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***Research Article** (Open Access)*

GHARIALS COMMUNICATE VIA ACOUSTIC "POP" SIGNALS

Jailabdeen AjjiM[1,2], Jeffrey W. Lang[2] and *G. Archunan[1,3]
[1]Department of Animal Science, Bharathidasan University, Tiruchirappali, Tamil Nadu, India
[2]Gharial Ecology Project, Madras Crocodile Bank Trust, Mamalapuram, Tamil Nadu, India
[3]Dean-Research, Marudupandiyar College, Thanjavur, Tamil Nadu, India
**Author for Correspondence: garchu56@yahoo.co.in*

ABSTRACT
Living crocodilians communicate by means of visual, acoustic, chemical, and/or tactile signals. This study aims to examine the acoustic signals produced by adult male gharial in various behavioural contexts during the breeding season. Detailed behavioural observations, supported by 24hr acoustic data and still/video imagery, at multiple breeding and nesting sites in successive years, have documented complex social interactions, including acoustic signalling amongst adults, as well as vocalizations by hatchlings assembled in large creches at communal nest sites. Adult male gharials produce explosive, concussive “pop” sounds underwater, in 1-3 short, loud and audible bursts. A pop is always sudden at a high volume. Using hydrophones and aerial mics, we recorded over 500 samples of pop signals of 14 male gharials, behaving normally under natural conditions. Each male gharial produced a stereo-typed series of 1-3 pops underwater. Temporal patterning, rather than frequency differences, is a primary feature of this unique crocodilian signal which presumably facilitates individual recognition. Immediately preceding a pop, infrasound is produced. Duration of the pop (P) ranges from 0.013 to 0.036 seconds, and the time interval between pops (IPI) ranges from 0.045 to 0.745 seconds. Distinctive low and high frequencies of pop were observed ranging from 100-2400 Hz to 10,000-22,000 Hz. During breeding (late Feb-early Mar), popping occurs in four distinct contexts, namely 1) alert (AL), 2) patrol (PA), 3) male-male encounters (MM), and 4) male-female interactions (MF). At one site frequented by a breeding male, with relatively few (<10 in 2017) vs. many (>30 in 2018) females, recruiting pops directed at females dominated in 2017, whereas challenging pops dominated in 2018, when challenger males approached or intruded. Later, during hatching in late May-early July, at each communal nesting site, a guardian male will pop often to 1) alert and recruit hatchlings, and 2) announce his presence and location to females in the vicinity of the crèche. Each male, whether breeding and/or guarding, can be identified by its distinctive pattern of popping, which appears to be consistent over successive years.

***Keywords:** Acoustic Communication, Gharials, Critically Endangered, Crocodilians*

INTRODUCTION
Crocodilians are known to communicate using visual, acoustic, chemical, and/or tactile signals (Vergne *et al.,* 2009). The gharial (Gavialis gangeticus) is a Critically Endangered (CR) species, with an estimated 300-900 mature adults globally, of which 600+ are resident in the National Chambal Sanctuary (NCS) in North India (Lang *et al.,* 2019). The Chambal population is the largest, self-sustaining wild population, and constitutes ~ 80% of the remaining global total (Gharial Ecology Project 2018; Lang 2018). Over the last 15 years (2008-2022; 15 field seasons; Lang and Whitaker, 2010), The Gharial Ecology Project (GEP) has produced a detailed description of gharial behavioural ecology in National Chambal Sanctuary (NCS), including seasonal, long-distance migratory movements of 200+ km by breeding adults and complex social interactions at large crèches of hatchlings (Lang *et al.,* 2013; Lang *et al.,* 2016; Lenin 2018; Sohn 2018). Genetic studies are underway to reveal genetic relatedness among crèche participants, including how large, big ghara male guardians are related to hatchlings at crèches (Singh *et al.,* 2018). According to previous studies, gharials vocalize only rarely, and reportedly do not produce infrasound (Dinets, 2013). Here we report that acoustic communication in gharials involves “pops” performed by large males with big gharas, and subtle “clicks” produced by hatchlings and nesting females (AjjiM *et al.,* 2017; AjjiM *et al.,* 2018). In this preliminary report, we describe acoustic

parameters of the adult male gharial pop signals, and we examine the contexts in which these are performed. Furthermore, we show that the certain spectral features associated with timing are not only context-dependent, but also individually distinct. Finally, we suggest that the gharial POP functions as an acoustic signature for an adult male gharial possessing a ghara.

