

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

3 Gokarna Jung Thapa<sup>1,2</sup>, Kanchan Thapa<sup>1,\*</sup>, Ramesh Thapa<sup>3</sup>, Shant Raj Jnawali<sup>1</sup>, Serge A.  
4 Wich<sup>2,4</sup>, Laxman Prasad Poudyal<sup>3</sup>, Suraj Karki<sup>5</sup>

5 1. WWF Nepal, Baluwatar, Kathmandu, Nepal

6 2. Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Science Park  
7 904, 1098 XH Amsterdam, The Netherlands

8 3. Department of National Parks and Wildlife Conservation, Babarmahal, Kathmandu

9 4. Liverpool John Moores University, School of Natural Sciences and Psychology, James  
10 Parsons Building, Byrom street, L33AF, Liverpool, UK

11 5. Advanced College of Engineering and Management, Kupondole, Lalitpur

12 \* Corresponding Author: [kanchan.thapa@wwfnepal.org](mailto:kanchan.thapa@wwfnepal.org)

13

14

15

16

17

18

19

20

21 **Abstract**

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

35

36 **Keywords**

37 UAV, gharial, mugger, count, monitoring

38

39

40

## 41 **Introduction**

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

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

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

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

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

78 UAVs represents a new frontier in environmental research, but their use has been mainly limited  
79 to terrestrial or marine animals with few studies in river systems (Chabot & Bird, 2015; Linchant  
80 et al., 2015b). A majority of earlier gharial studies (Chowfin & Leslie, 2014; Rajbhandari &  
81 Acharya, 2015; Acharya et al., 2017; Singh & Rao, 2017) carried out in multiple sites in India  
82 and Nepal employed visual encounter surveys (Crump & Scott, 1994) while walking random  
83 transect along riverine habitats to estimate gharial population size. We applied UAV technology

84 to count gharials along a 46 km Babai river stretch within Bardia National Park which is  
85 regarded as strong hold for gharial population in the western part of Nepal. We assumed that the  
86 winter season habitat along the river stretch would provide excellent basking sites for the  
87 crocodilians (gharial, as well as mugger, *Crocodylus palustris*), and therefore would allow for  
88 aerial counts and differentiation among animals through images captured from the UAVs. Thus,  
89 we hypothesized that conducive environmental conditions (turbidity: clean water, season: winter  
90 and behavior: basking) would allow for a UAV study of these species. Lastly, we compared  
91 UAV derived gharial count with results from periodic traditional surveys carried out along Babai  
92 River in Bardia National Park (more in data analysis sections) in the past. We hypothesize that  
93 UAV derived gharial counts can be compared with the visual encounter surveys carried in the  
94 past.

## 95 **Materials and methods**

### 96 **Study Area**

97 Bardia National Park (BNP) is located in the southwestern part (28°15'-28°40'N; 81°15'-  
98 81°40'E, 968 km<sup>2</sup>) of Nepal. Two major perennial rivers, the Karnali and Babai flow along a  
99 North-South gradient and form their respective flood plains. The Babai river (hereafter referred  
100 as Babai) within BNP is approximately 46 km long with Chepang as the upstream point in the  
101 north-east and Parewaodhar in the south as the downstream point (Fig. 1). The total catchment  
102 area formed by the Babai is ~2,602 km<sup>2</sup> encompassing the northern & southern Churia range and  
103 foothill areas. Seasonal variation in surface water temperature are recorded along the Babai

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

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

#### 114 **Methodology**

115 We used a fixed-wing UAV to capture images across the side of river banks while flying pre-  
116 programmed aerial routes along the river stretch. Flying altitude was restricted to 80m following  
117 the local civil aviation regulation and avoiding potential disturbance to the species in  
118 investigation (Hodgson & Koh, 2016). We used fixed wing TBS Caipirinha ([http://www.team-](http://www.team-blacksheep.com)  
119 [blacksheep.com](http://www.team-blacksheep.com), model discontinued) equipped with an APM 2 flight controller. We used the  
120 Mission Planner (1.3.37, <http://ardupilot.org/planner/docs/common-install-mission-planner.html>)  
121 to program flight routes. We used the android application (Droid-planner android application  
122 V2\_8.6\_RC3) for real-time tracking of UAV during the flight operation on a Samsung tablet.  
123 With payload, this model has a flight duration of approximately 20 minutes. This platform was  
124 ideal for our use due to its portability (850 mm-wingspan), and low weight (~0.65 kg). A 3DR  
125 radio telemetry (V1.0) was attached to a tablet for communicating between UAV and ground

126 stations (tablet). Multiplex Smart SX transmitter radio controller was used for landing and  
127 takeoff.

