



thanks for major financial support from these organizations:



Behavioral Ecology of Gharial on the Chambal River, India

Jeffrey W. Lang and Pankaj Kumar

**Madras Crocodile Bank Trust & Gharial Conservation Alliance,
Vadanemelli Village, Post Bag 4, Mahabalipuram 603104 INDIA
(jeff.w.lang@gmail.com; 1385 Brompton, St Paul, MN 55108 USA)**

Abstract

The Gharial Ecology Project, also known as the Gharial Telemetry Project, was initiated in June 2008 to investigate the circumstances of the 2007-08 mass die-off of gharials in the 2-4m size class, totaling 110+ individuals in the lower Chambal River. To date, 20 radio-tagged gharials have been tracked successfully throughout the annual seasonal cycle, monsoon and dry periods, for an average of 2+ years per animal, since June 2008 through May 2013. Individual gharials show different patterns of seasonal movement and residency, primarily dependent on size/age. Adult females move as far as 80-120 km each seasonal cycle to join dry season basking-breeding aggregations (>60 adults), and to locate suitable nesting areas. In contrast, sub-adult gharials exhibit restricted movements, typically 10-30 km seasonally, and occupy seasonal residencies only 5-15 km in extent. Some sedentary sub-adults showed virtually no movements, either upstream or downstream.

Gharial feed primarily during the monsoonal months of June through September, and bask daily for long periods during the winter months of November through February. Large basking aggregations form in December and January. Mixed basking groups of all age/size classes shift to primarily groups of large sub-adults and adults by mid-February when courting and mating commence. Nesting follows in late March/early April when smaller groups of reproductive females assemble near sandbanks adjacent to deep water. Yearlings (9 months old) from the previous years' hatch often remain close to the dominant male, rather than nesting females, and the male responds to nearby yearlings with specific displays. Colonial nesting sites are located in areas of minimal disturbance, but locations shift from year to year, depending on local restructuring of the nesting sites. Females open the nests, but do not transport the young to water. Adult females and a singular dominant male remain with hatchlings for 1-2 months, attend the young, and guard them against potential predators. Large male gharials, with well-developed and prominent gharas, remain individually associated with large groups of young (200-1000+). Large crèches remain together, and young have been observed feeding regularly on small fish.

These results are directly relevant to conservation and management. First, the long distance movements of adult reproductive females, and likely adult males responsible for breeding, indicate that an open, dynamic, free-flowing river is critical. Second, illegal fishing, sand removal, and/or riverside cultivation anywhere along the river constitutes disturbance to which wide-ranging gharials are exposed, consequently would have adverse effects on their well-being and survival. Third, the detailed behavioral observations of social and reproductive activities indicate that the gharial population inhabiting the lower Chambal is healthy and thriving, and that annual recruitment is high. Fourth, egg removal to *ex situ* artificial incubation facilities, and the subsequent captive rearing of young (=head starting) is not necessary for the Chambal population presently, and should be discouraged/prohibited. Fifth, any reintroduction or translocation schemes to move gharials into new habitats should take into account the proclivity for sub-adult gharials to move 10-20+ km, and for adults to move 80-100+km. Lastly, this study sheds new light on the mass die-off of 2007-08. The event was specific to gharials, rapid in its effects and restricted to 12 weeks (from early December through February), and very local in its geographic extent, extending from 12 km above the Yamuna-Chambal confluence in the lower Chambal River to 75 km upriver.

Introduction: background, rationale for project, and study objectives

The Gharial Ecology Project, also known as the Gharial Telemetry Project, was initiated in June 2008 to investigate the circumstances of the 2007-08 mass die-off of gharials in the 2-4m size class, totaling 110+ individuals in the lower Chambal River. The project was conceived and initiated by D. Basu, Rom Whitaker, and Jeff Lang to provide new ecological information about the gharial population inhabiting the National Chambal Sanctuary (NCS). In particular, the emphases were on spatial data about gharial movements, and related behavioral observations relevant to all phases of gharial life and natural history.

