REPTILES & AMPHIBIANS

Population Changes in Gharials (*Gavialis gangeticus*) Vary Spatially in Chitwan National Park, Nepal

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Abstract.—Gharials, large crocodilians found only in South Asia, are widely seen as a flagship species for river conservation in Nepal, especially in Chitwan National Park, where a headstart program has supplemented the population since 1981. The population has shown signs of recovery only in the last decade, so continued monitoring of population trends is vital for conservation. We conducted annual winter population surveys for gharial in Chitwan between 2017 and 2022, during which we also characterized riverbank substrate availability and basking preferences. We documented potential threats to the species in Chitwan throughout the year. Overall, we counted an increasing number of Gharials in Chitwan; however mixed-effects modelling of Gharial encounter rate showed that increasing encounters rates are not evenly distributed throughout available habitat, with some river stretches having stable or decreasing trends. Encounter rates on the Rapti River increased in all transects, compared to more variable results on the Narayani River, likely attributable to higher levels of human disturbance and the impact of captivity on habitat selection. Fewer Gharials were seen in transects with high levels of disturbance due to sand mining and the extraction of river substrates, highlighting this threat as a major concern. Regular reports of bycatch in illegal gillnets was the major observed source of mortality. A lack of an increasing population trend in the stretch above a large barrage suggests that recruitment is minimal in this area, and the dam likely has a negative impact on upstream Gharial recruitment. We cautiously suggest that the Chitwan population is recovering, but that recovery is hampered by threats, especially substrate extraction, illegal gillnet fishing, and river fragmentation by a dam.

Gharials (*Gavialis gangeticus*) (Figs. 1–3) are large crocodilians of high conservation priority, due to the species' Critically Endangered status and high functional and phylogenetic distinctiveness (Lang et al. 2019; Griffith et al. 2023). Once widespread throughout South Asia, Gharials survive in only a few disconnected populations in India and Nepal, all of which, except the Chambal River population, are precariously small (Lang et al. 2019). Gharial conservation has led to patchy and often short-term successes (Whitaker 2007). Following estimates of fewer than 200 Gharial worldwide by 1976 (Whitaker et al. 1974), the Governments of Nepal and India promptly initiated conservation strategies that relied on 'headstarting' or 'rear-and-release,' aiming to bolster numbers of mid-sized Gharials to promote faster population increases (Maskey 1989; Singh 2018). By 2004 over 5,000 Gharials had been released into the wild, and surveys in the 1990s led to assumptions that populations were recovering and conservation had succeeded (Whitaker 2007). However, by 2006, fewer than 250 adult Gharials remained (Choudhury et al. 2007; Sharma and Basu 2004), showing the precarious nature of increases predicated on headstart programs without substantial efforts to remove threats, protect habitats, and engage those living alongside Gharials.

Recovery of gharial populations is therefore a long-term process, with increases from headstarting often short-lived. Understanding if recovery is taking place therefore requires repeated monitoring to understand population trends. One of the largest remaining Gharial populations is in Chitwan National Park, Nepal, where the population has been supplemented by a headstart program since 1978 (DNPWC 2022). Surveys in 2016 suggested rapidly increasing Gharial populations in Chitwan (Acharya et al. 2017). However, numbers of Gharials being released in Chitwan also substantially increased beginning in 2012, from an average of 18 per annum to 84

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Figure 1. Gharials (*Gavialis gangeticus*) in their natural habitat in the Rapti River and its tributaries in Chitwan, Nepal. Gharials basking on a typical sandy island, an important basking habitat used by Gharials of all age classes, Mugger Crocodiles (*Crocodylus palustris*), and wading birds. Photograph by Phoebe Griffith.

Figure 2. Two adult female Gharials (*Gavialis gangeticus*) basking on a small sandbar, illustrating the exceptionally long/thin jaw morphology that is unique among extant crocodilians. Photograph by Phoebe Griffith.

Figure 3. A young adult male Gharial (*Gavialis gangeticus*) with a "ghara," the unique distinctively enlarged tip of the snout in adult males. Photograph by Phoebe Griffith.

per annum since 2012 (DNPWC 2022). Consequently, it was difficult to determine if the 2016 surveys only showed short-term responses to recent releases. Continued monitoring of the population is vital for understanding whether this is the sustained increase in Gharial numbers required for population recovery.

