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Counting crocodiles from the sky: Monitoring the critically endangered gharial (*Gavialis gangeticus*) population with an Unmanned Aerial Vehicle (UAV).

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Abstract

Technology is rapidly changing the methods in the field of wildlife monitoring. Unmanned aerial vehicle (UAV) is an example of a new technology that allows biologists to take to the air to monitor wildlife. Fixed Wing UAV was used to monitor critically endangered gharial population along 46 km of the Babai River in Bardia National Park. The UAV was flown at an altitude of 80 m along 12 pre-designed missions with a search effort of 2.72 hours of flight time acquired a total of 11,799 images covering an effective surface area of 8.2 km^2 of river bank habitat. The images taken from the UAV could differentiate between gharial and muggers. A total count of 33 gharials and 31 muggers with observed density (per km^2) of 4.64 and 4.0 for gharial and mugger respectively. Comparison of count data between one-time UAV and multiple conventional visual encounter rate surveys data showed no significant difference in the mean. Basking season and turbidity were important factors for monitoring crocodiles along the river bank habitat. Efficacy of monitoring crocodiles by UAV at the given altitude can be replicated in high priority areas with less operating cost and acquisition of high resolution data.

Keywords

UAV, gharial, mugger, count, monitoring

Introduction

Technology is rapidly changing the methods with which wildlife is being monitored (Pimm et al., 2015). Unmanned Aerial vehicle (UAVs) is one such an example of new technology that allows biologists to take to the air to monitor wildlife, allowing for more cost-effective wildlife monitoring (Watts et al., 2010; Chabot & Bird, 2015). UAVs allow for very high-resolution data acquisition in both the spatial and temporal domain (Whitehead & Hugenholtz, 2014). UAVs have been used in several civilian disciplines for research and monitoring: agriculture (Hunt et al., 2010); forestry (Wing et al., 2013); biodiversity monitoring (Getzin et al., 2012) including wildlife (Koh & Wich, 2012; Wich et al., 2015; Hahn et al., 2017). The use of UAVs in wildlife studies is relatively recent and have focused more on the possibility of species detection than on determining wildlife density and abundance (Linchant et al., 2015a).

In this study, we tested whether UAVs can facilitate the detection of the critically endangered gharial (*Gavialis gangeticus*). The species was selected for two reasons. First, their survival is increasingly threatened as a result of changes in land-use, water flow and river morphology, poaching, and through being caught in fishing nets (Dudgeon, 2000; Smith & Reeves, 2000; Hussain, 2009). Second, as the species occurs along long stretches of rivers there is a need for cost-efficient survey methods as current ground-based methods are too costly and logistically challenging to conduct on a regular basis which is needed for monitoring purposes.

The gharial is a critically endangered crocodilian species found only in running freshwater ecosystems (IUCN, 2012). Currently, their distribution is limited to Nepal and India with an estimated population size of less than 200 breeding adults in the wild (Choudhury et al., 2007).

Until the 1940s, gharials were found in much larger numbers, estimated between 5,000-10,000, and distributed in all the major river systems ranging from the Indus in Pakistan in the west across to the Gangetic flood plains of India, Nepal, Bangladesh, Bhutan, and to the Irrawaddy in Myanmar in the east (Neill, 1971; Maskey, 2008). Since then habitat alteration through dams and irrigation, increasing river pollution, human activities such as illegal fishing practices and poaching for *ghara* (bulbous growth on the tip of the male's snout) have contributed to their decline (Choudhury et al., 2007).

Despite ex-situ conservation efforts with release of over 520 gharials in Nepal from 1981-2005, the decline from an estimated 436 adult gharials in 1997 to 93 in 2004 (DNPWC, 2008) represents a 78% reduction across its range. From, 2004-2016 the combined number of adult and sub-adults have gradually increased in Nepal. This increase has been attributed to ex-situ conservation measures and in-situ nesting success (Acharya et al., 2017). However, the numbers of adults have been low and female biased, with very few males recorded (Acharya et al., 2017). Given their low abundance and threats to their survival, regular periodic monitoring has become necessary so that conservation interventions can be implemented with as little lag time as possible.

