CSG SRAS Report

On-farm Investigation into Potential Uses of Shade Balls in the Commercial Raising of Hatchling Saltwater Crocodiles (*Crocodylus porosus*)

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1. Executive Summary

1. This report presents the results of on-farm trials involving 401 new-born saltwater crocodile (*Crocodylus porosus*) hatchlings, from known clutches, hatched at the same time (24-25 February 2020), and raised in two consecutive trials until 83 days of age (18 May 2020).

2. The 4 pens used were unconventional. They contained a deep 21 kl refuge pond subject to ambient temperature, a 1 kl heating channel with thermostatically controlled temperature, and a separate land feeding area.

3. The primary goal of the first trial was to determine whether floating "Shade Balls" (black HDPE 100 mm diameter spheres), with the potential to restrict visual contact between hatchlings [implicated in agonistic behaviour (Brien *et al*. 2014a)], enhanced growth and survival rates and influenced rates of "runtism" (Isberg *et al*. 2009; Brien *et al*. 2014b).

4. The same mix of clutches was in each pen. In 2 pens the balls covered the surface of the refuge ponds with no gaps between, and in the other 2 pens there were no balls in the refuge ponds. A more spread out configuration of balls (each 100 mm apart) was tested in the heating channel of 2 pens, 1 pen with balls in the refuge area and 1 without.

5. The first trial lasted 34 days (27 February 2020 to 1 April 2020). The body weight (BWT) and snout-vent length (SVL) of hatchlings from the 2 pens without shade balls [mean BWT= 109.6 ± 28.1 g (SD); N= 198; range 56 to 194 g; mean SVL= 177.4 ± 12.0 mm; N= 198; range 148 to 211 mm)], were 13.6% (BWT, t-test $p<0.0001$) and 2.0% (SVL, $p= 0.004$) higher than in the pens with shade balls in the refuge areas [Mean BWT= 96.5 ± 26.0 g; N= 193; range 54 to 185 g; mean SVL= 173.9 ± 11.3; N= 193; range 149 to 207 mm]. The variances for neither BWT (F-test, $p= 0.28$) or SVL ($p= 0.42$) were significantly different.

6. With the balls within the heating channel, ho consistent difference in growth or survival could be demonstrated. This may reflect that most hatchlings spent most of the day in the refuge area, moving back and forth through the heating channel for feeding (remote camera observations).

7. The closely-packed shade balls in the refuge pond had significantly altered the thermal environment. During the day the black shade balls absorbed heat, with the upper surface reaching 65-75ºC by midday, and heat was radiated back into the air space, increasing ambient air temperatures by 5+ºC. The shade balls actually reduced surface water temperature (100 mm deep) by 1-2ºC. Heat transfer through the balls to the water surface was not sufficient to compensate for the lack of heat uptake caused by shading the water's surface.

8. Hatchlings from the first trial (N= 391) were mixed and subdivided on the basis of size and body condition for the second trial. Variation in these broad size categories had occurred in pens with (B) and without (NB) shade balls: Large (N= 118; 53%B, 47%NB), Medium (N= 180; 49%B, 51%NB), Small (N= 48; 42%B, 58%NB) and Very Small (N= 45; 49%B, 51%NB). Differences in growth clearly occurred between treatments, but by this age was relatively subtle.

9. The second trial was aimed at quantifying growth in Large and Medium animals, but more important, stimulating growth in the Small and Very Small hatchlings, thereby avoiding losses to runtism (Isberg *et al*. 2009; Brien *et al*. 2014b). The shade balls were removed from the refuge areas (but left in the heating channels), and hatchlings were raised in size-specific groups using the same 4 pens and 2 additional ones, using the same basic procedures. The trial commenced on the same day as the Inventory (1 April 2020) and lasted for 47 days (18 May 2020).

8. The majority of Small and Very Small animals did start feeding and growing (3 died; 3.2%), and by the termination of the second trial (18 May 2020) the mean increase in BWT relative to hatching was 159% and 154% respectively. When all surviving animals were returned to conventional farm raising pens (18 May 2020), only one additional mortality was reported after a further 5 months of raising.

9. Details of the feeding and management regime used to rehabilitate animals on a runt growth trajectory are provided, as are observations on their behaviour. Remote camera monitoring indicated "runt" animals were both highly aggressive, and highly active, spending hours "pacing" - patrolling the perimeter of the pen to escape.

10. "Runtism" is a phenomenon restricted to captive raising environments, with no evidence that it occurs in the wild (Brien *et al*. 2014b). It raises the obvious question as to what selective advantage could explain voluntary starvation?

11. It is proposed here that "runtism" is a consequence of hatchlings switching to "dispersal behaviour". That when the raising environment becomes inadequate for individuals, possibly for multiple reasons, selection favours dispersal, which occurs in wild hatchlings (Webb *et al*. 1977). As dispersal cannot be achieved in enclosed pens, it results in relentless pacing, the energetic cost of which exceeds the energy available in the amounts of food eaten during the feeding period.

12. In the shade ball trial, clutch effects were controlled across treatments, but significant clutch variation occurred within treatments. The known incubation history of each clutch was examined, and some clutches, from both wild and farm origins, were probably compromised by high nest temperatures prior to the eggs being collected and incubated at constant temperature. The relatively high constant temperature used for incubation (32.6ºC) could also have been problematic.

13. It was concluded that the new raising pens, without shade balls packed in the refuge area were effective in giving a normal distribution of hatchling sizes, and relatively high and acceptable mean growth rates. The configuration of shade balls tested (completely covering the refuge pond with shade balls), was not beneficial and constrained growth. In contrast, the configuration of shade balls used in the heating channels appeared to limit agonistic behaviour during the second trial, and perhaps contributed to the recovery of the Very Small animals. This arrangement in the refuge pond is likely to be more effective.

2. Acknowledgements

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3. Introduction

Pioneering efforts to farm crocodilians for commercial and conservation purposes, based on captive breeding (Youngprapakorn *et al*. 1971; Bustard 1971) and/or ranching (Hutton and Webb 1992), were confronted with many novel problems. Two fundamental ones were maximising the production of hatchlings from viable eggs, and maximising the survival and growth rates of hatchlings in the immediate post-hatching period (Hutton and Webb 1992; Manolis and Webb 2016).

The potential of hatchlings to grow and survive is a fundamental measure of their "fitness" for farming purposes, and largely dictates the biological and economic viability of farming (Hutton and Webb 1992; Manolis and Webb 2016). With saltwater crocodiles (*Crocodylus porosus*), clutch effects are strongly implicated in explaining variation in individual growth rates within all trials manipulating raising variables (eg Webb *et al*. 1990, 1992, 1994; Manolis and Webb 1988; Manolis *et al*. 1989). But over and above genetic variability (Isberg *et al*. 2006), variation is also introduced by the incubation environment to which eggs are exposed (Webb and Cooper-Preston 1989). Different crocodilian species, incubated and raised in identical environments, show profound differences in growth and survival rates (Webb *et al*. 1994), to which global farming technologies have evolved in different ways in different countries (Hutton and Webb 1992; Manolis and Webb 2016): there is no uniform model for raising hatchlings that fits all species.

Saltwater crocodile hatchlings are often reported as one of the more problematic species within commercial scale raising of hatchlings (Isberg *et al*. 2006, 2009; Brien *et al*. 2014b). The nesting season is prolonged (October to May), spanning both summer and winter (Webb *et al*. 1977, 1983). This species is also considered one of the most aggressive of extant crocodilians (Lang 1987a). In captive environments, agonistic behaviours are exhibited within days of hatching (Brien *et*

al. 2013a,b,c), more so in some raising environments than in others (Brien 2015). These behaviours create variable growth trajectories in individuals by three-weeks (Brien *et al*. 2014b), and unless the raising environment is rectified, increased numbers of individuals fail to thrive, become "runts", and die prematurely (Isberg *et al*. 2009; Brien *et al*. 2014b).

Brien et al. (2013a) found agonistic behaviour occurred mainly in the water, at or after feeding, and later found (Brien *et al.* 2014a) that if the water's surface was subdivided with visual barriers, agonistic behaviours were largely curtailed, although no significant increase in growth rates was reported. Brien (2015) also found the standard pen design he was using, which left hatchlings exposed out of water during daily cleaning, did not give equivalent growth to a more naturalised pen in which hatchlings had constant refuge and cleaning did not leave them exposed out of water.

The raising trials reported here extend Brien's (2015) findings by:

1. Testing a new type of pen in which hatchlings had access to two separate water bodies, a smaller one (1 kl of water) for heating and feeding, drained and cleaned daily, and a larger, refuge pond (21 kl of water), in which hatchlings had security, which was not drained and cleaned daily. This arrangement provided a variable rather than constant thermal environment, that could be better suited to the thermoregulatory needs of hatchlings (Lang 1987b; Brien *et al*. 2012).

2. Simultaneously, we testing a novel product - 100 mm diameter floating "shade balls" - as a potentially cost-effective method for reducing visual contact between hatchlings. Basic data on the thermal dynamics of floating shade balls were collected, and two configurations of them were tested:

    a. Completely covering the refuge area water surface, with the balls in contact with each other; and,

    b. The balls separated from each other by 100 mm (restricted to the heating channel), blocking visual exposure to some degree but not constraining movement on the surface.

3. Together, we were testing the combined effects on hatchling growth, of a new enclosure with minimised disturbance and a potentially new method of minimising visual contact between individuals.

4. The trial (first trial) was terminated after 34 days when it appeared growth of some individuals was being compromised.

5. Hatchlings were mixed and graded according to body weight and body condition, and raised (without shade balls in the refuge pond) for a further 46 days.

6. During this second trial, particular attention was given to stimulating feeding and growth in hatchlings that were failing to thrive in the first trial, and heading towards runtism.

7. Clutch-specific influences on growth, and the possible role of the incubation environment in explaining clutch effects, were investigated.

Following the final trial, all animals were returned to a commercial raising farm, where they were housed separately and their progress checked after a further 5 months.

4. Methods

4.1. Pens

Four near identical pens (A1-A4; 9 x 4å m; Fig. 1) were located within a compound covered by netting to prevent access by birds (Fig. 2). Pens were made of concrete, with a rectangular refuge pond (9 m x 2.0 m by 1.0-1.3 m deep; 21 kl of water), lined with 1.5 mm thick high-density polyethylene (HDPE) film. A floating, basking platform (Fig. 2), made from PVC pipe (100 and 50 mm) and covered with shade cloth, was anchored 200 mm from the wall in each refuge pond. The edge of the refuge pond from the heating channel contained a strip of HDPE mesh (1 cm squares) along its length, extending into the water (10-15 cm), to assist hatchlings to climb out of the refuge pond, to access the heating channel and feeding area.

