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A multi-method approach for the inventory of the adult population of a critically endangered crocodilian, the Gharial (*Gavialis gangeticus*) at Dhikala, Corbett Tiger Reserve incorporating direct counts and trail cameras

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The Corbett Tiger Reserve (CTR), a very highly rated protected area in the State of Uttarakhand, India, is home to the third largest breeding population of adult gharial globally. It contributes 20% to the estimated global population of 200 - 250 adults of the taxon and it is also the only known population of the taxon which lives predominantly in a lake-like environment. CTR was surveyed for gharial in 2008 which was the first systematic survey with regard to the taxon since 1974 and the meta-population here was found distributed amongst six sub-populations in the Sarpduli, Dhikala, Kalagarh, Sonanadi, Palain and Adnala Ranges of the Reserve. This paper documents a multi-method approach for the estimation of gharial at Dhikala (Dhikala Range) namely: at the confluence of the Ramganga River with the Kalagarh Reservoir. It details the use of trail cameras combined with boat surveys along the shoreline and stationary counts for estimating the adult population of gharial at Dhikala, the site of the largest sub-population of gharial in CTR. Using this multi-method approach to count basking animals, we estimated the adult population in the area to consist of 32 adults (inclusive of seven adult males) based on the maximum ± minimum (MM) method. We also considered the unknown proportion of adults that may have gone undetected during these surveys by subjecting the data to a Double Sampling analysis. The results are indicative that we were able to sample 88.9% of the adult gharial population at Dhikala using this Multi-Method Approach. Based on our three population estimates (n= 29, 32 and 36) we averaged the adult population at Dhikala as 32.3 ± 1.69 adults (Mean ± SE) with an encounter rate of 4.01 ± 0.33 adults km^{-1} over 8.06 km of shoreline. Further, comparing population estimates between 2008 and 2013 based on the maximum ± minimum (MM) method, we estimated that the number of adults in Dhikala increased by 77.8% between 2008 and 2013. This increase in adult gharial numbers detected in the study area between 2008 and 2013 is primarily a result of: (1) Improved survey techniques which detected more number of animals in the area due to the cumulative effects of population growth from sub-adults to adults, in-migration and the possibility of some animals being missed during the 2008 surveys; (2) improved knowledge and familiarity with the study area; (3) effective protection measures already in place in CTR particularly in Corbett National Park (CNP), which has allowed the adult population to increase naturally without any disturbances. The ability of this multi-method approach in detecting these changes in numbers is important for monitoring the taxon and studying population trends within CNP.

Key words: Gharial, *Gavialis gangeticus*, Corbett Tiger Reserve, Corbett National Park (CNP), trail cameras.

INTRODUCTION

The gharial (*Gavialis gangeticus*), which is a freshwater crocodile endemic to the North Indian Sub-Continent, was categorized as Endangered up until its up listing to Critically Endangered in 2007. The population at present is estimated at no more than 200 - 250 adults globally (Choudhury et al., 2007 in IUCN, 2013).

The factors identified for the decline of the gharial population in the past 60 years have been over hunting for skin and trophies, egg collection for consumption, killing for indigenous medicine, and retaliatory killing by fishermen. Dams, barrages, irrigation canals, siltation, changes in river courses, artificial embankments, sand mining, riparian agriculture and land use changes to accommodate domestic and feral livestock have all caused irreversible loss of riverine habitat contributing to limiting the range of the taxon. These threats continue to increase further threatening the very survival of the species (Whitaker et al., 2007).

Until 2008, Corbett Tiger Reserve (CTR) was home to very few gharial, with limited breeding success and therefore with a negligible contribution towards the global gharial population. Due to these factors, the gharial population in CTR has never been surveyed systematically and thus remains one of the least studied and therefore least understood of the global gharial populations. The Reserve was systematically surveyed for Gharial in the winter month of February, 2008, which was the first systematic survey conducted on the taxon since 1974 (Whitaker, 1979), by counting basking animals and the meta-population in CTR was estimated to consist of 42 adults, inclusive of 10 adult males and 59 smaller size classes distributed amongst six sub-populations. These were the Ramganga River (Sarpduli and Dhikala Ranges), Dhikala (Dhikala Range), Gaujeda (Adnala Range), Palain River (Palain and Adnala Ranges), Sonanadi River (Sonanadi Range) and Boksar (Kalagarh Range) sub-populations. These surveys confirmed that CTR is home to the third largest population of the taxon globally and contributes 20% towards the 200 - 250 estimated global adult population. The Gharial meta-population in CTR may best be described as an endemic as it is a closed population. It is also the only known population of the taxon which lives and breeds predominantly in a lake-like environment (The Wildlife Chronicles www.subirchowfin.blogspot.com).

