# SRAS Final Report: Gharial Recruitment at Katerniaghat Wildlife Sanctuary, Uttar Pradesh, North India: Augmentation with an In-Situ Riverside Hatchery, And Pre-Monsoon Hatchling Release

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The study examines the effectiveness of artificial nesting sites for gharials (*Gavialis gangeticus*) in the Katarniaghat Wildlife Sanctuary, India, and highlights the importance of suitable incubation conditions and habitat management for the species' survival.

## *Abstract*

The gharial (*Gavialis gangeticus*) is a critically endangered, freshwater crocodilian, endemic to the Indian sub-continent. The gharial population in Girwa River in Katerniaghat wildlife sanctuary has continued to nest along the Girwa River since 1976, subject to seasonal flooding in recent decades. In 2010, a natural flood upstream in Nepal resulted in a permanent reduction in the mainstream river flow. Consequently, the sandy substrates, open sand banks and mid-river islands, were converted gradually to riverbanks with woody vegetation. Gharial nesting sites and nest numbers declined by more than 40% by 2018. In an attempt to reverse the observed decline in nesting, we intervened with vegetation removal (VR) in 2019 and artificial sand addition (SA) in 2020, to augment available nesting opportunities at potential nesting locations. The number of nests increased with SA ($n$=36 in 2020) but were decreased with VR ($n$=19 in 2019), relative to the prior year without intervention ($n$=25 in 2018). Hatching success increased significantly to 93% with SA, compared to 63% in VR. Artificial sand banks were resource efficient as they required approximately one-third work hours and cost much less than removing vegetation, thereby reducing disturbance and resource needs by the forest department. Our study indicates that gharial will respond favorably to newly created sand banks that provide open, sandy riverside nesting areas, in contrast to sites with dense vegetation removed.

## *Introduction*

Gharial is a freshwater crocodile endemic to the Indian sub-continent. It has viable breeding populations in India and Nepal with at least two identifiable trans boundary populations in Karnali-Ghaghara and Narayani-Gandak Rivers. Landscape gharial habitat alteration resulted from the initial development projects, especially irrigation and electricity production via damming of rivers, in the 1960–70's in India. Gharials are excellent swimmers but lack effective terrestrial locomotion and hence resort to river channels for movement and dispersal. Furthermore, river damming altered the sediment transport dynamics of the channels, converted rivers in large reservoirs and permanently altered the sediment deposition-erosion processes. Gharial employ the riverine sandy substrates such as riverbanks and midriver sandbars for nesting, and having a temperature based sex determination (TSD) in hatchlings, further highlights the importance of good quality sandy sites. Gradually the habitat alteration augmented with hunting, nest poaching, fishing net entanglement and sand mining, reduced the gharial numbers to less than 200.

Girwa River in Katerniaghat hosts a wild breeding gharial population since the inception of Project Crocodile in 1975 and was one of the source populations for the captive rear and release program. However, the presence of Girijapuri irrigation barrage (=dam) at the confluence of Girwa-Kaudiyala Rivers limited the gharial habitat to <20 km in total with nesting restricted to a mere 10 km. In 2010, a channel shift diverted the main river flow from Girwa to Kaudiyala (Khanal et al. 2016) and augmented with the effects of the Girijapuri barrage, resulted in rapid vegetation succession on sandy substrates in Girwa (Figure 1 (a)). It led to decline in nest numbers and hatching success, and increased the egg and hatchling mortality (Vashistha et al. 2021a). My initial research focused on determining the long term trends of gharial population and habitat using primary data supported by secondary published sources which was analysed with EVI and GIS.

To counter the nesting decline, we experimented with *in situ* habitat restoration via vegetation removal at large scale (2019) and construction of artificial sand banks (2020). The SRAS supported the 2020 artificial sandbank construction to assist in gharial nesting.

## *Methods*

Study site

The Girwa River within Katerniaghat Wildlife Sanctuary (KWS) has a resident wild breeding population of gharials currently estimated at about 70 animals (Vashistha et al., 2021a). Gharial nesting habitat is restricted to a less than 10 km stretch of Girwa River, from Pathrahna to Madho nala inside KWS and juvenile recruitment has been poor (Vashistha et al., 2021a). Between 2015 to 2018, at least six (N2–N6, N8) of the Initially identified eight nesting sites in the study area (N1–N8) were under vegetation cover. By 2018, three of the eight initial sites were already abandoned (N5, N7, N8; Vashistha et al., 2021a). By late 2018, four additional sites (N2, N3, N4, N6) became inaccessible due to vegetation growth and were unfit for gharial nesting. In 2019, one additional site was identified for restoration, N9; and in 2020, two more sites were added, N10 and N11. Nesting sites on the Bhawanipur mid-river (BMR) sand bar in Girwa River have been consistently used for nesting (2015–2018) but were under dense vegetation cover. Sites N9, N10, N11 have had no prior history of nesting, but were chosen to apply the habitat restoration to verify whether gharials respond to these new artificial sites.

