SRAS Final Report: Post-Release Monitoring of Headstarted Gharial in Chitwan National Park, Nepal

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Abstract

A long-term headstarting programme for gharial (*Gavialis gangeticus*) in Chitwan National Park, Nepal, has not led to substantial population recovery over the last forty years, despite the release of over 1300 gharial. In this study we used radio-telemetry to investigate the survival and spatial patterns of 20 captive-reared juvenile gharial, ~5-8 yrs old when released in March 2019 and monitored for almost 2 years post-release.

Overall, our results highlight that, under these conditions, the headstarted gharial were unlikely to contribute to population recovery. We found post-release mortality rates were high, with 25-50% of gharial dying within two years of release, mostly due to bycatch in gill nets. Larger gharial did not show improved survival rates. Notably, one-third of the gharials did not settle in a specific river stretch, suggesting a failure to adapt to wild conditions post-release, with larger individuals less likely to settle than smaller ones. Dispersal distances ranged from 10 to 112 km, with most gharials moving 20-60 km from the release site, although some travelled much farther. The likelihood of a successful reinforcement via this headstart-release strategy is especially questionable 1) if human causes of mortality in-situ have not been eliminated, and/or 2) if release sites are close to river barriers such as dams.

Post-release monitoring using telemetry is an effective way to evaluate headstarting as a reinforcement strategy, and should be part of an overall adaptive management approach for conserving at-risk populations. These results support the growing body of evidence that in-situ conservation of gharial – such as habitat protection and elimination of direct mortality – are likely to be the most productive strategy in most instances. The cost/benefit trade-offs of headstarting gharial should be critically re-evaluated, ideally with a comprehensive programme of post-release monitoring that is well-designed and well-funded.

Introduction

Reinforcement, 'the intentional movement and release of an organism into an existing population of conspecifics' (IUCN/SSC, 2013), aims to enhance population viability of very small wildlife populations by increasing size above a critically low threshold (Seddon, 2010). One common form of reinforcement is headstarting. Headstarting involves collecting eggs or hatchlings from the wild, protecting them in captivity, and releasing them at a larger size, assuming that larger individuals will have higher survival rates due to reduced predation (Burke, 2015). However, many programmes fail to achieve sustainable recovery (Ballouard et al., 2010; Burke, 2015), with underlying causes often poorly understood (Bennett et al., 2017). Post-release monitoring is critical for assessing translocation outcomes (IUCN/SSC, 2013; Sutherland et al., 2010), especially identifying the reasons for failure (Parker et al., 2013). Therefore, evaluation of headstarting effectiveness requires post-release monitoring that is species-specific, population-specific, location-specific, and threat-specific. What works in one system may not be appropriate in other systems where some or all of the above differ.

The gharial is a large, riverine, primarily piscivorous crocodylian found historically in the Ganges, Indus, Brahmaputra and Mahanadi river systems (Lang et al., 2019). Despite the historically wide distribution of the species in South Asia, it is now confined to less than 14 isolated populations, of which only one, in the Chambal river, is a self-sustaining viable population (Lang, 2018; Lang et al., 2019). Listed as Critically Endangered on the IUCN Red List, conservation of the species is of national interest in range states, and international interest due to the evolutionary and functional uniqueness of the species (Griffith et al., 2023; Lang et al., 2019). Headstarting has been widely used as the major conservation intervention for gharial rangewide, since the initiation of Project Crocodile in India and the Gharial Conservation Breeding Centre (GCBC) in Nepal (Stevenson, 2015). Programmes have involved collecting eggs from the wild, rearing individuals in ex-situ local facilities, and releasing them as juveniles. By 2005, India had released over 5000 gharial (Whitaker, 2007), and in Nepal over 1700 by 2022 (DNPWC, 2022). Initially considered a success in the 1980s, these programmes were deemed largely ineffective by the early 2000s, (Ballouard et al., 2010; Whitaker, 2007) yet many still continue as the underlying reasons for failure were poorly understood.