The general questions were: 1) how far do gharials move seasonally throughout the year, and during a lifetime?, 2) how do gharials respond to the annual monsoon, and consequent high water?, 3) how do gharials use the river habitats throughout the seasonal high water and low water periods?, 4) when and where do gharials feed?, 5) how does social behavior influence their distribution on the river?, 6) when and where do they court and mate, nest, incubate eggs, and guard hatchlings? Prior to this study, partial or incomplete information about all of the above questions was conjectured from notes recorded in captivity and/or from anecdotal observations in wild populations. Answers to these questions are necessary in order to formulate management and conservation-related strategies for the continued well-being, health, and survival of wild gharials in the Chambal which is still an open and dynamic river.

In late June 2008, with assistance from WWF-India, the Madras Crocodile Bank Trust and the Gharial Conservation Alliance received Ministry of Environment and Forests and state government permissions to capture, radio-tag, and monitor up to 30 wild gharials in the size range of 2-4m, the die-off size range, in three episodes of 10 animals/tagging operation. A rapidly advancing monsoon in June 2008 cut short the tagging effort, and only one individual was tagged, and intermittently tracked. A subsequent tagging in March 2009 resulted in 10 animals tagged, and another 10 were tagged in November 2010.

Results: New Spatial and Behavioral Findings

To date, 20 radio-tagged gharials have been tracked successfully throughout the annual seasonal cycle, monsoon and dry periods, for an average of 2+ years per animal, since June 2008 through May 2013. At present, five gharials are still being tracked into the 2013 monsoon from the 2010 group. A total of 2300+ animal-specific locations were recorded for the 2009 group, and more than 1500+ locations, 1-3 x weekly, have been logged for the 2010 group. These findings are summarized in Tables 1 and 2. Preliminary results have been published in the Wildlife Telemetry Issue of the ENVIS Bulletin, and numerous reports summarize the results to date for government departments and funding agencies (see reference list).

In brief, these ecological studies, based on detailed observations of the radio-tagged, wild gharials resident in the lower Chambal, have indicated that the population is spatially-structured. Individual gharials show different patterns of seasonal movement and residency, primarily dependent on size/age. The most remarkable finding is that adult reproductive females routinely move as far as 80-120 km each seasonal cycle to join dry season basking-breeding aggregations (>60 adults), and to locate suitable nesting areas where they nest communally and remain with eggs/young until monsoon floods arrive. Then, adults move rapidly downstream, in 30-50 km trips within days/few weeks to the lower stretches of river near the Yamuna-Chambal confluence. Then, as water levels subside, they regularly return upstream long distances to the same localities, over weeks/several months during the post-monsoon period (Figure 1)

In contrast, sub-adult gharials exhibit restricted patterns of movement, typically 10-30 km seasonally, and occupy seasonal residencies only 5-15 km in extent. Monsoon residences are located downstream, and these gharials make short upstream movements to dry season residences. Some sedentary sub-adults showed virtually no movements, either upstream or downstream. Instead, they occupied very restricted sections of river, only totaling 12-18 km in extent, regardless of season (Figure 2).

In addition to this new information on the spatial ecology of gharials living in the lower Chambal River, this study has provided, for the first time, a picture of the behavioral ecology of this population. Specifically, data have been recorded for the seasonal cycles of maintenance, social, and reproductive behaviors (Table 3). Gharial feed primarily during the monsoonal months of June through September, and bask daily for long periods during the winter months of November through February. Large basking aggregations form in December and January. Mixed basking groups of all age/size classes shift to primarily groups of large sub-adults and adults by mid-February when courting and mating commence. Nesting follows in late March/early April when smaller groups of reproductive females assemble near sandbanks adjacent to deep water. At these colonial sites, eggs incubate for 2 months, and hatch in early-mid June.

Colonial nesting sites, typically with 5-15+ nests, are located in areas of minimal disturbance, but locations shift from year to year, depending on local restructuring of the nesting sites (Figure 3). Females open the nests, but do not transport the young to water. Instead, the young move from the nest to water nearby where other hatchlings have assembled in groups. Adult females and a singular dominant male remain with hatchlings for 1-2 months, attend the young, and guard them against potential predators. Large male gharials, with well-developed and prominent gharas, remain individually associated with large groups of young (200-1000+). Up to 12 males have been observed in one season, and 16 different male-young groups are recorded over three nesting seasons, 2010 through 2012 (Table 4). Multiple females are present as well with these groups, and routinely attend/guard hatchling groups until water levels rise. Large crèches remain together, and young have been observed feeding regularly on small fish (Figure 4).