Two hundred and fifty seven (257) captive breed gharial were also released in CTR and these releases were limited only to a 40 km stretch of the Ramganga River. It was estimated from these releases that only eight individuals survived to adulthood (Rao et al., 1995). Available data indicate that these releases were conducted in eight batches between 1985 and 1994 (pers.comm. Basu, 2008) (Table 1). However, data on the size classes of the animals released was unavailable.

Table 1. Gharial release, CNP (pers.comm. Basu, 2008).

Date of release	Numbers released
24 March, 1985	16
24 March, 1985	11
12 April, 1990	40
27 March, 1991	25
20 November, 1991	55
4 February, 1993	35
6 March, 1994	25
12 March, 1994	50
Total	257

With no further releases for the next 20 years, corresponding to a generation length of the taxon since the last releases in 1994, the Corbett meta-population sustained itself during this period and indicates that some of the gharial sub-populations in CTR, like those found in Boksar, Palain and Sonanadi, may have lived and breed largely undetected, being a part of the original gharial meta-population in CTR which remained unknown until the surveys conducted in 2008.

Surveys in 2008 and since suggest that the recruitment of gharial in CTR is primarily through natural regeneration as is evidenced by the current population structure of gharial in Corbett National Park (10 adult Males, 39 adults, 16 sub-adults, 4 juveniles, 2 yearlings and 350-400 hatchlings recorded in surveys this far and which are in progress) as well as the presence of nesting areas (Chowfin, 2010, 2011; Chowfin and Leslie; 2013).

MATERIALS AND METHODS

Study area

The core area of CTR, formerly known as Hailey National Park, was the first such Park to be created in India in 1936. It was renamed Corbett National Park in 1956-1957 and declared a Tiger Reserve in 1991. The reserve is situated at the foothills of the Western Himalayas in the civil districts of Nainital, Almora and Pauri Garhwal in Uttarakhand and encompasses an area of 1288.3 km². This is comprised of 520.8 km² of Corbett National Park, 301.1 km² of Sonanadi Wildlife Sanctuary and the remaining 466.3 km² are buffer areas. The reserve lies between Latitude 29°25′N to 29°40′N and Longitude 78°5′E to 79°5′E. Geologically, the park belongs to Shivalik formations composed of conglomerates, sand, rocks, stones and boulders. The altitude varies from 330-1200 m with undulating topography. The building of the Kalagarh Dam in 1974 on the Ramganga River led to the formation of the Kalagarh Reservoir (84 km²) altering riverine habitat in CTR along the Ramganga River to a predominantly lake-like habitat. The aquatic habitat in CTR consists of the Mandal, Palain and Sonanadi rivers which are tributaries of the Ramganga River within the Reserve, the 84 km² Kalagarh Reservoir and numerous mountain springs called *sots*. The IUCN WCPA recognizes Corbett National Park as a

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Table 2. Gharial size classes, 2011 - 2012.

Adult male with Ghara	Adult w/o Ghara	Large adult	Medium sized adult	Small adult	Large Sub adult	Small Sub adult	Large juveniles	Small Juveniles	Yearlings	Hatchlings
> 4 m	> 4 m	3.6 - 4 m	3 m - 3.6 m	2.7 - 3 m	2.4 - 2.7 m	2.1 - 2.4 m	1.8 - 2.1 m	0.9 - 1.8 m	0.6 - 0.9 m	0.3 - 0.6 m
>400 cm	>400 cm	360 - 400 cm	300 - 360 cm	270 - 300 cm	240 - 270 cm	210 - 240 cm	180 - 210 cm	90 - 180 cm	60 - 90 cm	30 - 60 cm

Table 3. Gharial size classes, 2013.