Herein we report the results of winter surveys for Gharials over a four-year period (winter 2017–18 to winter 2021–22), showing that the increasing population trend in Chitwan continues. We looked at eight sections of the river system through time, with differing levels of National Park protection and infrastructure, to investigate how population trends differ spatially. We also investigated basking site selection by Gharials, as availability of different substrate types could influence Gharial occurrence and response to threats that impact substrates.

Methods

The Narayani River is a large, glacier-fed river that is part of the Gangetic Basin in Chitwan and Nawalparasi Districts of Nepal, before crossing the Nepal-India border where it becomes known as the Gandak River. The regional climate is humid subtropical, with a pronounced wet season from June to August (Gurung 1983).

Our survey efforts were concentrated on the final stretches of the Narayani River before the Indian border, and the lower 60 km of its major tributary, the Rapti River. These two rivers form the western and northern boundaries of Chitwan National Park, Nepal, a protected area since 1973. Surveys were conducted during the winters (December/January) of 2017–18, 2018–19, 2019–20, and 2021–22 (hereafter listed by the second year of each winter season). In 2022, we also surveyed 8 km of two tributaries of the Rapti (the Dungre Khola and Budhi Rapti Rivers) that pass through the buffer zone of the National Park.

Daylight surveys were conducted from traditional dugout canoes piloted by two experienced boatmen and travelling downstream. Winter was chosen for surveys as this is when Gharials spend most of the day basking, and therefore detectability is thought to be at its highest. Surveys were generally conducted between 1030 and 1630 h; however, if visibility was poor due to fog, surveys were delayed until visibility was adequate.

The survey team used binoculars to scan both sides of the river for any crocodilians and recorded all sightings of Gharials and sympatric Mugger Crocodiles (*Crocodylus palustris*). Based on visually estimated total lengths (TL), Gharials were classified into hatchlings (< 100 cm TL), juveniles (101–200 cm TL), subadults (201–300 cm TL), adult females (> 300 cm TL), and adult males (> 400 cm TL with a "ghara," a clear protuberance at the tip of the snout) (Lang and Kumar 2016; Bashyal et al. 2021). The GPS location and basking substrate (see classification below) of each Gharial were recorded.

Single daylight counts were conducted over consecutive days on all routes. Daylight counts are generally used for Gharials (e.g., Maskey 1989; Hussain 2009; Bashyal et al. 2021) (nocturnal surveys are not possible in Chitwan due to potentially dangerous terrestrial megafauna). Such counts provide an index of relative density, since not all crocodilians present will be observed during a single survey. However, since the relationship between count and population size is assumed to remain fairly constant over time (due to using the same methodology and team for each survey), changes in counts over time can be indicative of a directional change in the underlying population (Bayliss 1987).

Riverbank characterization.—In 2021, substrates were characterized by sampling the riverbank at 500-m intervals on both banks along each river transect (Hussain 2009). We used a slightly modified version of the classification scheme of Maskey et al. (1995). Sandy banks were comprised of banks of fine sand without vegetation. Mud banks were comprised of banks of fine clay with or without vegetation. Sand-grass banks were comprised primarily of fine sand with sparse vegetation cover, such as *Saccharum* spp. Rocky banks were comprised of stones with diameter of 50–250 mm.

Statistical analysis.—We determined distances travelled during each survey using GIS maps of the study site (TerraMetrics 2021). We divided the river into transects of 14.5–31.2 km based on sections with varying anthropogenic impacts due to varying levels of National Park inclusion and protection (Fig. 4; Table 1)

To identify increasing, decreasing, or stable trends in the Gharial population, we conducted a linear regression using the combined abundance data from each year as well as a model for each individual river (Rapti and Narayani).

To compare how changes over time differed between sections of the rivers, we calculated encounter rates for surveys conducted in each of the eight transects of our survey. Encounter rates were calculated as the number of Gharials observed per kilometer (Bayliss 1987). We used a linear mixed-effects model with transect as a random effect to determine if a change over time in encounter rates had occurred across all transects. Since transect-effect was considerable, we then conducted a linear model for each individual site to identify population trends in each transect.

