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Cover: Western African lion couple in Niokolo-Koba National Park © Dimitri Dagorne.

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ARTICLE

A citizen science approach to monitoring of the Lion *Panthera leo* (Carnivora: Felidae) population in Niokolo-Koba National Park, Senegal

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Abstract: A voluntary citizen science approach was used in a pilot study of the relict population of the Critically Endangered western African Lion *Panthera leo* in Niokolo-Koba National Park (NKNP) in Senegal. In total, 93 observations involving 253 lion sightings were made by NKNP guides and their clients over a period of four and a half years in the central tourist area of the Park which represents about 3% of the total area of NKNP. Identification sheets were produced for 10 individual lions on the basis of whisker spot patterns measured from photographs contributed by the tourists. Although we were not able to identify a sufficient number of individual lions to estimate the lion population in the zone, extensive data on the geographic distribution, age-class and sex, and behaviour of the observed lions are presented. Data are also presented to tentatively support a relationship between the annual variations in lion observations and the total rainfall in the preceding year. The advantages of this citizen science approach in terms of complementing mainstream science, as well as in promoting tourism development and conservation sensitisation, are discussed, and recommendations are made for pursuing this cooperative effort at a higher level of effectiveness.

Keywords: Asiatic Lion, fur hue, genome, group size, nose colour, population, sex ratio, western African Lion, whisker spot.

Abbreviations: DPN—Direction des Parcs Nationaux | GIE NIOKOLO—Groupement d'Intérêt économique des guides du Parc National du Niokolo-Koba | NKNP—Niokolo-Koba National Park.

French abstract: Une approche science citoyenne bénévole a été appliquée pour une étude pilote de la population relicte du lion *Panthera leo* dans le Parc National du Niokolo-Koba (PNNK) au Sénégal, population appartenant à la sous-population des lions de l'Afrique de l'Ouest en Danger Critique d'Extinction. Au total, 93 observations conduisant au repérage de 253 lions ont été faites par les guides du PNNK et leurs clients pendant une période de quatre ans et demi dans la zone centrale touristique du Parc National qui représente environ 3% de la surface totale du PNNK. Dix fiches d'identification individuelles des lions ont été élaborées sur la base de motifs des racines de vibrisses identifiés à partir des photographies prises par des touristes. Bien que nous n'ayons pas pu identifier un nombre suffisant de lions individuels pour estimer la population de lions dans la zone, une quantité importante de données sur la distribution géographique, l'âge, le sexe, et le comportement de ces lions est présentée. D'autres données appuient de manière provisoire l'hypothèse d'une relation entre la variation annuelle du nombre d'observations des lions et la pluviométrie totale de l'année précédente. Les avantages de l'approche science citoyenne en tant que complément à la science traditionnelle ainsi que pour la promotion du développement du tourisme et de la sensibilisation en matière de conservation sont discutés, et des recommandations sont données pour la poursuite de cet effort coopératif à un niveau accru d'efficacité.

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INTRODUCTION

The African Lion *Panthera leo* has attracted particular attention as an example of the recognised critical decline in biodiversity worldwide, having declined to 35,000 individuals occupying 25% of its historic range (Henschel et al. 2014). Study of mitochondrial DNA (Bertola et al. 2011) showed that western and central African Lions form a distinct clade which is more closely related to Asiatic Lions than to the southern and eastern African Lions, which can be explained by a Pleistocene extinction and subsequent recolonization of western Africa from the Middle East; the relationships among the different African and Asiatic lion populations were recently further refined through whole genome studies (Bertola et al. 2019). The current status of the isolated western African population is especially worrisome, and it has now been listed as Critically Endangered by the IUCN (Henschel et al. 2015). This decision was based on the findings of Henschel et al. (2014) who had estimated the total number of West African Lions to be only 406, using survey data which confirmed the presence of lions in only four large protected areas in the region, including Niokolo-Koba National Park (NKNP) in southeastern Senegal (see Figure 1). NKNP is home to the westernmost and northernmost lions in Africa.

NKNP is one of the largest and most important nature sanctuaries in western Africa with an area of 913,000ha. The exceptional biodiversity of the Park was recognized in 1981 with its designation by UNESCO as a biosphere reserve (UNESCO 2007) and as a world heritage site (UNESCO 2019). Since 2007, however, NKNP has been listed as a world heritage site in danger. Poaching, incursion of livestock and illegal mining are among the factors that have contributed to this situation, which has resulted in dramatic decreases in the populations of megafauna in the Park (Renaud et al. 2006; Galat et al. 2015; UNESCO 2019). Henschel et al. (2014) estimated that in 2011 there were a maximum of 54 lions in the Park and stated that the population was small and appeared to be declining. A more recent report established by IUCN (Tiomoko & Van Merm 2015), however, states that the census conducted by the Park authorities in April 2015 noted positive signs of increased wildlife and in particular that the "lion, assumed absent from the property [sic] for several years, is now present." Regular surveys and scientific studies of the lions of NKNP (Bauer & Van Der Merwe 2004; Henschel et al. 2014; Kane et al. 2015) have not yet provided complete data on their number, distribution, physical, and behavioural characteristics, probably in part due to the difficulties in mobilising sufficient funding and human resources towards this goal.

The cooperative of local NKNP guides (Groupement d'Intérêt économique des guides du Parc National du Niokolo-Koba, hereafter referenced by its acronym GIE NIOKOLO), which has been at the forefront of efforts to improve and promote the Park and to foster sustainable development in the communities that surround it, began in 2015 to systematically document lion sightings in the course of their guiding work. The hypothesis of the present study is that the NKNP guides and the tourists they accompany could, through a voluntary citizen-science effort, contribute meaningful complementary scientific knowledge on the lions and at the same time help to advance lion conservation in the Park.

The main objectives of the present pilot study, conducted by GIE NIOKOLO with advice from an international scientific advisory team, have been: (i) to test the reliability and sustainability of such a citizen science lion monitoring effort and (ii) to collect and present data on the numbers, movements and behaviour of lions present in the main tourist zone of the Park (Figure 1). A secondary objective has been to gradually build expertise in identifying individual lions and, thereby, to contribute to the broader inventory of the lions of NKNP.

MATERIALS AND METHODS

Methods

There are about 30 NKNP guides; they have relatively little formal education but are very bush savvy, and most have over 20 years of experience in guiding tourists in the Park. The guides are certified by the Ministry of Tourism but, except for three who are employed by hotels, they are freelance professionals; they cooperate closely with, but do not have any direct administrative link to, the Direction des Parcs Nationaux (DPN) which is the government agency responsible for protecting the Park and managing its wildlife and the infrastructure.

We define a lion observation as viewing a group of lions and a lion sighting as spotting one lion within that group. Our pilot study aimed to document all lion observations made by tourist groups during four and a half calendar years of field study (from January 2015 to May 2019). While the study was uninterrupted during this period, the frequency of tourist safaris and accessibility of tracks in the Park varied considerably from month to month (see below). Fortuitous observations by personnel working in the Park were also included when

Image 1. Sub-adult Lion *Panthera leo* in Niokolo-Koba National Park.

these were brought to the attention of the guides. There are very few tourist groups visiting NKNP at any time but in the case that more than one tourist group observed the same lions in the same spot on the same half-day we grouped these observations into a single observation (in fact there were only two such occurrences among the 93 observations).