UAVs represents a new frontier in environmental research, but their use has been mainly limited to terrestrial or marine animals with few studies in river systems (Chabot & Bird, 2015; Linchant et al., 2015b). A majority of earlier gharial studies (Chowfin & Leslie, 2014; Rajbhandari & Acharya, 2015; Acharya et al., 2017; Singh & Rao, 2017) carried out in multiple sites in India and Nepal employed visual encounter surveys (Crump & Scott, 1994) while walking random transect along riverine habitats to estimate gharial population size. We applied UAV technology to count gharials along a 46 km Babai river stretch within Bardia National Park which is regarded as strong hold for gharial population in the western part of Nepal. We assumed that the winter season habitat along the river stretch would provide excellent basking sites for the crocodilians (gharial, as well as mugger, *Crocodylus palustris*), and therefore would allow for aerial counts and differentiation among animals through images captured from the UAVs. Thus, we hypothesized that conducive environmental conditions (turbidity: clean water, season: winter and behavior: basking) would allow for a UAV study of these species. Lastly, we compared UAV derived gharial count with results from periodic traditional surveys carried out along Babai River in Bardia National Park (more in data analysis sections) in the past. We hypothesize that UAV derived gharial counts can be compared with the visual encounter surveys carried in the past.

Materials and methods

Study Area

Bardia National Park (BNP) is located in the southwestern part (28°15’-28°40’N; 81°15’-81°40’E, 968 km^2) of Nepal. Two major perennial rivers, the Karnali and Babai flow along a North-South gradient and form their respective flood plains. The Babai river (hereafter referred as Babai) within BNP is approximately 46 km long with Chepang as the upstream point in the north-east and Parewaodhar in the south as the downstream point (Fig. 1). The total catchment area formed by the Babai is ~2,602 km^2 encompassing the northern & southern Churia range and foothill areas. Seasonal variation in surface water temperature are recorded along the Babai

(Yadav, 2002). Surface temperature (in °C) varies between 17 – 22 in January – March; 25 – 28.5 in April – June; 27 – 28 in July – September; 18 – 25 in October – December respectively.

The gharial, mugger, and smooth-coated otter (*Lutrogale perspicillata*) are the top freshwater predators found in the surveyed river stretch. The 125 species of fish that were recorded in BNP form a major prey base to crocodilians (DNPWC, 2007). The Babai is the ecological lifeline to a majority of species including large mammals such as the Asian elephant (*Elephas maximus*), greater one-horned rhinoceros (*Rhinoceros unicornis*), and tiger (*Panthera tigris tigris*). The vegetation is sub-tropical, consisting of a mosaic of early successional floodplain vegetation along the Babai and its tributaries, and with large areas of Sal (*Shorea robusta*) forest on the upper, drier land (Steinheim et al., 2005).

Methodology

We used a fixed-wing UAV to capture images across the side of river banks while flying pre-programmed aerial routes along the river stretch. Flying altitude was restricted to 80m following the local civil aviation regulation and avoiding potential disturbance to the species in investigation (Hodgson & Koh, 2016). We used fixed wing TBS Caipirinha (http://www.team-blacksheep.com, model discontinued) equipped with an APM 2 flight controller. We used the Mission Planner (1.3.37, http://ardupilot.org/planner/docs/common-install-mission-planner.html) to program flight routes. We used the android application (Droid-planner android application V2_8.6_RC3) for real-time tracking of UAV during the flight operation on a Samsung tablet. With payload, this model has a flight duration of approximately 20 minutes. This platform was ideal for our use due to its portability (850 mm-wingspan), and low weight (~0.65 kg). A 3DR radio telemetry (V1.0) was attached to a tablet for communicating between UAV and ground stations (tablet). Multiplex Smart SX transmitter radio controller was used for landing and takeoff.

We used a GoPro Hero3+ Silver edition (GoPro, Inc) fixed to the UAV platform for capturing photographs. Photographs (jpg. format) were captured with a ~1 sec interval using a focal length of 3mm and ISO set at 100. At a flying height of 80m, each image covered approximately half of the riparian zone on either side of the Babai. Both sides of the riparian zone were combined during post-processing (see post-processing section) thus increasing the total search effort to approximately 102 km as three flight paths were needed in some sections to completely cover the wide river.

The selection of the appropriate season and time of day were crucial. The survey was conducted between Jan-Feb 2017. During this season, the turbidity of water flowing in Babai was low enough to allow some transparency for possible identification of crocodilians swimming above/below (~1m) surface water. We selected morning (8:00-11:00 AM) and evening (15:00-17:00 PM) time to capture the photographs from the UAV as these are the general basking times for the crocodiles.

The Mission Planner software was used to program flight missions. Each mission included a hand launch and automated landing. All 12 missions (Table 1, Fig. 1) were in accordance with local regulation and covered distance spanning 102 km focusing the floodplain habitat of Babai. All the missions were flown by the lead author.

Image Analysis

Post production for stitching of photographs: We used Microsoft's Image Composite Editor (MICE) (Microsoft, Inc.) to combine images per mission into one image. Photo number and time were the basis for stitching each of the consecutive photos taken during the mission. As a result, we had 12 combined images, one for each mission.