To analyze whether Gharials appeared to be selectively choosing a particular substrate for basking, we conducted a chi-square analysis comparing the basking substrate of Gharials with the availability of each substrate type from our randomly selected sites.

All analyses were conducted using R statistical software v4.2.0 (R Core Team 2021).

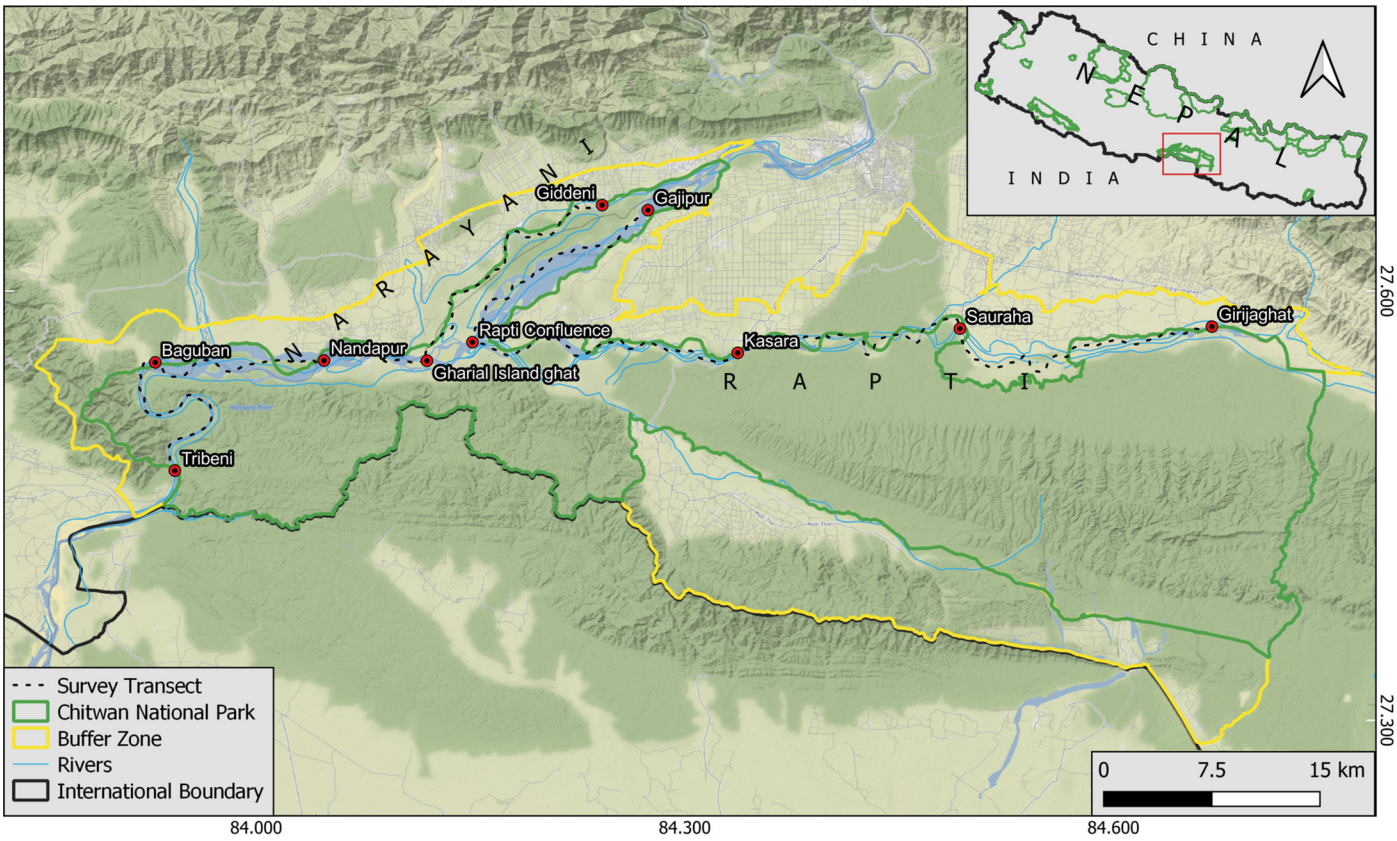

Figure 4. The Narayani River and its major tributary, the Rapti River, where Gharial (*Gavialis gangeticus*) surveys were conducted in 2017–2022. Key locations are indicated by red dots.