Adult Male with Ghara	Adult w/o Ghara	Adult	Sub Adult	Juvenile	Yearling	Hatchling
> 4 m	> 4 m	2.7 - 4 m	2.1 - 2.7 m	0.9 - 2.1 m	0.6 - 0.9 m	0.3 - 0.6 m
>400 cm	>400 cm	270 - 400 cm	210 - 270 cm	90 - 210 cm	60 - 90 cm	30 - 60 cm

Category II Protected Area and the Sonanadi Wildlife Sanctuary as a Category IV Protected Area.

The study area in Corbett Tiger Reserve is limited to the following Ranges: 1) Sarpduli (Corbett National Park); 2) Dhikala(Corbett National Park); 3) Kalagarh (Corbett National Park); 4) Sonanadi (Sonanadi Wildlife Sanctuary); 5) Palain (Sonanadi Wildlife Sanctuary); 6) Adnala (Sonanadi Wildlife Sanctuary).

Use of Trail cameras to monitor wildlife populations

Trail Cameras are a powerful tool in the management of wild animal populations and data can be collected on presence/absence, animal movement and range size, minimum population size, demographic data (for example buck:doe and fawn:doe ratios), identifying nest predators, or cataloging vertebrate diversity.

Trail cameras have been extensively used in estimating densities of tigers, bobcats, snow leopards, jaguars, leopards etc by Capture - Recapture methods which are possible by studying pelage patterns in the identification of individuals (Larrucea et al., 2007) while Tobler et al. (2008) demonstrated the effectiveness of camera traps for inventorying large- and medium-sized terrestrial animals.

With regard to crocodilian species, trail cameras have proved valuable in monitoring nest predators as demonstrated by a study of *Crocodylus johnstoni* nests in Lake Argyle depredated by dingos (Somaweera et al., 2011).

Methodology

The Dhikala sub-population is found at the Ramganga - Kalagarh Reservoir Confluence in CNP which consists of mud-flats and sand banks with the Ramganga River bifurcating into two before it joins the reservoir. The distribution of mud flats and sand banks undergo seasonal changes depending on monsoonal rains in the Ramganga Catchment of the Central Himalayas of Uttarakhand. Estimating the gharial sub-population in Dhikala is very challenging and thus ideally best conducted by first observing the topography of the mud-flats and sand banks along with the distribution of basking gharial in the area, before starting the actual count.

To estimate the population of adults in the area, we first used the maximum ± minimum (MM) method. Messel et al. (1981 in Seijas et al., 1999) described this method as calculating the population structure of crocodiles using the maximum number of individuals in a particular size category, regardless of the survey in which they were observed. This is then assumed to be the best estimate for that particular size class for that year.

Using a single observer, surveys in 2008 were conducted in February using a 3.6 m fibre-glass boat (fitted with a 25 Hp petrol engine) by moving along the shoreline. Observations of basking gharial were made from the boat using a pair of Nikon 7x binoculars and basking gharial were assigned to pre-determined size classes based on these ocular estimates.

To estimate the population size of gharial in CTR in 2011-2012 a size classification was predetermined (Table 2) with the aim of detecting minor changes in population structure over a multi-year period. However, during field surveys, it was found that such a size classification was ambitious and unworkable in most situations being affected by sighting distances between the observer and animals. This often led to difficulties in size classification. In addition, approaching gharial by boat to reduce sighting distances often resulted in disturbing them, causing the animals to swim back into the water.

To overcome these difficulties, a revised size classification was used in 2013 so as to classify animals from an observable distance without disturbing them during the count (Table 3). This size classification was found workable during field surveys and there was minimized chance of error during data entry in the field when undertaking visual observations.

To estimate the population of adults at Dhikala in 2013, surveys were conducted during February (winter) using a multi-method approach to count basking gharial. This multi-method approach included the use of trail cameras, boat surveys along the shoreline, stationary counts and a

Map 1. Demarcation of Dhikala into three sections for purposes of surveys, CTR.

Single Observer as part of this exercise. Survey routes and field events were recorded on a Garmin 72H GPS unit while photographs for photographic enumeration were taken using a Canon 1000D camera attached to a Celestron Spotting Scope at 20x and 40x magnification. Nikon 10 × 50 Binoculars were used for scanning the area for basking groups and individual basking gharial. While conducting boat surveys along the shoreline we used a 3.8 m inflatable boat fitted with a Torqeedo 1003 s Electric Boat Engine, with low decibels as compared to a petrol engine. Advantages included fewer disturbances to the animals as well as being able to access shallower sections of the shoreline.