Image geo-rectification: We used ArcGIS (version 10.2, ESRI, Inc.) to rectify the 12 combined images using google earth images as a base layer (Zhuo et al., 2017). We obtained geo-referencing by using a minimum of 10 clearly identified locations and the estimated root mean square error (RMSE). We accepted RMSEs that were less than 0.0015 cm for each mission indicating good agreement between UAV and google imageries taken at this scale. At the end, we stitched the remaining 12 mission photographs using MICE and prepared one combined image of the river channel.

Approach to counting crocodilians: We used three image analysts for counting the crocodilians in each of the photographs from the 12 missions. Each image analyst counted the individual gharials and muggers on the photographs and tallied the total. The consensus approved by each of the three image analysts was used as final count data. Any discrepancy in manual identification between image analysts were discarded and not used in final derived count. Gharial and mugger species identification on UAV images relied on the visual inspection of its external morphological characteristics (Ballouard et al., 2010). From 80m height, the images acquired with the UAV do not provide the resolution to distinguish between sexes and age classes and as a result only provides a total number of gharial/mugger individuals. We used two approaches for identification of crocodilians in the photographs. Firstly, each image analysts looked in for clusters visible in the photographs, then examined the shape and length of the snout to differentiate between gharials and muggers (Ballouard et al., 2010) on possible clusters seen on the photographs. Gharials have a long and slender snout while muggers have a short snout (Fig. 2). Secondly, each of the positive samples (images) identified through consensus by the image analysts were further screened using *countingsthing* software (Dynamic Venture, Inc.). This step also verified the clusters identified by the image analysts in step one. The software differentiates and identifies any object/clusters seen on the photograph. Each of the identified objects were then finally labelled either as gharial and/or mugger manually by image analyst at the end.

Data Analysis

Basic sampling unit was "mission". Detailed coordinates of the 12 missions have been deposited in a common repository (Supplementary data) for easy access to the database. Each count of an individual identified in the UAV photographs were summarized and expressed as UAV derived counts. We used simple encounter rate index (Kelly, 2008) expressed as number of derived count per hour of UAV flown to measure the relative abundance of gharial and mugger in Babai. We also calculated observed density as number of derived count per km^2 of surface area. Surface area is measured as total surface area encompassed by each of the missions (Table 1).

Due to logistical issues, we could not simultaneously survey gharials and muggers on the ground. So, we compared the UAV derived count data with data from three replication data collected from conventional gharial surveys conducted in 2016 (Acharya et al., 2017). We also compared the gharial count data with data collected over the multiple temporal surveys (Khadka et al., 2008; Thapaliya, 2011; Acharya et al., 2017) carried out in the winter season at different time frames employing visual encounter surveys (Crump & Scott, 1994). Due to a lack of data on muggers, we only used the gharial count data from multiple studies. All the published count data from multiple studies were standardized in a single scale as per the mission length segment. We used box-and-whisker plots to visually examine the count data from UAV and ground surveys carried out over multiple years. We used a Kruskal-Wallis non-parametric test for comparing the means between the four independent surveys. All the analysis was carried out in R (R, 2017).

Results

We flew the UAV at an altitude of 80m, at a speed of 10-12m/sec, along 12 pre-designed missions with a search effort of 2.72 hours of flight time covering a total of 102 km (mean: 8.5 km (SD: 0.64)) spatial (aerial distance) river bank habitat (Table 1). Collectively, UAV took a total of 11,799 photographs covering an effective surface area of 8.2 km^2 of river bank habitat in 12-missions. All the photographs (including discarded ones) were carefully searched for the presence of gharial and/or mugger. At the final stage, only 7,708 photographs (66%) were selected for the final stitching of photographs.

Three image analysts separately searched for the crocodilians in each of the stitched photographs from 12 missions (Fig. 2). Collectively, there was consensus with a total of 64 crocodiles counted, gharial -33 and mugger-31, irrespective of age groups and found spatially distributed in clusters along the Babai river bank. Relative abundance based on mean encounter rate index (no of animals per hour flight time (SD)) was found to be 13.6 (21.45) for gharial and 11.7 (12.30) for mugger but with high variances respectively (Fig. 3). The observed density (number of animals per km^2 (SD)) was found to be 4.64 (7.32) and 4.0 (4.3) for gharial and mugger respectively (Fig. 3).

UAV derived count data was found to be highest (+10) when compared to each of the three ground-based surveys. The UAV surveys show few records (n=2) as outliers, however the rest of the data were within the 75% quartile range (Fig. 4). The 95% CI overlaps between each of the independent surveys indicates no significant changes in gharial population along Babai (Fig. 5). A statistical evaluation using a Kruskal Wallis test did not find significant differences between the various population surveys (H=3.18, d.f=3, *p*=0.36) conducted at multiple times.