Table 1. The Narayani River and its tributary, the Rapti River, and the eight transects of the survey.

River Section	Settlements at Transect Start and End	Length (km)
Rapti (eastern)	Girijaghat to Sauraha	16.9
Rapti (central)	Sauraha to Kasara	21.4
Rapti (western)	Kasara to Rapti Confluence	19.7
Narayani (north, western)	Giddeni to Gharial islandghat	26.4
Narayani (north, eastern)	Gajpur to Rapti confluence	31.2
Narayani (central, eastern)	Gharial islandghat to Nandapur	16.7
Narayani (central, western)	Nandapur to Baguban	14.6
Narayani (south)	Baguban to Tribeni	19.0

Results

Abundance.—Surveys counted an increasing number of Gharials from 2018 (n = 148) to 2022 (n = 228) (Fig. 5A). The trend in overall numbers was best explained by a quadratic relationship, although this was not statistically significant (R^2 = 0.97, $F_{(1, 2)}$ = 51.65, P = 0.10). When split into the two rivers, a linear regression showed a significant increase over time in the Rapti River (R^2 = 0.92, $F_{(1, 2)}$ = 35.19, P < 0.05)(Fig. 4B), and a quadratic relationship significantly explained population change on the Narayani River (R^2 = 0.99, $F_{(2, 1)}$ = 1480, P < 0.05)(Fig. 4C).

Encounter Rate.—The linear mixed-effects model showed that, once site was controlled for (transect as random effect), Gharial encounter rate rose from an estimate of 1.1 Gharials per km in 2018 to 1.5 Gharials per km in 2022 (Fig. 6). Although the general trend is increasing, Gharial numbers differed considerably between sites (modelled here as the random effect). Encounter rates in transects varied between sites (Fig. 7). Those in transects in the Narayani River were either stable, increasing, or decreasing, whereas all three Rapti River transects had increased encounter rates.

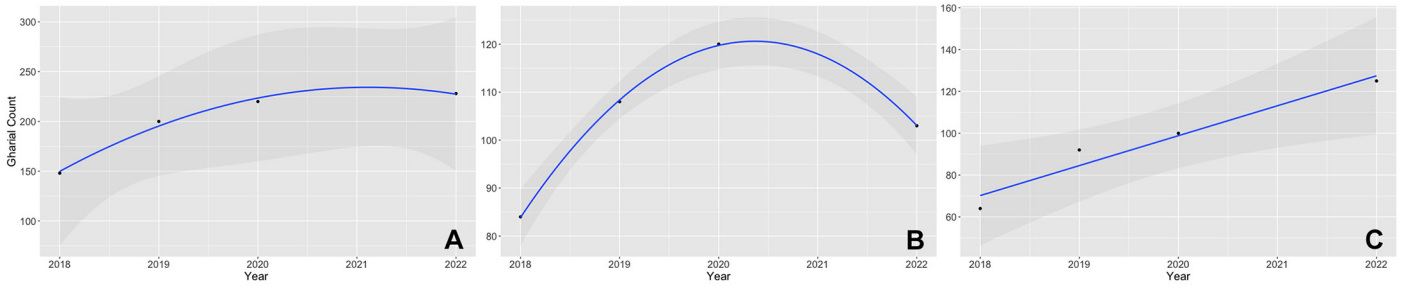

Figure 5. Scatter plot showing the total number of Gharials (*Gavialis gangeticus*) counted in each survey from 2018 to 2022 (A); total counts for the Narayani River (B) with quadratic regression; and for the Rapti River (C) with linear regression. Blue lines show the quadratic regression fit to data points and gray areas show confidence intervals.