The study site at Dhikala was first categorized into three areas / sections as was done in 2008 for the purpose of the count (Map 1). These were: 1) The Dhikala Channel; 2) The Dhikala Channel to Phulai Channel Area; 3) The Phulai Channel.

Systematic surveys of these sections were conducted by repeated boat surveys along the shoreline totaling 32.2 km. The average survey route was 8.06 km in length while shoreline surveys between Dhikala and Gaujeda were 16 km in length. We also conducted stationary counts using 1 h class intervals along with photographs of basking congregations and individual gharial and placed trail cameras in the area. Basking gharial from visual observations during surveys by boat along the shoreline and stationary counts were enumerated on the spot and placed into predetermined size classes as detailed in Table 3. Additionally, basking groups were also photographed for photographic enumeration especially in locations where trail cameras were not placed but where gharial congregated along the shoreline (Figure 2).

Prior to the start of the survey, we observed the area for two days to identify “trap spots” which can best be described as locations used by gharial basking groups along the shoreline. We used this approach for positioning cameras so as to maximize photo captures due to the availability of only a few cameras (n = 3). Once these sites were identified, gharial spoor at these locations were used as a reference for the placement of trail cameras by keeping a minimum of 10-15 m between the spoor and the camera. Three time lapse trail cameras were placed at different locations where basking gharial congregated along the shoreline.

The cameras were placed before the start of the day long basking schedules between 7:00 to 8:00 h and were removed once basking schedules and gharial numbers decreased after 16:00 h. Specific spots for placement of trail cameras at a site varied daily; however, the general locations remained broadly the same (Map 2). A time lapse interval of 10 s was set on each trail camera. Camera images were studied to determine group sizes and cohorts of basking congregations (Figure 1). The trail cameras helped in demarcating the study site into more manageable counting units by performing stationary counts at these so called “Trap Spots”. This had the added advantage of reducing the number of surveys

Figure 1. Time Lapse Sequence from a “Trap Spot” of basking Gharial of various size classes, Dhikala, CTR.

conducted by boat thereby reducing disturbances in the study area during surveys and errors that could occur during Direct Counts from Observers (Ogurlu et al., 2013), leading to improved counts at the study site.

Ocular estimates were conducted during boat surveys and whenever possible gharial were also photographed for photo estimates while stationary counts from vantage points were undertaken with counts being conducted every hour. A day’s count at the end of each day’s survey consisting of gharial numbers from boat surveys, stationary counts photo enumeration and trail cameras was tabulated and the population of adults was estimated using the Maximum ± Minimum (MM) method (Table 4, Graph 1).

