineae (Indonesia and PNG), Tomistoma (Indonesia and Malaysia) and C. siamensis (Thailand, Cambodia, Vietnam and Indonesia). The key position of Indonesia for many species draws attention to the importance of developing functional management and conservation systems for crocodilians in that country. The actions required are in many cases issues of legislation, regulation, and implementation of compatible management regimes across borders.

For those species currently in trade, the control of illegal trade and the promotion of the legal sources of these animals from sustainable use programs is an important need.

The working group reports draw attention to the widespread need for education of the public and of government officials about the value of crocodilians and the advantages of conserving them, particularly for sustainable use. Widespread prejudice against crocodiles is encountered throughout the region and there is an urgent need to provide incentives to offset the perception that crocodiles are vermin.

The working group reports contain many more specific recommendations for goals and priorities for each species. These comments have been recorded and collected and will be used for the revision of the Action Plan for Crocodiles. The working groups identified a current group of individuals and organizations with information concerning each species and a new list of species and country "CSG contacts" is being prepared for the Action Plan.

GUIDELINES ON MONITORING CROCODILIAN POPULATIONS

Drafted by Workshop D: Monitoring - How Do We Implement Practical Programs: Prof. F. Wayne King, chairman, Dr. J. Hutton, Charlie Manolis, Jeff Miller, Dr. Dietrich Jelden, Keiran McNamara, Dr. Miguel Rodriguez, Dr. J.P. Ross, Keith Saalfeld, Lic. Alvaro Velasco, Dr. G.J.W. Webb, Allen Woodward.

Many wild crocodilian populations are being conserved through sustainable utilization. To ensure that no more of the animals or their eggs are being harvested than will be replaced by population's normal reproductive rate, the population must be monitored (repeatedly censused) in a manner that will reveal whether or not the population remains stable, is increasing or decreasing. To facilitate this, the Crocodile Specialist Group offers the following guidelines for monitoring crocodilian populations.

Monitoring is a long-term effort. It does little good to monitor the status of a population for a year or two only to later abandon the program while the harvest continues. It is only possible to manage a sustainable utilization program for wildlife if data are available on the reproductive rate or alternatively on the stability of the population. The longer the monitoring program runs the more useful the data are in indicating population trends.

Crocodilian populations can be monitored by several direct and indirect methods: 1) by directly counting the animals sighted in all populations; 2) by counting the animals sighted in a selected portion of the population; 3) by recording the number of nests as a measure of reproductive effort; or 4) by recording the numbers of animals harvested from the population each season. The advantages and disadvantages associated with each of these methods are discussed below. Other standard wildlife techniques, such as mark and recapture studies, can be applied to restricted populations. Before the actual monitoring program gets underway, it is essential to decide specifically what management information is required and then to design a monitoring program that will supply that information. It may be useful to quickly explore a relatively large portion of the available habitat and to use the results of that first reconnaissance to select a few specific sites for long-term monitoring.

Details of the frequency of surveys, speed and distance surveyed, must be appropriate to each country and situation. Key variables dictating these factors are the size, complexity, and accessability of habitats; the density of the crocodilian populations; the rate at which population numbers might be changing; and the degree of precision required of surveys to detect these changes. Expert advice from experienced crocodile surveyors should be sought at the planning stage of monitoring programs.

Several types of direct surveys can be conducted. Two of the most frequently used direct survey methods are 1) night-time spotlight surveys on the waterway and 2) aerial surveys. There are many biases associated with spotlight counts. For example, crocodilians in hunted populations become wary and submerge when approached. Therefore, spotlight surveys should be conducted using powerful halogen spotlights of 200,000 candlepower or more which can spot animals at a distance, rather than weak 2- or 3-cell flashlight torches which require an approach closer than a shy animal will allow. Refer to the publications listed at the end of this article for detailed discussions of survey methods.

Monitoring all the populations. While it might seem desirable to survey all the crocodilians in a country, it rarely is possible and certainly is not necessary to do so. For example, to survey a large portion of the *Crocodylus porosus* habitat in Australia's tidal waterways at least once took more than 10 years and cost millions of dollars, and Australia lacks the vast wetlands characteristic of Bolivia, Brazil, Colombia, Indonesia, Nicaragua, USA, or Venezuela. If only one or two populations are being exploited, then monitoring those populations with controls (one or two unexploited populations for comparison), may be all that is needed.