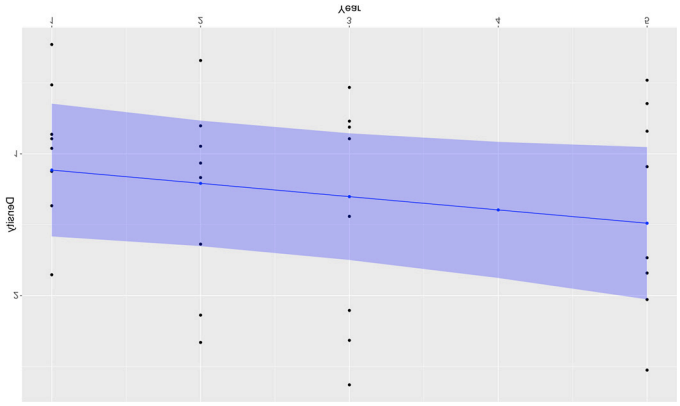

Figure 6. Results of a linear-mixed effects model showing how the encounter rate of Gharials (*Gavialis gangeticus*) in Chitwan National Park, Nepal (fixed effect), changed over time (2018–2022) once the random effect of transect was addressed. The blue band marks the upper and lower confidence intervals.

Riverbank characterization.—We characterized 728 sampling points at 500-m intervals over a total of 221 km of the two major rivers in the CNP (Narayani and Rapti) and two tributaries (Dhungre and Budi Rapti) (Table 2). Some habitat points could not be sampled due to inaccessibility. Overall, rocky and sandy banks predominated (Fig. 8). Along the Rapti River, rocky, sandy, and sand-grass banks were almost equally represented with highest proportion of sand-grass banks (Table 2). Along the Narayani River, rocky and sandy banks were almost equally represented and totalled more than 90% of sampled habitat points (Table 2). In contrast to the Rapti, sand-grass banks were present in only very low numbers along the Narayani.

Basking site selection by Gharials.—In both the Rapti (90%, n = 118) and the Narayani (99%, n = 102) Rivers, Gharials were predominately sighted on sandy banks. Gharial utilization of basking site substrates was significantly different from the availability of these basking sites ^{2} (3, N = 234) = 213.4, p = < 0.05. This suggests that Gharials were selectively basking on sandy banks.

Discussion

Surveys indicated an increasing number of Gharials from 2018 (n = 148) to 2022 (n = 228) (Fig. 2), with a consistent increasing trend in the Rapti River (from 64 in 2018 to 84 in 2022); however in the Narayani River, despite an increasing trend from 2018–2020 (84 to 120 Gharials), the number of Gharials counted in 2022 fell to 103. Changes in encounter rates suggest that population growth or decline varies between different parts of the river. Gharial population surveys using the same methodology generated an estimate of 166 Gharials in Chitwan in 2016 (Acharya et al. 2017), having increased from a disturbingly low count of just 39 individuals in 2005 (Ballouard and Cadi 2005). Consequently, Gharial numbers appear have continued to increase in Chitwan, although the rates of increase vary.

For this study we made the assumption that the relationship between count and population size will remain constant over time, and therefore that changes in counts reflect underlying directional trends in the population. However, detectability can vary between count days and years (Mazzotti et al. 2009; Barão-Nóbrega et al. 2022). The survey for winter 2021–22 was performed in December, whereas in previ-

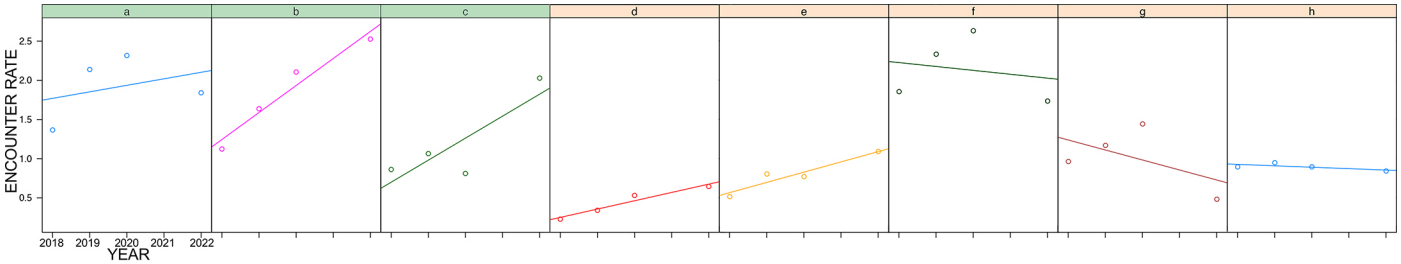

Figure 7. Encounter rates of Gharials (*Gavialis gangeticus*) in river transects during the winters 2018–2022. Sites a–c (green) are in the Rapti River, whereas sites d–h (orange) are in the Narayani River (see Table 1 for transect details). Trendlines show the linear changes in encounter rates for each site.