Features of underwater "popping" signal

Previous vocal studies of other crocodilian species emphasize "frequency" parameters, as characteristic of size / age / sex, and possibly for individual recognition (Vergne *et al.,* 2007; Vergne *et al.,* 2011). In our study, "temporal" patterns, rather than frequency features appear to be the main means of communication via acoustic POP signals (AjjiM *et al.,* 2017). Male gharials produce an explosive, concussive POP sound underwater, in 1-3 short, loud audible bursts, followed by a breathing display. A POP is always sudden and at high volume, resembling a stoppered bottle being opened rapidly, like a wine bottle being uncorked. Infrasound immediately precedes these audible POP events. In previous acoustic studies, this POP signal was mistakenly referred to as a jaw clap or head slap, similar to those described for other crocodilians (Dinets 2013). In contrast to other acoustic sounds, the POP signal is produced underwater, and no disturbance such as splashing or bubbling is noted on the water surface above. In gharials, the popping sound production mechanism is unknown, but may involve the large, bulbous narial ghara, found only on snout-tip of large adult males (>4.5m TL). The pot-shaped excrescence may function as a resonator to modify this unique gharial-specific acoustic signal, which is always followed immediately by a breathing sequence upon emergence at the surface.

METERIALS AND METHODS

We recorded the POP signals of 14 wild adult males with large gharas, (N=500+) during breeding (late Feb-early Mar) in 2017 and 2018. Underwater & aerial audio recordings were made as gharial behaved normally under natural conditions. Specific behavioural contexts were documented, and are listed below (Martin and Bateson, 1986). We used custom made D-series hydrophones by Jez Riley and Zoom/Tascam recorders for observations and field recording. Dominant males establish breeding arenas, along 500-750m of shoreline (Powell, 2000), so we deployed hydrophones in pairs to each of these arenas. We made detailed observations from opposite banks and recorded extensive video sequences of representative behaviours. We recorded 8 different breeding groups from 14:00-19:00hrs when animals were actively breeding. At one location, Garhaita, we made continuous 24/7 observations during breeding in three successive years, 2017 thru 2019.

We used Raven Pro 1.5 (Cornell Lab of Ornithology, USA) and AVISOFT (Avisoft Bioacoustics, Germany), to quantify time and frequency parameters of each recorded "popping" event. Each POP signal was analysed individually in wave form for temporal characteristics. Selections were made to denote POP (P) and the inter-pop intervals (IPIs) (Marler *et al.,* 1960; Frasier *et al.,* 2017). We calculated the time of P and IPIs, which is referred as delta time of pop and delta time of inter-pop intervals respectively (Figures 1&2). This delta time is used to create and compare the POP events in known different contexts based on video data corroboration.

Different contexts of underwater "popping" signal

We have identified four distinct behavioural contexts in which large males produce POPs.

Alert: when the male or the breeding group has been disturbed or approached closely by people or animals

Patrol: when the big ghara male gharial patrols his breeding area, from one end to the other, at times stopping, approaching another gharial closely, and frequently popping

Male-Male: encounters may be at a distance, or result from close approach, often instigated by a POP produced by the challenger or dominant male, and answered by the other

Female-Male: interactions with one approaching the other, resulting in a POP by the dominant male within the vicinity of the female

The signal parameters for each POP vary by different behavioural contexts with each individual, and appear to contain relevant features, unique to each individual and specific for that context.

RESULTS

Detailed Temporal analysis

We have named individual males by village localities nearby. Each male produced a distinctive POP pattern for each specific context, that was both context-specific and individual-specific. For example, in Table 1, the ALERT pops are different for these males, in terms of the delta times of the pop and the inter-pop intervals. In certain instances, such as Kamoni male and Maghera male, overlaps in both delta time of P and IPIs occurred, but these males were separated by 11kms from each other's territory. The standard deviation data for the alert context of the Garhaita male (monitored for entire breeding season) and Rhea male (monitored for a single day) shows same deviation of <0.010 sec. The POP event produced by each individual was very stereotyped, and varied little, regardless of sample sizes of recorded signals. Consequently, a distinct POP characterized each large ghara male as an individual, relative to other males. The overall overlap given in Table 1 including delta time of POP and IPIs is 35%, which is <1% when the location of each male (indicated by river distance; kms) is considered.