Discussion

This study is the first of its kind to use UAVs to monitor the critically endangered gharial population in South Asia. The results provide baseline information that can be used for future aerial monitoring of the population. Our results are an addition to the literature on the use of UAVs to work on aquatic species such as penguins (Ratcliffe et al., 2015), sea otters (Williams et al., 2017), crocodiles (Evans et al., 2016), and sea turtles (Bevan et al., 2016). UAV technology seems to be a suitable method of collecting crocodile population count data in this habitat because of its ability to take high resolution images of basking sites and rivers habitat, which can be counted carefully in the lab and compared through time, therefore reducing the uncertainty of estimates in traditional observer counts (Van Gemert et al., 2014; Hodgson et al., 2016).

Turbidity (which incorporates a coarse measure of water depth) affects the sighting rates of aquatic animals along the surface of water (Hodgson et al., 2013). Although we did not test for the effect of turbidity on the sighting rates of the gharial, low turbidity of the running water allowed for the additional benefit of counting gharial swimming in the surface of the water and below it (n=7). This increased the probability of detecting the Gharial. Often detection of objects is higher vertically downward as from UAV, than from horizontal azimuth as done from ground surveys.

As with any survey method it is important to evaluate whether there is disturbance to the animals surveyed. A recent review study shows that disturbance to animals depends both on UAV characteristics (such as loud noise) and the characteristics of animals themselves. Non-breeding period and large animal groups are shown to trigger behavioral reactions (Mulero-Pázmány et al., 2017). In our study, we did not observe any behavioral changes that could be interpreted as disturbance. The crocodiles were not seen to be moving on consecutive photographs nor did their head position change in consecutive images. This indicates that flying at 80 m seems appropriate and led to sufficient ground resolution. It is important to note though that disturbance does not necessarily express itself in terms of a behavioral response but can also lead to physiological responses such as changes in heart rate (Ditmer et al., 2015).

UAV application could be an add-on in predicting species distribution with imperfect detection using analytical metrics such as occupancy framework (MacKenzie et al., 2006). William et al (2017) provides a useful and promising tool for estimating occupancy, abundance, and detection probability from aerial photographic surveys. Variation in UAV application because of variety of platforms and sensor availability allows biologist to collect population data at higher resolutions followed by habitat ancillary data (example shown in Fig. 7). Data gathered can been integrated in modelling the covariates affecting the gharial occupancy in the freshwater river habitat.

Choice of equipment was traditional in the current survey even though it fulfilled the research objectives. The current choice of platform in fixed wing category was selected keeping in view to survey larger area. Use of more advanced platform such as DJI Phantom Pro 4 (non-fixed wing category) and Parrot Sequoia (sensor) can be explored, However, their use needs be tested in terms of its quality, resolutions, and detectability within the range of gharial distribution. With minor adjustment in field protocol like doubling flight time (survey field effort) in non-fixed wing category might give better image resolution and quality along with extra benefit of vertical take-off and landing facility which is crucial for operating environment such as our study area.

Initial cost of UAV was ~US$ 2,500 including field operating cost. With advancement of technology, cost of fixed wing UAVs is becoming cheaper. Subsequent use of UAV is an added benefit producing high resolution images (including videos) in detecting species and acquiring ancillary habitat information in multiple surveys with less operating cost. Comparison of field operating cost between UAV and encounter rate survey (~US$ 500 for the three days survey) in gharial monitoring program is similar but differs in the quality and type of data acquisition. The efficacy of UAV in monitoring gharial and mugger population with high resolution data (such as images and videos) and monitoring methodology explained could be replicated in other high priority sites, such as as the central population hub of gharial in Chitwan National Park (Acharya et al., 2017) and elsewhere along with the choice of advance sensors including non-fixed wing UAV platforms.

Contributions

GJT, KT and SRJ conceived the project; GJT and SK carried out field surveys; RT provided logistical services and necessary permits; GJT and KT analyzed the data; KT and GJT wrote a draft manuscript; GJT, KT, RT, SRJ, SW, LPP and SK provided input to the draft manuscript.

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Table 1. Search effort and number of photos captured by the UAV, gharial/mugger count in each of the 12 pre-designed missions.

mission plan	search effort		# of total captured photos	# of selected photos	# of gharial count	# of mugger count	# surface area covered
	distance covered (in km)	flight time (in minutes)					
1	9.1	15	1,162	726	2	3	0.62
2	8.0	13	1,067	513	4	8	0.55
3	7.8	12	928	648	10	6	0.71
4	8.4	14	900	657	1	2	0.53
5	9.5	15	1,139	593	1	3	0.71
6	8.2	13	775	599	0	0	0.58
7	8.5	14	999	656	0	0	0.62
8	8.7	14	958	688	1	0	0.78
9	9.2	15	932	640	1	0	1.06
10	8.8	14	1,037	800	0	5	0.94
11	8.3	13	999	555	1	3	0.61
12	7.2	11	903	633	12	1	0.50
Total	101.7	163	11,799	7,708	33	31	8.21

Fig. 2. Study area showing two major (Karnali and Babai River) freshwater habitats of Gharial and Mugger. Gharial (▲) and mugger (□) count was done along the river stretch in Babai River in Bardia National Park. Flight path of UAV belong to one of the pre-designed mission across the Babai River stretch within Bardia National Park. The mission was designed in *Mission planner* following software manuals. Each green bubble represents coordinates of the yellow highlighted flight path.