Monitoring a selected portion of the population. Often it is possible to use satellite photographs, aerial photographs, recent 1:25,000 or 1:10,000 scale topographic maps, or aerial surveys from helicopter or fixed-wing aircraft to distinguish between areas of habitat that have been lost to urbanization, agricultural development, boat traffic, pollution or other causes, and those which are most likely to contain crocodilians. Interviews with hunters and fishermen also can yield information on the location of abundant and depleted populations. This information allows the monitoring efforts to be localized in selected areas. The selected areas should contain both harvested and non-harvested populations so the effect of harvesting can be demonstrated. At the same time this information may help clarify other, non-harvest, factors that impact the population.

Survey routes frequently are along rivers and shorelines, but can be straight-line transects across marshes or wetlands.While the area surveyed will depend on the amount of habitat available, the length of the rivers, and the size of estuaries, lagoons, lakes and wetlands, the smaller the area surveyed, the less likely the results will be representative of the whole population. For example, on a long waterway, it would be better to survey 30 or more kilometers than to survey only 2 kilometers. Ideally, between 2.5% and 10% of the suitable habitat should be included in the initial survey.

Monitoring nests as a measure of population abundance. Counting the number of nests produced each year gives an index of the reproductively active segment of the population. This is easily accomplished in crocodilian ranching programs in which eggs are collected from the wild to stock commercial farms. In some selected areas, there should be an attempt to count all the available nests. At the time of collection, the total number of nests should be recorded, and in a random sample of nests, the number of eggs in each clutch and the egg dimensions and weight should be recorded. A decrease in the number of nests found may indicate a decline in the number of nesting females, and since young females of some crocodilian species lay smaller clutches and smaller eggs, a change in the number of eggs or egg size might reveal a change in the age of the nesting females.

It also is possible to estimate the number of adult males and females in the population by correlating nest counts with data from direct counts of the number of animals in a population.

Monitoring the numbers of animals harvested from the population each season. It is possible to use data on the number of crocodilians harvested (the number of skins traded) as a measure of the status of the wild population. However, this can only be accomplished when the data provide an estimate of hunting effort which might include: 1) the numbers of hunters, 2) number of hunting days, 3) the area hunted (reasonably specific localities, not a country-wide pooling of data), 4) the number and 5) size of the animals harvested. The latter data can be obtained from the hides traded. Some information may be collected from hunter and buyer interviews, but information from such sources can be biased and must be treated with care. A shift in the size of the animals killed may reflect a change in the population structure. A decline in the number of animals killed is hard to interpret in the short term. However, if the same number are killed each season or if there is an increase in the number killed, this may not indicate a stable or increasing population. The numbers may reflect increased hunting effort or an increased hunting area, hence the need for information on the number of hunters, hunting days, and hunting area. In addition, any program which ultimately depends on harvest data to monitor population trends also should, on at least a small sample of the population, use spotlight counts, nest counts, or some other direct method of monitoring to confirm inferences from the trade data.

Regardless of the method used, survey or monitoring programs are acceptable only if they can be repeated by other independent researchers. Surveys that cannot be repeated are not scientific. To be repeatable, each survey must include the following minimal data:

- Exact start point (preferably recorded as latitude and longitude degrees, minutes and seconds).
- Exact end point (preferably recorded as latitude and longitude degrees, minutes and seconds).
- The distance and route surveyed between the start and end points.
- Date and time of survey.
- Season, if appropriate (wet or dry).
- The number of crocodilians sighted.
- Water level or tide level.
- Water temperature and air temperature.
- Wind strength.

In addition to the above minimal data, there are additional data sets which are desirable:

- Size classes of the crocodilians sighted, recorded in standard units of measure (feet or half meters)
- Location along the survey route of each crocodilian sighted.

Global Positioning System (GPS) instrumentation is useful in accurately determining latitude and longitude of start and end points. Spotters should be well trained and, to avoid introducing unwanted variability, whenever possible, the survey should be conducted using same spotters and at the same time of year and same water level.

Night-time spotlight survey techniques are described in detail in:

Bayliss, P. 1987. Survey methods and monitoring within crocodile management programmes. pp.157-175. *In:* G.J.W. Webb, S.C. Manolis, and P.J. Whitehead (eds.). Wildlife Management: Crocodiles and Alligators. Surrey Beatty & Sons,Ltd., Chipping Norton, Australia.

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CSG WORKSHOP - INCORPORATING "CONSERVATION VALUE INTO THE MARKETING OF CROCODILIAN PRODUCTS"

(Chairman: Grahame Webb)

The term "Status" is a good one for examining the crocodile industry. Status is a relative measure-the performance of something at one point in time relative to that at another. There are two levels of resolution at which the status of the crocodile industry can be examined - Short and Long term.

1. Short Term Status

   This period encompasses the last few years which has seen a peak and then a sharp decline in skin prices, as supply outstripped demand - the total supply appears to be around 1 million skins per year and the demand is clearly less than the supply.