Therefore, to assess the restoration of nesting sites, we selected sites located on BMR (Table 1). Two different approaches were tested: (i) vegetation removal (VR) in 2019 and sand addition (SA) in 2020. We chose BMR for the assessment as it has been used for nesting for over a decade and large number of gharials including males were basking and breeding near the BMR owing to previous season habits and safety from human disturbance. The methods have been reported in Vashistha et al. 2021(b) in the journal *Ecological Solutions and Evidence,* and are being reported here verbatim to make them comprehensible for the reader.

**Vegetation removal**: VR was carried out at three sites: N4, N6 and N9, respectively (Figure 1(b), Table 1). A 30 m wide strip with total length of 1 km was marked parallel to the river bank on the three selected sites. This resulted in a total area of 3 ha under VR habitat management. The above-ground vegetation was manually cleared to allow movement of tractors (Figure 2(a)). Some portions of N4 and N6 were burnt to speed up the vegetation clearing process. We used a tractor to loosen the top layer (layer with most fibrous and lateral roots) and moved this entire layer (at least 1.5 ft deep) to the sides of the site (Figure 2(b) and (c)). Harrowing was repeated to loosen the underlying compact sand layer to allow it to dry and attain its natural moisture and texture. Remnants of deep roots from woody plants that

remained after harrowing were manually extracted. Shoreline of the VR-managed site had dense vegetation comprising *Saccharum spontaneum* and *Phragmites karka* that were half submerged and on the edges of managed sites. Consequently, gharials did not have access to the newly managed area. Therefore, while creating a slope, we moved the top layer on shoreline towards the river (Figure 2(d)). We did not attempt to remove vegetation in the water at the shoreline. All boat and human activities in the area were stopped after VR was completed.

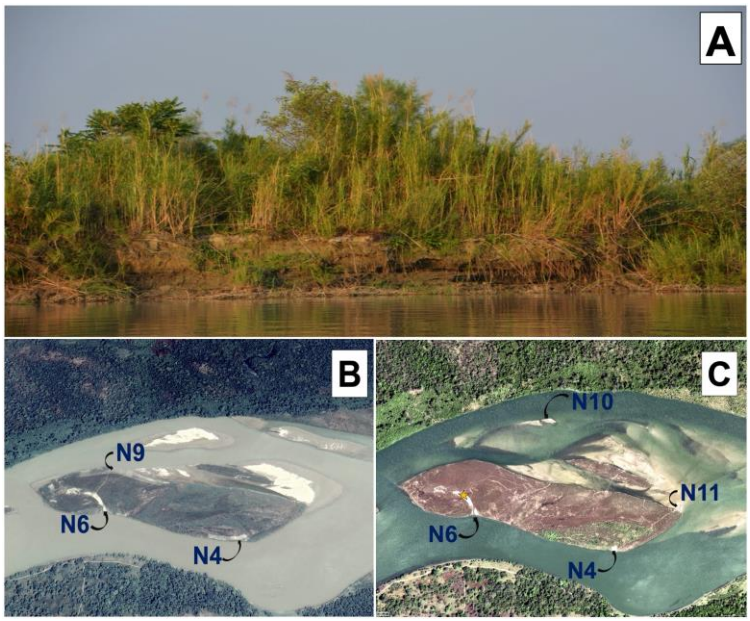



Figure 1. (a) shoreline view of a vegetated nesting site (site N5; Bhawanipur mid-river sand bar, Katerniaghat Wildlife Sanctuary) illustrating that the entire column of substrate above the water has root penetration. (b) satellite imagery of Bhawanipur mid-river sand bar showing vegetation removal sites in 2019 and (c) sand addition sites in 2020. Yellow star marks the site of sand collection in 2020.




Figure 2. Vegetation removal (VR) in 2019. Initially, a local crew cropped the vegetation to clear a path for the tractor (a). Subsequently, a tractor harrowed the substrate, disrupting the

underlying layer of roots (b) and (c). Lastly, a steep slope was constructed at the shoreline (d).