The study methodology was designed to benefit from the daily routine presence in the Park of NKNP guides able to spot lions in the bush, along with tourists who are fairly often equipped with good photographic equipment (every tourist group must be accompanied by a local guide while in the Park), in order to scientifically document visual lion observations. The guides are a closely-knit group, and the relatively rare lion sightings in the Park are of interest to all, so that the number of unreported observations was in principle very low.

At the end of each tourist visit, the accompanying guide provided details of lion observations to the local project coordinator for GIE NIOKOLO, who recorded data for each observation (number of lions, location, composition of the group in terms of age-class, sex and other physical characteristics, and behaviour) in a spreadsheet. A computer was available at the Park exit to deposit lion photographs contributed by the tourists, and, if this was not possible, the tourists were reminded by email to provide copies of their photographs. The tourists were encouraged on site by their guides to take the best possible photographs, especially trying to capture the whisker spot patterns as the most reliable method for the identification of individual lions (Mara Predator Project undated). A brochure developed to explain the project and to provide guidance on lion photography and identification was made available free of charge to visitors starting in autumn 2017, in order to enlist their cooperation and to enhance their understanding of the importance of lion conservation.

The collected observation data and photographs were regularly transmitted by the local project coordinator to the international advisory team of two experienced amateur naturalists (who either hold or are working on post-graduate scientific degrees) and one professional carnivore specialist (for details see the insert on Author Contribution and the Acknowledgements) who corrected and clarified the data together with the local project coordinator, and added the coordinates of the described observation sites. When there were doubts about the details of an observation, notably about classification by age and sex, the coordinator of the advisory team initiated a dialogue with the local project coordinator who in turn consulted the contributing guide if necessary. When photographs of sufficient quality were available, the advisory team analysed the physical characteristics of each lion, including scars, dentition and whisker spot patterns, and when possible created an individual lion identification sheet or added the observation to an existing lion identification sheet. The master database was maintained by the advisory team, with updates regularly transferred to the GIE NIOKOLO group.

The data collected, as well as the analysis (lion identity sheets and distribution maps), are available on an open access basis to all interested parties and have been regularly shared with the Park authorities. In addition to their scientific value, these citizen science data are used by the guides to help in their work and to encourage involvement in the lion conservation effort by the local community and by visitors to the Park.

The data were collected from vehicles in the Park and at fixed observation points next to wetlands and watercourses. In this pilot project we were unable to record information on the trajectories of the tourist safaris (other than those points at which lions were observed) or on the sampling effort in each area or site.

In order to ensure consistency in methodology, a protocol for collection, analysis and management of data and photographs was developed by the advisory team, employing the identification criteria on the website of Mara Predator Project (undated). A basic training workshop in lion photography and identification was organised for the guides in September 2017 based on the above protocol.

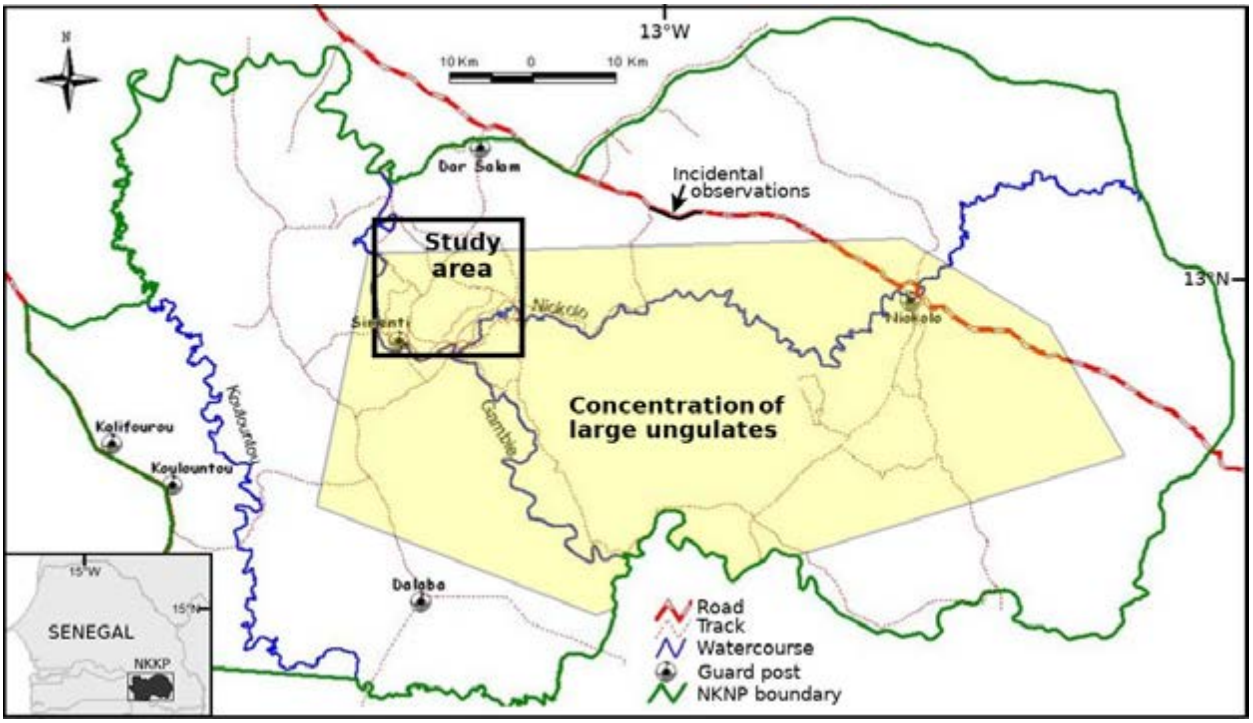

Figure 1. Niokolo-Koba National Park showing the 'study area' for observation of lions and the main area of concentration of large ungulates (main map and yellow polygon derived from Renaud et al. (2006)).

The study area

The study area was not pre-determined but can be defined as the zone within which the guides observed lions during their routine work of guiding tourists in NKNP. This area is shown in Figure 1, with corners at (13.159, -13.322), (13.159, -13.163), (13.014, -13.163) and (13.014, -13.322), and spanning 16.1km north-south by 17.2km east-west which represents an area of 28,300ha or about 3% of the Park. 97% of the lion observations (90 out of the 93) were within this area, while three additional incidental observations were made between 16 and 22 km to the east of the study area on the national highway traversing the Park.

Galat et al. (2015) and Tiomoko & Van Merm (2015) describe the main physical and biological characteristics of NKNP which are summarised below with particular reference to the study area.

Climate and hydrology

Annual precipitation in NKNP ranges from 900 to 1,200 mm of rainfall with a rainy season lasting from June to October. The hydrological system of the Park represents over 10% of the catchment of the Gambia River, which runs westward along the southern border of the study area then north along the western border. The Niokolo-Koba stream traverses the study area from east to west and joins the Gambia River. These two watercourses are quasi-permanent, although they may stop flowing continuously at the end of the dry season (with large permanent pools remaining in the Gambia River). More than 200 temporary or permanent pools have been identified in NKNP. Mare de Simenti at approximately 40 ha is the largest in the study area and is generally permanent because the level is managed by pumping water from the Gambia River. Ten smaller seasonal wetland areas in the study area are also accessible for observations by visitors.