In addition, detailed behavioral observations have been made on social interactions primarily associated with breeding. Males tolerate other males initially as large basking groups form in January and early February, but then begin to establish social hierarchies, with a dominant, large ghara male engaging in most courtship and mating at specific localities, often associated with nesting areas. In late February and early March, the dominant male patrols an area where reproductive females congregate, and courtship and mating were observed with multiple females over periods of several weeks. Then, females select nesting sites, often frequented by dominant males following breeding, but prior to nesting. At these times, yearlings (9 months old) from the previous years' hatch often remain close to the dominant male, rather than nesting females, and the male responds to nearby yearlings with specific displays (Figure 5).

Relevance of Ecology Study Results to Management and Conservation

The results of the Gharial Ecology Project are directly relevant to the conservation and management of the gharial population inhabiting the lower Chambal River, National Chambal Sanctuary. First, the long distance movements of adult reproductive females, and likely adult males responsible for breeding, indicate that an open, dynamic, free-flowing river is critical. The lower Chambal should be maintained without obstructions and with sufficient water flow throughout the year for continued successful breeding and recruitment. Individual gharials live in 100+km of river. They inhabit downstream sections during 2-4 months of high water, and return each year to upstream segments for the remaining 8-10 months. The river is an important corridor between their widely-spaced seasonal residences,

and adequate water flow connecting these areas is vital year-round, especially in the post monsoon when upstream movements take weeks to months. Likewise, any major disturbances or obstructions that would inhibit or prevent such seasonal movements would be detrimental and adversely affect the gharial population.

Second, illegal fishing, sand removal, and/or riverside cultivation anywhere along the river constitutes disturbance to which wide-ranging gharials are exposed, consequently would have adverse effects on their well-being and survival. Restriction, and eventually elimination of these activities, especially fishing and sand mining, should be viewed as necessary enhancements to riverine habitats.

Third, the detailed behavioral observations of social and reproductive activities indicate that the gharial population inhabiting the lower Chambal is healthy and thriving, and that annual recruitment is high. During the three year period from 2010 through 2012, the total nests counted were 38, 76, and 80, respectively. Hatched nests totaled 31, 48, and 69 respectively in 2010, 2011, and 2012. Using an average hatchlings per nest of 40, hatchlings during these years totaled 1240, 1920, and 2760 respectively. Furthermore, loss of eggs/hatchlings was highest among nests that were not located at colonial sites; these nests were typically lost by predation/disturbance. Usually, few if any guarding adults were present at these nests, and no guarding males were in association with these.

A possible in situ strategy would be to relocate these isolated/few nests to nearby colonial nesting areas where the probability of successful hatching would be greater, and predation loss minimized. This approach has the additional benefit of re-focusing management efforts on intact, natural nesting areas, and could be augmented with increased monitoring and protection from disturbance at these sites. This could be initiated on an experimental basis for a few years and based on the results, a decision can be taken to adopt it as the official policy.

Fourth, egg removal to ex situ artificial incubation facilities, and the subsequent captive rearing of young (=head starting) is not necessary for the Chambal population presently, and should be discouraged/prohibited. Survival of captive hatchlings has been low (mortalities over 50%) at most rearing facilities. Behavioral observations of wild hatchlings indicates that they benefit from very high pre-monsoon ambient temperatures, and begin feeding on live fish almost immediately after hatching. Adults, both attending females and guarding males, protect hatchlings from most predators until monsoon waters rise and the adults move back downstream.

Fifth, any reintroduction or translocation schemes to move gharials into new habitats should take into account the proclivity for sub-adult gharials to move 10-20+ km, and for adults to move 80-100+km. Relocations or re-introductions within restricted areas of protected riverine habitat would likely result in gharials moving into unprotected nearby sites where net fishing and/or sand mining may pose serious threats to their continued survival.

The five points enumerated above regarding the relevance of this study to management concerns are only some examples of how knowing more about gharial ecology is directly applicable to the conservation of this critically endangered species. Undoubtedly, other management decisions/actions will be informed by accurate knowledge of gharial ecology.