In Chitwan National Park, Nepal, 1369 gharial had been released by 2021, yet the population by that time was just ~300 individuals, of which less than 50 were adults (Griffith, 2023). Therefore over 1000 released gharial appear to be 'missing'. Past work speculated that gharial were washed downstream over a barrage at the Nepal-India border, preventing their return (Ballouard et al., 2010; Maskey, 1989), but there was limited evidence to confirm this was the major issue, and populations downstream of the barrage remained low. Population surveys and resighting efforts were shown to be inadequate for post-release monitoring (Maskey & Percival, 1994). Radio telemetry offers a promising alternative, as VHF telemetry has been very successfully used for gharial monitoring in India by the Gharial Ecology Project (Lang & Kumar, 2016; Lang & Whitaker, 2010). The Chitwan gharial population is of conservation importance, and has been identified as part of a broader population with recovery potential in the draft IUCN gharial Green Status assessment (Ajji M et al., 2025).

In this study we used VHF telemetry to monitor 20 gharial released in Chitwan National Park in 2019. We assessed the effectiveness of using radio telemetry to determine fate, dispersal, and movement patterns in gharial. We hypothesised that VHF telemetry monitoring would provide more accurate mortality data, and enable us to investigate if downstream dispersal leading to one-way movement across the Nepal-India barrage was a major limiting factor for the Nepal headstarting programme.

Methods

Study Site and Conservation Programme

The major gharial population in Nepal is found in the rivers that border the Chitwan National Park in the south of the country. This the largest gharial population in Nepal (Acharya et al., 2017) although accurate population counts are challenging due to annual releases of up to 100 headstarted gharial, which tend to inflate and/or confound counts (Griffith, 2023). Gharial are found in the Narayani River, its major tributary the Rapti, and their tributary streams (Figure 1). Gharial are largely confined to protected river stretches within the park or its adjacent buffer zone. A large barrage at the India-Nepal border (Figure 1, red rectangle) signifies the end of Park protection, after which the river enters India and becomes known as the Gandak. The Gharial Conservation Breeding Centre (GCBC), located within Chitwan National Park, was established in 1978 by Nepal's Department of National Parks and Wildlife Conservation (DNPWC) in response to the near collapse of the local gharial population during the 1960s. Eggs for the headstarting programme are collected from in-situ nest sites and reared in captivity. Since 2004, most releases have occurred at the Rapti River site near Kasara (Figure 1, red circle). Gharials are released annually at 5-8 years old, typically in February or March.