Vegetation

The northern section of NKNP, including the study area, is Sudano-Sahelian in character and consists of a rich variety of habitats: wooded and scrub savannah, small zones of open grassland and closed gallery forests. The topography is relatively flat, with altitude ranging from 16m above sea level to about 70m (from measurements along the tracks with a Garmin Etrex 30 GPS unit). Seasonally flooded grasslands show a tendency towards encroachment and take-over by Giant Sensitive Tree *Mimosa pigra* (invasive) and False Abura *Mitragyna inermis* (native) and are actively managed by the Park authorities. Botanical studies conducted in NKNP have identified around 1,500 different plant

species, but no data are available on the number of species in the study area.

Wildlife

Eighty species of mammals, 360 species of birds, 36 species of reptiles, 20 species of amphibians and 60 species of fish have been identified within NKNP. The large- and medium-sized fauna that populates NKNP is very representative of the savannah biome. The common medium-sized mammals likely to provide prey for lions include: Guinea Baboon *Papio papio*, Bushbuck *Tragelaphus scriptus*, Bush Duiker *Sylvicarpa grimmia*, Red-flanked Duiker *Cephalophus rufilatus*, Oribi *Ourebia ourebi* and Common Warthog *Phacochoerus africanus*. Renaud et al. (2006) showed that these were widely distributed in the Park, including within the study area. The large ungulates present in the Park are Western Derby Eland *Taurotragus derbianus derbianus*, Roan Antelope *Hippotragus equinus*, Western Hartebeest *Alcelaphus buselaphus major*, Western Buffon's Kob *Kobus kobus kob*, Defassa Waterbuck *Kobus ellipsiprymnus defassa* and West African Buffalo *Syncerus caffer brachyceros*. Renaud et al. (2006) showed that, with the exception of the Roan Antelope which is widely distributed, the large ungulates were limited to a polygonal zone of about 325,000ha (shown in Figure 1) representing about 36% of the Park; all except the Western Derby Eland were present in the study area. The giant herbivores are only represented in the study area by the Hippopotamus *Hippopotamus amphibius*. Other than the lion, the large carnivores present in the study zone are Leopard *Panthera pardus*, Spotted Hyena *Crocuta crocuta* and African Wild Dog *Lycaon pictus*.

RESULTS

The details of 93 unique lion observations that were recorded during the study, involving 253 lion sightings, are analysed below. Thirteen of these 253 represented sightings or re-sightings of individual lions that could be identified and three others represented probable re-sightings. Therefore, 237 (94%) of the sightings were of lions that could not be individually identified. Given the relatively small number of individually identified lions, we have chosen to treat all 253 lion sightings equally in our analysis, recognising that these data substantially over-count the number of individual lions observed; the consequences of this are reviewed in the discussion section. The statistical calculations were performed with the "R" software package (https://www.r-project.org/), version 3.4.4.

Based on a total of approximately 2,000 visitors to NKNP in 2015 (Ndiaye 2015) and an estimate of about 4 tourists spending two days per visit (almost all during the dry season of eight months from November to June), 93 lion observations over 4.75 dry seasons (missing November and December of 2014) would equate to a roughly estimated likelihood of about 4% (probability = 93 × 4 / 2000 / 4.75) for a Park visitor to see a lion or of about 2% per day in the Park. On the other hand, the above approximations would imply about 4,750 days (2000 × 4.75 × 2 / 4) of observation by the guides.

Spatial distribution of lion observations

Figure 2 presents a map displaying the localisation of the observations and Table 1 summarises them by type of site, including the corresponding average group sizes observed.

The largest set (44 observations involving 108 lion sightings) consisted of observations made in close proximity (<100m) to water, such as those at the Mare de Simenti, small seasonal wetlands or the banks of the Gambia River (including during boat trips) and Niokolo-Koba stream.

The next largest number of observations (36 involving 121 lion sightings) were made away from water (≥100m) during the circuits by vehicle in the Park. It is interesting, referring to the map in Figure 2, that 27 of this second group of observations (75% of the total), which involved 100 lion sightings (83% of the total for the second group) were made in or very close to (<100m) wooded areas (as defined by submissions to the participatory cartographic website Open Streetmap (2019) based on the latter's publicly available satellite imagery). Relatively very few lions were observed in areas designated by Open Streetmap as open scrubland but it is difficult to draw a definitive conclusion since the relative observation efforts in scrubland and wooded areas are not known.

Ten fortuitous observations, involving 16 lion sightings, were made inside human occupied sites (lodging facilities or guard posts): two observations during the night within or in close proximity to the buildings and eight during the day. The location of the three additional sightings along the N7 national highway is surrounded by thick forest of African Lowland Bamboo *Oxytenanthera abyssinica*.

Combining the observations from around the Mare de Simenti with those from the adjacent Simenti Hotel (the zone of the Park most visited by tourists) yields 21 observations (23% of the total) involving 50 lion sightings (20% of the total) and lions were seen in this zone in

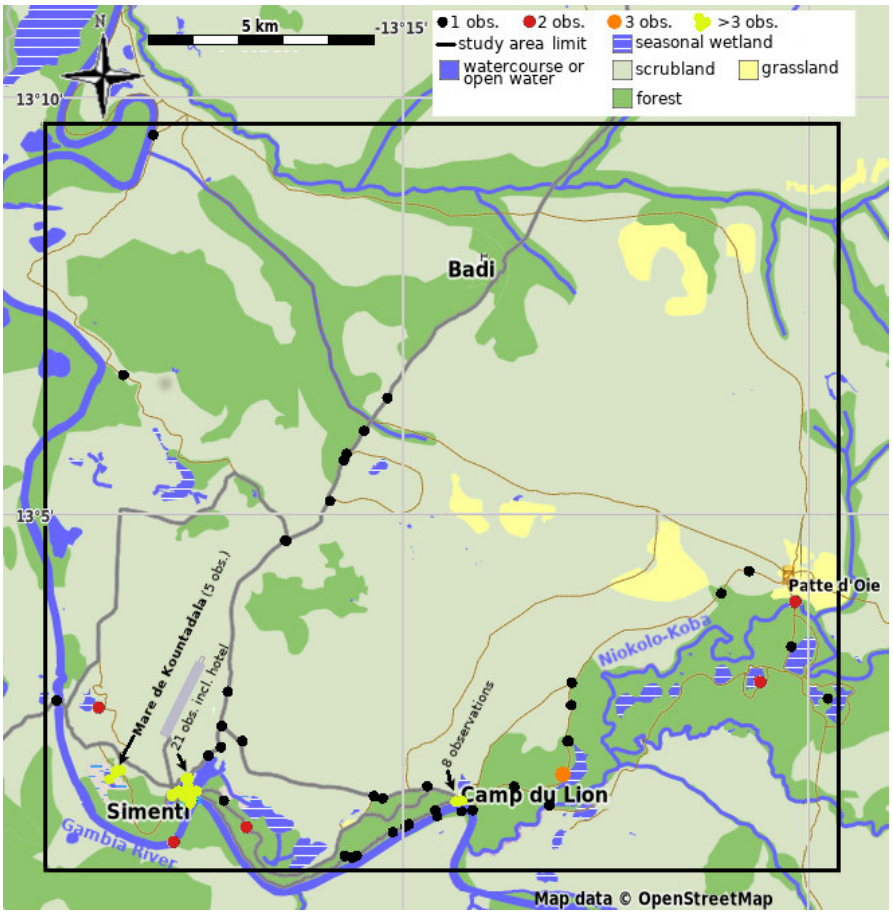

Figure 2. Localisation and frequency of the lion observations within the study area.