Comparison of Context specific signal for 4 males

Every male exhibited an individually specific popping pattern for each behavioural context. For example, in tables 2&3, we have data of 4 different males at two localities. These data show different ranges for 4 different contexts for continuous 2 years breeding seasons. The overall overlap in POP for tables 2&3 is 25%. However, overlap is <5% when considering individuals and contexts.

Examples of context specific communication

At the Maghera locality, two males were present during breeding in both years. The dominant Male and Challenger at Maghera had a conflict in 2017, which was evident in the male-male context. However, in 2018, they established separate territories about 750 meters apart and did not exhibit any male-male communication. In 2018, both males increased pops in the male-female context (Table 2).

At the Garhaita locality, only the resident male was involved breeding in 2017. During this period, the popping was 80% for female recruitment. In 2018, a Challenger Garhaita male appeared in the vicinity. Consequently, the Garhaita male produced pop signals in the male-male context. The Challenger Garhaita Male produced few male-male pops, but primarily produced POP signals in the male-female context (Table 3).

DISCUSSION

Male gharials with ghara produce occasional POP signals throughout the year, but this behaviour seems to be especially prevalent during the breeding (Feb-Mar) and also during the hatching (June-July) seasons. In the present report, we have focused on the signalling patterns during the breeding season, based on our detailed audio and video observations during 2017-2018. Preliminary analyses of the hatch-creche period suggests that each large ghara male resident at a nesting site uses popping to advertise his presence to potential predators at the crèche, in his role as guardian and protector. In addition, he communicates with hatchlings and females by "popping" in specific contexts. Some of the observed functions of popping during the post hatch seasons are to: 1) alert hatchlings about potential predators presence, 2) recruit hatchlings to gather into compact groupings near the guardian male, 3) announce his presence and location to attendant females, and 4) provide an alert to possible disturbances near the hatchlings.

In addition to our studies focusing on the popping signals of large male gharials, we also examined female and/or hatchling communications during the hatch-creche season. Females and hatchlings make frequent underwater "clicks" at this time. Hatchlings vocalise often during the first two weeks after hatch, but this behaviour rapidly disappears after 4-6 weeks post hatch. These initial observations suggest that gharial communication may contain other unique components via acoustic signalling, not previously described in other extant crocodilians (Vergne *et al.,* 2011).

CONCLUSION

Acoustic POP signals are unique to big ghara male gharials, as compared to all other species of living crocodilians (Vergne *et al.,* 2011). POPs are stereotyped, individually consistent, and context specific. Unlike other crocodilians, each individual male can be identified by its unique temporal patterning, possibly functioning in mate selection and other social interactions. We observed minimal over-lapping in temporal features which may be related to environmental correlates such as river distances between individuals, habitat features, ambient noise, etc. Currently, we are investigating gharial signalling, in different seasonal contexts to add to the present report on male signalling during breeding.

Table 1. Consolidated table of alert (AL) context for all males for 2 breeding seasons (2017&18)

Male Id	River Distance from Yamuna Confluence (km)	Year	No. of sample collected days	Alert (AL)				
				No. of samples analyzed	Delta time of P [A,C in fig.1&2 / E in fig. 1] (Sec)	Delta time of 1st IPI [B in fig.1&2] (Sec)	Delta time of 2nd IPI [D in fig.1] (Sec)	Standard deviation (SD) of delta time of POP
Tighra Down-side Dominant	210	2017	2	1	0.013	0.045	-	0
		2018	Animal data is not available for 2018					
Babasingh gir Dominant	201	2017	1	1	0.019	0.292	-	0
		2018	Animal data is not available for 2018					
Rhea Dominant	161	2017	1	5	0.018-0.036	0.191	-	0.009487
		2018	1	1	0.018	0.190		0
Challenger Rhea	161	2017	1	1	0.015	0.100	-	0
		2018	1	1	0.015	0.103		0
Gohera Dominant	103	2017	Animal data is not available for 2017					
		2018	1	1	0.022	0.423	-	0
Maghera Dominant	90	2017	6	2	0.016-0.018	0.325-0.559	-	0.001155
		2018	6	2	0.016-0.018	0.325-0.559		0.001155
Challenger Maghera	90	2017	6	2	0.023-0.026	0.336-0.372	-	0.001732
		2018	6	1	0.024-0.026	0.365	-	0.001414
Dinnpura Dominant	85	2017	1	3	0.046-0.055	0.249-0.253	0.443-0.487	0.0045
		2018	Animal data is not available for 2018					
Kamoni Dominant	79	2017	2	3	0.015-0.021	0.282-0.356	-	0.002875
		2018	2	2	0.016-0.019	0.282-0.356	-	0.001732