2. Long Term Status

   This period compares the present situation (1 million skins) to that which existed at the peak of the industry in the late 1950's and early 1960's (5 to 8 million skins).

Most of the discussions about marketing which have taken place at the last three CSG meetings have been directed at changing the short-term status - increasing the immediate demand relative to hat last year, so that it can match current supply.

The central question that this workshop addressed was whether "Conservation Value" could be used as an effective marketing tool at both levels of resolution. This possibility stems from a number of observations:

1. There is a high possibility that the dramatic change in the long-term status of the market is due to the general trend away from using wildlife products—the concept that conservation is about not killing and using wildlife.
2. Most retail outlets have little if any information about the conservation benefits of trade, yet conservation through sustainable use is now widely accepted as a valid approach to conservation.
3. The magnitude of the long—term market decline is of such a magnitude that even minor changes in the short—term status, may not impact upon it significantly.
4. That 100's of millions of dollars are being spent each year by people trying to help conservation, often with no tangible return for their expenditure. If that contribution could be made through the purchase of products—"help conservation-buy a crocodile skin handbag" the long-term dramatic decline may be able to be addressed.

DISCUSSION

The discussion focused mainly on the short term status problem rather than the long term decline.

THE CSG POSITION

Marketing problems are fundamentally an industry responsibility and it is up to the industry to address them.

The CSG could, and has promoted forums to discuss the issue and has offered its expertise to the industry. However, as a conservation organisation it cannot take the initiative this must come form the industry, as discussed and resolved by the CSG resolution passed at the Victoria Falls meeting.

The whole concept of conservation through sustainable use is one the CSG promotes. If it could be used effectively in marketing, which is up to the industry to determine, it would be consistent with CSG goals.

EDUCATION

There is a lack of information flowing through to the community on conservation through sustainable use. It was suggested that at the very least the CSG should prepare critical facts about sustainable use, that CSG members in the industry could distribute.

MARKETING

Professional marketing expertise was widely recognised as being essential to correcting the short term status problems and perhaps the long term ones.

On behalf of the CSG, Brian Vernon offered to undertake a preliminary survey of the opinions of people in the industry. His proposal is to send a questionnaire to all the tanneries and ask then to have it completed by at least 8 people who distribute crocodile finisbed products or own retail stores that sell crocodile products. The data collected would be presented at the next CSG meeting at Pattaya. This could then be followed by a retail survey conducted by market researchers to establish if out customers at the store level are basing their buying decisions on the factors that the industry survey suggests.

SIMPLE MESSAGE

There was a need for a simple message, for example:

> "Help Crocodile Conservation - Buy a crocodile skin handbag" or
> "It' Legal!" (most people think it is illegal to buy crocodile products).

EXPENSE

Some participants though that the cost of crocodile skin products was a significant factor constraining the market.

PANEL DISCUSSION ON CROCODILIAN SKIN TRADE AND ECONOMICS

A panel discussion on crocodilian trade and economics was convened following presentations by Wayne King, Debbie Callister, and Allan Woodward. Panel members were selected to provide a diverse group of trade interests from major producing programs and traders. The panel included chairman, Vic Onions (Farmer - Australia), Yoichi Takehara (Tanner/Trader - Japan), Frank Garcia (Farmer - Colombia), Brian Vernon (Farmer - Papua New Guinea), Wayne King (Trade Specialist - U.S.A.), Dietrich Jelden (CITES Scientific Authority - Germany), Ruth Elsey (Louisiana Program Rep. - U.S.A.), and Allan Woodward (Florida Program Rep. - U.S.A.).

Graham Webb (International Consultant - Australia) posed a question to the panel regarding how marketing strategies should approach the problem of negative consumer perceptions about wildlife use. King replied that marketing tactics should provide positive information about the use of wildlife products. Elsey noted that anti-use sentiment was prevalent in Louisiana and added that the Louisiana Fur and Alligator Advisory Council has identified consumer resistance to alligator products as a major problem and is taking steps to promote the conservation incentives of the use of alligator products. Vernon emphasized that more market research is needed to look at buyer attitudes toward using crocodilian products and added that we should seck outside professional marketing specialists to assess the situation. King concurred with Vernon and stated that promotional efforts directed at the industry (tanners, traders, manufacturers, and retailers) were not as important as promotions to customers such as educational programs, product labeling, and image enhancement.

A member of the audience inquired as to whether anti-wildlife use groups were invited to the conference. Webb replied that no specific effort was made to invite any group but that this conference was well advertised through the I.U.C.N. which should have given any concerned groups ample opportunity to attend.

Webb raised a question regarding the apparent large margin between the price of raw skins and finished crocodilian products. No explicit answers were given by the panel.