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

135 The selection of the appropriate season and time of day were crucial. The survey was conducted  
136 between Jan-Feb 2017. During this season, the turbidity of water flowing in Babai was low  
137 enough to allow some transparency for possible identification of crocodylians swimming  
138 above/below (~1m) surface water. We selected morning (8:00-11:00 AM) and evening (15:00-  
139 17:00 PM) time to capture the photographs from the UAV as these are the general basking times  
140 for the crocodiles.

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

#### 145 **Image Analysis**

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

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

157 *Approach to counting crocodilians:* We used three image analysts for counting the crocodilians  
158 in each of the photographs from the 12 missions. Each image analyst counted the individual  
159 gharials and muggers on the photographs and tallied the total. The consensus approved by each  
160 of the three image analysts was used as final count data. Any discrepancy in manual  
161 identification between image analysts were discarded and not used in final derived count. Gharial  
162 and mugger species identification on UAV images relied on the visual inspection of its external  
163 morphological characteristics (Ballouard et al., 2010). From 80m height, the images acquired  
164 with the UAV do not provide the resolution to distinguish between sexes and age classes and as a  
165 result only provides a total number of gharial/mugger individuals. We used two approaches for  
166 identification of crocodilians in the photographs. Firstly, each image analysts looked in for  
167 clusters visible in the photographs, then examined the shape and length of the snout to



168 differentiate between gharials and muggers (Ballouard et al., 2010) on possible clusters seen on  
169 the photographs. Gharials have a long and slender snout while muggers have a short snout (Fig.  
170 2). Secondly, each of the positive samples (images) identified through consensus by the image  
171 analysts were further screened using *countingsthing* software (Dynamic Venture, Inc.). This step  
172 also verified the clusters identified by the image analysts in step one. The software differentiates  
173 and identifies any object/clusters seen on the photograph. Each of the identified objects were  
174 then finally labelled either as gharial and/or mugger manually by image analyst at the end.

## 175 **Data Analysis**

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

183 Due to logistical issues, we could not simultaneously survey gharials and muggers on the ground.  
184 So, we compared the UAV derived count data with data from three replication data collected  
185 from conventional gharial surveys conducted in 2016 (Acharya et al., 2017). We also compared  
186 the gharial count data with data collected over the multiple temporal surveys (Khadka et al.,  
187 2008; Thapaliya, 2011; Acharya et al., 2017) carried out in the winter season at different time  
188 frames employing visual encounter surveys (Crump & Scott, 1994). Due to a lack of data on  
189 muggers, we only used the gharial count data from multiple studies. All the published count data

190 from multiple studies were standardized in a single scale as per the mission length segment. We  
191 used box-and-whisker plots to visually examine the count data from UAV and ground surveys  
192 carried out over multiple years. We used a Kruskal-Wallis non-parametric test for comparing the  
193 means between the four independent surveys. All the analysis was carried out in R (R, 2017).

## 194 **Results**

195 We flew the UAV at an altitude of 80m, at a speed of 10-12m/sec, along 12 pre-designed  
196 missions with a search effort of 2.72 hours of flight time covering a total of 102 km (mean: 8.5  
197 km (SD: 0.64)) spatial (aerial distance) river bank habitat (Table 1). Collectively, UAV took a  
198 total of 11,799 photographs covering an effective surface area of 8.2 km<sup>2</sup> of river bank habitat in  
199 12-missions. All the photographs (including discarded ones) were carefully searched for the  
200 presence of gharial and/or mugger. At the final stage, only 7,708 photographs (66%) were  
201 selected for the final stitching of photographs.

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

210 UAV derived count data was found to be highest (+10) when compared to each of the three  
211 ground-based surveys. The UAV surveys show few records (n=2) as outliers, however the rest of

212 the data were within the 75% quartile range (Fig. 4). The 95% CI overlaps between each of the  
213 independent surveys indicates no significant changes in gharial population along Babai (Fig. 5).  
214 A statistical evaluation using a Kruskal Wallis test did not find significant differences between  
215 the various population surveys ( $H=3.18$ ,  $d.f=3$ ,  $p=0.36$ ) conducted at multiple times.

## 216 **Discussion**

217 This study is the first of its kind to use UAVs to monitor the critically endangered gharial  
218 population in South Asia. The results provide baseline information that can be used for future  
219 aerial monitoring of the population. Our results are an addition to the literature on the use of  
220 UAVs to work on aquatic species such as penguins (Ratcliffe et al., 2015), sea otters (Williams  
221 et al., 2017), crocodiles (Evans et al., 2016), and sea turtles (Bevan et al., 2016). UAV  
222 technology seems to be a suitable method of collecting crocodile population count data in this  
223 habitat because of its ability to take high resolution images of basking sites and rivers habitat,  
224 which can be counted carefully in the lab and compared through time, therefore reducing the  
225 uncertainty of estimates in traditional observer counts (Van Gemert et al., 2014; Hodgson et al.,  
226 2016).