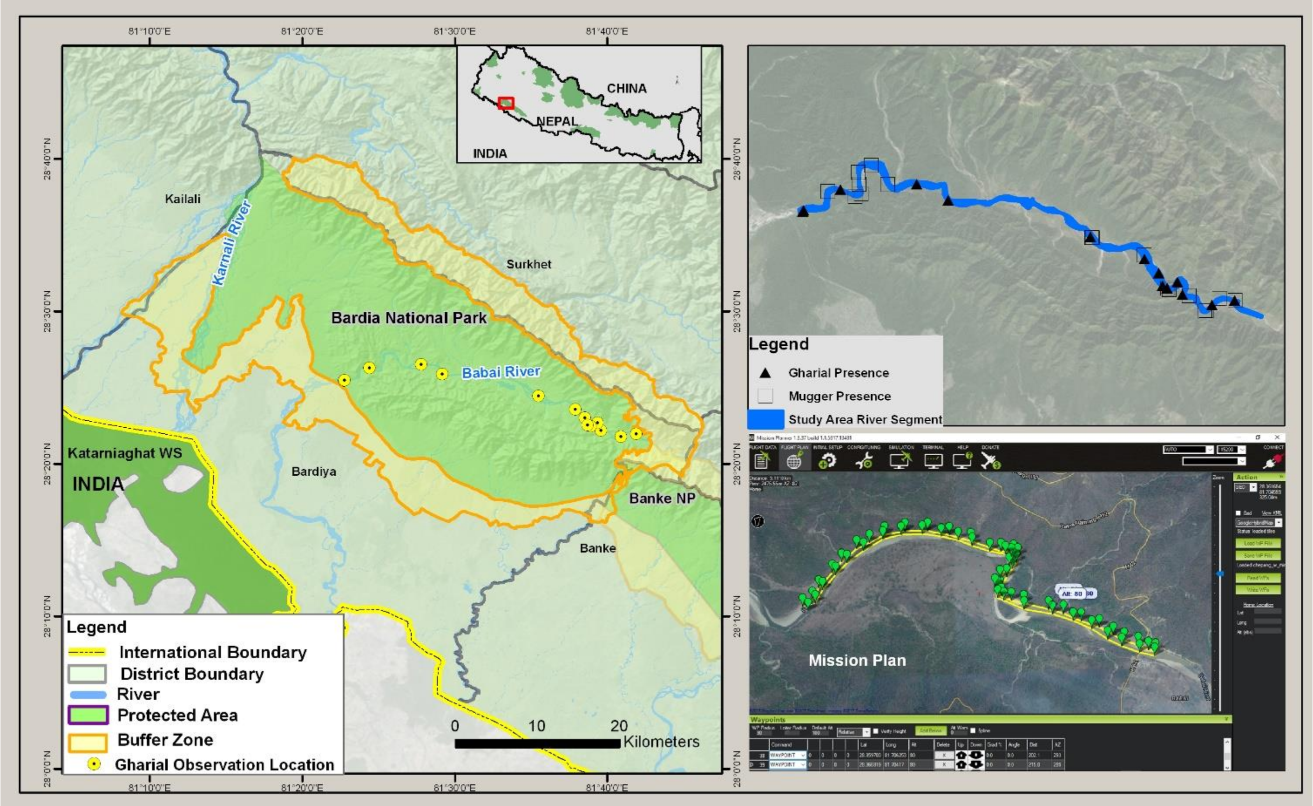


Fig. 2. Mission 1 (~10.1 km) stitched photographs showing the gharial (▲) and mugger (■) recorded position along Babai River. Inset shows differentiation between gharial (triangular box) and mugger (rectangular box) based on physical appearance (shape) as seen on UAV images.