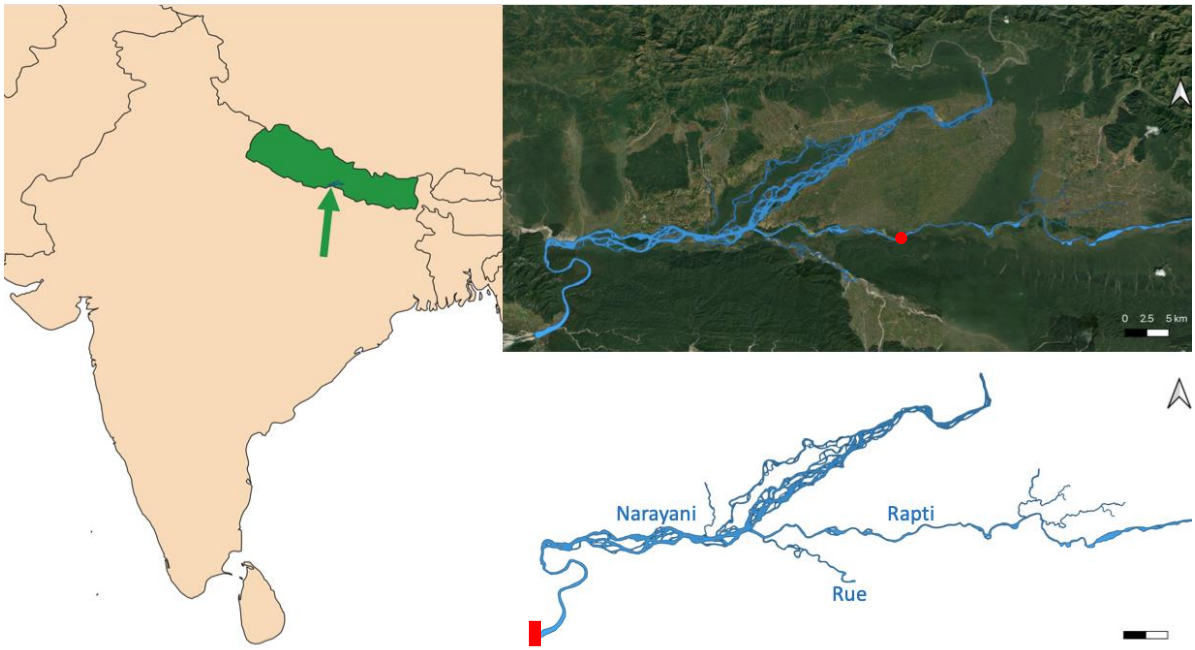


Figure 1. The location of the study site. Clockwise, from left: the location of Nepal in South Asia, with the central location of Chitwan indicated; satellite imagery of Chitwan with the river system superimposed for clarity, forested areas south of or within the river are the Chitwan National Park; the river system with the major rivers labelled. The red dot indicates the location of Kasara, where the headstart release site is located, and the red rectangle indicates the location of the barrage on the Nepal-India border. Adapted from Griffith (2023).

Tag Attachment, Release and Tracking Procedure

In March 2019, 20 juvenile gharials (170-197 cm) from the 2011 (n=11) and 2014 (n=9) cohorts were tagged with VHF transmitters (151 MHz; Advanced Telemetry Systems, USA) using the protocol of the Gharial Ecology Project (GEP, pers. comm.). Numbered cattle tags were also attached to assist identification. Morphometric measurements were collected including mass, snout-vent length, vent-tail length, total length, snout width, head length, head width, mid-body girth and sex. Gharial were soft-released at Kasara (Figure 1) using a temporary enclosure made of elephant grass beside the riverbank. The enclosure allowed gradual exit into the river as the grass barrier became permeable

with time. Releases followed the GCBC's standard protocol over March 8-10, 2019. Permission was obtained from the Department of National Parks and Wildlife Conservation, and ethics were reviewed by the University of Oxford (APA/1/5/ZOO/NASPA/WildCRU/Gharial).

The VHF-tagged gharials were manually tracked until the transmitters' battery life expired. An ATS R410 scanning receiver and a Yagi directional antenna were used to locate the animals weekly or monthly, depending on accessibility. Tracking included listening posts every 2-3 km and occasional boat-based tracking for precise GPS locations (Griffith, 2023). The Wildlife Trusts of India (WTI) also tracked missing gharials during a March 2020 survey on the Gandak River (WTI, 2020).

Analysis of Mortality

Gharials were classified as alive, dead, missing (presumed dead), missing (presumed dispersed), or unknown at the study's conclusion, namely 700 days, or almost two years. "Alive" indicated confirmed sightings after battery failure, while "dead" included recovered carcasses or body parts. Gharials presumed dead disappeared without evidence of dispersal, while those presumed dispersed exhibited increasing displacement trends before vanishing near the barrage on the border. Missing gharials with no clear evidence of fate were classified as unknown. Post-mortem inspections were conducted with veterinarians where possible. T-tests were performed to compare the size (total length, girth, and mass) of surviving and deceased gharials, treating unknown fates either as dead or excluded. A chi-squared test examined the relationship between survival and hatching year (2011 vs. 2014).