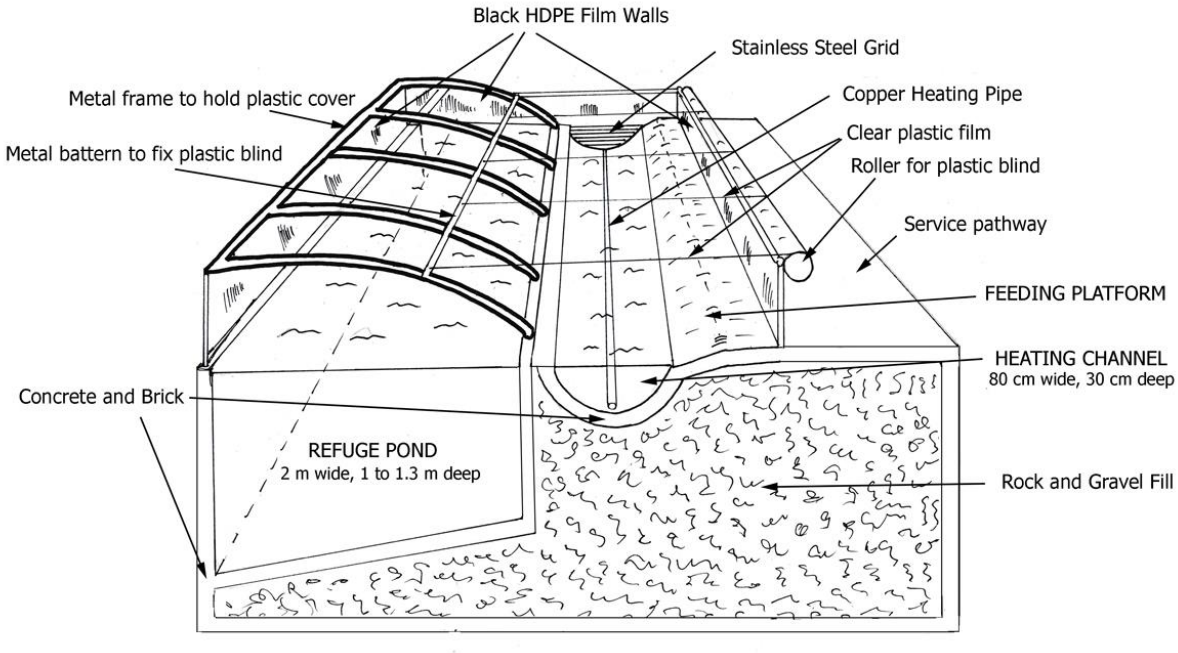


Figure 1. Schematic design of the hatchling raising pen used for the trials

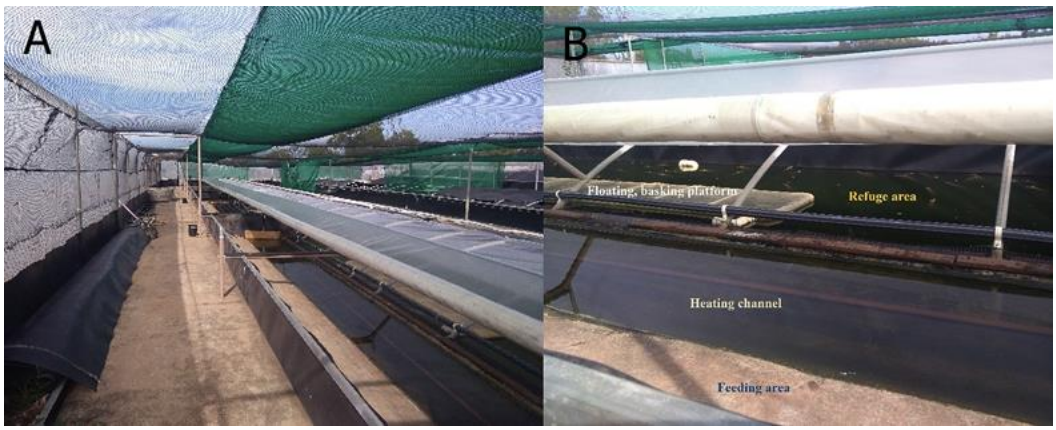


Figure 2. Service path and basic pen showing refuge, heating and feeding areas

The edge of the heating channel was 200 mm from the refuge pond. The curved concrete channel was 0.8 m wide, and sloped along its length from 20 cm deep in Pen A4 to 40 cm deep in Pen A1, where the channel was drained. Pens were separated from each other by a wall of HDPE film, with a grid, made from 10 mm stainless steel rod, separating the continuous water in the heating channel at each pen boundary (Fig. 1). Grids could be lifted if needed for cleaning. A 30 mm diameter copper heating pipe ran the length of the heating channel (Fig. 3). It circulated hot water and was connected to a thermostatically controlled, gas heater, with the sensor (thermistor) in the heating channel at the junction of Pens A2 and A3.

The feeding platform, adjacent to the heating channel, was a gently sloped in two stages and 0.75 m wide (Fig. 1). The back and sides of each pen had HDPE walls (0.8 to 0.9 m high), on metal frames, to prevent hatchlings escaping (Fig. 1).

A metal frame over the refuge pond (Fig. 1) was covered with an attached clear plastic film (0.5 mm thick) over the top half of the refuge area. The same material was used to make a rollable blind, that could cover both the heating channel and feeding area, using a 150 mm polyethylene pipe as the roller (Fig. 4). It extended the length of all four pens. The water supply for the refuge and heating channel, and for general hosing and cleaning, was from a freshwater dam and/or bore, and was not treated.



Figure 3. Heating channel (70 cm wide; 20-40 cm deep) in relation to feeding area and refuge pond.



Figure 4. Plastic blind rolled back to the edge of the heating area (A) during the day, and rolled down over the heating and feeding areas (B) at night.

4.2. Shade Balls

Two pens (A2 and A4) had the complete water surface of the refuge pond (18 m^2) covered with shade balls, and the other two pens (A1 and A3) had the refuge areas uncovered (Figs. 5 and 6). The HDPE shade balls each weighed 40 g, and when floating, penetrated the water by 15-20 mm. This created hidden air spaces between adjoining shade balls, which could potentially provide breathing spaces with high levels of visual exclusion for hatchlings at the water's surface.

When the trial started, it became apparent that agonistic behaviour was occurring in the heating channel, next to the feeding area. After 2 weeks, it was decided to trial 3 rows of shade balls, on fishing line cables, separated by a 10 cm piece of irrigation plastic pipe (5 mm diameter), in the heating channel of two pens. There were thus 4 configurations (Fig. 5):

A.1 - open refuge, no shade balls in heating channel
A.2 - shade balls in both refuge and heating channel
A.3 - no shade balls in refuge but shade balls in heating channel
A.4 - shade balls in refuge, but none in heating channel.

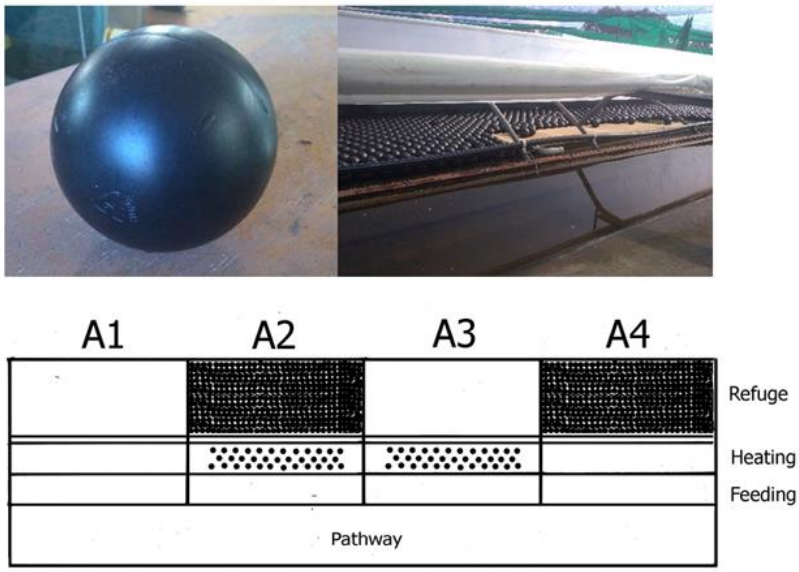


Figure 5. 100 mm diameter "shade ball" (A), shade balls tightly packed *in situ* in the refuge areas, except for the floating basking platform (B), and a diagrammatic representation (not to scale) of the distribution of shade balls in different pens (A1 to A4) for the first trial.

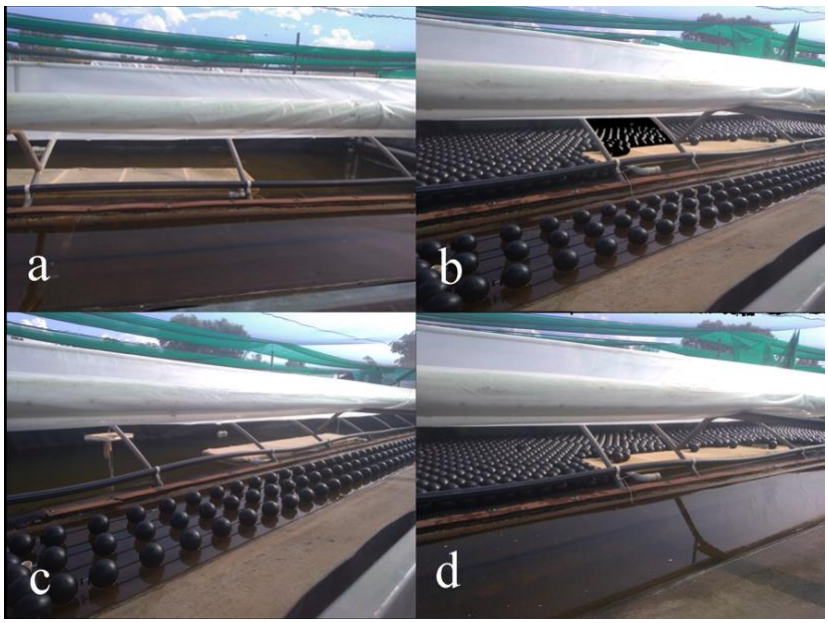


Figure 6. Pens A1 (a), A2 (b), A3 (c) and A4 (d) for the first trial.

4.3. Temperature and Water Management

The fundamental objective was to provide hatchlings with a mosaic of temperatures. It was anticipated that warm water areas (>32ºC) would be available in the heating channel, and cooler areas in the refuge areas (<32ºC), feeding area, floating basking platform, and along the edges of the refuge pond. The pen was exposed to diurnal temperature variation, and the plastic over the heating and feeding area was open during the day (0800-1700 h). As this was the first time shade balls had been tested, their temperature characteristics needed to be quantified.

a. Heating Channel

The water was changed daily (0800-0900 h). Food was provided daily on the feeding area (1630 to 1730 h), and hatchlings fed in the late afternoon and evening. Hatchlings would grasp food and retreat to the heating channel to manipulate and swallow it, but dropped reasonably large amounts in the water while doing so. Relatively few hatchlings took food from the heating channel back into the refuge pond, which was only

drained when an inventory took place. The heating channel, typically heated to over 32ºC with the sun, but a gas heater was available if required.

b. Refuge Area

The refuge area was not artificially heated. It gained heat from the sun and was protected from wind by the plastic cover. Evaporation was compensated for by a ball valve, and each few days 2-3 kl of water per pen (bore water) was placed in the bottom of the refuge area, so that surface waters would overflow. Increasing the flow of bore water (approximately 29-30ºC) was an option available for heating the refuge area should temperatures fall below 27ºC.

c. Temperature Monitoring - Long-term

General temperature cycling was monitored crudely with 16 data loggers (0.5ºC readability), calibrated against a certified thermometer, and recording temperatures each 1 hour. Temperature loggers in each pen monitored: 1. a shaded air temperature 40 cm above the refuge water level in each pen; 2. Surface-water temperature in the refuge pond (10 cm deep) of each pen; and 3. Deep-water temperature in the refuge pond of each pen (100 cm deep). The heating channel was monitored (10 cm deep) with a single logger at the junction of pens A.2 and A.3. Loggers were downloaded when convenient.

d. Temperature Monitoring - Short-term Spot Checks

On a daily basis, surface water temperatures in the refuge area (adjacent to the feeding platform) and in the heating channel, were both measured for each pen in the morning (0800-0900 h) and late afternoon (1630-1730 h) with an Infrared Thermometer Fluke (± 1°C). This was a basic check on what was happening with temperature, between downloads from the data loggers.

e. Shade Balls

Insights into the temperature relations of the shade balls were obtained from a temperature logger inserted into the top (exposed) and bottom (submerged) of a single shade ball. The monitored shade ball was locked in a vertical position by attachment to 3 other balls and this floating unit was placed in Pen A2 refuge area (with balls), 50 cm from the heating channel, and 2 m from the dividing wall with Pen A.3.

4.4. Hatchlings

Hatchlings (N= 401) were provided from the Darwin Croc Farm, and came from captive-laid and wild eggs collected in the ranching program (Saalfeld *et al.* 2016). Eggs came from 15 clutches (9 captive, 188 hatchlings; 6 wild, 213 hatchlings). All completed their incubation on open racks at 32.6 ± 0.2ºC (SE), in a 99% humidity environment (Manolis and Webb 1991), but were not necessarily collected on the day of laying. Depending on the age at collection, sex (which is temperature-dependent) was determined in the nest or in the incubator (Webb *et al*. 1987). All clutches hatched within 2 days (24-25 February 2020) and for the purposes of these trials, all are assumed to have hatched on 24 February 2020.