Table 1. Nest sites at five riverside locations on the Girwa river used by gharials during 2015–2020. RB = river bank, SB = mid river sand bar, 0 = vacant site, + = nesting (no counts), -- = no subsequent nesting. Experimental habitat modification in 2019 = Vegetation removal (VR), and in 2020 = sand addition (SA). Numerical values in each column indicate number of nests observed at each site with or without modifications.

| Location | Site no./ type | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|
| Pathrahna | N1/ RB | + | + | 3 | 5 | 13 | -- |
| | N12/SB | 0 | 0 | 0 | 0 | 0 | 2 |
| Amba ghat | N2/RB | + | + | 2 | 3 | -- | -- |
| | N3/RB | 0 | 0 | 2 | 1 | -- | -- |
| Bhawanipur ghat | N4/SB | + | + | 21 | 15 | 6 VR | 27 SA |
| | N5/SB | + | + | 1 | -- | -- | -- |
| | N9/SB | 0 | 0 | 0 | 0 | 0 VR | 0 |
| | N10/SB | 0 | 0 | 0 | 0 | 0 | 0 SA |
| | N11/SB | 0 | 0 | 0 | 0 | 0 | 0 SA |
| Cement tower | N6/SB | 0 | 0 | 0 | 1 | -- VR | 7 SA |
| | N7/SB | + | + | 1 | -- | -- | -- |
| Madho nala | N8/RB | 0 | + | 2 | -- | -- | -- |
| Total number of nests | | NA | 35 | 32 | 25 | 19 | 36 |




Figure 3. Sand addition (SA) in 2020. A local crew collected sand in recycled cement bags from Bhawanipur mid-river (BMR) sand bar (a) and transported it by boat to the selected sites (b). Sand was deposited to create artificial sand banks with a slope (c). Gharial and mugger crocodiles basking on artificially deposited sand at site N10 (d).

**Sand addition**: Four sites (N4, N6, N10 and N11) were selected for SA (Figure 1(c), Table 1). N4 and N6 had been used previously for the VR in 2019 (Figure 1(b)) but N10 and N11 were not studied prior to SA (Figure 1(c)). Extensive VR was not carried out during SA in 2020. However, owing to regrowth of vegetation on N4 shoreline, the above-ground vegetation (~0.025 ha) along the river edge was cleared to allow sand deposition. Sand was

sourced from a sandy patch at BMR with no vegetation growth (~0.2 ha). Sand was transferred to selected sites in recycled cement packaging bags using a motor boat (Figure 3(a) and (b)). To mimic natural sandy nesting sites, we constructed high sand banks with steep slopes (~0.025 ha area) on the shoreline of each site (Figure 3(c)). After SA was completed, all boat or human movements were stopped on those sites. Within a day or two of cessation of human activities, gharials and mugger crocodiles (*Crocodylus palustris*) started basking on these newly constructed sand banks (Figure 3(d)).

**Nesting data**: Morning boat surveys were conducted from late March to early April in 2018–2020 to locate trial and actual nests in the study area based on spoor marks and trial nests. Nest parameters such as GPS coordinates, distance from water, depth, etc. were collected. Egg laying was confirmed by manual search of possible sites. Data on clutch size and hatching was collected in June, only after the nests hatched. Hatching success was calculated as the total number of live hatchlings per total number of eggs laid in a nest.

**Soil temperature data**: Ibutton thermochron data loggers ((Maxim Integrated, USA, model DS 1921G-F5#) were installed to record substrate soil temperature data at non-vegetated and vegetated sites.

**Statistical analysis**: Statistical analyses were performed in R version 1.3.1056 (R Core Team, 2020). Normality of data distribution was tested with a Shapiro–Wilk test. Differences in means of non-parametric data (hatching success) were analyzed with a Kruskal–Wallis test followed by a pairwise Wilcoxon test with Bonferroni correction. Differences in means of normally distributed soil temperature data were analyzed with a one-way analysis of variance (ANOVA) followed by Tukey's post hoc test.

**Please note: The nesting season 2018 was used as a reference for analysis and data interpretation because no significant large-scale interventions were done to restore gharial nesting habitat till 2018.**