Garhaita Dominant	74	2017	15	2	0.022	0.482	-	0
		2018	22	18	0.020-0.023	0.450-0.482	-	0.009671
Challenger Garhaita	74	2017	Animal data is not available for 2017					
		2018	22	1	0.040	0.340	0.530	0
Khera Dominant	56	2017	Animal data is not available for 2017					
		2018	1	1	0.017	0.248	-	0
Khera channel	54	2017	1	1	0.025-0.027	0.382	-	0.001414
		2018	6	5	0.025-0.027	0.372-0.382	-	0.001054
Kasaua Dominant	46	2017	Animal data is not available for 2017					
		2018	2	2	0.013-0.016	0.265-0.278	-	0.001732

Table 2: Consolidated table of temporal component in 2 different contexts (AL & PA) for 2 places (Garhaita & Maghera) for 2 breeding seasons (2017&18)

Male Id	Year	Alert (AL)				Patrol (PA)			
		No. of samples analysed	Delta time of P [A,C in fig.1&2 / E in fig. 1] (Sec)	Delta time of 1st IPI [B in fig.1&2] (Sec)	Delta time of 2nd IPI [D in fig.1] (Sec)	No. of samples analyzed	Delta time of P [A,C in fig.1&2 / E in fig. 1] (Sec)	Delta time of 1st IPI [B in fig.1&2] (Sec)	Delta time of 2nd IPI [D in fig.1] (Sec)
Maghera Dominant	2017	2	0.016-0.018	0.325-0.559	-	2	0.028	0.272-0.327	0.522-0.675
	2018	2	0.016-0.018	0.325-0.559		3	0.028	0.272-0.319	0.522-0.675
Challenger Maghera	2017	2	0.023-0.026	0.336-0.372	-	1	0.048	0.307	0.439
	2018	1	0.024-0.026	0.365	-	0	-	-	-
Garhaita Dominant	2017	2	0.022	0.482	-	8	0.029-0.045	0.327-0.384	0.469-0.741
	2018	18	0.020-0.023	0.450-0.482	-	36	0.029-0.043	0.327-0.370	0.469-0.745
Challenger Garhaita	2017	Animal was not available in 2017							
	2018	1	0.040	0.340	0.530	0	-	-	-

Table 3: Consolidated table of temporal component in 2 different contexts (MM & MF) for 2 places (Garhaita & Maghera) for 2 breeding seasons (2017&18)

Male Id	Year	Male-Male encounter (MM)				Male-Female interaction (MF)			
		No. of samples analyzed	Delta time of P [A,C in fig.1&2 / E in fig. 1] (Sec)	Delta time of 1st IPI [B in fig.1&2] (Sec)	Delta time of 2nd IPI [D in fig.1] (Sec)	No. of samples analyzed	Delta time of P [A,C in fig.1&2 / E in fig. 1] (Sec)	Delta time of 1st IPI [B in fig.1&2] (Sec)	Delta time of 2nd IPI [D in fig.1] (Sec)
Maghera Dominant	2017	2	0.013-0.022	0.372-0.469	-	3	0.008-0.020	0.407-0.475	-
	2018	0	-	-	-	3	0.008-0.020	0.407-0.475	-
Challenger Maghera	2017	3	0.036-0.049	0.235-0.281	0.448-0.465	1	0.072	0.249	-
	2018	0	-	-	-	6	0.065-0.072	0.238-0.252	-
Garhaita Dominant	2017	0	-	-	-	91	0.025-0.033	0.352-0.520	-
	2018	48	0.042-0.050	0.633-0.642	0.813-0.856	80	0.026-0.033	0.352-0.520	-
Challenger Garhaita	2017	Animal was not available in 2017							
	2018	1	0.036	0.385	-	11	0.043-0.056	0.278	-