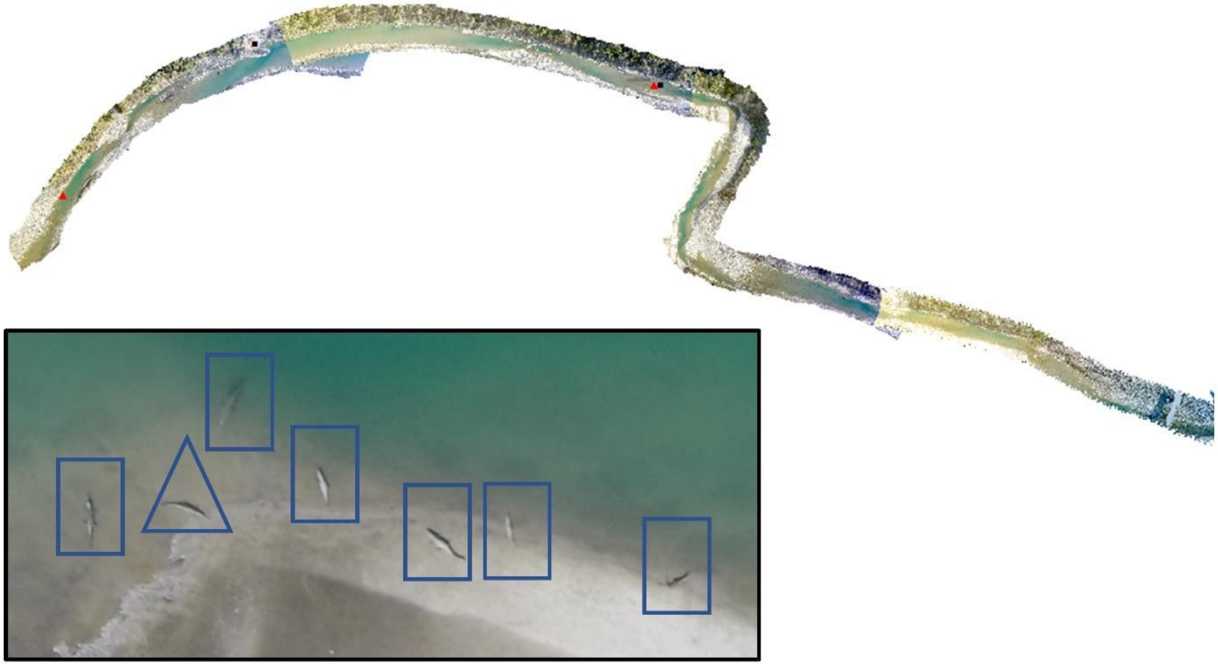


Fig. 3. Relative Abundance Index (RAI; ■) and Observed Density (OD; ♦) of Gharial and Mugger along the river bank of Babai in Bardia National Park.

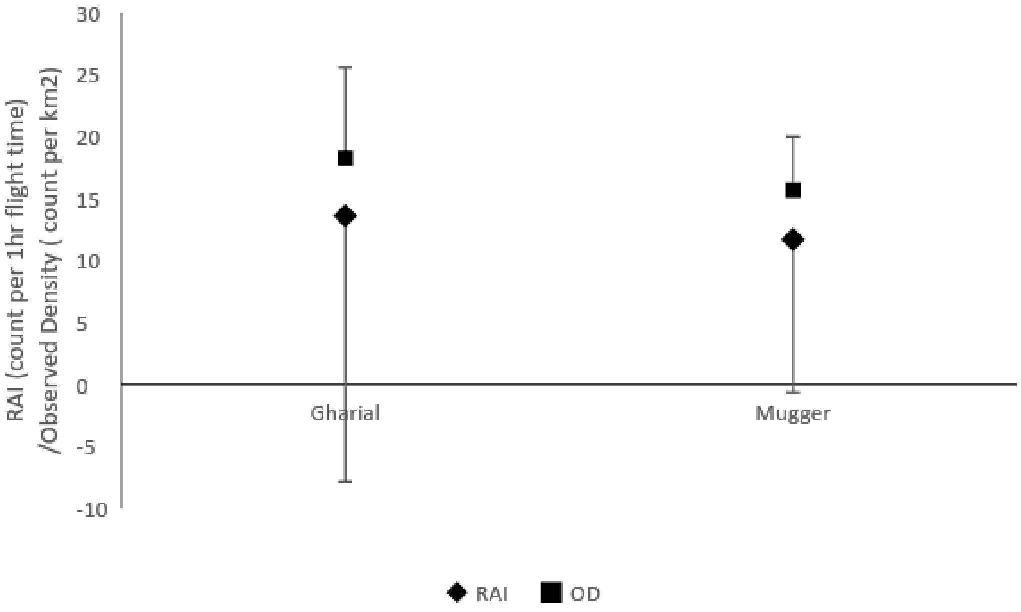


Fig. 4. Box-and-whisker plot showing distribution of count data derived from UAV platform and visual encounter surveys conducted at different time frames. F2011 represents survey carried out on fiscal year in 2011 and henceforth. R1F2016 represents first replication of survey carried out in fiscal year 2016. UAV represents current survey.