All hatchlings were processed in clutch-specific groups on 25 February 2020 and were given a unique number by clipping tail scutes (Richardson *et al*. 2002). Hatchling size is largely a function of egg size, superimposed upon which are effects of incubation temperature (Webb *et al*. 1987). The options for a given-sized egg range from a small hatchling with abundant yolk, or a large hatchling with little yolk (Webb *et al*. 1987). An indication of residual yolk was obtained by coding abdomen width: 1= very little, 2= normal, 3= slightly abundant, 4= abundant, and 5= excessive. Mid-point width of the yolk scar (to 0.5 mm; transparent plastic rule) was also measured (Smith and Webb 1987). If the residual yolk is very large, the hatchling is small and the yolk scar is relatively wide. This is a sign of embryo development problems, and is not "premature" hatching (Manolis and Webb 2016).

Each animal was inspected for any obvious structural anomalies, in particular whether the tail tip was complete, or spine was twisted, which effects comparative measures of SVL and/or TL (Webb and Cooper-Preston 1989). The main measure of hatchling size for assessing growth here was Body Weight (BWT, measured to the nearest g) with an electronic kitchen balance (Fig. 7a). Other measures were taken, but largely to allow internal checks, if one measure appeared anomalous: snout-vent length (SVL) was measured from the snout tip to the anterior of the cloaca, to the nearest mm, using a transparent plastic ruler held vertically (Fig. 7b); Head length (HL) was measured as the straight-line distance between the tip of the snout to the posterior of the cranial platform to the nearest mm, with a transparent plastic ruler (Fig. 7c); and, total length (TL) was measured from the snout tip to the tail tip on a horizontal metal tape to the nearest mm (Fig. 7d). All measurements were taken by the one person

(GW), as some length measures (SVL, TL) depend in part on the degree of stretch exerted by the measurer. Sex was determined initially by examination of the cliteropenis (Webb *et al.* 1984), with corrections made during later inventories when the same numbered hatchlings were larger and sexed again.



Figure 7. Measurements taken on hatchlings: from left; Bucket used for bodyweight (BWT); Snout-vent length (SVL; to front of cloaca); head length (HL); and, total length (TL).

The numbering system (Richardson *et al.* 2002) allocated single scutes on the posterior of the tail (100s) to assign clutch number, with scutes cut on the left (10s) and right sides (1s) for hatchling number (Fig. 8).

Hatchlings randomly selected from each clutch were distributed to each of the 4 pens, so that all four pens had the same mix of clutch-specific hatchlings, of the same age. All 401 hatchlings were released into their respective pens on 25 February 2020.



Figure 8. Scutes cut for hatchling number 12 from Clutch 7: actual scutes removed were 700, 5 and 7.

4.5. Trial: Assessing the Effects of "Shade Balls"

Efforts to initiate feeding were started two days after hatchlings were released into the pens (afternoon of 27 February 2020). They were offered diced wild pig meat, which appears to be a food widely accepted by different clutches of *C. porosus* hatchlings (Manolis *et al.* 1989; Webb *et al.* 1990). Diced meat is preferable to minced meat for initiating feeding (Webb *et al*. 2013), and it was cut (12 x 6 x 6 mm; 0.7 g) with a Trief 100-CE dicing machine. Dicalcium-phosphorous powder (DCP; 2% by weight) and a commercial vitamin-mineral premix (MV; "Monsoon Crocodile": Cu, Se and salt; 2% by weight) were withheld for the first week, as some data suggest they may adversely affect the initiation of feeding (Manolis *et al*. 1989).

Each pen had 100 or 101 hatchlings with a mean BWT of 75.4 g, hence a total pen biomass was 7.54 or 7.56 kg. Feeding started with 700 g of food per pen, about 6.9 to 7.0 g per individual, or 9.2 to 9.3% of hatchling BWT. The food was introduced at 1630 to 1730 h each day, and initially spread in 7 x 100 g piles or 100 g strips (<30 cm) along the 9 m long feeding area, 5-15 cm from the edge of the heating channel (Fig. 9).

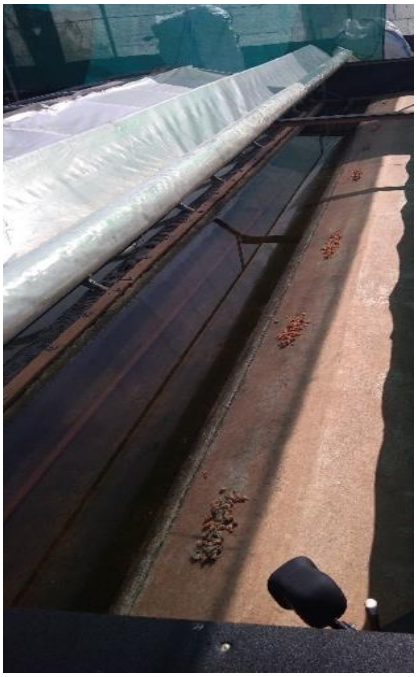


Figure 9. Food distributed in 100 g piles along the feeding-basking area.

The next morning, uneaten pieces on the bank, and in the heating channel, were collected and weighed, and corrections applied to determine approximately the amount of the original food that had been wasted. This daily record was the basis on which adjustments to the amount of food provided were made each day. Inspections of all pens were conducted twice daily (when cleaning and later feeding). Two remote cameras ("Arlo") were used to remotely observe hatchlings in different pens, on different nights.

On 9-10 March 2020 (after 12-13 days), all pens were drained and all animals were captured, inspected and remeasured (BWT and HL only). Some hatchlings had found an opening between Pens A3 and A4, which was repaired, and the animals were returned to their original pens. In addition, shade balls were added to the heating channels in two pens (Figs. 5 and 6) because the remote camera was detecting agonistic interactions. By this time, 6 mortalities had been recorded, but the possibility that they were hatchlings with developmental anomalies from incubation, could not be rejected.

The base diet was retained as diced pig meat, with DCP and MV. From 12 March 2020 onward, 25% of the diced pig meat was replaced with diced small "whitebait" fish (*Hyperlophus vittattus*). From 19 March onward, the diet was comprised of 40% diced pig meat, 40% minced chicken heads and 20% diced fish, with 2% DCP and 2% MV. At this time food was spread across the feeding area, rather than being in strips or piles, and 15 cm back from the edge of the water. If less than 5% of the food was left on the bank, the amount of food was increased. Taking waste food in the water into account, food consumption was usually 45<55% of wet weight of food provided.

The inventory on 9-10 March, and spot checks with the remote cameras, confirmed a disparity in the sizes of hatchlings was developing in different treatments, with lower growth rates in the two pens (A2 and A4) with shade balls in the refuge pond. The trial was terminated on 1 April 2020, with all animals (N= 391) weighed and measured. They were 36 days of age, had been in the raising trial for 33 days, with a total mortality of 10 individuals (2.5%).

4.6. Post-trial Growth and Recovery

The surviving animals (N= 391) were graded according to size (BWT) and a qualitative assessment of body condition during the 1 April 2020 Inventory. They were rehoused the same day, in the same pens, but with all shade balls in the refuge areas removed. The shade balls in the heating channels (Pens A2 and A3)(Figs 5 & 6) were retained. The largest animals ("L"; N= 118) were housed in two separate interconnected pens (Pens B15 and B16), of the same basic design, but with a black rather than clear plastic over the refuge area. The remainder (N= 283) were distributed in Pens A1 to A4 according to size: Medium (M, Pens A1 and A2, N= 180); Small (S, N= 48, Pen A4) and Very Small (VS, N= 45; Pen A3). They were raised for a further 47 days before a final inventory (18 May 2020) when surviving hatchlings were 83 days of age, and had been raised in the new pens for 80 days.

The same feeding regime was continued, and the base food for the L and M animals remained the same (40% diced pig meat, 40% minced chicken heads and 20% diced fish, with 2% DCP and 2% MV). For the S animals, some dietary manipulation occurred (fish was removed). The VS animals (N= 45), all judged to be both small, in poor body condition (prospective "runts") with a high probability of dying (Isberg *et al.* 2009; Brien *et al*. 2014b). A range of diets was tested iteratively with VS animals, and they were observed closely with the remote cameras.

At the final inventory (18 May 2020) it was discovered that some 52 of the 118 L animals had been stolen! All surviving animals (N= 326) were returned to the commercial farm, where they were housed in two pens, and their progress monitored generally by the farm staff.

5. Results and Discussion

5.1. Temperature Characteristics of Pens and Shade Balls

Understanding the thermal environment that prevailed in the pens during the trials, and the thermal implications of using or not using shade balls, was a fundamental goal of the trial. The general weather conditions (Table 1), to which all pens were exposed, were warm and stable during the day, with rain days and minimum temperatures (at night) reducing gradually during April-May as the dry season winter period approached.

Table 1. Weather reported at Darwin Airport, approximately 5 km from where the trials were conducted (February to May 2020) (BOM 2020).

Parameter	Jan	Feb	Mar	Apr	May	Jun
Mean maximum temperature (ºC)	31.8	**32.0**	**32.8**	**32.1**	**30.7**	30.6
Highest temperature (ºC)	36.1	**36.0**	**36.0**	**36.7**	**36.0**	35.0
Mean minimum temperature (ºC)	24.9	**24.8**	**24.6**	**24.0**	**22.2**	20.0
Lowest maximum temperature (ºC)	28.0	**27.7**	**27.6**	**27.4**	**25.6**	23.3
Mean 0900 h temperature (ºC)	30.2	**30.0**	**30.5**	**31.7**	**31.2**	29.9
Mean 1500 h temperature (ºC)	429	**370**	**314**	**102**	**21**	2
Mean days with >1 mm rainfall	19	**18**	**17**	**7**	**2**	<1

In days without interference from rain, shaded air temperatures in the pens, 40 cm above the water surface in each refuge pond (under the partial plastic cover) (Fig. 10), stabilised at around 28-31ºC during the night. During the day, air temperatures increased to 39-41ºC in pens without shade balls (A1 and A3) and 45-50ºC in pens with shade balls (A2 and A4). Periodic rain lowered air temperatures rapidly (see Day 2, 1400 h on Fig. 10), but typically for short periods of time.

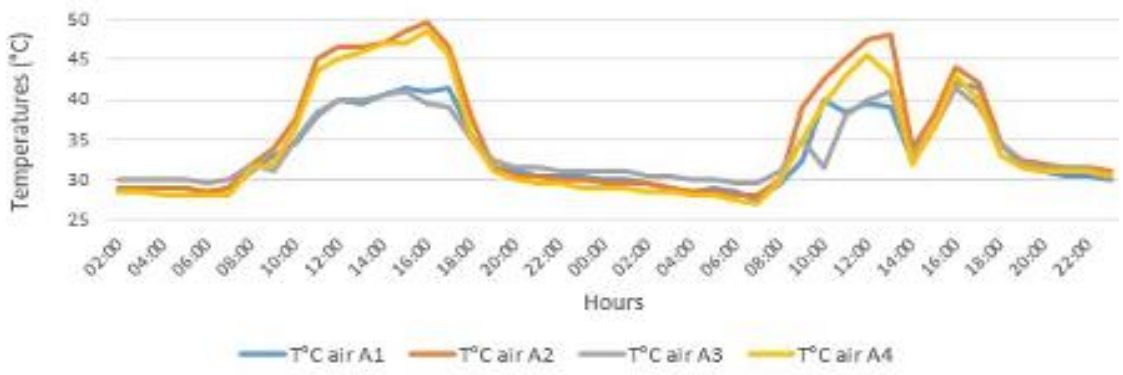


Figure 10. Typical shaded air temperatures above refuge areas with (A2 and A4) and without (A1 and A3) shade balls covering the refuge area water surface.