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

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

244 UAV application could be an add-on in predicting species distribution with imperfect detection  
245 using analytical metrics such as occupancy framework (MacKenzie et al., 2006). William et al  
246 (2017) provides a useful and promising tool for estimating occupancy, abundance, and detection  
247 probability from aerial photographic surveys. Variation in UAV application because of variety of  
248 platforms and sensor availability allows biologist to collect population data at higher resolutions  
249 followed by habitat ancillary data (example shown in Fig. 7). Data gathered can be integrated  
250 in modelling the covariates affecting the gharial occupancy in the freshwater river habitat.

251 Choice of equipment was traditional in the current survey even though it fulfilled the research  
252 objectives. The current choice of platform in fixed wing category was selected keeping in view  
253 to survey larger area. Use of more advanced platform such as DJI Phantom Pro 4 (non-fixed  
254 wing category) and Parrot Sequoia (sensor) can be explored, However, their use needs be tested  
255 in terms of its quality, resolutions, and detectability within the range of gharial distribution. With

256 minor adjustment in field protocol like doubling flight time (survey field effort) in non-fixed  
257 wing category might give better image resolution and quality along with extra benefit of vertical  
258 take-off and landing facility which is crucial for operating environment such as our study area.

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

## 270 **Contributions**

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

## 274 **Acknowledgements**

275 We would like to thank the Department of National Park and Wildlife Conservation for giving us  
276 research permits to carry-out the task. We are thankful to Bardia National Park for helping with

277 local permits and logistics to carry out survey work smoothly. Thanks to Karl Wurster, USAID  
278 for his effort in the implementation of the project. We are indebted to Ashok Bhandari, Motiram  
279 Paudel, and Madhav Kumar Nepal for providing the field assistance. Madhav Khadka and Shiv  
280 Raj Bhatta from WWF Nepal and TAL-PABZ team for coordinating and providing technical  
281 support for the survey. WWF-USAID Hariyo Ban Program for providing the financial support  
282 for the project. We would like to thank Mr. Keeyan Pang (ConservationDrones.org), and Dr.  
283 Krishnamurthy Ramesh (Wildlife Institute of India) for providing the UAV training with support  
284 from WWF-AREAS program. Sheren Shrestha for reviewing the earlier draft and Shayasta  
285 Tuladhar for support in desktop editing.

## 286 **References**

- 287 Acharya, K.P., Khadka, B.K., Jnawali, S.R., Malla, S., Bhattarai, S., Wikramanayake, E. & Köhl,  
288 M. (2017) Conservation and Population Recovery of Gharials (*Gavialis gangeticus*) in  
289 Nepal. *Herpetologica*, **73**, 129-135.
- 290 Ballouard, J.M., Priol, P., Oison, J., Ciliberti, A. & Cadi, A. (2010) Does reintroduction stabilize  
291 the population of the critically endangered gharial (*Gavialis gangeticus*, *Gavialidae*) in  
292 Chitwan National Park, Nepal? *Aquatic Conservation: Marine and Freshwater*  
293 *Ecosystems*, **20**, 756-761.
- 294 Bevan, E., Wibbels, T., Navarro, E., Rosas, M., Najera, B.M., Sarti, L., ILLESCAS, F.,  
295 MONTANO, J., PEÑA, L.J. & BURCHFIELD, P. (2016) Using unmanned aerial vehicle  
296 (UAV) technology for locating, identifying, and monitoring courtship and mating  
297 behaviour in the green turtle (*Chelonia mydas*). *Herpetol Rev.* 2016b, **47**, 27-32.
- 298 Chabot, D. & Bird, D.M. (2015) Wildlife Research and Management methods in the 21st  
299 Century: Where do unmanned aircraft fit in ? *Journal of Unmanned Vehicle Systems*, **3**,  
300 137-155.
- 301 Choudhury, B.C., Singh, L.A.K., Rao, R.J., Basu, D., Sharma, R.K., Hussain, S.A., Andrews,  
302 H.V., Whitaker, N., Whitaker, R., Lenin, J., Maskey, T., Cadi, A., Rashid, S.M.A.,  
303 Choudhury, A.A., Dahal, B., Win Ko, U., Thorbjarnarson, J. & Ross, J.P. (2007) *Gavialis*  
304 *gangeticus*. The IUCN Red List of Threatened Species 2007: e.T8966A12939997.
- 305 Chowfin, S. & Leslie, A. (2014) A multi-method approach for the inventory of the adult  
306 population of a critically endangered crocodylian, the Gharial (*Gavialis gangeticus*) at  
307 Dhikala, Corbett Tiger Reserve incorporating direct counts and trail cameras.  
308 *International Journal of Biodiversity and Conservation*, **6**, 148-158.

309 Crump, M. & Scott, N. (1994) Visual encounter surveys. Pàgs. 84-92. en: \_Heyer, MA, RW  
310 Donnelly, LA McDiarmid, C. Hayek & MS Foster (eds). *Measuring and Monitoring*  
311 *Biological Diversity: Standard Methods for Amphibians*. Smithsonian Institution Press,  
312 Washington, DC.