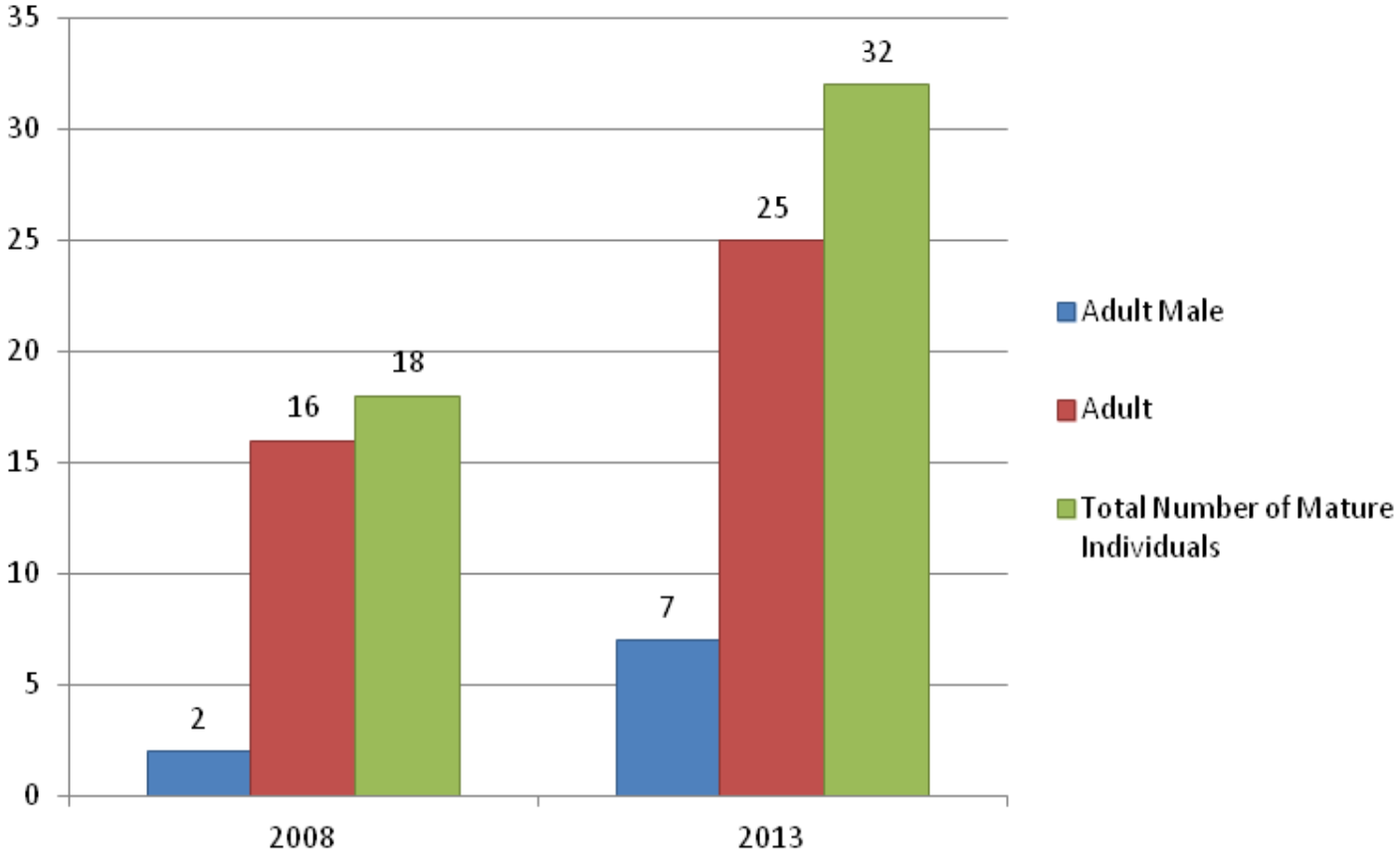
We also considered estimating the unknown proportion of adults that may have gone undetected during these surveys. For this we subjected our data to a Double Sampling Analysis where we treated the surveys on 21/2, 22/2 and 24/2 as “Intensive Surveys” followed by a

Figure 2. Photo enumeration of a basking gharial congregation in Dhikala, CTR.

Map 2. Boat survey routes, trail camera locations and stationary count locations.

Table 4. Counts of Adult Gharial, Dhikala, 2013.

Date	Type of survey	Adult Male	Adult	Total
	Boat Survey	1	9	10
21/2/2013	Stationary Count	6	14	20
Intensive Survey	Trail Cameras	0	0	0
	Days Count	7	23	30
	Boat Survey	4	4	8
22/2/2013	Stationary Count	2	14	16
Intensive Survey	Trail Cameras	0	7	7
	Days Count	6	25	31
23/2/2013	Survey abandoned due to bad weather			
	Boat Survey	6	14	20
24/2/2013	Stationary Count	0	3	3
Intensive Survey	Trail Cameras	1	2	3
	Days Count	7	19	26
25/2/2013	Boat Survey	7	20	27
Rapid Survey	Days Count	7	20	27
	Population Estimate using Double Sampling Analysis (Intensive Surveys)	7	22	29
	Population Estimate using the Maximum - Minimum Method	7	25	32
	Population Estimate based on the relation N=c/p	7	29	36
	Mean Population Estimate	7	25.33	32.33



Graph 1. Estimates of Adults in 2008 and 2013 using the Maximum ± Minimum (MM) Method, Dhikala, CTR.

"Rapid Survey" by boat along the Dhikala shoreline.

RESULTS AND DISCUSSION

Trail Cameras have been used in the monitoring of West African Nile Crocodile and West African Dwarf Crocodile at the Simandou Project, Guinea. However, we find that there are no earlier records or studies conducted on the use of trail cameras in the monitoring and census of wild gharial populations perhaps due to its highly aquatic nature and small population size. Thus, this study may be considered as pioneering work on the use of trail cameras incorporated as part of a multi-method approach in counting of gharial and would require further refinements.