Relevance of Ecology Study Results to Mass Mortality Event of 2007-08

Lastly, this study sheds new light on previous explanations/interpretations of the causes and consequences of the mass die-off of 2007-08. In fact, at present, all indications are that the event was specific to gharials, rapid in its effects and restricted to 12 weeks (from early December through February), and very local in its geographic extent, extending from 12 km

above the Yamuna-Chambal confluence in the lower Chambal River to 75 km upriver (Figure 6). More than half ($56/104=54\%$) of the deaths were located at 40-62 km upriver from the confluence, and 77% ($80/104$) occurred within the 29 km stretch from Khera Ajab Singh (62 km upriver) to Barchouli (33 km upriver). Likewise, 77% ($80/104$) of deaths occurred between 8 December and 19 January, a 42 day period of unusually cold weather during the winter months.

The spatial patterns of the sub-adult gharials in this study living close to the die-off epicenter suggest that the victims of the die-off were most likely similar resident sub-adults that resided year-round in the area and did not move seasonally. Four sub-adult male gharials in the 2010 tagged group were sedentary during the 2-3 years of this study, and moved only maximum distances of 12, 17, 17, and 18 km in total extent while being monitored (Figure 2). None of these sedentary, tagged gharials were ever observed within 30 km of the confluence, and subsequent to the die-off have lived presumably unharmed in the immediate area of the maximum die-off deaths. In addition, at least one other sub-adult that was tracked in this study lived during an entire dry season in the lower reaches of the Yamuna during 2012, but subsequently has moved back into the Chambal close to where it was captured.

These observations demand a re-examination of the previous explanation for the die-off. The prevailing explanation was that gharials living in the Chambal traveled to the confluence of the Yamuna-Chambal where they fed on tainted fish from the polluted Yamuna outflow and/or moved into the lower reaches of the Yamuna where pollution is sometimes heavy and widespread. Thus, it was surmised that exposure to toxins was due to eating polluted fish sourced from the Yamuna. In light of the findings from the present study, it is more likely that there was a point source for toxins in the lower Chambal well upstream from the confluence, and presumably located in the stretch of river between the Udi and Sashon bridges. Based on the concentration of deaths in the immediate localities between Khera Ajab Singh (62 km) and Chikni Tower (47 km), the epicenter of exposure was probably in this 15 km section of the river.

If so, the gharials resident in this area, particularly the sedentary sub-adult population with restricted movement patterns, were vulnerable and accounted for most of the deaths. A point source with local and rapid effects might have produced sub-lethal effects on certain sized fishes, incapacitating them so they could be easily caught by resident gharials. The gross finding of visible articular and visceral gout in the few specimens necropsied is consistent with this conjecture, but why only gharials were affected, and not muggers or other species is not known. Unusually cold weather has been implicated as an accessory condition that would have limited the capacity of affected individuals to clear the toxin fast enough to prevent lethal effects. Metabolism is well known in crocodilians to be strongly temperature dependent, and low ambient temperatures would have the effect of slowing any metabolic response to clear or otherwise neutralize an ingested toxin. The movement study results also suggest that most adult gharials would have already moved upstream prior to the period of deaths in the winter months. A re-analysis of the die-off mortality data is presently being prepared by the international team of veterinarians who produced the Final Report on Gharial Mass Mortality Event in 2007-08, with special reference to the findings of this study summarized here.

Current and Future Plans for Continuance of Ecology Study of Gharial in NCS

The current group of tagged gharial will be monitored during the remainder of 2013 until the radios cease to function. Representative staff and advisors at MCBT will be the primary project staff, in addition to the trackers, and will visit the project sites periodically and be

resident at Garhaita, Sashon, and Etawah, and continue to access the river habitats within the NCS by jeep, on motorbike, and on foot.

Continuance of the Gharial Telemetry Project is pending, depending on available financial support, operational and logistic planning, and the necessary permissions to continue. A tentative schedule for 2013 is to conduct a capture-tagging of another group of gharials to fit tracking devices for October-November when disturbance to social and breeding activities is low. The number and sizes of gharial to target remains to be determined, as well as specific locations where gharial will be tagged.