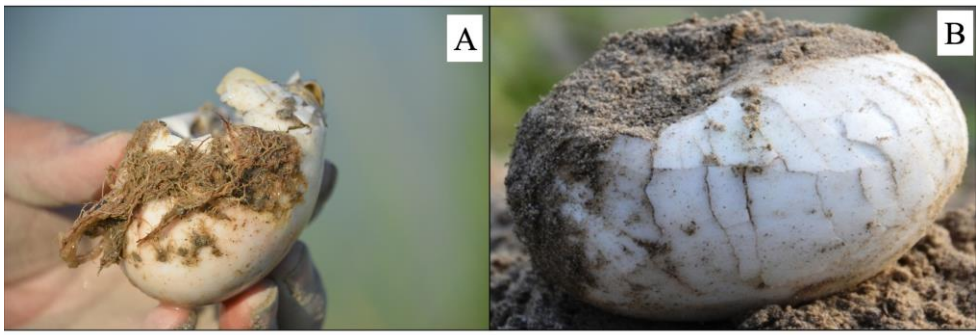



Figure 4. A gharial egg damaged by vegetation roots (a). Vegetation roots damaged the outer shell and penetrated the inner egg membrane, which exposed the embryo to external temperature and humidity, resulting in death of the embryo. A gharial egg damaged by compression from elephant movement (b). Compression damaged eggs had lateral cracks around the shell, with egg membrane remaining relatively intact. However, exposure to external factors, such as temperature and humidity, leads to infection, ant predation and ultimately death of embryo.

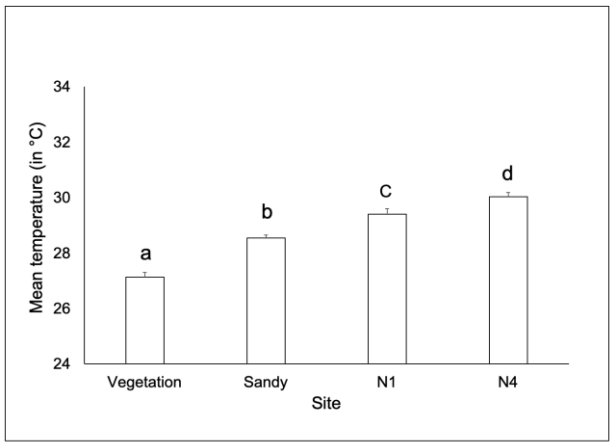



Figure 5. Differences in soil temperatures during the estimated thermosensitive period (15–45 days) during egg incubation at gharial nesting sites. Soil temperatures were lower at the vegetated site, relative to the other non-vegetated sites (sandy, N1, N4). Error bars indicate standard error of the mean. Different letters above the bars indicate significant differences in Tukey's post hoc test, $p \leq 0.05$.

### *Results*

1. The number of nests increased (nearly doubled) with Sand Addition (SA) but decreased with Vegetation Removal (VR). We recorded 36 gharial nests in 2020 compared to 19 in 2019 and 25 in 2018. 34 nests of the total 36 were laid on restored sites in 2020 compared to only six out of total 19 in 2019 (Table 2).
2. Hatching success increased significantly to 93% with SA, compared to 63% in VR.
3. No eggs were damaged due to vegetation root penetration (Figure 4(a)) or elephant movements (Figure 4(b)) in 2020 with SA.
4. Vegetated areas had lower soil temperature compared to non-vegetated areas (Figure 5).
5. The study found that gharials readily used the SA sites for nesting, with an increased hatching success observed in 2020.
6. I wish to highlight that found the year-to-year differences in the number of nests constructed in response to VR versus SA may have been influenced by possible disturbance levels related to VR in 2019.

Table 2. Gharial nesting in Girwa river after site management in 2019–2020. Unhatched eggs= damaged eggs+ infertile eggs+ embryonic deaths; VR= vegetation removal; SA= sand addition

| **Nesting parameter** | **VR (2019)** | **SA (2020)** |
|---|---|---|
| Total number of nests | 19 | 36 |
| Nests at managed sites | 6 | 34 |
| Mean clutch size (sampled nest) | 30.2±7.39 (15) | 30.08±6.071 (24) |
| Mean incubation period (in days) | 69.07±5.09 | 75.29±2.61 |
| Mean nest distance from water (in m) | 12.27±4.65 | 7.63±1.79 |
| Mean hatching success % (sampled nest) | 62.61 (10) | 92.53 (24) |
| Number of dead hatchlings | 12 | 4 |
| Unhatched eggs | 128 | 24 |
| Nests with vegetation roots at hatching | 11 | 0 |
| Eggs damaged by Vegetation roots | 24 | 0 |
| Eggs damaged by Veg. roots and Elephant movement | 39 | 0 |

Table 3: Difference in managed site use by gharials and resources used for site management.

| **Parameters** | **Vegetation removal** | **Sand addition** |
|---|---|---|
| Duration of completion | 1st week January–1st week March, 2019 | 4th week January–2nd week February, 2020 |
| Site use upon completion | Delayed | Immediate |
| Overlap with gharial breeding | Yes | No |
| Site used for basking | N4 | N4, N6, N10, N11 |
| Site used for nesting | N4 | N4, N6 |
| Time required in completion (days) | 40 | 15 |
| Approx. work hours | 5200 | 2500 |
| Approx. nesting area created (in ha) | 3 | 0.1 |