Shade balls absorbed heat from the sun during the day, reaching 60-70ºC on their upper surface (Fig. 11), and radiated heat back into the confined air space above the refuge pond, raising air temperatures by around 5ºC (Fig. 10). Within each shade ball, a large temperature gradient (25+ºC) existed vertically, with the temperature on the bottom surface of the shade ball, in water, being marginally higher (1-2ºC) than the surface water temperature during the day (Fig. 11).



Figure 11. Temperature on the top and bottom of a shade ball in the refuge area as a function of time. "TºC SW A2" is the temperature of the surface water (beneath the shade balls) at 10 cm deep, in the refuge area, which remains very stable.

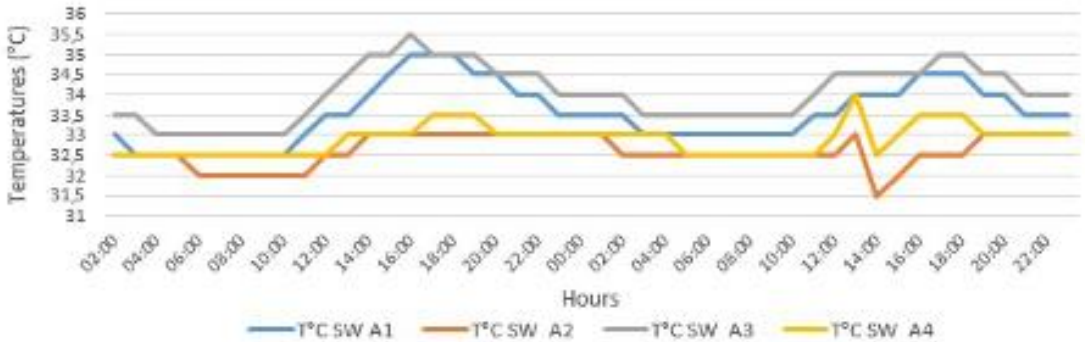


Figure 12. Surface Water Temperatures (10 cm deep) in the refuge area over a 2-day period in pens with (A2, A4) and without (A1, A3) shade balls.

Surface water temperature in the refuge ponds, of the two pens without shade balls (A1 and A3), increased to a higher temperature (<35ºC) than the surface water temperature in the two adjacent pens, with shade balls (<33C) (Fig. 12). In the refuge ponds with shade balls, surface water temperatures were 0.5-1.0ºC lower than the pens without balls at night, and up to 2.5ºC lower during the day.

By shading the water's surface, the balls resulted in less heat being absorbed, even through some heat was being transferred through the balls to the water surface. Yet the shade balls were radiating heat back into the air space, increasing air temperatures during the hottest periods of the day. These trends were clearly demonstrated in two adjacent pens, A2 (with shade balls in the refuge area) and A3 (without shade balls) (Fig. 13).

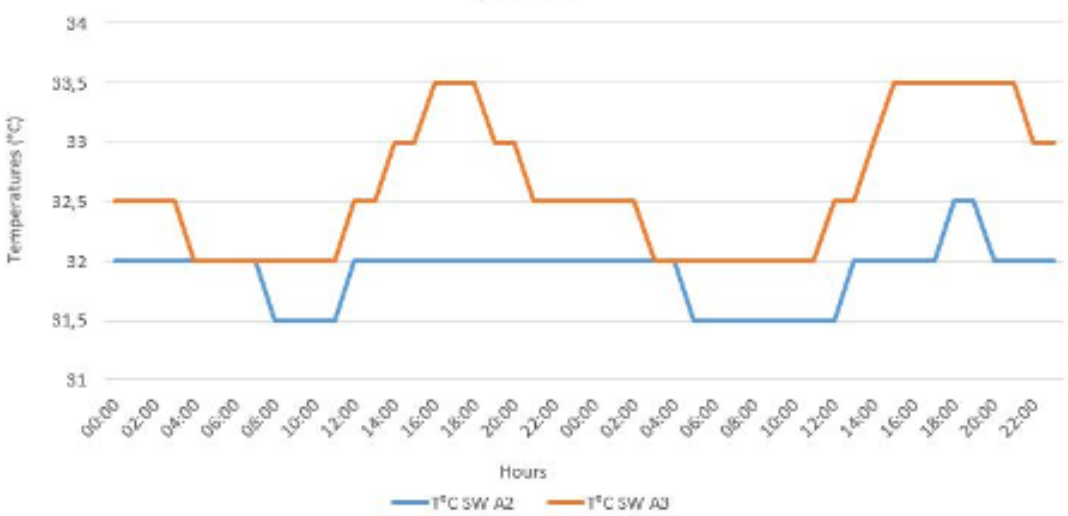


Figure 13. Surface Water Temperatures (10 cm deep) in the refuge area over a two-day period in two adjacent pens, A2 with shade balls and A3 without shade balls.

The refuge ponds contained 21 kl of water, with deep water temperatures measured 100 cm below the surface (Fig. 14). Temperatures were more stable than shallow water temperatures (Fig. 13), with less diurnal variation. In the pens without shade balls (A3) deep-water temperature tended to be 1.0-1.5ºC higher than in pens with shade balls (A2). Diurnal temperature variation was restricted to around 1ºC in both cases.

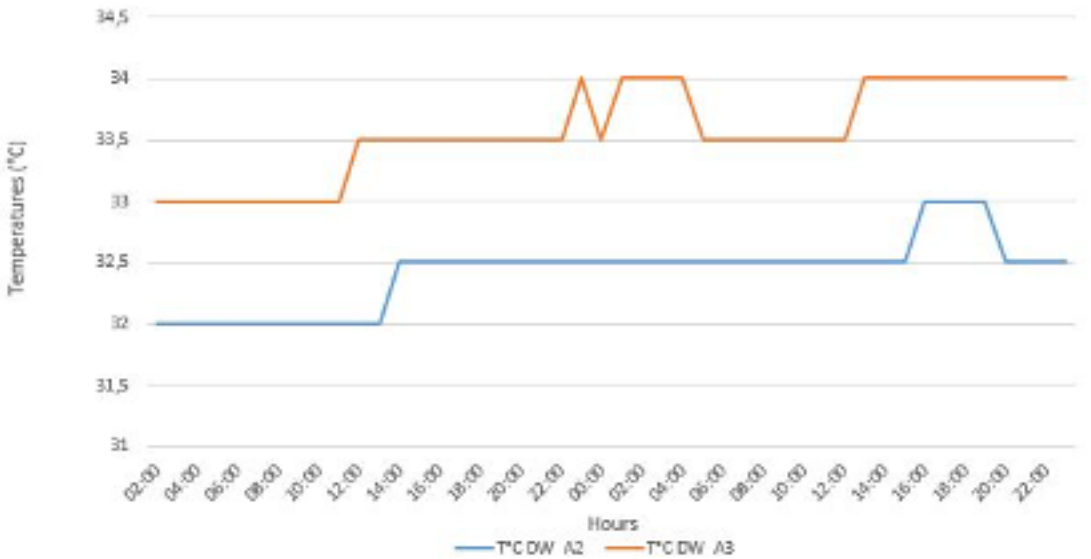


Figure 14. Deep Water Temperatures (100 cm deep) in the refuge area over a two-day period in two adjacent pens, A2 with shade balls and A3 without shade balls.

The heating channel (Figs. 2 and 3) was a relatively small water area (about 1 kl of water per pen) with a thermostatically controlled (32ºC) gas heater available. During this trial, with high ambient temperatures, the gas heater was only switched on between 2200 h and 0100 h to prolong warm conditions, immediately after feeding. By morning (Fig. 15) the water in the heating channel had cooled to ambient temperatures, generally 29-31ºC, which was when the channel was drained, cleaned and refilled with water at ambient temperature (29-30ºC; 0800-0930 h). Water temperature increased rapidly during the day from direct exposure to the sun, and started to cool in the late afternoon. The temperature environment between treatments, with and without shade balls, are summarised on Table 2.

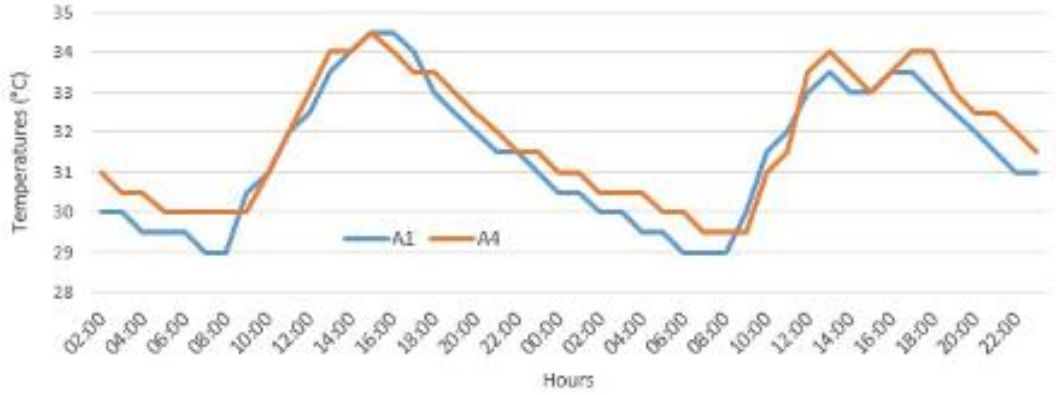


Figure 15. Typical pattern of temperature fluctuation in the heating channel during the raising trials, from the two pens (A1 and A4) at the opposite ends of the pen array. Heating was largely due to the sun, with gas heating restricted to 2200 or 0100 h to prolong war conditions during the night. Water was changed between 0800 and 0930 h.

Table 2. Mean hourly temperatures (ºC) for all pens (A1-A4), during the 48-hour period depicted in Figure 15. SD= standard deviation; SE= standard error.

Site	Mean	SD	SE	Minimum	Maximum
Air (Refuge) - A1	33.4	4.7	0.70	28.5	41.5
Air (Refuge) - A2	35.4	7.3	1.10	28.5	48.0
Air (Refuge) - A3	33.7	4.0	0.60	29.5	41.0
Air (Refuge) - A4	34.2	6.9	1.00	28.0	47.0
Surface Water (Refuge) - A1	33.0	0.7	0.10	32.5	35.0
Surface Water (Refuge) - A2	32.6	0.4	0.06	32.0	33.0
Surface Water (Refuge) - A3	34.0	0.7	0.10	33.0	35.0
Surface Water (Refuge) - A4	32.0	0.4	0.06	32.5	33.5
Deep Water (Refuge) - A1	32.9	0.3	0.04	32.5	33.0
Deep Water (Refuge) - A2	32.4	0.3	0.04	32.0	33.0
Deep Water (Refuge) - A3	33.6	0.4	0.06	33.0	34.0
Deep Water (Refuge) - A4	32.7	0.5	0.08	32.0	33.5
Heating Channel - A1	31.4	1.7	0.20	29.0	34.0
Heating Channel - A2	31.5	1.7	0.30	29.0	34.0
Heating Channel - A3	31.6	1.4	0.20	29.5	35.0
Heating Channel - A4	31.8	1.5	0.20	29.5	34.0

During the first trial (27 February to 1 April 2020) seasonal temperatures remained reasonably high and constant (Table 1). However, during the second post-trial raising, minimum ambient temperature began their normal seasonal decline (Table 1; Fig. 16). The time period gas was used to heat the heating channel was extended, and food consumption continued to increase.