Jelden indicated that the single worst influence on the image of crocodilian products in Europe is illegal caiman trade. He noted that consumers cannot be sure of the source of products they wish to buy and noted that this was especially true of small products such as watch straps.

Takehara reported that the green movement was not as serious in Japan as perceived in other parts of the world, but that image improvement was certainly needed in Europe and the U.S.A. He noted that control of crocodilian skin supply will be more difficult now than it was in the early-1980s. He indicated the need in Japan to expand the use of crocodilian leather to other products such as shoes. He stated that in recent years, 70-80% of crocodilian leather in Japan is sold as ladies hand bags. Traditionally, crocodilian leather shoes have not been popular in Japan, but changing customs may create an opportunity for shoe sales. He emphasized the need to have stable supplies of skins. Regarding demand, Takehara stated that during the mid-1980s 20,000 skins a year were needed to supply watch strap sales but that a 30% increase in raw skin prices during the late-1980s depressed demand. He added that until the end of 1991, demand for crocodilian products was only moderately reduced. Then, in late 1992 a drastic reduction was observed.

Jaques Berney (Dep. Secretary General - CITES) asserted that to increase the image of crocodilian products, legal producers in countries still implicated in illegal caiman trade need to denounce illegal trade and make every effort to ensure that all trade in their respective countries is legal.

Vernon commented on the problem of keeping track of caiman skins after they have been cut into pieces, noting that finishing skins in the country of origin and tagging them prior to export might be a solution.

Gerardo Ortega (Croc. Farming Inst. - Philippines) stressed that there is a need to identify regional differences and weaknesses in markets and the need to address problems specific to those areas.

Keith Cooke (Trader - Australia) questioned the panel regarding the effects of tanners of second grade skins on tanners of first-grade skins. Takehara replied that this is the first time that such a distinct division has occurred but that there is good potential in the U.S.A. because of the large supply of and potential market for second grade skins. He added that he didn't see much future in developing second grade skin tanneries in other countries such as Zimbabwe and Australia because of the limited availability of second grade skins and the high overhead costs of operating tanneries. He indicated that his firm, for example, performed contract tanning for second-grade skins.

Onions reasserted the need for more market research. King suggested the possibility of wider use of futures contracts to stabilize raw skin prices. He also related that vertical integration was a possible method for increasing profits at the producer level, but warned that this could be done from the top down (traders, tanners, and manufacturers owning producers) as well as from the bottom up (producers owning tanneries and manufacturers).

John Lever (Farmer - Australia) posed the perceived problem of too many middle-men in the industry. Takehara indicated that the tanning industry attempts to maintain a 17% [profit] margin. However, it requires a 100% mark-up at all levels from the tanner to the manufacturer to maintain that margin because of inventory costs, etc. He further stated that there was little chance of the industry changing this practice. He stressed that "middle-men" perform an important function in delivering products to customers and that elimination of them would result in a shrinkage of the market. Vernon commented that, over time, market forces will adjust margins that are out of line.

Alvaro Velasco (Program rep. - Venezuela) commented that the price of products should be related to their economic values. He emphasized that other non-commercial values of crocodilians should be considered.

Val Hristov (Economist - Australia) questioned Woodward regarding the supply and demand analysis curves that he had presented in his talk and wondered how they were constructed. Woodward replied that they were hypothetical curves based on known supplies, unknown demand, and the limited amount of price data available for raw skins. He added that they were presented to show general relationships and changes in supply and demand during the past 6 years.

Takehara related that he had been in the business for 30 years and over that time he observed that demand for products increases when people expect a better life.

R. J. Rao (Croc. Research - India) explained that it took a very long time to convince people in India not to kill crocodilians and that now he expects it will take a lengthy period for them to accept sustained-use. He stated his concern that if India begins skin production, will there be a market?

Webb expressed his concern that CITES unduly restricts trade, especially with regard to finished products and suggested that the CSG draft a resolution to request CITES to make it easier for international purchasing of products. Berney replied that it was not CITES that restricted trade but parties to the Convention (individual countries) that were imposing strict regulations on trade and, therefore, unduly restricting commerce. Hank Jenkins (CITES rep. - Australia) suggested the widespread use of short permits similar to those used by Zimbabwe to expedite trade in products. Jelden confirmed that in many countries, the export/import permitting of a single item is treated similar to a big shipment which discourages trade in small quantities.

The trade panel discussion was concluded at this point to maintain the meeting agenda. Several more questions from the audience were pending, indicating a keen interest in further discussions on crocodilian trade and economics. -- *Allan Woodward - Florida Game and Fresh Water Fish Commission*