Analysis of Dispersal Distance and Settlement

Post-release dispersal was quantified using detection data converted to point locations, with distances calculated using a least-cost pathway along the river (Baker et al., 2022; Griffith, 2023). Gharials were classified as settled if their dispersal distance plateaued (reached an asymptote) within a 15-20 km home range for over 100 days. Those who died or were lost within 200 days were excluded. T-tests were conducted to compare the size of gharial that settled and did not settle, and a chi-squared test for association with year of hatching. All analyses were performed in R (R Core Team, 2021).

Results

Gharial were tracked for approximately 700 days post-release, or until death or loss of the individual. Of the 20 gharial released in 2019, just 10 were confirmed to still be alive at the end of the monitoring period (Figure 2). Five gharial were confirmed to be dead, all of which had strong evidence they had been killed by human activities (Table 1). T-tests for associations between the gharial fate and size (length $t(14)=0.01$, $p>0.1$, mid-body girth $t(14)=0.45$, $p>0.1$) and chi-squared test for age (X^2 $(1,18)=0.18$, $p>0.1$) found no significant differences between alive or dead gharial.

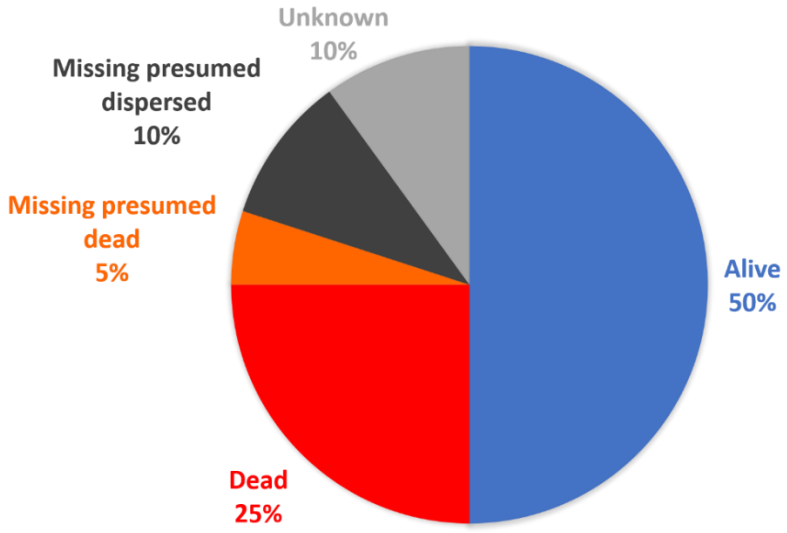


Figure 2: The fate of a cohort of 20 VHF-tagged released from the Gharial Conservation Breeding Centre in Kasara, March 2019, at the point of their last detection.

Most gharial showed highly variable dispersal distances for the first 180 days after release, corresponding to their first pre-monsoon and monsoon seasons post-release. Initially, 19 gharial initially moved downstream. The mean maximum recorded distance from the release site (dispersal distance) was 51 km (Table 1). The longest maximum dispersal distance recorded was 112 km, the shortest was 10 km, although it is possible two gharial dispersed further (missing presumed dispersed, Figure 2).

Gharial were categorised as "settlers" if their dispersal distance plateaued, or categorized as "non-settlers" if they had a continually changing or increasing dispersal distance during the 700 day study. Of the 15 gharial that survived in the study area long enough to be categorised, ten settled whereas five did not (Table 1). Gharial that did not settle were larger than those that did, shown by a t-test conducted on the size measures at release of mass ($t(13)=3.4$, $p=0.01$), length ($t(13)=4.2$, $p=0.01$), and mid-body girth ($t(13)=3.4$, $p=0.01$).

Table 1: The fate (alive or dead), settlement pattern (settler vs non-settler), age (hatch year), sex, and size (length, m=meter) of the 20 juvenile gharial monitored in this study via radiotelemetry, post-release at Kasara, Chitwan National Park, in March 2019.