Table 1. Lion observations summarised by site category.

Site category	Number of observations	Number of lions observed	Average group size
Tracks away from water	36	121	3.4
Mare de Simenti	18	45	2.5
Seasonal wetlands	14	34	2.4
Banks of watercourses	12	29	2.4
Human occupation	10	16	1.6
National Highway #7	3	8	2.7
Total	93	253	2.72

all years of the study. The second largest cluster of observations was in and around the Camp du Lion on the Gambia River (the only major tourist accommodation in the Park other than Simenti Hotel during the study period); this cluster totalled eight observations (9%) involving sightings of 13 lions (5%). A third major cluster of 5 observations (5%) involving sightings of 11 lions (4%) was at the Mare de Kountadala, approximately 1.7km west of Simenti.

Variations in lion sightings by year and age-class

The annual number of observations and lion sightings, including the break-down of sightings by age-class, are given in Table 2:

The substantial variability in the number of lions observed annually cannot, in the recollections of the guides, be explained in terms of variations in effort on their part nor by variations in the number of tourist parties. One possible factor could be the quantity of annual rainfall since, when there is high precipitation during the rainy season from June to October, the vegetation grows more densely and also dries more slowly during the succeeding dry season between November and June of the following year, thus delaying the managed burning of the undergrowth by the Park authorities. Higher undergrowth during this dry season would generally make the lions more difficult to spot. In addition, delayed drying could mean that potential prey can wait longer before aggregating at water sources, which might lead to wider dispersal of, and thus lower visibility of, the lions.

To test the hypothesis that the number of lion

Table 2. Yearly total and average number of lions sighted by age-class (Percentages relative to the total sightings given in parantheses).

	2015	2016	2017	2018	2019 partial	Mean 2015–2018	Total
Adults	51 (91.1)	13 (86.7)	71 (77.2)	33 (100)	41 (71.9)	42.0	209 (82.6)
Sub-adults	2 (3.6)	0 (0)	7 (7.6)	0 (0)	0 (0)	2.25	9 (3.6)
Cubs	3 (5.4)	2 (13.3)	14 (15.2)	0 (0)	16 (28.1)	4.75	35 (13.8)
Total lions	56	15	92	33	57	49.0	253
Observations	21	6	27	15	24	17.25	93

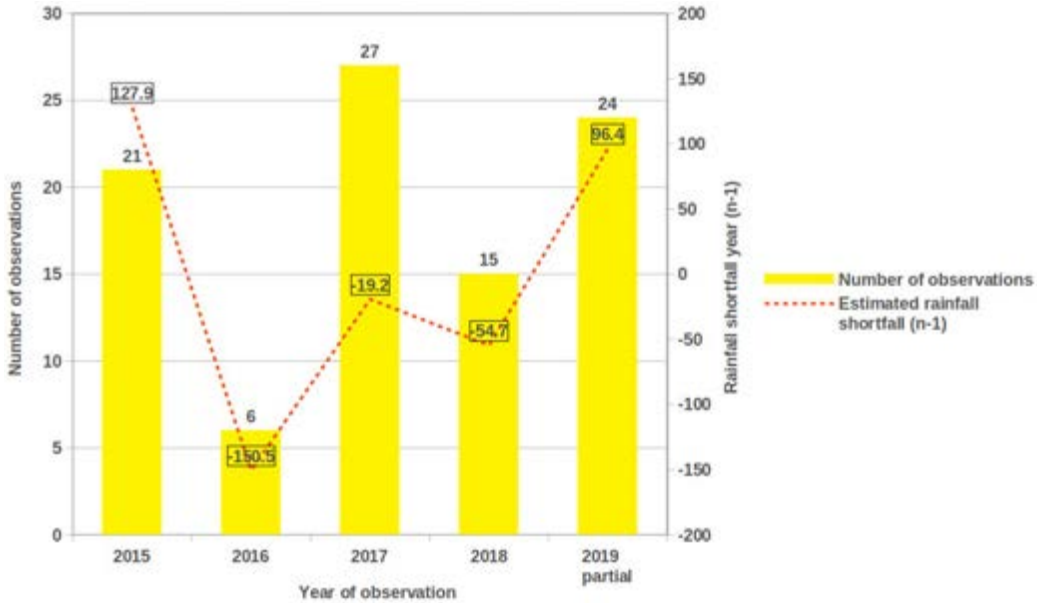

Figure 3. Comparison of the annual number of lion observations (year n) with the rainfall deficiency of the preceeding year (year n-1).

Table 3. Annual rainfall in Tambacounda and Kédougou along with their mean.

	2014	2015	2016	2017	2018	Mean
P_T	632.8	663.1	755.4	862.9	681.6	719.2
P_K	1061.0	1587.4	1232.6	1196.0	1075.2	1230.4
P_M	846.9	1125.3	994.0	1029.5	878.4	974.8

observations within the study zone is correlated with the annual rainfall of the previous year, we obtained rainfall data from the Senegalese weather bureau (Agence Nationale de l'Aviation Civile et de la Métorologie - ANACIM) at their two closest weather stations: Tambacounda (93km northwest of the centre of the study area) and Kédougou (123km east of the centre of the study area). We then approximated the annual rainfall in the study zone (P_M) by taking the mean of the values in Tambacounda (P_T) and Kédougou (P_K), as shown in Table 3.

The mean annual rainfall estimated for the study zone by this method (975 mm) falls in the range of 900–1,200 mm in NKNP given by Galat et al. (2015). When the rainfall data are offset for display purposes as the annual rainfall deficiency relative to the average rainfall in the period 2014–2018, the correlation between the number of lion observations each year and rainfall deficiency of the previous year seems evident (see Figure 3).