313 Ditmer, M.A., Vincent, J.B., Werden, L.K., Tanner, J.C., Laske, T.G., Iaizzo, P.A., Garshelis,  
314 D.L. & Fieberg, J.R. (2015) Bears show a physiological but limited behavioral response  
315 to unmanned aerial vehicles. *Current Biology*, **25**, 2278-2283.

316 DNPWC (2007) Bardia National Park and Buffer Zone Management Plan (2007-2011).  
317 Department of National Parks and Wildlife Conservation. Kathmandu, Nepal.

318 DNPWC (2008) Annual Report 2008-2009. *Department of National Park and Wildlife*  
319 *Conservation, Kathmandu, Nepal*.

320 Dudgeon, D. (2000) Large-Scale Hydrological Changes in Tropical Asia: Prospects for Riverine  
321 Biodiversity: The construction of large dams will have an impact on the biodiversity of  
322 tropical Asian rivers and their associated wetlands. *Bioscience*, **50**, 793-806.

323 Evans, L.J., Jones, T.H., Pang, K., Saimin, S. & Goossens, B. (2016) Spatial Ecology of  
324 Estuarine Crocodile (*Crocodylus porosus*) Nesting in a Fragmented Landscape. *Sensors*,  
325 **16**, 1527.

326 Getzin, S., Wiegand, K. & Schoning, I. (2012) Assessing biodiversity in forests using very high-  
327 resolution images and unmanned aerial vehicles. *Methods in Ecology and Evolution*, **3**,  
328 397-404.

329 Hahn, N., Mwakatobe, A., Konuche, J., de Souza, N., Keyyu, J., Goss, M., Chang'a, A.,  
330 Palminteri, S., Dinerstein, E. & Olson, D. (2017) Unmanned aerial vehicles mitigate  
331 human–elephant conflict on the borders of Tanzanian Parks: a case study. *Oryx*, **51**, 513-  
332 516.

333 Hodgson, A., Kelly, N. & Peel, D. (2013) Unmanned Aerial Vehicles (UAVs) for Surveying  
334 Marine Fauna: A Dugong Case Study. *Plos One*, **8**, e79556.

335 Hodgson, J.C., Baylis, S.M., Mott, R., Herrod, A. & Clarke, R.H. (2016) Precision wildlife  
336 monitoring using unmanned aerial vehicles. In *Scientific reports* pp. 22574.

337 Hodgson, J.C. & Koh, L.P. (2016) Best practice for minimising unmanned aerial vehicle  
338 disturbance to wildlife in biological field research. *Current Biology*, **26**, R404-R405.

339 Hunt, E., Hively, W., Fujikawa, S., Linden, D., Daughtry, C. & McCarty, G. (2010) Acquisition  
340 of NIR-green-blue digital photographs from unmanned aircraft for crop monitoring.  
341 *Remote Sensing*, **2**, 290-305.

342 Hussain, S. (2009) Basking site and water depth selection by gharial *Gavialis gangeticus* in  
343 National Chambal Sanctuary and its implication for river conservation. *Aquatic*  
344 *Conservation*, **19**, 127-133.

345 IUCN (2012) *Red List of Threatened Species Version 2012*. International Union For Nature  
346 Conservation. [http://www.iucnredlist.org/](http://www.iucnredlist.org/apps/redlist/details/22732/0) apps/redlist/details/22732/0

347 Kelly, M.J. (2008) Design, evaluate, refine: camera trap studies for elusive species. *Animal*  
348 *Conservation*, **11**, 182-184.

349 Khadka, M., Kafley, H. & Thapaliya, B.P. (2008) Population Status and Distribution of Gharial  
350 in Nepal. Forum for Natural Resource Managers.

351 Koh, L.P. & Wich, S.A. (2012) Dawn of Drone Ecology: Low-Cost Autonomous Aerial  
352 Vehicles for Conservation. *Tropical Conservation Science*, **5**, 121-132.

353 Linchant, J., Lisein, J., Semeki, J., Lejeune, P. & Vermeulen, C. (2015a) Are unmanned aircraft  
354 systems (UASs) the future of wildlife monitoring? A review of accomplishments and  
355 challenges. *Mammal Review*, **45**, 239-252.

356 Linchant, J., Lisein, J., Semeki, J., Lejeune, P. & Vermeulen, C. (2015b) Are unmanned aircraft  
357 systems (UASs) the future of wildlife monitoring? A review of accomplishments and  
358 challenges. *Mammal Review*, **45**, 239-252.

359 MacKenzie, D.I., Nichols, J.D., Royle, J.A., Pollock, J.E., Bailey, L.L. & Hines, J.E. (2006)  
360 Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species  
361 Occurrence. *Elsevier, San Diego, USA*.