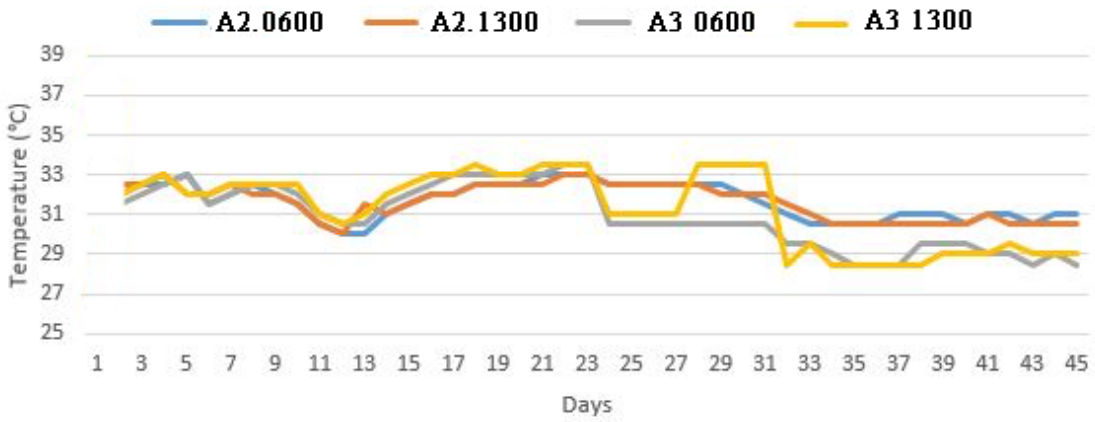


Figure 16. Deep-water temperatures in the refuge ponds in pens A2 and A3, neither with shade balls, at 0600 h (lowest) and 1300 h (highest) during the second experiment (47 days). The results demonstrate the onset of declining seasonal temperatures at this time (Table 1).

5.2. General Observations on Feeding Behaviour and Space Utilisation

Despite all pens being within a bird-proof compound (Fig. 1), the cameras confirmed that hatchlings spent most of the day within the refuge pond or on its edges, in pens with and without shade balls. Some emerged onto the floating basking platforms (Figs. 2 and 6), or on the edges of the refuge pond, but if disturbed they would dive into the refuge pond. Hatchlings rarely entered the heating channel or passed through it to the feeding area, during the day. This reluctance to leave the security of the refuge pond during the day and expose themselves in the heating channel or on the feeding area, is consistent with some form of innate avoidance of predators using visual cues (birds?).

Feeding in the late afternoon disturbed animals on the refuge wall or floating basking platform, which scurried into the water of the refuge pond. After food was spread out, and the plastic cover wound down for the night, covering both heating and feeding areas (Fig. 4), hatchlings would initially move out from the refuge area, into the heating channel, and then onto the feeding area. As the trial continued, the caution declined, and feeding occurred more rapidly, sometimes while the food was still being spread out.

Most animals fed within the first hour (1730-1830 h). They typically grasped food and retreated back to the heating channel to swallow it. Hatchlings would raise their heads above the water's surface and manipulate the food back into their throats. Sometimes this occurred immediately, but often they held the food without attempting to swallow it, for a few minutes. As the hatchlings got larger, more animals both grasped and swallowed food on the land. Food taken back into the water was often lost, and some extra food on the feeding area was displaced, and pushed back into the water, by the hatchlings movements to and from the heating channel.

The reluctance to occupy the heating channel and feeding area during the day was not evident at night. Individuals moved back and forth between the refuge area, heating channel and feeding bank, with around 20-30% of the animals in a pen occupying the heating channel at any one time at night. After the main feeding event, and if sufficient food remained, some individuals would continue to feed opportunistically until at least midnight.

5.3. Results of Shade Ball Trial

The trial started with each pen (N= 4) consisting of hatchlings of the same age, from the same mix of clutches, with the same mean sizes and variability (Tables 3, 4 and 5)(t-tests: means BWT p= 0.52 to 0.92; SVL p= 0.56 to 0.85; f-tests: variances BWT p= 0.31 to 0.91; SVL p= 0.31 to 0.97).

Table 3. Mean sizes of 401 hatchlings at the start of the First Trial (25 February). Y= yes; N= no. No balls were in the heating channels when the trial started.

	------- Body Weight (g) -------				---- Snout-Vent Length (mm) ----			
Pen	A1	A2	A3	A4	A1	A2	A3	A4
Mean	75.6	75.4	75.0	75.4	146.3	146.2	146.3	146.6
SD	7.2	6.7	6.5	6.8	5.6	5.0	4.8	5.6
Variance	52.2	44.8	42.6	46.1	31.7	25.2	22.9	30.8
N	101	100	100	100	101	100	100	100
Minimum	47	55	56	57	120	132	137	135
Maximum	90	90	90	87	159	158	156	159
Balls (Refuge)	N	Y	N	Y	N	Y	N	Y
Balls (Heating)	N	N	N	N	N	N	N	N

The distribution of hatchlings from each clutch to each pen initially, and after two weeks when they were re-caught and measured, is in Table 4. Clutch-specific growth in BWT during the first 2-week period is summarised on Table 5: 6 animals had died and these are thought to reflect congenital problems from incubation (compromised hatchlings).

Mean BWT had increased from +0.1% to +18.8% in different clutches, with the overall mean growth of 8.8 ± 7.7 g (SD) or 11.6 ± 10.0% of initial BWT (N= 391; range -8 to +28 g; -11.1% to 43.8% Initial BWT). The average animal clearly surpassed the 5% increase in BWT by 21 days, that Brien *et al*. (2014b) used as an indicator of runtism. However, some clutches (eg W313 on Table 5, with 0.1% mean BWT growth) clearly had compromised growth.

Table 4. Distribution of hatchlings from different clutches at the initiation (I) of the First Trial (N= 401) and after 2-weeks (2W).

Clutch	N	Pen A1		Pen A2		Pen A3		Pen A4	
		I	2W	I	2W	I	2W	I	2W
F64	17	4	4	4	4	5	5	4	4
F78	32	8	8	8	7	8	8	8	8
F80	25	7	7	6	5	6	6	6	6
F85	41	10	10	10	9	10	10	11	11
F90	21	5	5	6	6	5	5	5	5
F91	3	0	0	1	1	1	1	1	1
F98	10	3	3	2	2	2	2	3	2
F150	23	6	6	6	6	6	6	5	5
F173	16	4	4	4	4	4	4	4	4
W313	17	4	3	5	5	4	3	4	3
W341	53	14	14	13	13	13	13	13	13
W344	36	9	9	8	8	9	9	10	8
W346	16	4	3	4	4	4	4	4	4
W352	63	16	16	16	16	16	16	15	15
W458	28	7	7	7	6	7	7	7	7
Totals	**401**	**101**	**99**	**100**	**97**	**100**	**99**	**100**	**96**

Table 5. Clutch-specific hatchling BWT, from captive (F) and wild (W) clutches, at the initiation (N= 401) and after two weeks (N= 391).

Clutch	Egg Wt.	Initial BWT (g)			2-Week BWT (g)			Growth		Mortality
	(g)	Mean	SD	N	Mean	SD	N	g	%	
F64	136	80.8	2.4	17	87.2	6.5	17	6.4	**8.0**	0
F78	122	71.7	3.5	32	79.1	8.0	31	7.5	**10.4**	1
F80	132	77.8	3.9	25	86.7	7.8	24	8.8	**11.4**	1
F85	142	84.2	3.1	41	96.5	8.1	40	12.1	**14.3**	1
F90	122	71.5	3.6	21	82.5	8.7	21	11.0	**15.2**	0
F91	106	61.3	2.3	3	64.7	3.1	3	3.3	**5.4**	0
F98	129	76.2	2.9	10	83.0	8.3	9	7.1	**9.5**	1
F150	129	75.9	4.2	23	90.1	8.1	23	14.3	**18.8**	0
F173	131	77.3	3.7	16	8.0	10.3	16	3.7	**4.7**	0
W313	124	72.8	2.6	17	73.1	4.3	14	0.0	**0.1**	3
W341	132	78.3	2.5	53	85.2	7.5	53	6.9	**8.8**	0
W344	119	69.8	2.8	36	78.4	7.8	34	8.7	**12.5**	2
W346	123	72.3	1.7	16	79.8	5.2	15	7.4	**10.2**	1
W352	133	78.6	5.4	63	91.5	9.8	63	12.9	**16.3**	0
W458	106	61.4	4.1	28	66.3	8.0	28	4.9	**7.8**	0

An unexpected result, of the somewhat opportunistic inventory after two weeks, was that the BWTs (Table 6) were already indicating that the two pens with shade balls in the refuge pond (A2, A4), were growing slower than the two pens without shade balls (A1, A3). However, growth only reached statistical significance with Pen A2 versus A3 (t-test; p= 0.05), but the non-significant trends were clearly heading in this direction (Table 6). None of the variances were significantly different from each other by 2 weeks.

Table 6. Mean body weight (BWT) after 2 weeks in the First Trial (N= 391). Y= yes; N= no. Shade balls were introduced into the heating channels of Pens A2 and A3 at this time.

Pen	A1	A2	A3	A4
Mean BWT (g)	85.0	82.5	85.6	83.9
SD	12.1	11.3	10.9	10.8
Variance	146.1	126.8	118.4	116.7
N	99	97	99	96
Minimum (g)	47	56	57	62
Maximum (g)	111	108	107	113
Balls (Refuge)	N	Y	N	Y
Balls (Heating)	N	N	Y	N

As the trial continued, daily food consumption records, and camera observations, confirmed less food was being eaten in the two pens with shade balls in the refuge ponds (A2 and A4), although some small animals were failing to thrive, and heading towards runtism, in all 4 pens. The trial was terminated on 1 April 2020, after 33 days of raising, when the hatchlings were 37 days of age, and all animals were measured and weighed (Table 7).

Table 7. Mean sizes of hatchlings at the termination of the First Trial (1 April 2020) after 33 days of raising and 36 days since hatching. Y= yes; N= no. Shade balls were introduced into the heating channel after 14 days.

	------- Body Weight (g) -------				---- Snout-Vent Length (mm) ----			
Pen	A1	A2	A3	A4	A1	A2	A3	A4
Mean	108.5	95.0	110.7	98.0	177.3	172.9	177.4	174.9
SD	28.2	27.3	28.1	24.7	11.7	11.7	12.4	11.0
Variance	797.0	743.6	790.7	611.0	136.5	135.9	153.3	120.0
N	99	97	99	96	99	97	99	96
Minimum	56	54	58	54	150	149	148	151
Maximum	180	180	194	185	204	201	211	207
Balls (Refuge)	N	Y	N	Y	N	Y	N	Y
Balls (Heating)	N	N	Y	N	N	N	Y	N

The inventory results (Table 7) demonstrated:

1. The two pens without shade balls in the refuge area (A1, A3) were not significantly different from each other in mean BWT (t-tests; p= 0.58) nor mean SVL (p= 0.94), and nor were the variances significantly different (f-test; BWT p= 0.97; SVL p= 0.57).

2. Similarly, the two pens with shade balls in the refuge area (A2, A4) were not significantly different from each other in mean BWT (t-tests; p= 0.43) nor mean SVL (p= 0.24), and nor were their variances significantly different (f-test; BWT p= 0.34; SVL p= 0.54).

3. For assessing the general effects of shade balls on growth, hatchlings from the two pens (A1, A3) without shade balls were combined [mean BWT was 109.6 ± 28.1 g (SD; N= 198; range 56 to 194 g) and mean SVL was 177.4 ± 12.0 mm (SD; N= 198; range 148 to 211 mm)]. Hatchlings from the two pens with shade balls were also combined [mean BWT was 96.5 ± 26.0 g (SD; N= 193; range 54 to 185 g) and mean SVL was 173.9 ± 11.3 mm (SD; N= 193; range 149 to 207 mm)].

4. Using the combined data, mean BWT and SVL in the treatments without shade balls (N= 193) were 13.6% (BWT, $p<0.0001$) and 2.1% (SVL, p= 0.004) higher than the treatments with shade balls (N= 198). In neither case did differences in the variance reach statistical significance (p= 0.28, p= 0.42).

5. The range of sizes at the final inventory was similar across all treatments (Table 7)(with shade balls 54-186 g BWT, 96-207 mm SVL; without shade balls 56-194 g BWT, 148-211 mm SVL), but the distribution of sizes within that range was skewed: BWT skewness with shade balls = 0.696 versus = 0.299 without; SVL skewness with shade balls = 0.335 versus -0.051; without. The shade ball treatments resulted in more smaller animals.