## *Conclusion*

Gharials will respond favorably to newly created sand banks that provide open, sandy riverside nesting areas, in contrast to cut-over sites with dense vegetation removed. The primary reason is availability of vegetation free, good quality sandy substrate. In vegetation removal, though the vegetation was removed, the change in the substrate due to presence of vegetation, remaining roots and seed bank resulted in regrowth of the vegetation causing egg shell damages, hardening of the soil and attracting herbivore primarily elephants to graze. Furthermore, clearing of vegetation provided the elephants a clear sandy path to cross river channel and for sand bathing, resulting in increased elephant movement on the restored sites. Cumulatively, vegetation regrowth and elephant movement caused significant damage to the nests.

SA is a more effective management strategy for gharial nesting sites than VR as it easier to implement than VR, requiring less time and labor (Table 3). In SA, we simply need to collect sand from one location and pile it up at the selected sites while creating a steep slope towards the river water. If substantial human power is involved, the work can be finished in less than a week. It doesn't disturb the gharials, doesn't disturb the vegetation layer and avoid regrowth and most importantly is not preferred by elephants, hence reducing nest damages.

Proximity of nests to water is important for gharial nesting success. Girwa river is experiencing low water flow and rapid vegetation succession which is made worse by the annual closure of barrage during incubation period (April–May). Hence, selected sites should have deep water nearby to provide the females access to the nests during nest laying and hatching time. Most importantly, it is pertinent that we rely on the animal's knowledge and select only those sites which the animal has favored and used for nesting in the past. We found that the gharials didn't nest on any newly built sites if it didn't have prior nesting history, thus showing serious site fidelity.

We recommend that the construction of artificial sand banks should be parallel to the direction of river flow on a firm substrate, with a gradual slope for land access and deep water nearby to facilitate animal movement during nesting and hatching.

Finally, artificial sandbanks are not the long term solution in an ecosystem such as Girwa river which is threatened with reduced water flow, rapid vegetation succession and controlled

by barrage gates. In the following years (2021–24), we have encountered problems with finding vegetation free sand, change in barrage gate opening/ closure timings without proper information and administrative barriers due to frequent changes in the forest officials. Collectively, it has resulted in reduced efforts to maintain this program and led to decline in gharial nesting again which is evident by 33 nests in 2022, 29 in 2023 and 22 in 2024 season.

## *Further work*

Considering the situation in Katerniaghat, we started surveying outside the protected areas to establish the status of gharial population. Our main objective was to verify the hypothesis that the low recruitment of gharial hatchlings in its parent population inside Girwa is a natural phenomenon and the hatchlings are getting dispersed downstream into Ghaghara River across the barrage and possibly taking residence. In February 2023, our survey in the first 100 km of Ghaghara River, from the Girijapuri barrage to Chahlari Ghat, observed 84 gharials in total (Vashistha et al. 2024). The population was slightly skewed towards smaller size classes as we observed 30 gharials in adult and sub-adult category but 54 in the smaller juvenile and yearlings category. We didn't sight any male gharials but three females with bulging abdomen suggesting possible pregnancy. None of the animals were tagged (cattle tag or scute marked) which suggest that either they are dispersed animals from Girwa or naturally born animals from Ghaghara. Cattle tagged or scute tagged gharials were released in both Girwa and Ghaghara Rivers in past years, however, we didn't record any tagged animals.

## *Acknowledgements*

We wish to acknowledge the Uttar Pradesh state forest department for providing us the necessary research permits to be able to study the gharial population in Girwa River. We specially thank the Katerniaghat Wildlife Division (KWD) for hosting us, providing us with boat and forest staff, to conduct our work and in supporting the habitat restoration work across last five years. Mr. Sanjay Pathak (IFS, Former Director Dudhwa Tiger Reserve) and Mr. Akash Deep Badhawan (IFS, Former Divisional Forest Officer KWD) played a crucial role to ensure our work was recognized and involved in the forest department's action plan. We like to thank Gulam, Lakshman and Guddu (front line staff, KWD) who dedicate all their efforts in supporting us to conserve the gharials of Girwa. They were invaluable to our project and still a part of our research in Girwa.

We thank IUCN CSG and its members who helped us design the *in situ* restoration in Girwa. We thank Gharial Ecology Project for supporting us with advice and equipment during the implementation of the sand addition method. Further, it was CSG's kind support through the SRAS which supported our field work in the 2020 breeding season.

Finally, we thank all the local community members who helped us implement the restoration work in 2019 and 2020, and contributed to the conservation of gharials of Girwa.

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