362 Maskey, T.M. (2008) *Gharial conservation in Nepal*, Wildlife Watch Group.

363 Mulero-Pázmány, M., Jenni-Eiermann, S., Strebel, N., Sattler, T., Negro, J.J. & Tablado, Z.  
364 (2017) Unmanned aircraft systems as a new source of disturbance for wildlife: A  
365 systematic review. *Plos One*, **12**, e0178448.

366 Neill, W.T. (1971) *The last of the ruling reptiles: alligators, crocodiles, and their kin*, JSTOR.

367 Pimm, S.L., Alibhai, S., Bergl, R., Dehgan, A., Giri, C., Jewell, Z., Joppa, L., Kays, R. & Loarie,  
368 S. (2015) Emerging Technologies to Conserve Biodiversity. *Trends in Ecology &*  
369 *Evolution*, **30**, 685-696.

370 R (2017) The R foundation for statistical computing. Version 3.0.1. Vienna, Austria.

371 Rajbhandari, S.L. & Acharya, P.M. (2015) Population, basking and hatching success of *Gavialis*  
372 *gangeticus* in Narayani River, Chitwan National Park, Nepal. *Journal of Natural History*  
373 *Museum*, **27**, 1-11.

374 Ratcliffe, N., Guihen, D., Robst, J., Crofts, S., Stanworth, A. & Enderlein, P. (2015) A protocol  
375 for the aerial survey of penguin colonies using UAVs. *Journal of Unmanned Vehicle*  
376 *Systems*, **3**, 95-101.

377 Singh, H. & Rao, R. (2017) Status, threats and conservation challenges to key aquatic fauna  
378 (Crocodile and Dolphin) in National Chambal Sanctuary, India. *Aquatic Ecosystem*  
379 *Health & Management*, **20**, 59-70.

380 Smith, B. & Reeves, R. (2000) Report of the workshop on the effects of water development on  
381 river cetaceans, 26-28 February 1997, Rajendrapur, Bangladesh. *Biology and*  
382 *conservation of freshwater cetaceans in Asia. IUCN Species Survival Commission*  
383 *Occasional Paper*, 15-22.

384 Steinheim, G., Wegge, P., Fjellstad, J.I., Jnawali, S.R. & Weladji, R.B. (2005) Dry season diets  
385 and habitat use of sympatric Asian elephants (*Elephas maximus*) and greater one-horned  
386 rhinoceros (*Rhinoceros unicornis*) in Nepal. *Journal of Zoology*, **265**, 377-385.

387 Thapaliya, B.P. (2011) Population Status and Distribution of Gharial (*Gavialis gangeticus*) in  
388 Karnali and Babai River Systems, Western Nepal. B.Sc Thesis, Kathmandu Forestry  
389 College, Tribhuvan University, Kathmandu, Nepal.

390 Van Gemert, J.C., Verschoor, C.R., Mettes, P., Epema, K., Koh, L.P. & Wich, S. (2014) Nature  
391 Conservation Drones for Automatic Localization and Counting of Animals. In *ECCV*  
392 *2014 Workshop* (eds A. L., B. M. & R. C), pp. 255-270. Springer.

393 Watts, A., Ambrosia, V., Smith, S., Burgess, M., Wilkinson, B., Szantoi, Z., Ifju, P. & Percival,  
394 H. (2010) Unmanned aircraft systems in remote sensing and scientific research:  
395 classification and considerations of use. *Remote Sensing*, **4**.



396 Whitehead, K. & Hugenholtz, C.H. (2014) Remote sensing of the environment with small  
397 unmanned aircraft systems (UASs), part 1: a review of progress and challenges. *Journal*  
398 *of Unmanned Vehicle Systems*, **02**, 69-85.

399 Wich, S., Dellatore, D., Houghton, M., Ardi, R. & Koh, L.P. (2015) A preliminary assessment of  
400 using conservation drones for Sumatran orang-utan (*Pongo abelii*) distribution and  
401 density. *Journal of Unmanned Vehicle Systems*, **4**, 45-52.

402 Williams, P.J., Hooten, M.B., Womble, J.N. & Bower, M.R. (2017) Estimating occupancy and  
403 abundance using aerial images with imperfect detection. *Methods in Ecology and*  
404 *Evolution*, n/a-n/a.

405 Wing, M., Burnett, J., Sessions, J., Brungardt, J., Cordell, V., Dobler, D. & Wilson, D. (2013)  
406 Eyes in the sky: remote sensing technology development using unmanned aircraft  
407 systems. *Journal of Forestry*, **111**, 341-347.

408 Yadav, S.K. (2002) Hydrological Analysis for Bheri-Babai Hydropower Project-Nepal. MS  
409 Thesis in Hydropower Development.

410 Zhuo, X., Koch, T., Kurz, F., Fraundorfer, F. & Reinartz, P. (2017) Automatic UAV Image Geo-  
411 Registration by Matching UAV Images to Georeferenced Image Data. *Remote Sensing*, **9**,  
412 376.