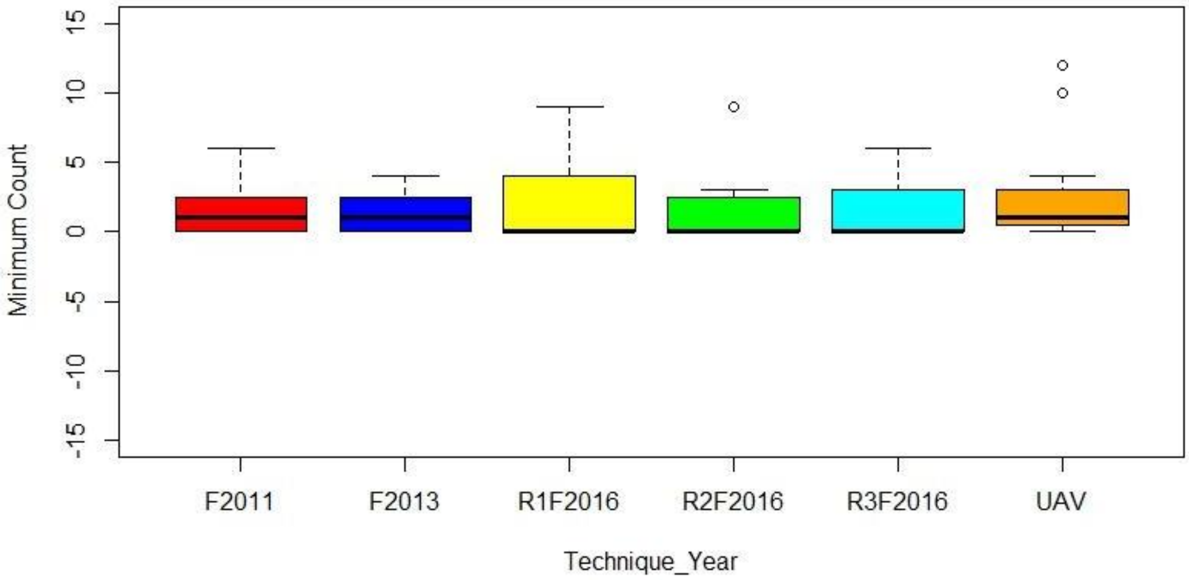


Fig. 5. Total derived count (Bar plot) and mean gharial count (mean, 95% CI) conducted at different time frame using visual encounter surveys and UAV platform. F2011 represents survey carried out on fiscal year in 2011 and henceforth. R1F2016 represents first replication of survey carried out in fiscal year 2016. UAV represents current survey.