Monitoring of gharials in the upper segments of this stretch, as well as a select group of larger adults, including one or more large, breeding males will shed additional light on gharial ecology, and provide baseline data on the health and status of the resident gharial population in the National Chambal Sanctuary. In addition, small juveniles presumably remain in the section of river near where they hatched, and may not make appreciable seasonal movements down or up the river, much like subadults, but as yet the spatial ecology of juveniles is not known. Management and conservation strategies in NCS, especially those focussed on gharials should be based on gharial biology.

There may be benefit in tagging a small number of mugger crocodiles as well. Mugger biology in the NCS is not well understood, and this species is implicated in increased conflicts with humans. Interestingly, mugger crocodiles were not affected by whatever was responsible for the gharial die-off, but the basis for this difference is not known.

PUBLICATIONS/TALKS/REFERENCES TO THIS PROJECT (downloadable at academia.edu under "JEFFREY LANG")

Application of telemetry techniques in crocodilian research: Gharial (*Gavialis gangeticus*) spatial ecology in the Chambal River, India, pp. 161--171, in Sivakumar, K. and Habib, B. (Eds.) 2010 Telemetry in Wildlife Science, ENVIS Bulletin. Wildlife and Protected Areas, Vol 13 No. 1, Wildlife Institute of India, Dehradun 248001. INDIA

Spatial Ecology of *Gavialis gangeticus* in the Chambal River, India, pp. 183--196, in Crocodiles, (2010) Proceedings of the 20th Working Meeting of the Crocodile Specialist Group, IUCN, Gland, Switzerland and Cambridge UK.

Adult-Young Associations of free-living Gharials in the Chambal River, India, p.197, abstract, in Crocodiles, (2010) Proceedings of 20th Working Meeting of the Crocodile Specialist Group, IUCN, Gland, Switzerland & Cambridge UK.

Gharial Ecology on the Chambal River, India, p.183, talk abstract, in Crocodiles, (2010) Proceedings of the 20th Working Meeting of the Crocodile Specialist Group, IUCN, Gland, Switzerland and Cambridge UK.

Gharial Ecology on the Chambal River in north India, abstract for talk at World Congress of Herpetology (WCH7), 8--14 August 2012, University of British Columbia, Vancouver BC CANADA

Gharial Ecology on the Chambal River, plenary talk presented at the Gharial Session, CSG 22nd Working Mtg., 20-24 May 2013 in Colombo, Sri Lanka

This project is a joint venture of Madras Crocodile Bank Trust (MCBT) and the Gharial Conservation Alliance (GCA), PO 4, Mahabalipuram 603104 INDIA

in collaboration with Ministry of Environments & Forests, Government of India, Uttar Pradesh and Madhya Pradesh Forest Departments, and Garhaita Village, Etawah UP.

We thank the following for their guidance, assistance, and support in various ways:
Dr. Anmol Kumar, MoEF; Dr. B.K. Patnaik & Staff, UPFD; Dr. H.S. Pabla & Staff, & R.K. Sharma, MPFD; Ravi Singh, Dr. P. Gautham, & Dr. S. Behra, WWF-India; R.P. Singh, Chambal Safari; Dr. Shailendra Singh & Staff, Turtle Survival Alliance; and to Rick Hudson, Brian Horne, F. Bill Zeigler, Kent Vliet, Perran Ross & Don Boyer.

Romulus Whitaker, Ms. Janaki Lenin, Samir Whitaker, Dr. Gowri Mallapur, Colin Stevenson, Dr. Ravi Chellam, K. Munuswamy and all staff at MCBT and GCA. Residents of Garhaita, Etawah Dt, & Riverside Villages, National Chambal Sanctuary

Thanks to the following sponsors for major project support/logistics:

The Rufford Maurice Laing Foundation, London, Great Britain; Ocean Parks Conservation Foundation, Hong Kong; Crocodile Specialist Group, IUCN, Gland Switzerland; Zoo Praha, Prague, Czech Republic; Cleveland Metro Parks Zoo, Ohio, USA; San Diego Zoo & Wild Animal Park, California USA; SeaArk Boats, Arkansas.