Table 8. Growth of hatchlings expressed as the percentage increase in BWT and SVL after 33 days of raising (36 days since hatching). Y= yes; N= no.

	------- Body Weight (%) -------				---- Snout-Vent Length (%) ----			
Pen	A1	A2	A3	A4	A1	A2	A3	A4
Mean	43.3	25.4	47.0	29.5	21.1	18.3	21.3	19.3
SD	35.1	31.8	33.6	29.7	7.1	6.1	7.2	5.7
Variance	1230.1	1011.6	1129.8	882.7	50.3	36.6	51.8	32.9
N	99	97	99	96	99	97	99	96
Minimum	-23.0	-20.5	-21.6	-19.0	4.9	5.9	3.4	7.2
Maximum	145.2	133.8	136.6	137.2	39.7	35.1	39.7	37.1
Balls (Refuge)	N	Y	N	Y	N	Y	N	Y
Balls (Heating)	N	N	Y	N	N	N	Y	N

Given the variation in size at hatching, the percentage increase in BWT (Table 8) is a better index of growth performance (Brien *et al*. 2014b). In the total sample (N= 391), the BWT of 62 (15.9%) hatchlings was equal to or less than their hatchling weight. Of these, 20 (32%) were from the control pens (Pens A1 and A3) and 42 (68%) from pens with shade balls in the refuge area (Pens A2 and A4).

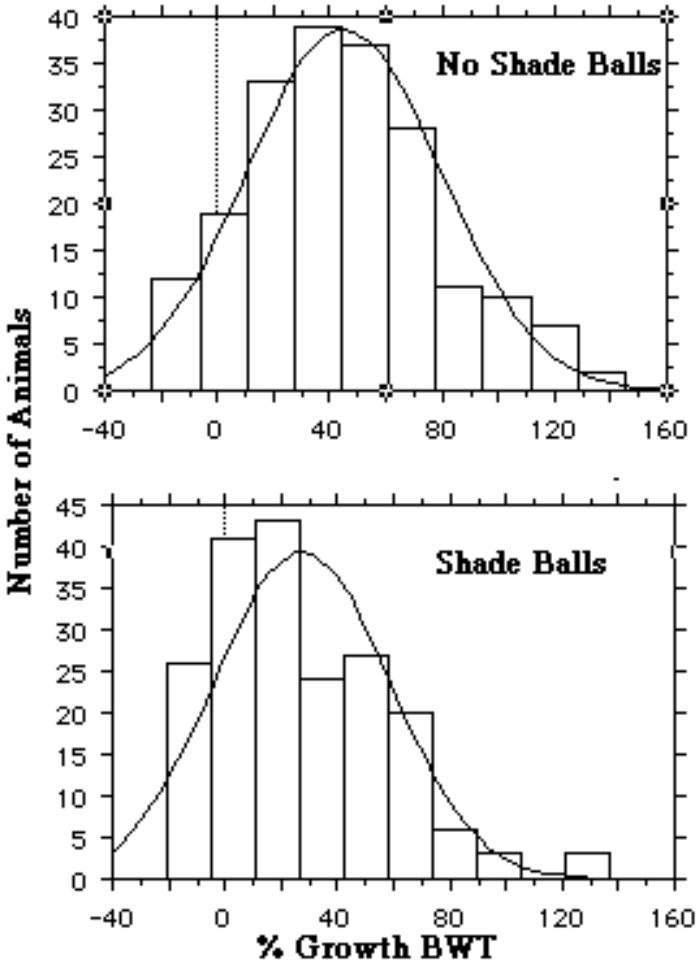


Figure 17. Percentage growth in BWT in pens with (lower) and without (upper) shade balls, demonstrating a similar range of growth values, but a skewed distribution to reduced growth in pens with shade balls.

There was a normal distribution (Fig. 17 upper) of growth in Pens A1 and A3 without shade balls (skewness 0.326; kurtosis = -0.129), relative to a distribution skewed towards slower growing animals in Pens A2 and A4 (Fig. 17 lower) with shade balls (skewness 0.851; kurtosis = 0.742).

5.4. Effects of Shade Balls on Survival

Ten animals (2.5% of 401) died or were missing, presumed dead, by the end of the first trial: 3 from the pens without shade balls (A1= 2, A3= 1) and 7 from the pens with shade balls (A2= 3, A4= 4). Of these, 6 died within the first two weeks.

5.5. Conclusions about Shade Balls from the Trial

1. The configuration of shade balls tested in this trial, in which the complete surface area of refuge ponds was covered with balls adjoining each other (Figs. 5 and 6) , resulted in lower mean growth rates, and a skewed distribution in the direction of animals with compromised growth.

2. The reasons for this are unclear, but may involve multiple factors:

    a. The shade balls marginally reduced (1^{o}C) surface water temperatures (Figs. 12 and 13) but radiated significant heat back into the semi-enclosed air space above the refuge pond, increasing air temperatures

by 5-10ºC during the day (Fig. 10), which may have added stress to the hatchlings. The temperature requirements of hatchlings are complicated, and as high temperatures are fatal, they can expect to be stressful (Lang 1987b; Brien *et al*. 2012; Grigg and Kirshner 2015).

b. Although theoretically allowing hatchlings to emerge within the refuge pond with visual exclusion (their behaviour could not be examined because of the balls), the tightly packed balls may have inhibited surface movements, again adding stress.

3. The different configuration of shade balls added to the heating channel after two weeks had no consistent detectable effect on growth, but they appeared to allow hatchlings to move freely across the water surface with minimal contact between individuals. This configuration of shade balls (each separated by 100 mm from each other) may well have been a more effective option for creating visual exclusion in the refuge ponds.

4. The general pen design and management regime appeared adequate, and in the pens without shade balls gave high mean growth, and a normal distribution of sizes.

4.6. The Second Trial: Post-Trial Growth.

The hatchlings inventoried on 1 April 2020 (N= 391) were rapidly graded on the basis of BWT and visual assessment of body condition (Table 9), with no consideration of their clutch or previous raising history, and redistributed back to the same pens that same day. The shade balls from the refuge areas were removed, but the shade balls in the heating channel were retained (Pens A2 and A3). The BWTs and growth (during the first trial) of animals introduced into each pen are summarised in Table 10, and the distribution of animals amongst pens is on Figure 18.

Table 9. Criteria for rapidly assigning hatchlings to different pens, at the inventory on 1 April 2020.

Category	Body Weight	Body Condition	N	Pen
Large (L)	>120 g	Good	118	B15-16
Medium (M)	80<120 g	Good	180	A1, A2
Small (S)	70<80 g	Good	48	A4
Very Small (VS)	<70 g	Poor	45	A3
Total			**391**	

Table 10. Body weight (BWT) of animals allocated to different pens (N= 391) for further raising on 1 April 2020, with their mean growth history during the Trial. L= Large, M= Medium, S= Small and VS= Very Small (Table 9). The VS animals had on average lost 10.1% of their hatching BWT during the first shade ball trial.

	------- Body Weight (g) -------				BWT Growth (%) in Previous Trial			
Pen	A1-A2	A3	A4	B15-16	A1-A2	A3	A4	B15-16
Size Class	M	VS	S	L	M	VS	S	L
Mean	99.0	62.6	75.2	136.2	31.3	-10.3	6.9	74.0
SD	11.0	4.5	3.5	17.5	17.5	8.4	11.3	24.4
N	180	45	48	118	180	45	48	118
Minimum	80	54	70	106	-3.5	-23.0	-10.1	31.4
Maximum	122	69	82	194	101.8	23.2	55.3	145.2

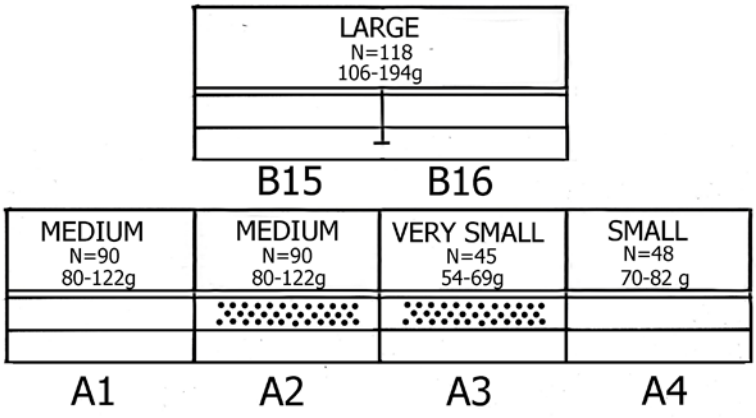


Figure 18. The arrangement of hatchlings raised in each pen in the second trial. Shade balls retained in the heating channels in Pens A2 and A3.

The animals (N= 391) were raised for 48 days until 18 May 2020 (Table 11; Fig. 19). At that inventory (N= 326 animals), it was found 56 of the Large animals (Pen B15-16) had been stolen. The pattern of food consumption indicated the theft had occurred during a number of nocturnal visits. The interference is thought to explain why the Large animals behaved differently. They seemed wary of approaching the food, and often carried food back to the refuge area, rather than consume it in the heating channel. Excluding the known stolen animals (N= 56), 9 additional animals died or were missing (2.3% of 391). Four were runts in poor body condition, 3 had good body condition but died of unknown causes, and 2 were missing: VS= 2 (4.3%); S= 0 (2%); M= 4 (1.1%); Large= 3 (2.5%). The 3 dead L and 2 missing M animals could be related to the interference and theft. The majority of animals were feeding and growing when the trial ceased.

Table 11. BWT and SVL of animals raised for 48 days (on 18 May 2020) without shade balls in the refuge ponds. % Growth is relative to their size when this second trial started (see Table 9 for BWT). L= Large, M= Medium, S= Small, VS= Very Small.

	------- Body Weight (g) -------				----Snout-Vent Length (mm)----			
Pen	A1-A2	A3	A4	B15-16	A1-A2	A3	A4	B15-16
Size Class	M	VS	S	L	M	VS	S	L
Mean	261.1	158.9	195.1	313.6	222.5	189.2	203.4	236.6
SD	70.8	54.1	64.6	79.7	18.5	17.2	19.3	16.6
N	176	43	48	59	176	43	48	59
Minimum	74	38	49	120	171	147	160	187
Maximum	418	287	377	572	263	220	239	289
Mortality	1	2	1	3	1	2	1	3
Stolen	0	0	0	56	0	0	0	56
% Growth	162.3	153.9	159.4	128.1	27.4	19.7	24.2	25.4
SD	59.8	84.6	86.1	41.9	9.3	10.2	11.1	6.7
Minimum	-16.9	-33.3	-1.9	-0.8	-0.6	-3.1	-0.6	2.8
Maximum	280	341.5	416.4	216.0	46.2	38.4	44.0	39.6

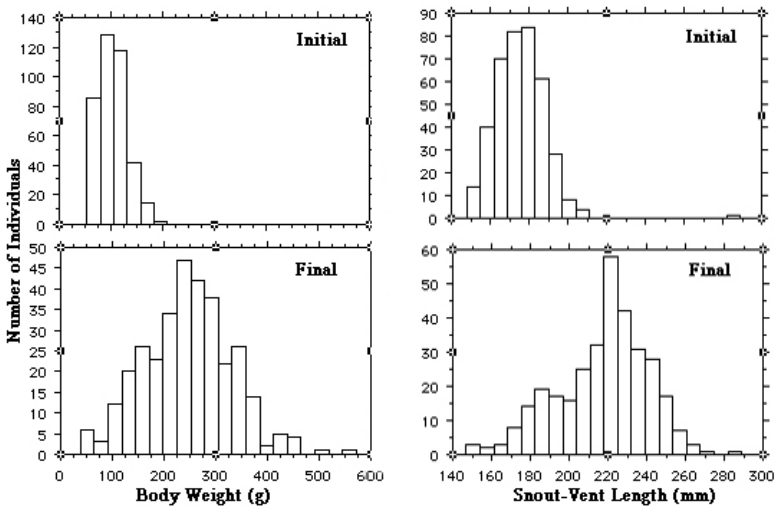


Figure 19. Size-frequency distribution of BWT and SVL at the start and finish of the 48-day post-trial raising period.