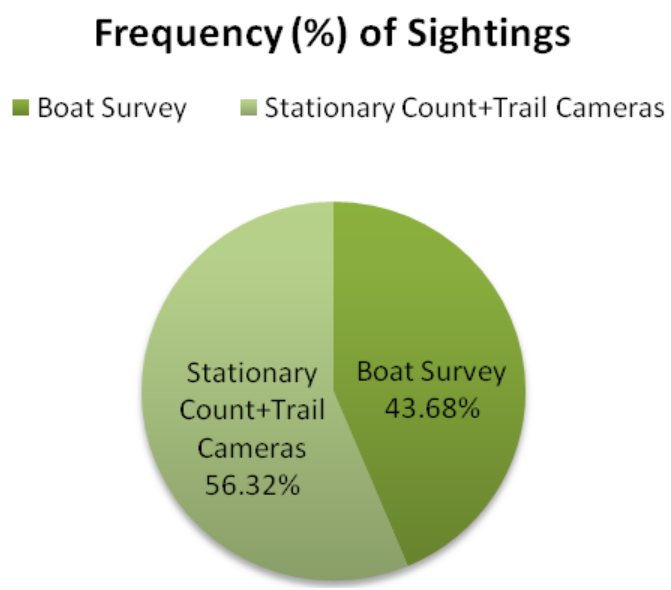
We treated the number of gharial counted viz. number of sightings by Stationary Counts and Trail Cameras as the same (since trail cameras essentially performed the functions of stationary counts) and compared them with the number of sightings from boat surveys on days when all three were conducted simultaneously. It is estimated that 43.7% of our sightings were made during boat surveys and 56.3% of our sightings were made due to the combined effort of stationary counts and trail cameras (Table 6, Graph 2).

Using the maximum ± minimum (MM) method our population estimates for Dhikala was 32 adults (inclusive of 7 adult males). We also considered that an unknown fraction of animals may have been missed during the enumeration work that is presence with non-detection. To determine this "unknown fraction" we subjected our data to a Double Sampling analysis where the mean adult population was estimated as 29 adults from "Intensive Surveys", sample size of three (n=3) followed by a "Rapid Survey" along the Dhikala shoreline during which we estimated the adult population as 27 adults. Probability (p) was calculated from "Intensive Surveys" which had a Variance (S^2) of 7 and Probability (p) was estimated as 0.76 indicating that the population at Dhikala had a positive binomial distribution. To estimate the unknown proportion of adult gharial at Dhikala (presence with non-detection), we used the relation n = c/p, where 'c' was estimated from the Rapid Survey as 27 animals. Thus, n = 27 / 0.76; n = 36 adults (inclusive of 7 adult males).

These results are indicative that we were able to sample an estimated 88.9% (n=32; inclusive of 7 adult males) of the adult gharial population at Dhikala using this multi - method approach of trail cameras, stationary counts and boat surveys along the shoreline.

Based on our three population estimates (n= 29, 32 and 36) we averaged the adult population at Dhikala as 32.3 + 1.69 adults (Mean + SE) with an encounter rate of 4.01 + 0.33 adults km^{-1} over 8.06 km of shoreline.

Further, in comparing population estimates for adults between 2008 and 2013, we used the Maximum ± Minimum (MM) Method, whereby which we estimated that the number of adults in Dhikala increased by 77.8 % between 2008 and 2013 (Table 5).



Graph 2. Frequency (%) of sightings.

Specifically, the adult male population increased by 250% while the adult population increased by 56.25% during this time period in the study area. The adult male: adult ratio in 2008 was 1:8 and in 2013 it decreased to 1:3.57 indicating smaller male-female sex ratios at Dhikala.