Copyright 2013 Jeffrey W. Lang

Table 1: Summary of Tracking Locations for Gharial tagged with radio transmitters in NCS Abbreviations noted in legend below table. Trackable locations are tallied for the initial group of ten (49 thru 75) tagged in 2008---09, and for the second group (21---41) tagged in November 2010. During the first half of 2011, as many as 16 gharial were being tracked on a weekly/biweekly basis at Chambal locations ranging from Sashon to above Naangoan.

ID	sex	tl(m)		2010	2010	2010	2011	2011	2011	2011			
				may--- jun	july--- sept	oct--- dec	jan--- mar	apr--- jun	july--- sept	oct--- dec		loc10--- 2011	total locat
49	F	2.9		KH	BD	KH	KH	KH				46	218
51	F	2.8		DN	CH	DN	DN	DN		***		49	246
53	F	2.3		DN	NK	DN	DN	DN		***		61	255
55	M	2.1		CH	CH	CH	CH	CH	CH	***		97	311
57	F	2.9		BD	BD	BD	**					38	228
59	M	2.0		KT	CH	KT	KT	KT	CH	***		62	174
61	F	2.9		CH	CH	CH		***		***		67	308
63	F	3.3		?	CH	CH						33	152
69	F	3.0		DN	CH			***		***		21	213
75	F	2.5		DN	NK	DN	DN	***		***		35	216
												=509	=2321
21	F	2.9				(PN)	GH	GH	SG	GH		70	
23	F	3.6				(PN)	GH	KH*	CF	SG		64	
25	M	2.6				(PN)	GD	GD	CF	SG		17	
27	M	2.2				(PN)	PN	PN	PN	PN		59	
29	M	2.2				(PN)	PN	PN	SG	PN		64	
31	M	2.3				(KH)	KH	KH	KH	KH		63	
35	M	2.3				(KS)	GD	GD	CF	SG		56	
37	M	2.1				(KS)	KS	KS	KS	KS		53	
39	M	2.3				(PN)	KH	KH	SG	KH		34	
41	F	3.1				(BR)	GH	GH	CF	GH		68	= 495

ID=gharial tagged with radio, e.g., 49 is 151.49 MHz, 51 is 151.51 MHz, etc
sex: F=female, M=male tl (m) is total length in meters

Chambal location abbreviations KH=Khera Ajab Singh; BD= Badpura; DN=Dinnpura;
CH=Chilonga; NK= Nachnoli; KT=Koroth; PN= Pituwan ka Nagla (Philmunnagara);
BR=Barchauli GH=Gohera; SG=Sashon Ghat; CF=confluence Yamuna---Chambal; GD=Godha;
KS=Kasaua

(PN), (KH), (KS), (BR)=capture/ release sites for gharial tagged in November 2010

***=visual observation of tagged gharial with radio attached, but no longer broadcasting

**=visual observation of tagged gharial, radio detached

*=this female was observed to have nested at Chikni Tower, just below Khera in 2011.

Table 2. Tracking Summary of ten wild Gharial with radio transmitters in National Chambal Sanctuary. Movements are summarized for second group (ID 21-41) tagged in late November 2010. Most were tracked weekly/biweekly; 25 & 37 were lost by end 2011, and 29 by early 2012. Seven were tracked for 26+months; five thru May 2013. Total animal-specific locations in from Dec 2010 into March 2013 =1009+

ID	sex	tl-m	cap		mns	locs	kms	loc to CFL	dry	Ukm	wet	Dkm	nest
23	F	3.6	PN		(30)	(133)	103	0 to 103	GH	+88	MS	90	CT,DN,DN
41	F	3.1	BR		(30)	(121)	121	0 to 103	GH	+93	PA	90	-, DN, ??
21	F	2.6	PN		26	113	90	15 to 105	GH	+73	SG	70	-, ??, ??
35	M	2.3	KS		(30)	(91)	135	-12-105, 16	GD, YM KH	+63 +16 +56	PA PD PA	-- 16 46	
25	M	2.6	PN		13	17	107	-2 to 105	GD	+71	SG	--	
29	M	2.2	PN		16	79	75	15 to 90	PN, MG	+ 0 +54	MS	21 75	
39	M	2.3	PN		26	118	18	29 to 47	CT	+11	SG	15	
27	M	2.2	PN		(30)	(124)	17	30 to 47	BA	+ 2	BA	0	
37	M	2.1	KS		12	47	17	30 to 47	TK	+ 2	TK	0	
31	M	2.3	KH		(30)	(166)	12	44 to 56	CT	- 2	CT	0	