After confirming with the Shapiro-Wilk test that the number of observations and the estimated rainfall do not significantly vary from normality (p-values = 0.656 and 0.735, respectively), a Pearson's correlation test gives a rather strong correlation coefficient of -0.729, but with a 95% confidence interval of -0.981 to 0.429 due to small sample size. To rigorously test this hypothesis, further annual observation data would be needed and more accurate rainfall data for the study zone should be obtained, either through a more sophisticated

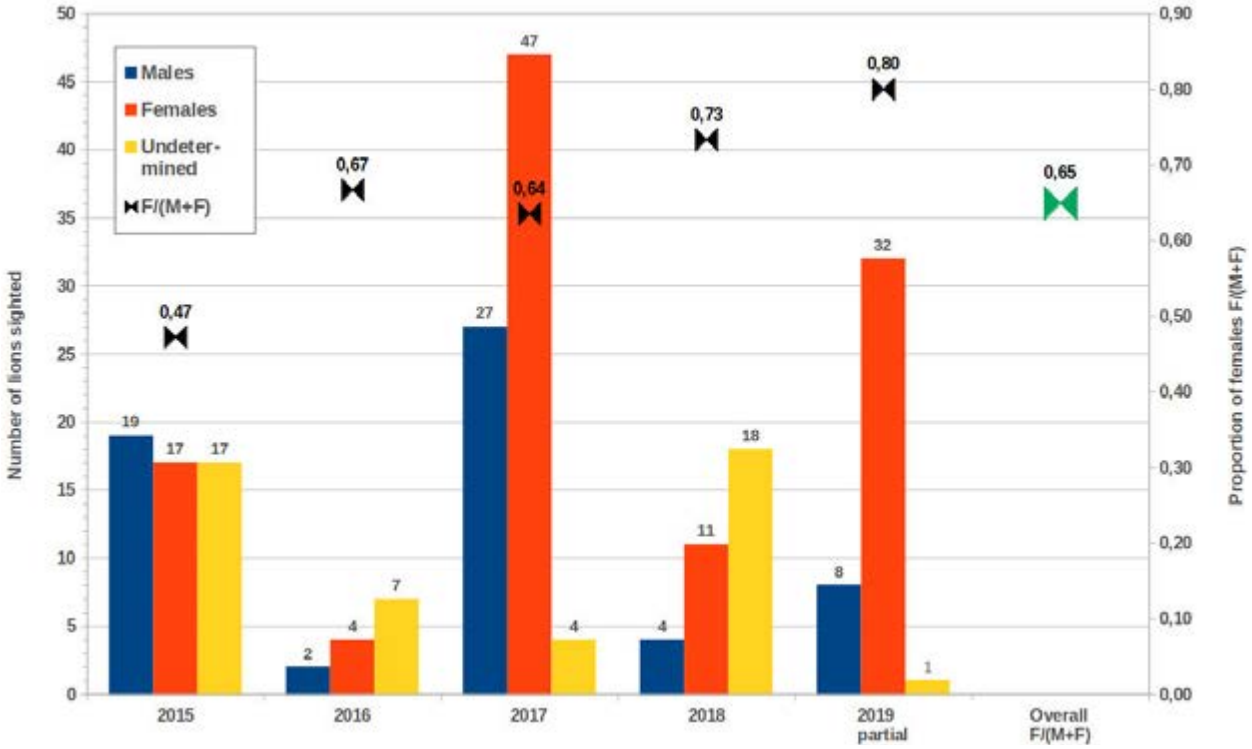

Figure 4. Number of adults and sub-adults by sex and proportion of females F(M+F).

meteorological model or by a locally-maintained rain gauge.

Another hypothesis implying the opposite effect of rainfall on lion observations is that low rainfall might reduce prey populations and thus lion numbers in the following dry season due to environmental stress on the prey, a factor that has been proposed to operate in NKNP over medium-term periods (Galat et al. 2015). There is, however, no evidence that such a mechanism could operate over periods as short as one year.

Sex ratio of lion observations

Figure 4 shows the number of male and female lions observed (excluding cubs, only one of which could be sexed from the data available), as well as the proportion of females to the total of both sexes observed.

The proportion (0.65) of females among the lions observed during the whole study is skewed towards females but with an outlying result for 2015 when more males than females were observed. We have included the partial data for January to May 2019 because for 2015–2018 these months represented a large proportion of the observations (74%).

We performed statistical analysis to test the significance of our sex ratio data, probing whether the skew towards females was a real effect. The values for the proportion of females over the five years were shown by the Shapiro-Wilk test not to significantly vary from normality (p-value = 0.796). We then applied a one-tailed t-test with the null hypothesis that the proportion of females is ≤0.54 and this hypothesis can be rejected at more than 95% certainty (p-value = 0.046).

Seasonal distribution of observations

Figure 5 shows the number of observations and the number of lions observed according to the month (excluding 2019 for which we have only partial data).

The number of observations should normally increase with the number of tourist parties (except if the increase in tourists differentially disturbed the lions, unlikely with the relatively small numbers of visitors to NKNP). These parties are most numerous in the period from December until March when the tracks have been cleared at the beginning of the dry season, decrease with the rise in temperatures from April to June and decrease further during the wet season from July until November when many of the tracks are impassable. The number of lion observations closely follows this pattern. There is also a factor of decreased visibility between July and November when thicker vegetation and undergrowth makes it more difficult to see lions although it is difficult to quantify this effect because the period of decreased

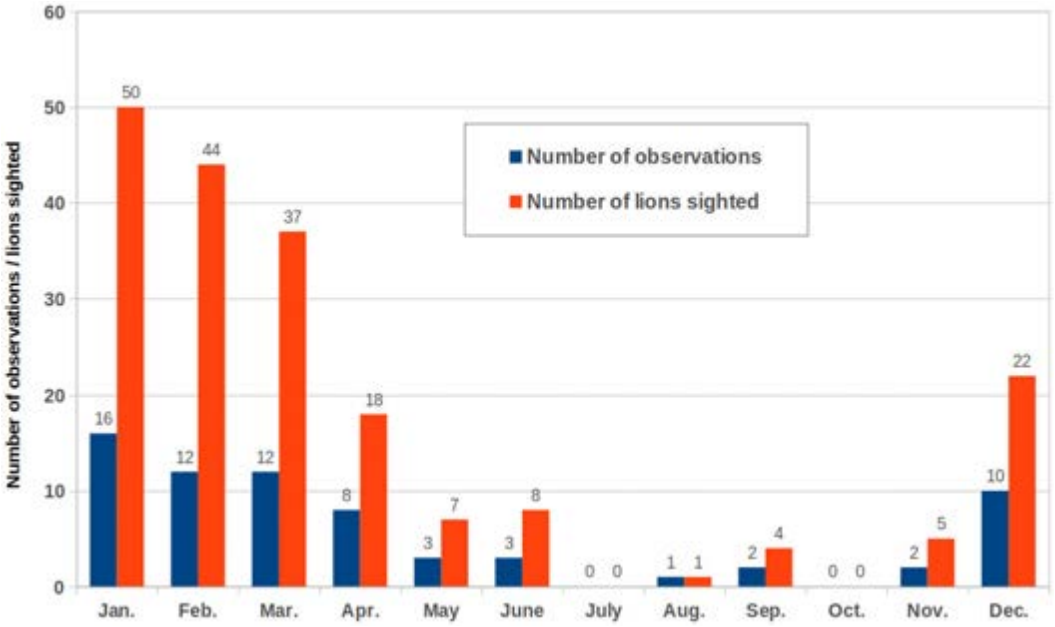

Figure 5. Number of observations and number of lions observed per month (2015–2018).

Table 4. Summary of individual lions identified from photographs (* = possible shared identity | ? = probable re-sighting).