To establish whether this increase in the number of adults at Dhikala was only because of population turnover of sub-adults to adults or due to the cumulative effects of population turnover, animals undetected during surveys in 2008 and in-migration into the area , surveys by boat were conducted in areas near the study site which showed presence of gharial sub-populations in 2008 and from where gharial could have possibly in-migrated to Dhikala viz. Gaujeda and the northern periphery of the Kalagarh Reservoir between the Phulai Channel and Gaujeda, with a survey route of 7.91 km (Map 3). In these areas, we estimated 5 adults (inclusive of 2 adult males) in Gaujeda and 5 adults (inclusive of 3 adult males) along the northern periphery of the Kalagarh Reservoir (between the Phulai Channel and Gaujeda) in 2008. In 2013, boat surveys did not record any gharial in these areas indicating that during the study period these adult gharial (n=10) were now possibly congregating at Dhikala (Map 4). This increase in the adult population detected in the study area is therefore likely to be due to a combination of population growth, in-migration of adult gharial and some individual adults being undetected (during the 2008 surveys) in the study area.

In addition, the Corbett National Park is free from many man induced anthropogenic pressures like irrigation canals, artificial embankments, sand mining, harvesting of gharial eggs for food, use of fishing nets in which gharials get entangled and drown, river use by domestic cattle and cultivation of seasonal vegetables at nesting

Table 5. Calculation of percent (straight line) growth rate of adults at Dhikala, CTR based on counts derived from the MM method.

Percent (straight line) growth rate (PR)	Count (2013)	Count (2008)	Calculation
$\frac{C\ (Present) - C\ (Past)}{C\ (Past)} \times 100$			$PR = \frac{C\ (Present) - C\ (Past)}{C\ (Past)} \times 100$
Where,	32	18	$PR = \frac{32 - 18}{18} \times 100$
C (Present) = Present count (2013)			$PR = \frac{14}{18} \times 100$
C (Past) = Past count (2008)			$PR = 0.7777 \times 100$
			$PR = 77.78\%$

Table 6. Number of Sightings.

Parameter	Number of sightings
Boat Survey	38
Stationary count +trail cameras	49
Total number of sightings	87

and basking sites as often seen in other crocodile sanctuaries in the country. Tourism is a regulated activity in the Reserve, with little or no access for tourists to gharial, thereby further reducing disturbance to these animals. However, in the Sonanadi Wildlife Sanctuary of CTR river use of the Palain and Sonanadi Rivers by the *Van Gujjar* pastoralists is well known and may well be affecting gharial populations there. The results indicate that minimal disturbances to the aquatic habitat in CTR particularly in Corbett National Park with no significant man induced anthropogenic pressures is benefitting the gharial population here indicated by the increase in adult gharial numbers at Dhikala.

Limitations

While trail cameras have showed encouraging results further refinements are required in incorporating the use of trail cameras in estimation work with regard to choice of trail cameras, placement and density of trail cameras in the field and data collection protocols and analysis.

Recommendations

1) The establishment of a Monitoring Programme for the taxon in CTR should be given impetus bearing in mind the change of the taxon to Critically Endangered by the IUCN Red List in 2007. Considering the contribution of the CTR meta-population of 20% towards the global population of 200-250 adults, the global decline of the taxon, and the endemism and uniqueness of this meta-population within the region, it is important that such a programme be undertaken annually for a number of years in collaboration with the CTR Authorities.

2) The multi-method approach incorporating the use of trail cameras, boat surveys along the shoreline and stationary counts should be continued with in this part of the Reserve.

The size classification used during the course of this study is recommended as a standard for classifying gharial cohorts for population studies within the Reserve and to compare future counts. Future studies should be planned so as to understand the ecology of the taxon in the reserve in relation to population trends, habitat preferences, size class distribution, and sex ratios.

3) Anthropogenic pressures on the taxon in Corbett National Park are negligible and the overall protection measures implemented in the Reserve, which also include the regulation of tourism in Corbett National Park have also proved beneficial for the taxon should be continued with and not diluted in any manner. In the Sonanadi Wildlife Sanctuary of the Reserve due to river use of the Palain and Sonanadi Rivers by the *Van Gujjar* pastoralists, protection of basking and nesting areas is important. Surveys in these areas should be conducted to monitor gharial populations, to identify nesting and basking sites and to document river use of the *Van Gujjar* pastoralists so that the CTR Authorities may also enforce relevant riverine protection measures effectively in the Sonanadi Wildlife Sanctuary.

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Map 3. Locations of Gharial sub-populations in 2008 at CTR.

Map 4. Areas surveyed for Gharial 2013, in Dhikala, CTR.

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