Gharial	Fate	Settlement	Hatch Year	Max dispersal (km)	Final dispersal (km)	Detection time (days)	Length (cm)	Sex
F	Alive	Non-Settler	2011	72	71	704	185	M
G	Alive	Non-Settler	2011	58	58	754	191.5	F
S	Alive	Non-Settler	2011	83	59	754	183	F
B	Alive	Non-Settler: crossed barrage, then returned	2014	112	67	753	184	F
I	Alive	Settler	2011	31	17	654	177	F
J	Alive	Settler	2011	75	70	753	174	F
C	Alive	Settler	2014	10	4	766	175	F
D	Alive	Settler	2014	62	57	756	182	M
E	Alive	Settler	2014	84	84	703	173	F
A	Alive	Settler	2011	29	16	857	185	F
K	Dead: bones buried in forest	Settler	2011	32	16	674	173	F
R	Dead: drowning after net entanglement	Settler	2014	41	37	339	175	F
H	Dead: killed by blow to head after gill-net entanglement	Non-Settler	2014	57	57	239	197	F
L	Dead: killed by blow to head after gill-net entanglement	Settler	2014	51	51	342	181	F
Q	Dead: tail cut off and buried.	Non-Settler	2014	41	41	205	182	F
T	Missing (presumed dead)		2011	0	0	58	178	F
P	Missing (presumed dispersed)		2011	47	47	107	186	F
N	Missing (presumed dispersed)		2014	42	42	97	170.5	F
M	Missing (unknown)	Settler	2011	18	10	521	173	F
O	Missing (unknown)		2011	22	20	118	176.5	M

Discussion

Radio-telemetry is an effective methodology for gharial post-release monitoring

Our findings highlight the importance of incorporating telemetry into all gharial headstarting programmes to guide adaptive management based on local environmental conditions. This approach proved to be a valuable tool for post-release monitoring of gharial in Chitwan, enabling more accurate estimates of mortality rates, causes of death, and dispersal patterns than population surveys alone. By following individuals, we could determine individual movement patterns, as well as recover dead gharial that had been buried, were deep in the forest, or submerged. Telemetry-based monitoring may provide critical insights for improvements, particularly in river systems affected by barriers like dams.

Post-release mortality was high for headstarted gharial

VHF telemetry was critical for recovering bycatch gharial, and the lack of such post-release monitoring in the past may have led to the impact of this threat being underestimated. Post-release mortality in monitored gharial was unexpectedly high, contrasting with nearly 100% annual survival in similarly sized wild gharial in the Chambal River (GEP, pers. comm.). This raises concerns that headstarted individuals in Chitwan may have a lower probability of surviving to adulthood than their wild counterparts, particularly when combined with high captive mortality. Human-related killings, primarily due to drowning following gill-net entanglement or bludgeoning, were the main cause of gharial mortality. Most gharial deaths likely began with entanglement in fishing gear, highlighting the underestimated impact of bycatch-related threats.

Gharial declines in South Asia correlate with the introduction of monofilament gill nets in the 1950s-60s (Radhalekshmy & Gopalan Nayar, 1973). Bycatch-related mortality has long been a critical issue for gharial and other freshwater megafauna (Behera et al., 2013; Lang et al., 2019; Lu et al., 2014). Alongside river fragmentation due to the building of dams and barrages, by-catch is likely a key historical and ongoing threat. The failure to address this persistent issue, which contributed to original population declines, undermines the headstarting programme's effectiveness. Gill-net fisheries are illegal in Chitwan but remain widespread, especially at night, posing significant risks to gharial.

We speculate that releasing gharial at larger sizes may increase, rather than reduce, the threat of bycatch mortality. This is because headstarted gharial are first caught in nets at a large size, when they are already difficult for fishers to handle, so they are therefore likely to induce fear and be killed. Wild-hatched gharial are first caught at small sizes, when they are easy to handle and release, so may therefore have greater chances to learn avoidance behaviours.