Chambal River loc: GD=Godha; GH=Gohera; MG= Maghera ka Pura; DN=Dinnpura; KH=Khera Ajab Singh; KS=Kasaua; CT=Chikni Tower; PN= Pituwan ka Nagla (Philmunnagara); BR=Barchouli; SG=Sashon Ghat; Mahua Sunda=MS; PA=Patharra-Bihar; CF= Yamuma-Chambal confluence; YM= Yamuna; PD=Pachnada, below Y-C confluence. (PN), (KH), (KS), (BR)=capture/release sites.

legends: tl-m=total length, metres; cap=capture location; mns=months tracked; () =current tracking; locs=locations recorded; kms= maximum movement distance, in kms; loc to CFL= location on Chambal, relative to confluence (CF)=0; dry=dry season location; Ukm=seasonal upstream movement, in km; wet=wet season location; Dkm= seasonal downstream movement, in kms.

23 nested in 2011 at CT, in 2012 at DN, and 2013 at DN; 41 nested in 2012 at DN. In 2013, nesting by 41 and 21 still uncertain.

Table 3. Summary of Gharial activities and behaviors observed on the lower Chambal River (National Chambal Sanctuary) throughout the annual cycle (shown here bimonthly). In general, gharial of all size classes are most concentrated at late winter basking sites prior to breeding, and are most dispersed at high water levels during monsoonal rains when main channel flow is swift, and resting and basking sites along the shoreline are limited. Capture and tagging should be restricted to October-November when adults move upstream, when social interactions are minimal, and when reproductive activities do not occur.

annual cycle		weather/season	size/age/sex distribution	spatial pattern	group size	dominant activities	river habitats
July-Aug		monsoon high water	all size classes	dispersed	1-5 5-10	feeding basking	shallows, edges, side channels
Sept-Oct		post monsoon receding water	all size classes	small, mixed grps	5-10 10-20	feeding basking	main channel, shallows, edges
Nov-Dec		early winter cool temps	all size classes	medium, mixed grps	10-30	basking	sand bars, river bends
Jan-Feb		late winter cool temps	adults – subadults multiple males ≥ 4 <u>juveniles-s-adults</u>	large grps breeding marginal	30-90 5-15	basking, breeding	mid river bars, bends, rocks
Mar-April		early summer warm temps low water	nesting females egg incubation attendant male(s)	restricted to nesting locations	10-30	trial nests, nesting, incubation	river bends, high sand banks, w/ deep water
May-June		pre monsoon very high temps lowest water	nesting females hatchlings guarding male=1 juveniles-s-adults	restricted to nesting locations marginal	10-30 5-15	incubation, egg hatch, creches	river bends, high sand banks, w/ deep water

Table 4: Spatial distribution of nest sites on lower Chambal River, referenced to upstream distance from Yamuna confluence (=0 km). Fourteen nest sites were used during three nesting seasons, producing 38, 76, and 80 nests respectively in 2010, 2011, and 2012. The number of nests that produced hatchlings in each year are shown for each location in the bottom panel. Predated nests=()=pd. For example, the Rhea site (*RH*) had 11, 20, and 30 total nests, and 11, 19, and 28 nests hatched in 2010, 2011, and 2012, respectively. Bolded, underlined entry indicates that a male was observed guarding hatchlings at nest site, and often resident post-hatching.

[illegible]