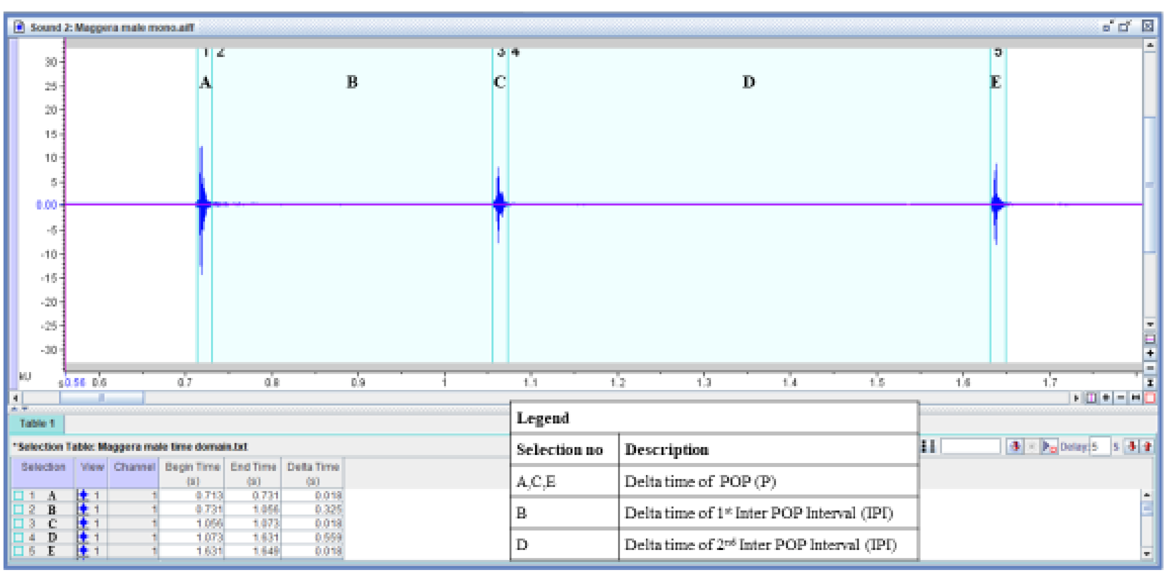

Figure 1: Waveform of POP signal (3x) in Raven Pro 1.5 and detailed description of temporal analysis

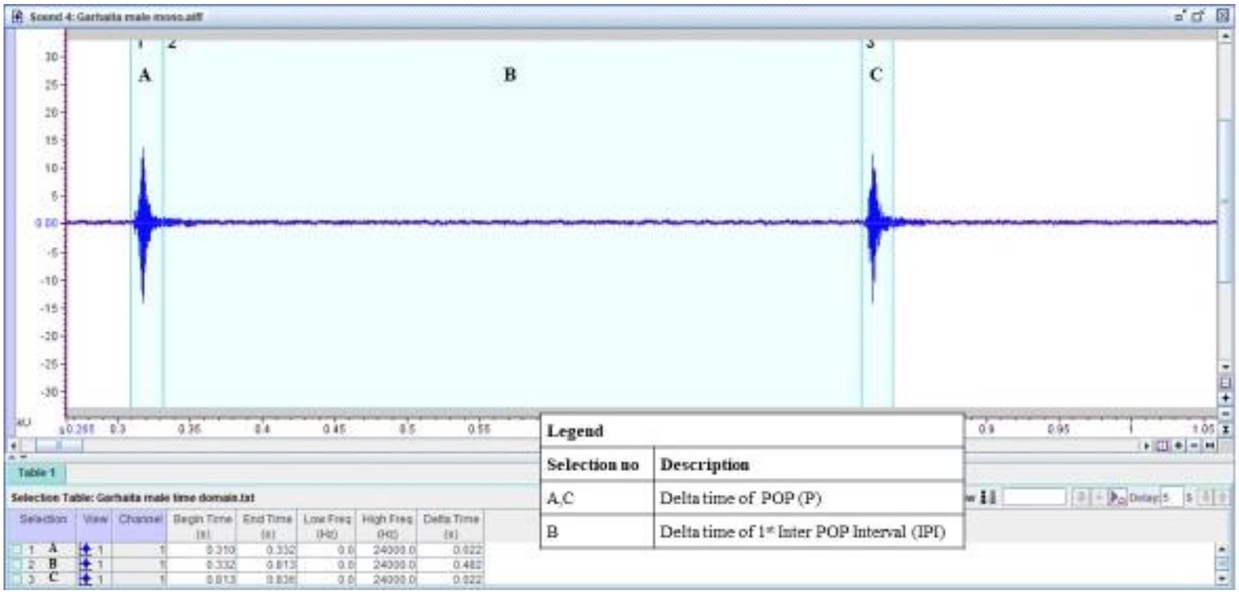

Figure 2: Waveform of POP signal (2x) in Raven Pro 1.5 and detailed description of temporal analysis

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