File number	Name of lion	Sex	Estimated birth year	First observed	Characteristics	Relationships	Re-sightings
1	Alakay*	M	2014–2015	15.i.2017	Whisker spots left side	Possibly same as Kaly, seen with 3 brothers + mother	
2	Fidji	M	2009–2013	09.ix.2017	Whisker spots left and right, multiple scars	Seen with Gia	
3	Gia	F	<2010	09.ix.2017	Whisker spots left and right, multiple scars, vitrious right eye	Seen with Fidji	
4	Dinbadjinma	F	2015	15.xi.2017	Whisker spots left side, multiple scars, deformed right ear	Seen with Kekindo (probable sister), plus mother	24.xii.2017 21.i.2019?
5	Kekindo	F	2015	15.xi.2017	Whisker spots left and right, cut on right ear	Seen with Dinbadjinma (probable sister) plus mother	24.xii.2017 12.ii.2018?
6	Adama	F	2010–2011	08.ii.2018	Whisker spots left side, scar on left hind leg	Seen with Awa	03.iv.2018
7	Awa	F	2011–2013	08.ii.2018	Whisker spots left side, scar on right front leg	Seen with Adama	03.iv.2018?
8	Banna	F	2015	16.ii.2019	Whisker spots right side, scars on right front leg and at base of tail	Seen with Binta	
9	Binta	F	2015	16.ii.2019	Whisker spots right side, small ear marks	Seen with Banna	
10	Kaly*	M	2012–2015	30.iv.2019	Whisker spots right side, badly scarred muzzle, broken upper left canine	Possibly same as Alakay, seen with 2 other lions	

visibility corresponds closely to the period of fewest visits. It is also possible that internal migration within the Park could explain some of the seasonal variation even though zones of increased lion presence during the rainy season have not been reported.

Identification of individual lions

Tourist parties submitted photographs and videos of 22 lion observations, using equipment ranging from smartphones to professional level cameras. On the basis of the best of these images, identification sheets for 10 individual lions (described in Table 4) were established and have been made available at http://niokolo-safari.com/lions.htm

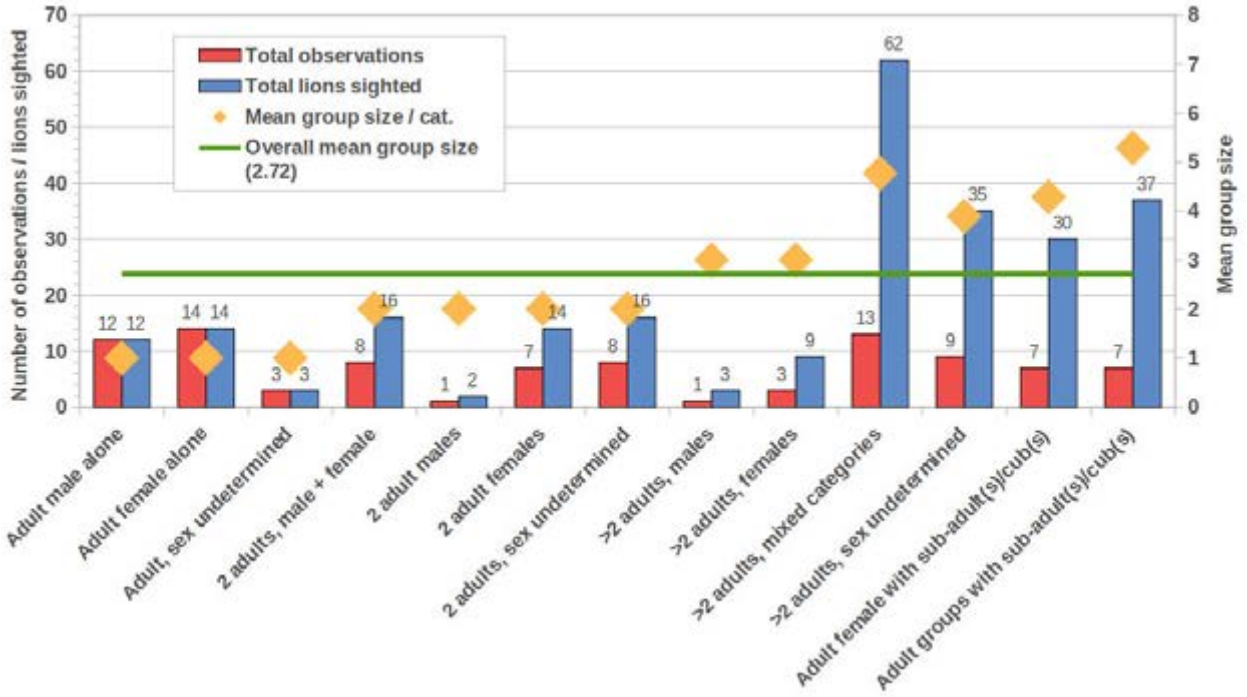

Figure 6. Composition of the groups of lions observed.

Table 5. Comparison of group sizes (adult and sub-adult lions, not including cubs) observed in the present and earlier studies.

Group size	1	2	3	4	5	6	7	8	9	10	Total number of observations	Total number of lions observed	Mean group size
Number of observations Bauer et al. (2003)	8	10	1	1	1	0	0	0	0	0	21	40	1.90
Number of observations present study	33	28	21	4	1	1	3	1	0	1	93	218	2.34

Distinguishing characteristics of the NKNP lions

According to the NKNP guides, some of the lions in the Park have greyish rather than tan fur and these lions are reputed to be generally more massive and with fuller manes. Indeed, in our photographs there appear to be large variations in fur hue among the lions observed, both for males and for females, ranging greyish to tan, although the apparent hue of a particular lion's fur varied substantially between photos of the same lion in different conditions. The three greyish males photographed did not have notably more ample manes than their browner counterparts. In the Mara Predator project (Kenya), greyish lions were rare (personal communication, Sara Blackburn) and a photograph of a greyish adult male lion named Marley, with a mane less full than average, can be seen on the website of the project (Mara Predator Project undated). It should be noted that Pocock (1939) indicates a high variability in fur colour in his description of the Asiatic lion.

Compared with the lions of eastern Africa (Serengeti/Ngorongoro in Tanzania as described by Whitman et al. (2004) and in the Masai Mara National Reserve in Kenya (Mara Predator Projet undated)) which are born with pink noses that darken by becoming increasingly freckled with age, all of the lions photographed with good resolution in NKNP, including the three sub-adults and one cub, had quite uniformly dark noses without freckling. In addition, in contrast with the lions of Masai Mara, many lions in NKNP retain substantial spotting on their underparts and legs into adulthood and the manes of the males in NKNP are smaller than those in the Masai Mara, with many adult males having only sparsely developed manes.

Observed lion behaviour

Lions were observed individually or in groups of 2 to 10 individuals. The most frequently observed category (31.2%) was of single lions, while 79.6% of the observations involved groups of 3 or fewer lions. The mean group size was 2.72 (including cubs). Figure 6

shows the number of observations and the number of lion sightings in such groups for different combinations of age-class and sex.

The majority of studies into the social behaviour of African lions have concentrated on populations in eastern and southern Africa and the results were summarised by Bauer et al. (2003): "[A] pride (10–20 lions) is composed of groups (3–6 lions) with varying composition that may regularly be observed together, so-called fission-fusion. A pride typically has a territory, defended by 1–3 males for 2–4 years against nomadic males." A more recent review of data from Serengeti National Park in Tanzania (Mosser & Packer 2009) defines a lion pride as composed of 1–21 adult females, their dependent offspring and a temporary coalition of 1–9 adult males.