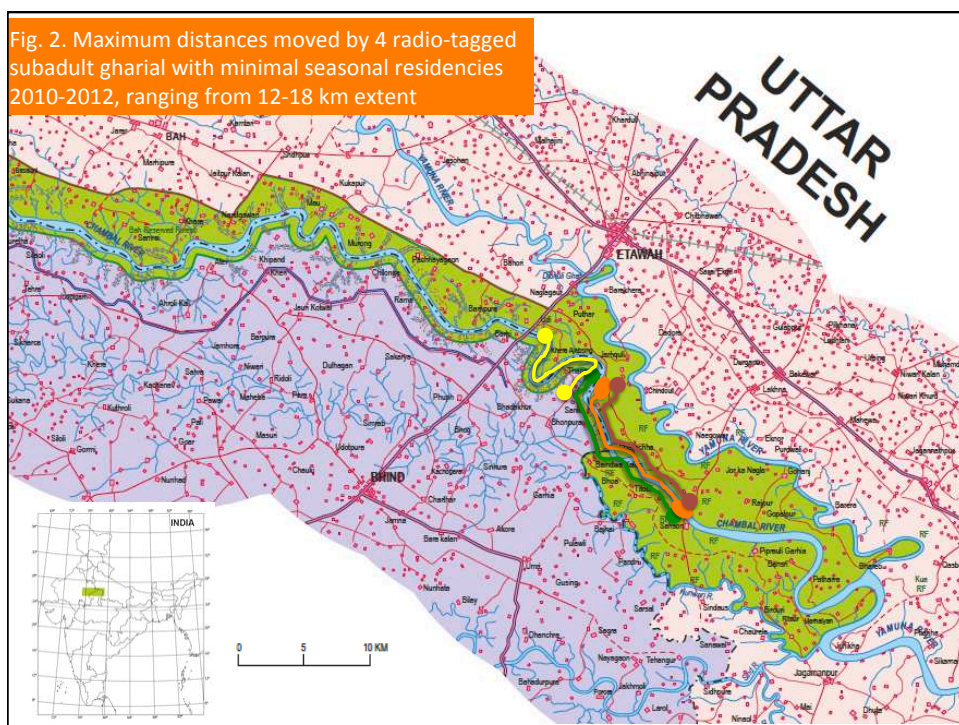
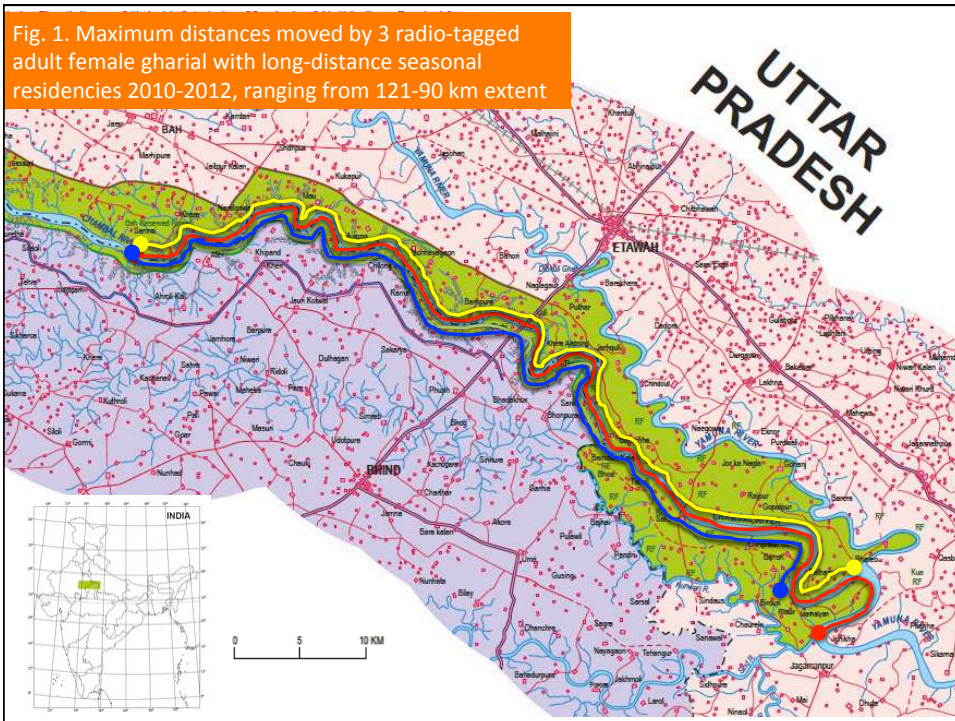


Fig. 3. In 2010, 2011, and 2012, nest sites, nest numbers at sites, and nest predation varied. In 2012, 6 sites had mean nest/site=13.3, range=3 to 30, & 3 new sites (dk red sq).