One third of gharial did not reach a settlement phase

Post-release gharial exhibited typical translocation behaviours, starting with an exploratory phase marked by erratic movements and elevated mortality, with six deaths occurring during this period. After this, surviving ten of the gharial showed evidence of settling into a small home range, as is typical for juvenile gharial, generally in areas with a high density of conspecifics. One-third of released gharial failed to reach a settlement phase, with larger individuals particularly struggling. We suggest this could potentially be due to stress-related impacts from captivity or captivity-induced behavioural problems. These findings challenge the assumption that headstarting larger gharial improves survival, suggesting it may instead hinder settlement. This warrants further investigation, particularly into the release of smaller and younger gharial.

The impact of captivity on phenotypic traits has been highlighted as a concern for reintroduction programmes, including through different or relaxed selection, stress, and artificial social environments (Crates et al., 2023). Age of gharial upon release, and consequently length of time spent in captivity,

could have major pre- and post- release implications that should be investigated. Recaptured gharial from the headstarting programme in Chitwan had shown little to no growth in the first two-years post-release (Khadka et al., 2022), and an adult-size female gharial who had the oldest age at release (10.7 years) of any recaptured radio-tagged gharial did not breed for the three years she was monitored despite being larger than other breeding females (Griffith, 2023). These observations further raise concerns of the long-term impact of captivity on headstarted gharial. Understanding and reducing the phenotypic costs of captivity on gharial in headstarting programmes should be part of an adaptive management regime.

Gharial in our study were most likely to disperse 20-60 km

Most gharial dispersed a maximum of 10-120km downstream from the release site, with multiple gharial then moving back towards the release site before settling. Gharial in our study dispersed an average of 50km. While based on a small sample size (n=20), we suggest release sites less than 50km above a dams or protected area edge are likely to be unsuitable for gharial. Most long-distance downstream movements were in the first monsoon post-release, and for gharial that had already reached the larger Narayani river at the start of monsoon floods. Although most of the VHF tagged gharial dispersed less than 120km downstream, two untagged gharial from the 2020 release cohort travelled over 1000 km to West Bengal, but both faced poor outcomes, with one dying after stressful human encounters, and another removed to captivity (Khadka, 2020; WTI, 2020). These cases underscore that dispersal to areas outside targeted release zones is a conservation failure, necessitating efforts to mitigate such movements.

Headstarting as a tool for education and awareness

This study focused solely on the contribution of headstarting to population recovery in Chitwan, and we recognize that there are alternative conservation incentives for headstarting programmes, including education, awareness building, and improving understanding of gharial biology. Where the evidence suggests headstarting is not contributing to population recovery, but has separate conservation benefits, such programmes should investigate alternative options including short-term headstarting (holding gharial for months rather than years), limiting egg or hatchling collection to a much smaller number of gharial, and focusing on the headstarting of captive-bred gharial. Changes such as these will also result in greatly reduced costs for headstarting programmes, which can then be redistributed for other aspects of gharial conservation

Management Recommendations

1. **Adaptive management**
   - An adaptive management approach is widely seen as one of the best available frameworks for structured decision making to underpin effective reintroduction management (Keith et al. 2011; Nicholls & Armstrong 2012), allowing managers to account for high levels of uncertainty (Gillson et al., 2019).
   - We recommend gharial headstarting programmes adopt an adaptive management approach, using data on pre-release phenotypes and post-release survival and behaviour to continually improve approaches (Crates et al., 2023; McCarthy et al., 2012)

2. **Importance of post-release monitoring**
   - Essential to evaluate headstarting failures in gharial and other amphibious species.
   - Radio-telemetry provides critical data, including locating dead individuals, unavailable through population surveys.

3. **In-situ threats should be removed if headstarting is to succeed**

- The primary cause of gharial mortality in Chitwan is human-related killing, mainly illegal fisheries bycatch.
- Conservation programmes must first address root threats, like bycatch, to ensure effectiveness.
- Headstarting may inadvertently worsen bycatch issues by increasing gharial size at first entanglement.

4. **Recommendations for release site selection**
    - Release sites should be at least 60 km, ideally over 100 km, upstream of human river barriers.
    - In Chitwan, shifting the release site further upstream on the Rapti River could improve retention within National Park boundaries.
    - Similar dispersal challenges likely exist in other sites, including Bardiya, Corbett, and Katerniaghat, and this should be investigated.