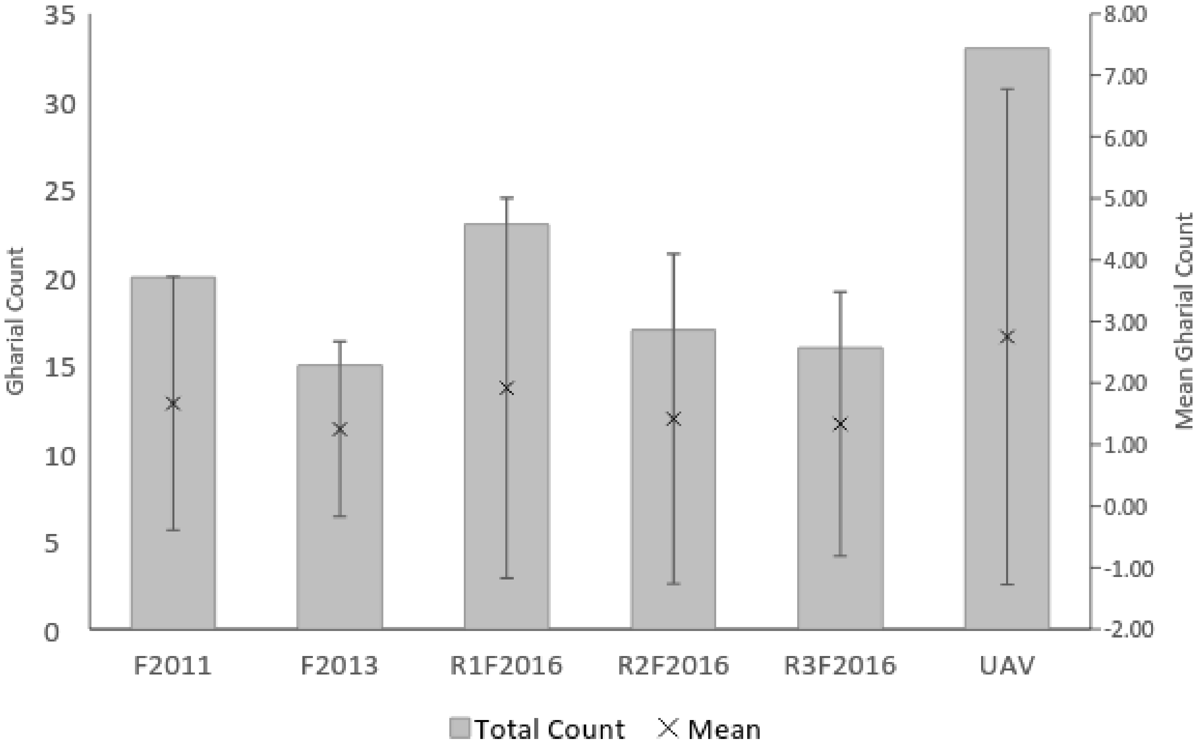
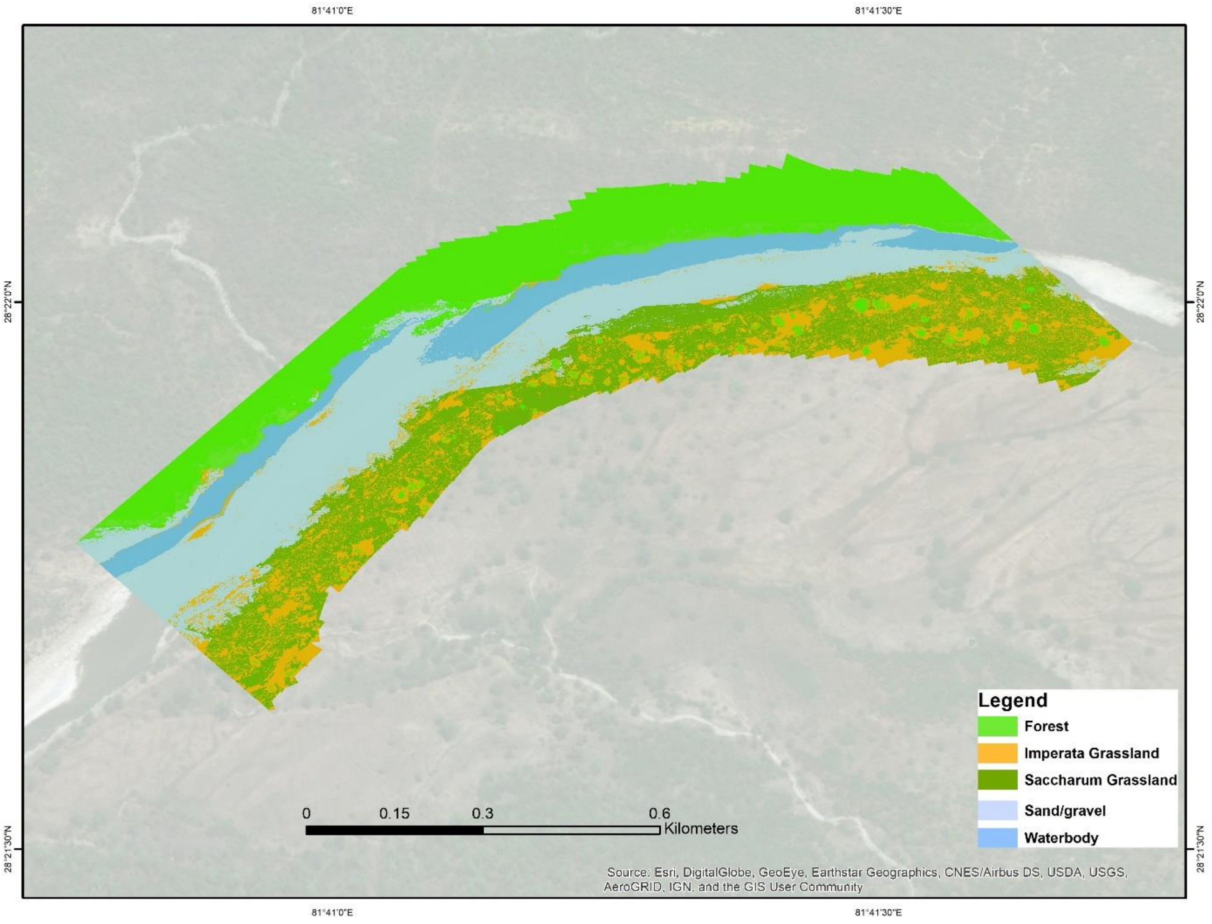


Fig. 6. Example of habitat mapping along a part of Mission-1 riverine stretch using TBS Caipirinha UAV platform and GoPro sensor camera used in gharial count.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community