5.7. Post-Trial Growth - Runtism

a. Basic Statistics

Brien *et al.* (2014b) had established that if hatchlings had not increased their BWT by 5% in the first 3 weeks, and are retained in the same raising environment, "runtism" would be exacerbated, and they will have a high probability of dying.

At the start of the second raising trial, when hatchlings were 36 days of age (7 weeks), 75 (19.2% of the 391) had BWTs less than +5% of their original hatchling BWT, which skewed the frequency distribution from normal (Figs. 17 and 19). Had they been retained in the same pens without grading and without removing the shade balls, most would have died.

The 75 individuals with <5% increase in BWT in the first trial were allocated to VS (N= 43; 96%), S (N= 23; 48%) and M (N= 9; 5%). Most started feeding and growing during the next 7 weeks. Of the 75 animals, 4 died and at the final inventory 7 still had BWT less than 5% of Hatchling BWT: VS= 4, S= 1, M= 2.

b. Assumptions about Runtism

i. All evidence indicates that "Runtism", caused by voluntary starvation, is an anomaly restricted to captive raising environments.

ii. While reported commonly in captivity (Isberg et al. 2009; Brien *et al.* 2013a-c; 2014b; Hutton and Webb 1992; Manolis and Webb 2016), voluntary starvation in hatchlings has not been reported in the wild, despite wild hatchlings being sighted and/or caught in large numbers over decades (Webb and Messel 1978; Webb *et al*. 1978; Taylor 1979; Messel *et al*. 1981; Fukuda *et al*. 2011).

iii. Poor growth in wild hatchlings occurs in individuals with congenital jaw abnormalities (Webb *et al.* 1977). That they survive, despite growing slowly, suggests runts in the wild are lost to predators before anyone sees them.

iv. Runts behave differently. They do not eat enough food to sustain their metabolic needs, lose body condition, eventually cease feeding, become debilitated, often infected with secondary diseases, and die (Isberg *et al*. 2009).

v. High levels of runtism are linked by cause and effect to a variety of known physical and biological stimuli within captive raising environments. Noise, vibration, low temperatures, high temperatures, social interactions, handling and various other factors appear to trigger the runtism syndrome (Manolis and Webb 2016). However, once switched on, it is not easily switched off. Even if a known triggering stimulus is removed, it takes a long time for hatchlings to start feeding and putting on body condition, if indeed they do.

vi. A complete change in the raising environment and management protocols sometimes results in runtism behaviours being abandoned and recovery occurring (Brien 2015).

vii. Changing the food can be implicated in rehabilitation of runts, but it is unclear whether this is due to the new food *per se*, or to the breaking of an association between the smell of previous foods and whatever other stimulus may have triggering runtism. For example, social interaction and agonistic behaviours may trigger runtism. They occur mainly at the time of feeding (Brien *et al*. 2013a-c), hence the smell of food by association could aso act as a trigger.

viii. Size-based grading and rehousing, so that afflicted animals are maintained together, and isolated from larger animals (assumed to be more dominant), is a management intervention that most farmers apply to reduce the size disparity that forms within a pen of hatchlings (Manolis and Webb 2016).

c. Specific Actions to Promote Growth in Runts in the Second Trial

i. **Size-grading.** The majority of small and compromised animals were grouped together (Table 9), particularly as VS and S (Pens A3 and A4), which included 88% of animals with less than 5% increase in BWT during the first trial. Some larger hatchlings (N= 9), larger size but low growth, were in the M size category (Pens A1 and A2).

ii. **Density Reduction**. The VS group contained 45 animals and about 2.8 kg of crocodile per pen, and S contained 48 animals and 3.6 kg of crocodile per pen (Table 11). They had previously been housed at 96-99 animals per pen, with 9-11 kg of crocodile per pen. So the new housing was at much lower densities.

iii. **Altered Pen Environment**. Shade balls from the refuge ponds, which had been constraining growth, were removed.

iv. **Altered Food and Feeding.** VS and S individuals had exhibited low feeding and growth rates on the standard diet (40% diced pig meat, 40% minced chicken heads, 20% diced fish). It was unknown whether the food itself was the cause, but different foods were tried:

1. **Feeding Protocol**. Feeding started with the standard diet, with separate strings of food, within 10 cm of the water's edge. Total food consumption was estimated daily (Fig. 20), but different foods were offered on the bank, in alternating patterns along it, and used to search for obvious preferences.

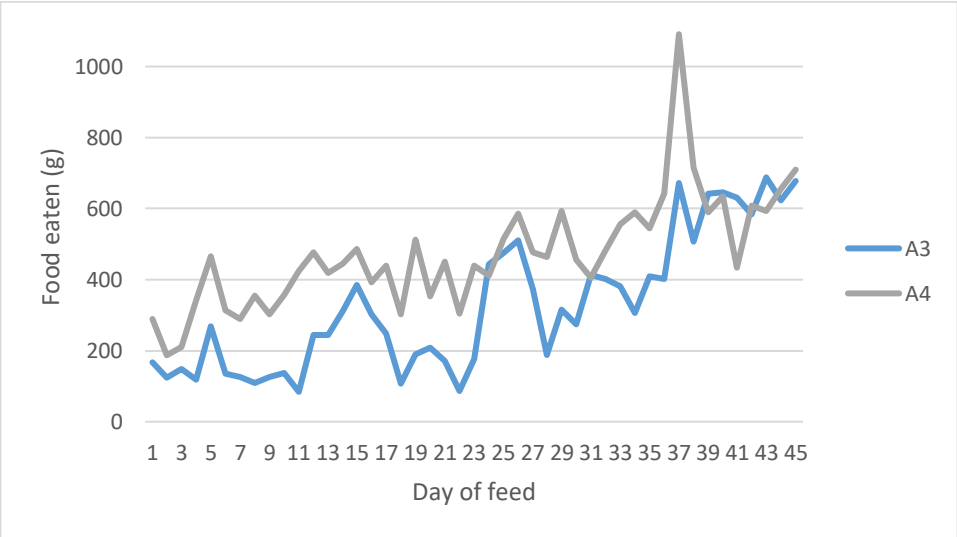


Figure 20. Daily estimates of food consumption for very small (VS - Pen A3) and small (S - Pen A4) hatchlings during the second trial.

2. **Red Prawns**. In tidal rivers, *C. porosus* hatchlings feed mainly on prawns and small crabs (Webb *et al*. 1991). Imported vannamei prawns (probably *Penaeus vannamei*), cooked with shell and head on, and bright red in colour, were used. Whole prawn bodies (head removed) were cut by hand

into small pieces 5-10 mm long. Initial testing involved presenting piles of the standard food (40% pig meat, 40% chicken heads, 20% fish), with and without chopped prawn added, and then comparing these with piles containing 100% prawn. 100% red prawns, were eaten in preference to mixed red prawns and standard diet.

3. **Grey Prawns**. Raw banana prawns (*Penaeus merguiensis*) were tested and preferred over the standard diet, but red prawns were preferred over grey prawns.

4. **Prawn Heads**. Red prawn heads minced into a puree and added to the standard diet was better than the standard diet alone, but inferior to red prawns alone.

5. **Pig, Chicken and Fish**. In the standard diet, with chopped prawns added, pig was marginally preferred over chicken, and both were preferred over fish. Fish was excluded from all diets for VS and S (but was still used for M and L animals).

6. **Dicalcium-Phosphorus Powder.** The addition or deletion of DCP to red prawns made no discernible difference to food consumption.

7. **Monsoon Vitamin-Mineral Mix**. The vitamin-mineral premix (VM) deterred feeding, which could be due to the smell of the carrier used to bulk out the premix (Turton *et al*. 1997). When stimulating feeding, particularly in the VS animals, it was added each few days rather than each day.

8. **Red and Green Colouration**. The preference for red prawns raised the possibility that the colour of the food could be involved. Food piles with or without red or green vegetable dyes made no difference to food consumption. Grey prawns coloured red, were still inferior to red prawns.

9. **Position of the Food Relative to the Water's Edge**. The positioning of food within 10 cm of the water's edge, in discrete piles or strips, increased wastage (food knocked into the water), and reduced food consumption. This was overcome, and food consumption increased, by shifting the food further up the bank, and then spreading it out in very small piles over a wider area of the bank, rather than in discrete strips or larger piles.

10. **Final Diets - VS**. After Day 9 (Fig. 19), the VS animals (Pen A3) were largely restricted to Red and/or Grey prawns with DCP and occasionally MV. Food consumption increased sharply. Pig meat (60-80%) and Red Prawns (40-20%) was introduced on Day 17, and food consumption declined sharply, then started to increase gradually. By Day 25, DCP and MV were added daily to all food.

11. **Final Diets - S**. The S animals (Pen A4) started feeding much more easily than the VS animals (Fig. 19) on the standard diet (70-80%) and Red Prawns (20-30%), with DCP and MV. Feeding increased when the fish in the standard diet was removed (Day 4). By Day 11, the Red Prawn was removed, and they were fed pig (50%) and chicken (50%) plus DCP and MV but no fish. Colouring the food (red or green) was tested but made no difference.

12. **Final Inventory.** The final inventory (Table 11) confirmed that the majority of VS and S animals did begin to feed, and by the final inventory had increased in BWT by a mean of 154% and 150% respectively.

d. Runtism and Dispersal Behaviour

i. **Creche Behaviour**. In the wild, *C. porosus* hatchlings often form creches at the water's edge, near their nest, with the attendant female (Webb *et al.* 1977; Magnusson 1979, 1980). Creches of hatchlings are commonly seen at nests during the commercial egg collection, often with an attendant adult female. Vocalisation between hatchlings and the adult female, are both implicated in maintaining the creche together.

ii. **Dispersal**. In one group of hatchling creches in the wild, by two months of age, when individual BWT had increased by about 40-50% hatchlings started to disperse (Webb *et al.* 1977). Some joined other creches, but others remained alone. Magnusson (1979) described earlier dispersal by some hatchlings, that did not form creches, and were not guarded by an attendant female.

iii. **Very Small (VS) Animals were Highly Mobile**. Prior to feeding, the VS hatchlings were in the refuge area, but at and after feeding, they were highly mobile at night, pacing along the length of the HDPE barrier fence (Fig. 1), often raising themselves up against it, as if trying to climb over it. When they reached the end of Pen A3 (where the camera was positioned), they would often remain next to the grid separating the heating channel from Pen A2. Here they would put the tip of their snout through the grid, where animals from Pen 2 were also congregated, vocalising, and pushing their snouts through the grid the opposite way. This may also have occurred at the opposite end (the connection to Pen A4) but no camera was there to record what was happening.

iv. **Pacing**. Some animals engaged in pacing behaviour, along the barrier fence, in all pens, but with the VS animals it was more common and continuous during the night. It left little doubt that the objective was to find a way of escaping from the raising environment, in which they were not feeding and growing. They appeared more determined to achieve this than the S, M or L animals.

v. **Previous Observations**. Brien (2016) and Brien *et al*. (2014b), noted in their raising trials that hatchlings in high density treatments were noticeably more active and mobile tan ones in lower density treatments. Further insights were gained from hatchling density trials carried out by Webb and Manolis (unpublished). The treatment with the highest density, where higher numbers of runts results, also had high numbers of individuals pacing the perimeter of the pen all night. A level of pacing behaviour much higher than in the low-density treatments with few runts.

vi. **Hypothesis**. There is no selective advantage in voluntarily starving. However, there is an obvious selective advantage in hatchlings dispersing from a raising environment, that for one reason or another, is perceived as being threatening. Dispersal can be exhibited in the wild with no constraints (fences or barriers), and there are no runts in the wild. But the commitment to disperse, within an environment where no escape is possible, with continual activity and energetic costs, is what appears to be happening. It provides a plausible explanation for runtism.

vii. **Barrier Fence Colour.** The barrier fence, against which some animals paced back and forth and tried to climb in all pens (but not with the commitment of the VS animals), was black in colour, shiny, and may have provided reflections exacerbating the behaviour. One fence (Pen A2) was painted with a low-gloss white paint. The response was animals lined up on the feeding area, all facing the white barrier, and moving forward trying to push through it! The "light" colour appeared to trigger dispersal activity, which ceased when it was repainted black the next day.

e. Runtism and Agonistic Behaviour

1. Contrary to expectations, the VS animals (A3) were highly aggressive to each other. Although small and in poor body condition, when confronted with another nearby crocodile they would adopt the aggressive behaviours describe by Brien *et al.* (2013a-c), raising themselves in a rigid elevated stance, with mouth open, vocalising and flicking their head at any individual that ventured within range.