413

414

415

416

417

418

419

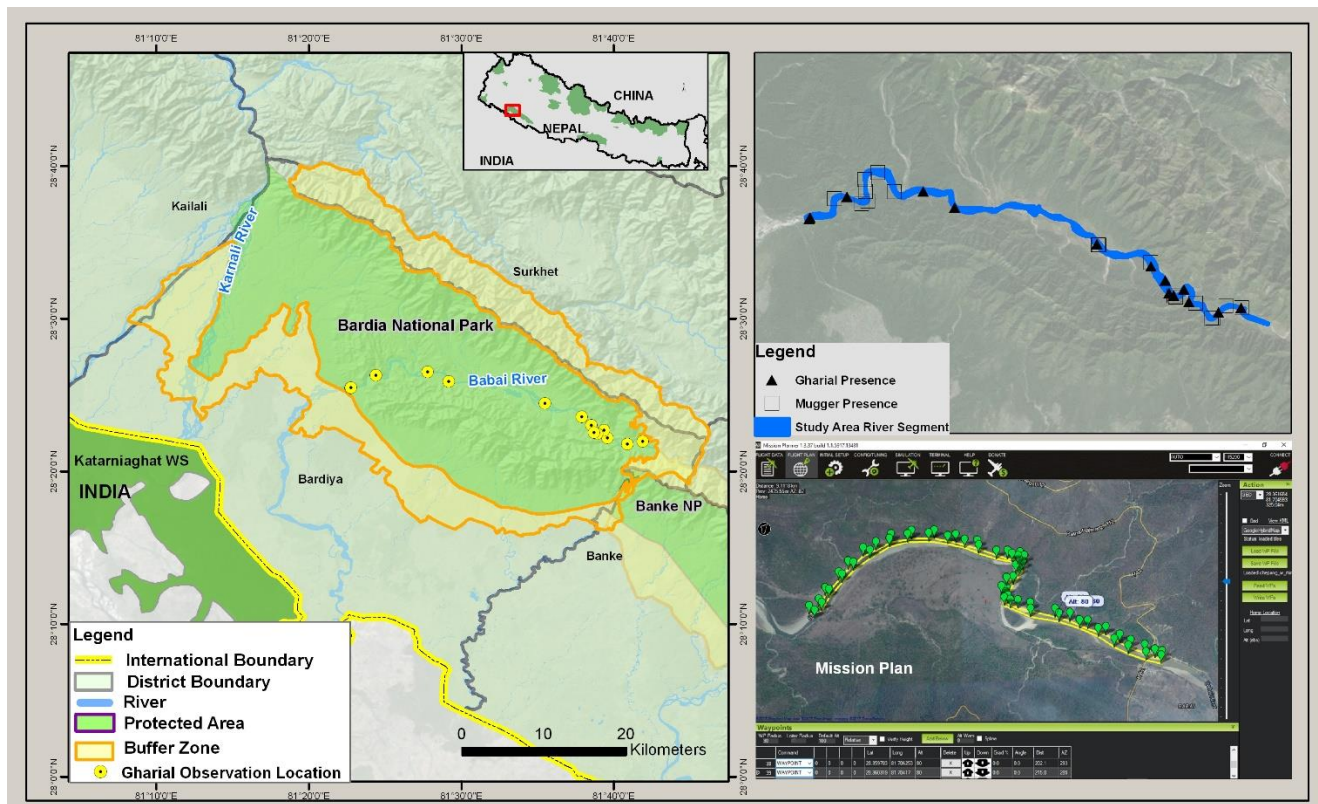
420

421

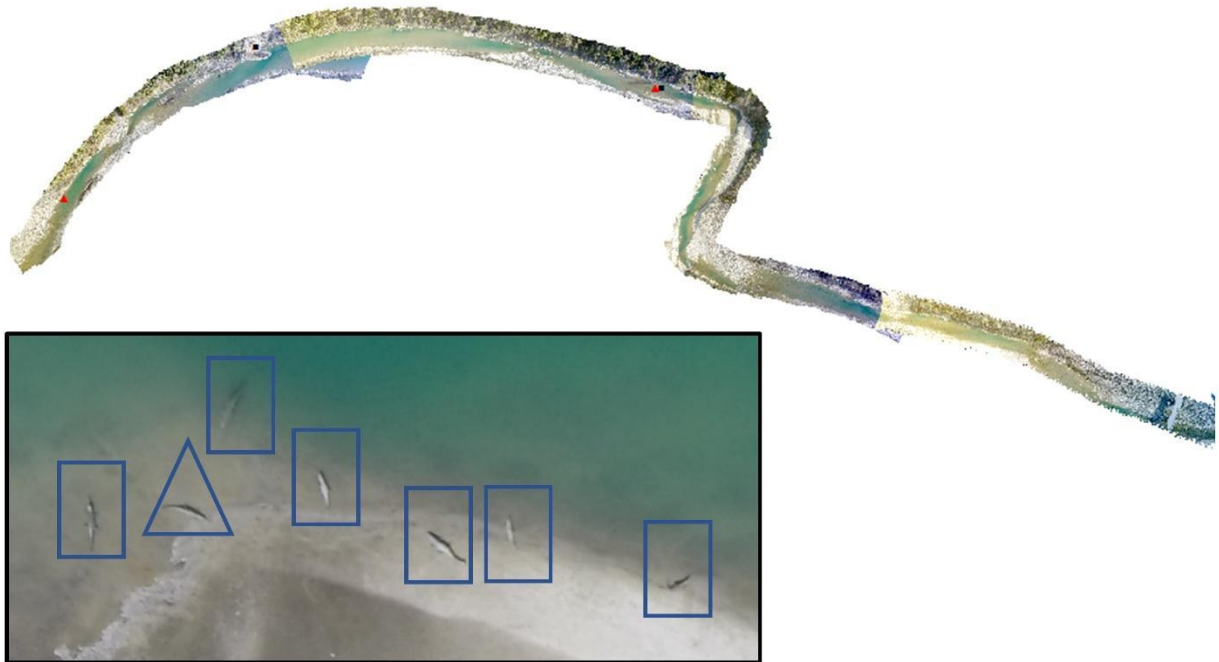
Table 1. Search effort and number of photos captured by the UAV, gharial/mugger count in each of the 12 pre-designed missions.

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
<b>Total</b>	101.7	163	11,799	7,708	33	31	8.21

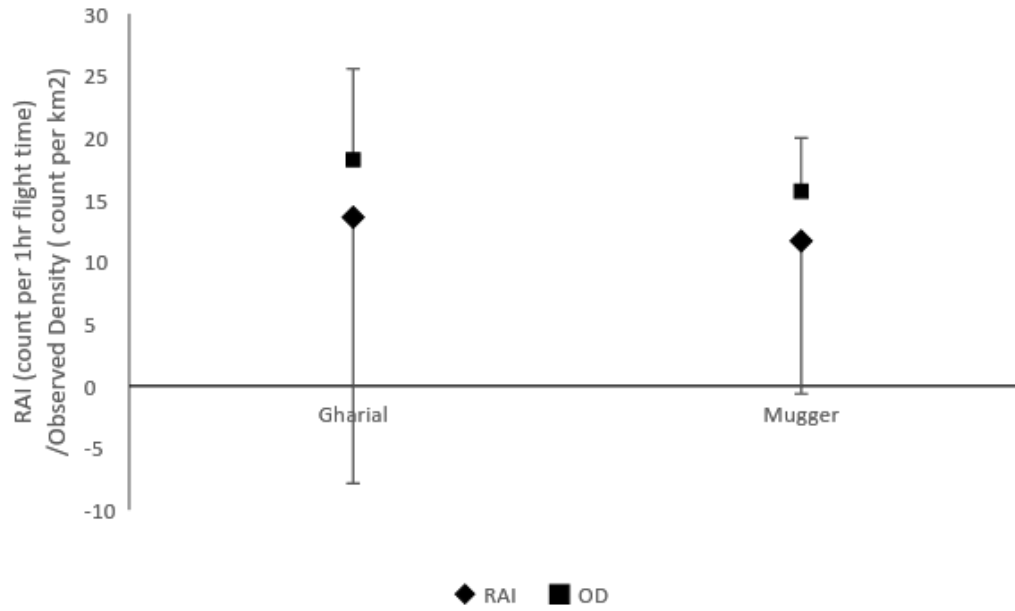
**Fig. 2.** Study area showing two major (Karnali and Babai River) freshwater habitats of Gharial and Mugger. Gharial (▲) and mugger (□) count was done along the river stretch in Babai River in Bardia National Park. Flight path of UAV belong to one of the pre-designed mission across the Babai River stretch 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.