Table 2. Proportion of different substrate types at sampling sites along rivers in Chitwan National Park, Nepal, and the substrate type at basking sites of all Gharials (*Gavialis gangeticus*) recorded during surveys in winter 2021–22.

River	Substrate type	No. (proportion) of sampling points	No. of Gharials
Rapti	Rocky Bank	76 (0.33)	3
	Sandy Bank	65 (0.28)	118
	Muddy Bank	4 (0.02)	0
	Sand-grass Bank	85 (0.37)	4
	Total	**230**	**125**
Narayani	Rocky Bank	232 (0.48)	1
	Sandy Bank	217 (0.45)	102
	Muddy Bank	4 (0.01)	0
	Sand-grass Bank	27 (0.06)	0
	Total	**480**	**103**
Dhungre	Rocky Bank	0 (0.00)	0
	Sandy Bank	0 (0.00)	0
	Muddy Bank	6 (1.00)	2
	Sand-grass Bank	0 (0.00)	0
	Total	**6**	**2**
Budi Rapti	Rocky Bank	0 (0.00)	3
	Sandy Bank	2 (0.17)	0
	Muddy Bank	5 (0.42)	0
	Sand-grass Bank	5 (0.42)	1
	Total	**12**	**4**

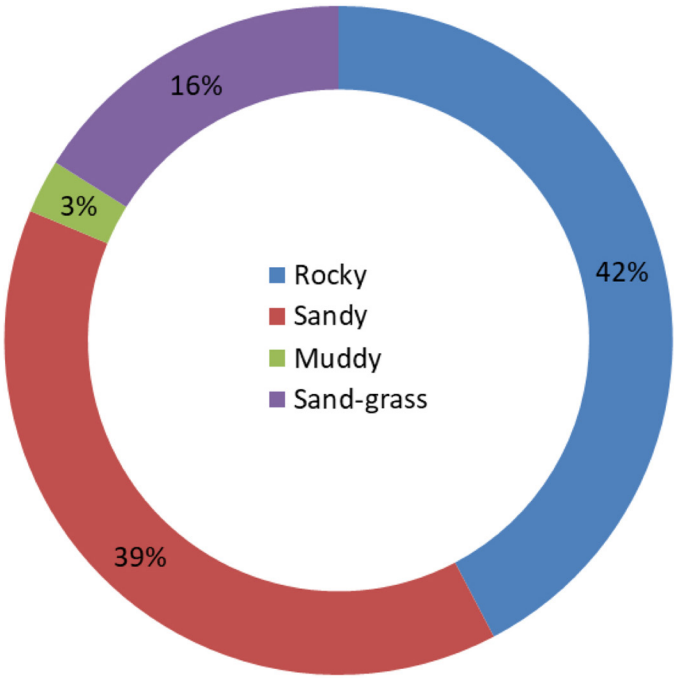

Figure 8. Proportion of different riverbank substrates at 728 sampling sites along the Narayani, Rapti, Dhungre, and Budi Rapti Rivers in Chitwan National Park, December 2021.

ous years surveys were done in January. This may have led to lower detectability as the weather is warmer in December. Similarly, weather can affect detectability, with days of clear, sunny weather expected to have higher counts. However, this is unlikely to have impacted our observed trends, as the only year with overcast conditions was 2020, when we had the highest counts. Furthermore, we used the same methodology and highly experienced team of observers each year, minimizing potential count variation.

The population increases from 2005–2022 suggest that the release of Gharials from the headstart program is resulting in at least some released Gharials surviving and being recruited into the resident population. However, a majority of released Gharials (1,369 released before 2022) apparently are still being lost from the system, an issue that has been persistent throughout the program (Maskey 1989; Ballouard et al. 2010). Between the first and last surveys in this study, 404 Gharials were released; however, the count only increased by 80. We therefore call for continued research into causes of Gharial mortality in Chitwan, and post-release monitoring of individuals released from captivity. Mortality from illegal fishing gear remains high in Chitwan (Khadka, unpubl. data) and an unknown number of released Gharials disperse downstream into the Gandak River in India (Khadka 2020a).