5. **Considerations for husbandry and release protocols**
    - The phenotypic impacts of captivity on gharial should be investigated, with data on pre-release conditions compared to post-release survival and behaviour
    - Age and size of gharial at release should be investigated for each system, without the assumption that 'bigger is better'
    - Release sites should be on smaller tributaries rather than large rivers to limit downstream movement.
    - Post-monsoon releases are recommended to provide longer acclimation periods before the first monsoon.

6. **Headstarting as a tool for education and awareness**
    - Some headstarting facilities, such as the GCBC in Chitwan, play important roles in public education and awareness of gharial conservation
    - Rearing gharial for less than one year, and rearing a much reduced number of gharial, could enable the continued role of the GCBC (or other headstarting facilities) whilst minimising costs

Conservation Implications

- Headstarting gharial is likely to be ineffective for population recovery if the original causes of population decline continue, for example river barriers and bycatch in gill-net fisheries. Therefore, headstarting in the absence of concerted in-situ conservation efforts will result in failure for gharial, and likely all species of crocodylian.
- Holding gharial for longer times in captivity, and growing them to larger sizes, does not appear to have a positive effect on survival and post-release behaviour, and may even be detrimental. Age (developmental stage) of captive reared animals upon release in the wild might be one of the most significant and relevant variables in this whole head-start-captive release scenario, for gharial and other croc species generally.
- All gharial headstarting programmes should include targeted, telemetry-based post-release monitoring to inform ongoing assessment.
- All headstarting programmes should adhere to a system of adaptive management, and if evidence does not support the continuation of the programme, headstarting should be re-evaluated. Headstarting should be ceased if the sole objective is population recovery, whereas if there are educational and other benefits to programmes, re-designed programmes with fewer gharial held for shorter periods of time can continue to enable these objectives to continue
- Alternatives to headstarting, such as habitat protection (protecting nesting sites and nests in-situ) and working with fishermen to reduce bycatch (e.g. through providing training in gharial release and handling) should be centred in future gharial conservation efforts.

Acknowledgements

With huge thanks to my supervisors Jeffrey Lang, Samuel Turvey and Claudio Sillero. I gratefully thank my co-researchers in Nepal: Bed Bahadur Khadka, Prakash Basnet, Haribhadra Acharya, Alina Chaudhary, Babu Ram Lamichhane, Laxman Prasad Poudyal, and Bhogendra Rayamahji. Very many thanks to everyone who made this work possible, including the Gharial Conservation Breeding Centre team particularly Aitaram Bote, Prem Sharma, Ram Mahji, Bea Bahadur Bote, and Santa Bahadur Bote. Thank you to all Chitwan Chief Conservation Officers in-post during our work: Bed Badadur Dhakal, Narayan Prasad Rupakheti and Ananath Baral. Thank you to the staff of the Chitwan National Park and Department of National Parks and Wildlife Conservation. Kind thanks to the team of the National Trust for Nature Conservation Nepal, especially at the Biodiversity Conservation Centre, and the team of Himalayan Nature. Many thanks to the team of the ZSL Nepal Office past and present, especially Hem Sagar Baral, Bhagawan Raj Dahal, Shailendra Raj Giri and Bhogendra Rayamahji. Very many thanks to Jailabdeen and the Gharial Ecology Project team, and to Soham Mukherjee. I finally want to thank all of the fishermen and residents of the Chitwan Buffer Zone who helped us in finding our tagged gharial (especially once batteries died!): all advice, reports and observations were hugely useful and appreciated. Thank you to the IUCN SSC Crocodile Specialist Group Student Research Assistance Scheme, UK Trust for Nature Conservation in Nepal, National Geographic Society, Satch Kranz Conservation Fund and British Herpetological Society for funding the field research, and the UK National Environment Research Council for supporting Phoebe Griffith through the DTP in Environmental Research.

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