2. This same aggression was exhibited on land by the VS animals, often when two animals crossed paths on the feeding area.

3. One smaller crocodile in Pen A2, occupied the same position on the same part of the feeding area each evening, but concentrated on catching flies rather than eating the food. Although small (perhaps as a consequence of eating flies), the individual was highly aggressive to any of the mostly larger hatchlings, that approached too close.

4. Aggressive agonistic behaviours may be more common in smaller animals within a group, than previously recognised.

5. Pen A3 (VS) had shade balls in the heating channel, with 100 mm gaps between them, whereas Pen A4 (S) did not. The shade balls appeared to significantly reduce agonistic interactions along the feeding channel for the VS animals relative to the S animals, which would sometimes chase each other the length of the heating channel.

6. It appeared that the shade balls played an important role in allowing the VS animals to approach the feeding area, without having to see other animals down the length of the heating channel. With the VS animals, strongly aggressive interactions between individuals occurred, but they were largely restricted

to the ends of the heating channels, where the strings connecting the shade balls were brought together, leaving around 1 m with strings but no shade balls to break vision across the surface.

5.8. Incubation and Clutch Effects on Hatchling Growth

During the first trial, clutch effects in the 4 pens (fig. 5) were controlled because each pen had the same mix of hatchlings. However, within treatments, clutch effects on growth were obvious and can be demonstrated from the animals (N= 198) raised with no shade balls in the refuge areas (Pens A1 and A3; Tables 5 and 13).

Amongst the 198 hatchlings from Pens A1 and A3, raised without shade balls, 24 surviving individuals had BWT growth <5% of HBWT. Three additional runts had already died (W346= 1; W313= 2). Runts were clearly not randomly distributed across clutches: 19 runts amongst 51 hatchlings (37.3%) came from 5 clutches (F64, F173, W313, W444 and W346), versus 8 runts amongst 150 hatchlings (5.3%) from 10 clutches (Table 13).

None of the variation in clutch-specific growth rates (Table 13), expressed as either a percentage increase in HBWT, or in absolute growth (g), could be explained by HBWT ($p= 0.93$ and $p= 0.41$ respectively). Post-hatchling growth is largely independent of hatchling size (BWT) within the range tested here. Mean growth up to 36 days of age was 32.4 ± 13.5 g BWT or 43.9 ± 17.9% increase in HBWT.

Table 13. Clutch effects on size and growth amongst the animals raised in the first trial, without shade balls (N= 198; Pens A1 and A3). *= only 1 hatchling; HBWT= hatching BWT; FBWT= Final BWT at end of first trial; Runts = animals <5% increase in HBWT by the first trial; SD= standard deviation.

Clutch	N	HBWT (g)	FBWT (g)	%Growth	SD	Runts	% Runt
F64	9	79.9	117.2	46.6	34.7	2	22.2
F78	16	72.0	113.3	56.9	30.3	0	0.0
F80	13	78.2	121.0	55.5	45.8	1	7.7
F85	20	84.1	132.2	57.3	34.1	1	5.0
F90	10	72.4	113.4	56.4	29.2	0	0.0
F91	1	60.0	96.0	60.0	*	*	0.0
F98	5	74.2	114.4	54.6	23.4	0	0.0
F150	12	76.2	125.3	64.1	22.4	1	8.3
F173	8	77.0	92.9	19.4	40.2	4	50.0
W313	6	73.0	81.7	11.2	26.8	3	50.0
W341	27	78.4	105.7	34.7	24.5	2	7.4
W344	18	69.7	89.6	28.8	34.8	4	22.2
W346	7	72.1	81.0	12.3	16.0	3	42.9
W352	32	78.2	117.0	50.3	30.9	2	6.3
W458	14	61.4	92.8	50.6	38.9	1	7.1

Table 14. Incubation history of hatchlings used in the experiments. HT-F= high temperature female, M= male, LT-F= low temperature female. With farm eggs, all eggs were assessed, but for wild nests eggs that were obviously dead or infertile were discarded in the field. DDI= dead during incubation; HAb= hatched abnormal; HN= hatched normal; Adel.= Adelaide River; Goom.= Goomadeer River.

Nest	Source	Eggs Collect.	Eggs Incub.	Date in Incubator	Date Hatched	Days of Incubation	Age (30ºC)	Sex in Incub'n	Expected Sex	DDI	HAb	HN
F64	Farm	36	18	5 Jan	24 Feb	50	32	Yes	HT-F	0	1	17
F78	Farm	50	33	9 Dec	24 Feb	77	0	Yes	HT-F	0	1	32
F80	Farm	40	25	9 Dec	24 Feb	77	0	Yes	HT-F	0	0	25
F85	Farm	45	42	11 Dec	24 Feb	75	1	Yes	HT-F	0	1	41
F90	Farm	73	41	12 Dec	24 Feb	74	2	Yes	HT-F	1	4	36
F91	Farm	39	10	12 Dec	25 Feb	75	1	Yes	HT-F	2	5	3
F98	Farm	45	13	13 Dec	24 Feb	73	4	Yes	HT-F	0	3	10
F150	Farm	41	24	31 Dec	24 Feb	55	26	Yes	HT-F	0	1	24
F173	Farm	47	18	10 Jan	24 Feb	45	38	Possible	M or F	0	1	17
W313	Adel.	39	32	16 Dec	25 Feb	71	6	Yes	HT-F	6	9	17
W341	Melacca	54	53	27 Dec	25 Feb	60	20	Yes	HT-F	0	0	53
W344	Adel.	41	40	27 Dec	25 Feb	59	22	Yes	HT-F	0	4	36
W346	Arafura	35	31	5 Jan	24 Feb	51	31	Yes	HT-F	1	15	16
W352	Arafura	54	49	5 Jan	24 Feb	50	32	Yes	HT-F	0	1	48
W458	Goom.	35	34	20 Jan	25 Feb	36	49	No	M or F	1	8	27

The incubation history, with egg collection dates, hatching dates, known incubation temperatures (32.6ºC), and calculations made using development rate coefficients in Webb *et al*. (1987) are in Table 14. Whether sex was determined in the incubator (where 32.6ºC could be expected to produce high temperature females), or in the nest prior to collection, was predicted.

The following are considered important:

1. Embryo development rate is highly predictable at constant temperature incubation (Webb *et al*.1987), hence embryo age, when placed in the incubator, can be estimated accurately from incubation temperature and hatching date. Larger eggs take up to 3 days longer than smaller eggs to incubate (Webb *et al*. 1990).

2. The farm-laid clutches (N= 9) had incubation times ranging from 45 to 77 days (Table 7), which indicates:

    a. Based on embryo development rates (Webb *et al.* 1987), a development time of 77 days, with a normal sized egg (or hatchling), could be expected from 32.5-33ºC (Webb *et al*. 1987), which is consistent with the farm incubation temperature (32.6ºC).

    b. Two clutches (77 days incubation time) were probably collected on the farm on the morning after laying (9 December 2019).

    c. The other 7 farm clutches, were laid at or near the same day (9 December 2019), but were not collected for 1 to 22 days after laying.

    d. This period (9 December 2019 to 5 January 2020) was particularly hot and dry, with temperatures in the nest likely to cause abnormal development or death (Webb and Cooper-Preston 1989) prior to the eggs being collected and placed in the incubator.

    e. A constant incubation temperature of 32.6ºC is higher than normally used nor recommended (Webb *et al*. 1987; Manolis and Webb 1991) and deserves closer scrutiny. If there are problems, it perhaps should be reduced to 32.0-32.2ºC.

    f. The sex-determining mechanism is temperature dependent, and 32.6ºC would be expected to produce mainly high-temperature females with some males. Hatchlings were sexed by examining the cliteropensis. Where sex could be confidently determined, at the final inventory (N= 316; Table 15), 85.1% of animals were assessed as females (assumed to be mostly high-temperature females).

Table 15. Sex by clutch for 316 hatchlings in which a confident determination could be made, confirming a strong female bias.

Clutch	Females	Males	Question	%Female
F64	6	5	1	54.5
F78	21	7	1	75.0
F80	16	4	1	80.0
F85	20	3	0	87.0
F90	14	3	0	82.4
F91	3	0	0	100.0
F98	3	2	1	60.0
F150	10	6	1	62.5
F173	13	0	1	100.0
W313	13	0	0	100.0
W341	35	5	1	87.5
W344	28	2	2	93.3
W346	12	3	0	80.0
W352	49	5	0	90.7
W458	26	2	0	92.9
Totals	**269**	**47**	**9**	**85.1**

g. High numbers of dead eggs at the time of collection or during incubation, and abnormalities at hatching, are all consistent with exposure to high incubation temperatures in the nest and/or in the incubator.

3. The six wild clutches (Table 13) had incubated in the field, at unknown temperatures, for 8 to 41 days before collection. Some were probably exposed to high ambient temperatures during late December and early January 2019, prior to collection.

4. Abnormalities (Table 13) for clutches W346, W313 and W458, includes small animals with abundant yolk, which is an index of abnormal development: embryos strive to complete development and hatch to escape metabolic problems (Webb and Manolis 2016). Two of these clutches (W346 and W313) were ones with high proportions of runts (Table 12).

5. It is unclear whether the other clutches that produced high proportions of runts (F64, F173, W444) had incubation problems. Only 50% of F64 eggs were incubated (the others were deemed dead and/or infertile), and 38% of F173 were incubated (the others deemed dead): 1 hatchling from each was deemed abnormal. W444 had 4 hatchlings deemed abnormal.

6. General Discussion and Conclusions

Brien *et al*. (2014b) found that structures on the water's surface, that restricted visual contact between saltwater crocodile hatchlings, reduced agonistic behaviours. These behaviours are implicated in the establishment of dominance hierarchies, which cause a bimodal pattern of growth with crocodiles being raised, with the lower mode becoming runts (Isberg *et al*. 2009). The problem is that there is no cost-effective or practical way of building visual barriers into a conventional pen.

The genesis of this study was that a new product (shade balls), used for restricting evaporative water loss from water reservoirs, could have application for restricting visual contact between individual crocodiles being raised in communal pens.

The configuration of shade balls tested with hatchlings here, involved the balls being tightly packed across the water's surface. For reasons that are not clear, this configuration interfered with hatchling growth. It certainly altered the thermal environment in the pen, in the direction of significantly increasing air temperatures, and slightly reducing water temperatures, but it seems likely that swimming on the surface between the balls, could have been excessively hot.

In contrast, a different configuration of the balls, tested superficially in the heating channels, with the balls spread rather than packed together, did not restrict movement, appeared to reduce agonistic behaviour, and merits further testing.

The shade ball trial was followed by a second raising trial, without shade balls in the refuge ponds, with two aims. Firstly to quantify further growth in the new pens for hatchlings already feeding and growing, and secondly, to try and rehabilitate runts, by stimulating them to start feeding and getting back onto a positive growth trajectory. Both these aims were achieved, and new insights into runtism were obtained.

Clutch-specific variation in growth and runtism was also quantified, and examined as a function of egg incubation regimes. The results suggest that some of the variation in growth, runtism and mortality, may be related to the incubation environment.

The fact remains that raising saltwater crocodile hatchlings, although critically important to production efficiency, is a truly "wicked problem". There is a vast array of potentially interacting variables involved, many of which only become apparent when trying to solve the problem (Rittel and Webber 1973; Conklin 2006).

We still consider that shade balls have considerable potential to improve the production efficiency of hatchling raising, but new approaches to using them need to be tested.

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