Bauer et al. (2003) studied the social grouping of western African lions in three large protected areas, including NKNP, and found that group sizes were significantly smaller than those in eight studies in East and southern Africa, as reported by Van Orsdol et al. (1985). Bauer et al. (2003) describe three hypotheses for this difference (low prey density, low prey body size and greater reliance on livestock as prey) without providing conclusive proof for their relevance. They express scepticism that this difference in social behaviour could be an innate characteristic of the two populations but in the light of the recent study showing the genetic uniqueness of the western African population this possibility should be reassessed. This latter possibility may be strengthened by the observation of Jhala et al. (2009) of an average group size for adult female Asiatic lions in the Gir Protected Area of only 1.3 (although they cite earlier studies which observed adult female group sizes averaging 2.1 and 4.5).

The group sizes in NKNP documented by Bauer et al. (2003), tabulated without counting cubs (lions aged less than 2 years as per the Smuts et al. (1970)), are presented in Table 5 in comparison with similarly adjusted data from the present study. The mean group size per observation (total number of lions observed divided by the total number of observations) was 1.90 for Bauer et al. and 2.34 for the present study.

The differences in paired values were shown by the Shapiro-Wilk test not to significantly vary from normality (p-value = 0.624). Therefore, the paired samples t-test was applied to the differences adjusted by multiplication of each difference by the corresponding group size (in order to ensure that the mean of each series corresponded to the respective mean group sizes of 1.90 and 2.34) and by division by the number of observations in each study (n = 21 or n = 93). The significance of the test was determined to be α = 0.05. The null hypothesis that the mean group sizes of the two surveys was identical could not be rejected as statistically significant (p-value = 0.569). It should, however, be noted that Bauer et al. (2003) (n = 21) saw no groups of greater than 5 lions whereas the present study (n = 93) observed 6 such groups (6.45% of the groups observed), including one group of 10 adult or sub-adult lions. Therefore, the conclusion of Bauer et al. that "if there was a level of organisation higher than the small groups, their interaction was rare and hardly ever observed" does not seem to have been confirmed in our results.

In the large majority of observations (84 out of 93, corresponding to 90%), the lions showed banal behaviour, including resting, walking, observing the tourists and their guides, drinking (one observation) and fleeing the vehicle (one observation). In seven observations (7.5%) the lions were seen attentively watching or stalking potential prey (Western Buffon's Kob *Kobus kobus kob* in one observation (two adult female lions), Common Warthog *Phacochoerus africanus* in two observations (two adult male lions with an adult female, then a single adult female)). In one observation four adult lions (two males and two females) were feeding on the carcass of a Guinea Baboon *Papio papio*. No observations of actual predation attempts were observed. In another observation two adult lions (a male and a female) entered at dawn into the kitchen of a tourist camp to take some dried fish.

DISCUSSION

The study compiled a substantial amount of data on the lions observed by tourists and their guides, as a means of complementing the research by the Park authorities and the scientific community while helping the guides to improve their services and contribute to better protection of the lions of NKNP. A number of useful conclusions were drawn from the analysis of this data, some fully validated and others providing starting points for further study. In assessing the usefulness and effectiveness of the work, it should be noted that the study was organised on a strictly voluntary basis by the guides and the advisory team, without any external support (with the exception of an air ticket and some in-kind assistance with automated cartography).

The great experience of the guides in detecting and identifying wildlife, even in thick undergrowth, ensured efficiency in spotting lions. In general, the accuracy and precision of assignment of sex and age-

class steadily increased from 2015 to 2019, as the guides gradually became more competent and confident in lion identification. The difficulties originally encountered in obtaining photographs taken by tourists were gradually reduced through active sensitisation and mobilisation of visitors to the Park.

Beginning in 2017, we were able to receive photographs of sufficient resolution to identify individual lions although the percentage of lion sightings backed up with photographic evidence at adequate resolution remained low (13 sightings out of 182 (or 7%) for 2017–2019). This was too low to have confidence that our identified lions covered the entire local population.

Therefore, other than our observations of individually identified lions, we recognise that our data on the absolute numbers of lions observed, and the breakdown in terms of age-class and sex, cannot provide reliable estimates of the number of distinct lions observed due to the high probability of multiple counting individual lions. If we assume that, on average, the over-counting should tend to apply equally to the different lions, the calculated percentages of the age-classes and sexes (see Table 2 and Figure 4) are expected to be more reliable than the absolute numbers and may be seen as qualitatively useful.

The data provide interesting qualitative information on the spatial distribution of lions observed in the study area but without logs of the time spent observing and the field of view at each site and along each trajectory, the geographical abundance or the lions cannot be quantitatively deduced.

Henschel et al. (2014) state that 40–60% of a lion population typically consists of immature individuals although the underlying data for this statement come from populations in Tanzania and Namibia, while Banerjee & Jhala (2012) found a proportion of 37% of cubs and sub-adults in the Gir Protected Area in India. We recorded a proportion of cubs and sub-adults of only 17.4%, and although it is possible that this figure indicates low levels of reproduction, in NKNP the cubs are typically hidden in thick vegetation and some are thus likely to have been overlooked. It is also possible that some sub-adults were counted as adults, since during the first half of the study we did not distinguish between these age categories and had to attempt to subsequently clarify the dataset for this period on the basis of photographs and the recollection of the guides.

Pocock (1939) described several morphological differences between Asiatic and African lions (the African specimens apparently being from southern and eastern Africa), the former having different hair patterns including smaller manes as well as differences in cranial morphology, but we have not identified a scientific study of the morphological differences between western African Lions and either Asiatic Lions or those of southern and eastern Africa. Thus our observation of relatively less ample manes in our subjects relative to those of lions in southern and eastern Africa, although conforming to statements often seen in informal accounts, cannot at present be scientifically confirmed as a characteristic of the NKNP population.

Similarly, we have found no references in the scientific literature to study of the nose colour of immature Asiatic or western African lions. We have, however identified a photograph of an Asiatic lion cub (Chauhan (2015) with a mostly dark nose without freckling and of a sub-adult with a uniformly dark nose (Wakefield 2017), thus providing some corroboration for our observation that the immature NKNP lions have quite uniformly dark noses without freckling.

We are not in position to say to what extent the observed differences in fur hues are due to morphological variations among the lions or are possibly correlated with factors like season, stage of development, sex, or health, or whether they might at least partly depend on artefacts such as (i) different camera models and settings, (ii) lighting conditions, and (iii) external factors such as foreign material in the fur. We propose to continue to document the apparent fur hue which may well prove to be empirically useful in identification when combined with other data.

The guides were highly motivated to participate in this study and 22 of them contributed 90 of the 93 observation descriptions (two were from hotel employees and one from a government agent traversing the Park). Their contributions were unequally distributed, with three guides submitting 33 (37%) of the 90 descriptions (the amount of time spent within the study area by each guide is not known). The tourists were in general interested and cooperative once the lion monitoring project was explained to them. The major obstacles to obtaining more and better-quality photographs were that the tourists often had only smartphones or, if they had cameras with them, were generally not experienced wildlife photographers, while the guides generally had insufficient equipment and lacked photographic experience.