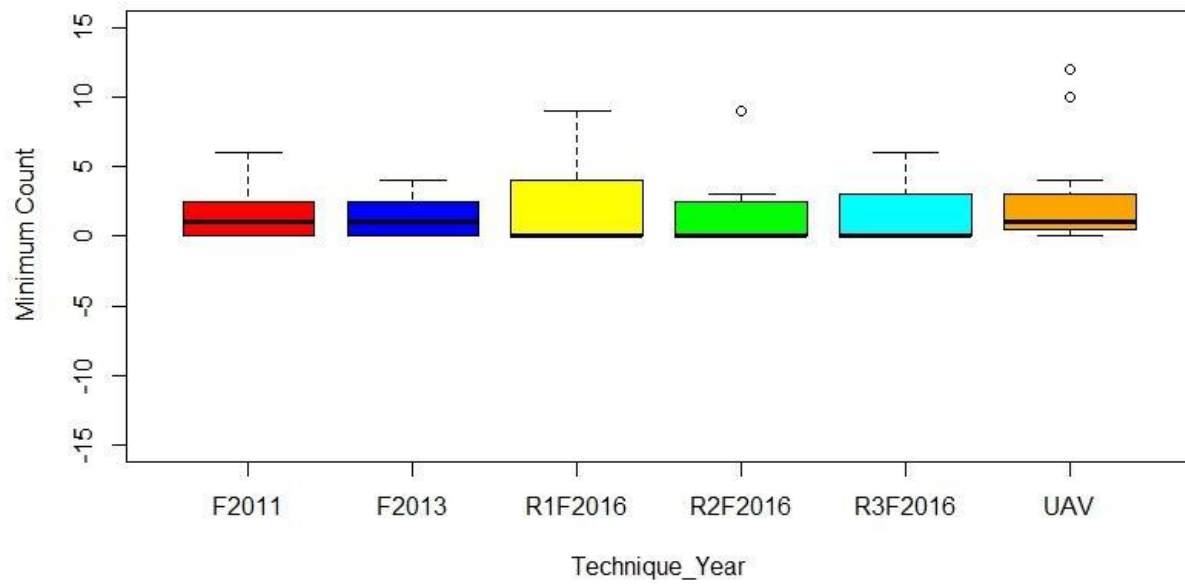
**Fig. 2.** Mission 1 (~10.1 km) stitched photographs showing the gharial (▲) and mugger (■) recorded position along Babai River. Inset shows differentiation between gharial (triangular box) and mugger (rectangular box) based on physical appearance (shape) as seen on UAV images.



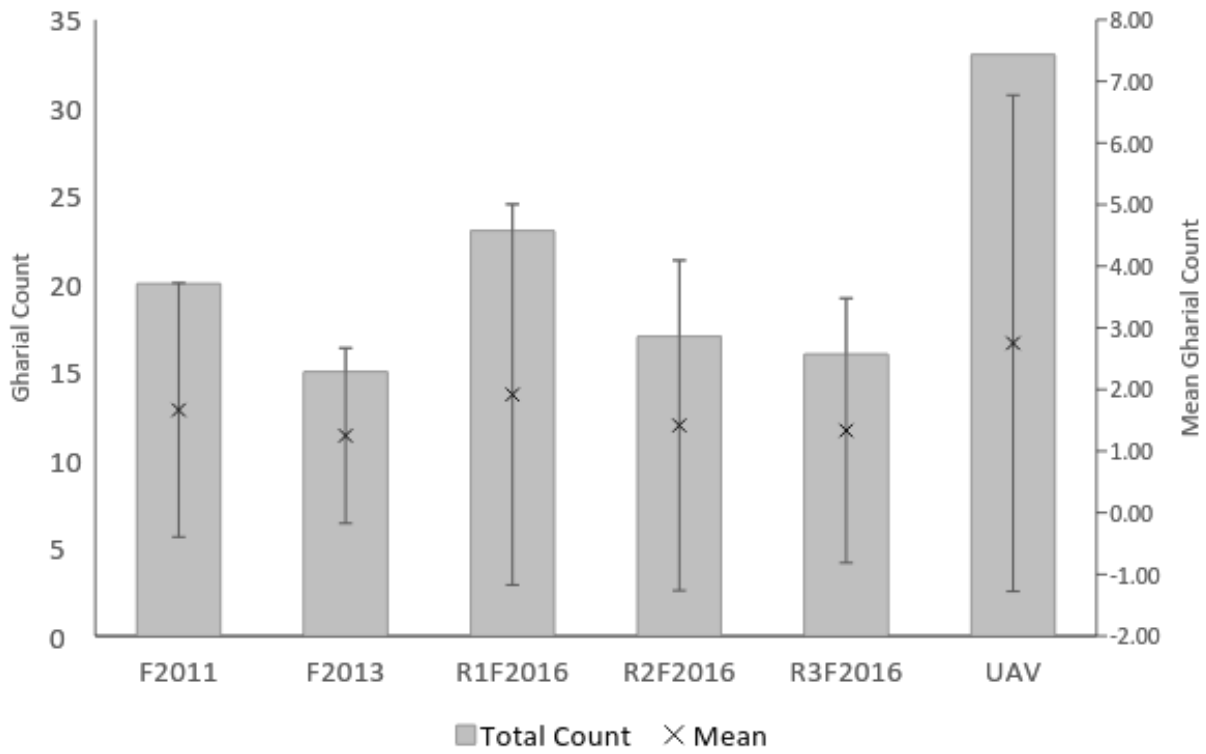
**Fig. 3.** Relative Abundance Index (RAI; ■) and Observed Density (OD; ◆) of Gharial and Mugger along the river bank of Babai in Bardia National Park.



**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.