Although the overall trends indicate a slowly growing population, declining counts on the Narayani River in 2021–22 are cause for concern. To further investigate these declines, we examined changes in encounter rates in different transects across the river. Gharials are mobile and able to migrate hundreds of kilometers (Lang and Kumar 2016); therefore changes in encounter rates in different transects could indicate that Gharials are either moving to different winter habitats between years. Either way, declining encounter rates indicate the presence of threats to Gharials in the areas where the declines occurred.

Two transects on the Narayani River (Gharial Islandghat to Nandapur and Nandapur to Baguban) had declining trends in encounter rates, largely driven by considerably lower counts in winter 2021–22. This is likely due to two interacting factors. Excessive sand mining and boulder extraction is ongoing near Thumsi upstream of these transects. This area is outside the National Park buffer zone, and therefore more vulnerable to unsustainable extraction. This extraction over multiple years appears to have altered the river flow, diverting more water toward the Eastern Channel of the Narayani and

therefore reducing the suitability of western channel habitat. Secondly, severe flooding in the Nandapur area in June 2021 severely altered feeder streams and reduced the number of suitable basking sites, likely causing Gharials to move to other sites. Similarly, one transect on the Rapti River (Girijaghat to Sauraha) had lower encounter rates in 2021–22. Considerable boulder extraction from feeder streams in the buffer zone of Girijaghat in recent years likely impacted the Gharial population and river structure hydrology. Declining encounter rates in areas with high levels of river substrate extraction highlight the need for research into how to conduct extraction in a sustainable manner while minimizing negative impacts.

The most stable trend was in the final transect of Baguban to Tribeni. In this transect, river channels converge into a single deep channel that cuts a gorge through the Churia Hills. This section of river has core National Park on both banks and access is exceptionally difficult. Consequently, little to no anthropogenic disturbance or illegal fishing occurs in the area, which has good basking and nesting sites and two resident males. This likely leads to resident Gharials remaining in the area (or repeatedly migrating back to this area before winter, when the surveys were conducted). The lack of an increase in this population suggests that headstarted Gharials are not settling here, and hatchlings from this area are not being recruited into the local population. This could be due to the downstream dam, through which young Gharials might pass during post-release or post-hatching dispersals, and then be unable to return, whereas adult Gharials can avoid the dam. However, the habitat might be more suitable for adults and subadults than for juveniles. This situation is similar to the Babai River in western Nepal, where a 46-km protected stretch is upstream of an irrigation weir, with an unprotected stretch farther upstream. Gharials there appear to restrict their spatial distribution to the protected stretch (Bashyal et al. 2021).

Our findings that Gharials preferentially bask on sandbanks in both river systems, regardless of the availability of these substrate types, support the results of other studies (Hussain 2009; Neupane et al. 2020). These sandy banks made up 45% of sampled sites on the Narayani, and just 28% on the Rapti. Considering these proportions, and that the Narayani is a longer and larger river, one might suspect to find a higher Gharial density on the Narayani; however, densities were generally higher on the Rapti River. Observations during field surveys suggest that threats and disturbances are present on both rivers, with some stretches of the Narayani River having less disturbance than on the Rapti. Consequently, the higher densities on the Rapti could at least in part reflect the fact that Gharials from the captive-breeding program are released on the Rapti River, so counts may be inflated by recently released individuals. However, the number of nesting adults is also higher on the Rapti (Khadka 2020b), which is not explained by recently released Gharials. We suggest that this difference could show a preference of the captive-reared animals for the warmer water and lower flow rate of the Rapti River. This could be a learned preference after spending their first 5–6 years in captivity, and certainly is an important area for future research.

Gharial recovery due to headstarting programs in India has previously seen remarkable recoveries followed by equally dramatic declines (Whitaker 2007), so we interpret the overall increasing trend with cautious optimism. The importance of regular surveys to monitor population trends and of in-depth monitoring and evaluation to investigate the impact of conservation interventions cannot be overstated. The slow recovery of Gharials in Chitwan is just beginning, and Gharials must remain a priority species for conservation action if such recovery is to be sustained into the future.

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