Lion population within the study area

Although lion vocalisations and fresh pugmarks are commonly encountered in NKNP, lion sightings are relatively rare and there is little published data

on the number of lions present. Although DPN, with the support of various scientific organisations, has conducted periodic inventories of megafauna in the Park, the survey methods (mainly transects by foot, by vehicle and by airplane) have not been specifically designed for the recording of lions (Renaud et al. 2006; Tiomoko & Van Merm 2015). A camera-trap study by Kane et al. (2015), covering 285.4km^2 (representing approximately the southern half of our study area plus an adjacent area to the east of the same size) during 78 days in February-April 2013, provided a density of 3.02 adult lions/100 km^2 (1.72–5.57/100 km^2). Applying this figure to the encompassing "state space area" of 1,687.20km^2 associated with their model yields a minimum population for the Park of 29–94 adult lions. Given that the "state space area" represents about 15% of NKNP, this estimate appears higher than the maximum of 54 lions (including immature subjects) estimated in 2011 by Henschel et al. (2014). Bauer & Van Der Merwe (2004) reported estimates of the NKNP lion population between 20 and 150 animals but the only published data they cited dated from 1976 (Dupuy & Verschuren 1977) and this publication did not present any details on the survey methodology employed.

Taking into account the number of males and females of different age groups observed, we can only state that a minimum of 10 adults (some of which could have been sub-adults) were present in the study area (five males and five females seen together in 2017). If we also count cubs, at least 21 individual lions must have been present in the study area (the above plus 4 unsexed cubs seen together in 2017 and 7 cubs seen together in 2019).

In the present pilot project, our data did not permit accurate calculation of the home ranges of the lions observed, nor of the lion density in the study zone, as was done in the Masai Mara area by Blackburn & Frank (2010) and Blackburn et al. (2016), principally because of our high level of unidentified lions. This is largely due to the difficulty in sighting, approaching and identifying lions in the thick vegetation of NKNP but also to insufficient expertise of the observers and their equipment in the field. It may, however, be noted that the presence of 10 adult lions in the study zone would equate to 3.5 lions per 100km^2 (or about 5 per 100km^2 if we consider only the polygon in which lions were observed), which is comparable to the results of Kane et al. (2015) and lower than the densities recorded in the Masai Mara area by Blackburn & Frank (2010).

We have every reason to expect that with improved organisation, local skills and equipment the quantity and quality of the lion monitoring data can be improved significantly. It would be very useful in this context to be able to compare our data on individual lions with those obtained in other studies in NKNP, notably by the use of camera traps. This would help in understanding the home range of the lions and in determining accurate estimates of the total population.

Sex ratio

A recent analysis of multiple studies in Tanzania and Zimbabwe (Barthold et al. 2016) showed that the average proportion of females varied from 0.51 at birth to 0.55 at less than one year old (in this study the term "sex ratio F:M" is used to refer to the proportion of females, F/(F+M)). This same study showed that male mortality was higher than female mortality in both populations for all age groups (although there were significant differences between the two populations) meaning that the average proportion of females in a population of adults and sub-adults would be greater than 0.55. Banerjee & Jhala (2012) found a proportion of females (excluding sub-adults and cubs) of 0.63 in a study of Asiatic lions in the Gir Protected Area, and said that "Demographic parameters of genetically less-diverse Asiatic Lions did not differ from those of African Lions."

Our results indicating a substantially higher proportion of females than males, are thus consistent with other studies although that does not exclude a systematic bias in our observations or explain the outlying value of 0.47 for 2015 when more males than females were observed.

Male and female lions differ in hunting methods, social behaviour and territory, resulting in many factors that could potentially bias our observations, which were limited to accessible areas of a small study zone and to daytime visits. Only two hypotheses will be discussed here as examples:

1. There might be a preference of male lions for areas of thicker vegetation in which they are less easy to observe. In South Africa, Loarie, Tambling and Asnera (2013) showed that male lions hunt in thicker vegetation than females and, therefore, they may be less frequent than females in the more open, intentionally burned zones where lions were mainly observed in NKNP (although the above study found only differences in hunting areas and not in resting areas).

2. Bauer et al. (2003) studied the home ranges of two male and three female radio-collared lions in Waza National Park in Cameroon. Their non-quantified spatial diagram showed home ranges of the females to be roughly the size of our NKNP study zone and those of the males to be substantially larger. Therefore, it is

possible that the males in our local population were more likely than the females to be outside the study zone. Likewise, if the male lions were moving in and out of the study zone more than the females, this could also be a factor in explaining the preponderance of males in our observations from 2015.

It is also possible that a small fraction of adult males seen at a distance with under-developed manes were under-counted, increasing the proportion of females recorded.

FUTURE DEVELOPMENT OF LION MONITORING IN NKNP

The citizen-science lion study presented here provides an important and informative methodology to support lion conservation in NKNP and complements the previous scientific or technological approaches that have been favoured for researching the lion populations in the Park, including studies undertaken by DPN and the international scientific community (Henschel et al. 2014; Kane et al. 2015). Although the citizen-science approach depends on the travel plans, itineraries and collaboration of visitors to the Park (thereby reducing programmability and consistency), its reliance on the engagement of the local community and guides make it more cost-effective in terms of external investment and, therefore, more likely to be sustainable over longer timeframes. The approach also facilitates responsible lion observation by tourists visiting Senegal, which in turn will contribute to the viability of the Park and, indirectly, to the better protection of lions in NKNP, as well as promoting public awareness of the precarious situation of lions in western Africa.

This citizen-science approach to lion monitoring can be made more effective by:

i) the acquisition of a greater number of high quality photographs enabling the identification of individual lions by providing suitable cameras and training to the guides

ii) building rigorous data collection and management capacity at the local level, with the medium-term aim of transferring administrative and scientific responsibility for the project to a Senegalese team

iii) collaboration with institutions and scientists studying the NKNP lions, and particularly with the DPN, in providing advice to the guides and in sharing and comparing data with them.

To address these ideas, the authors are seeking international and national support for continuation and reinforcement of the citizen-science lion monitoring project in NKNP over the next three years.

It may be noted that this consolidation effort has already been initiated with a 10-day training course in methodology of collection and management of observational data and in wildlife photography, organised by the authors for the guides in October 2019.

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Author contribution: The collection of data was carried out on a voluntary basis by GIE NIOKOLO through a project led by one of the authors (AK). JBR coordinated the international advisory team and the drafting of this article. DD was responsible for developing the data protocol and the identity sheets.

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COMMUNICATION

Status, distribution, threats, and conservation of the Ganges River Dolphin *Platanista gangetica* (Mammalia: Artiodactyla: Cetacea) in Nepal

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Abstract: The Ganges River Dolphin *Platanista gangetica* has been classified as Endangered in the IUCN Red List of Threatened Species. The IUCN changed its status from 'Vulnerable' to 'Endangered' in 1996 as the species population was declining in its entire distribution range. It is, however, classified as 'Critically Endangered' in Nepal. Historically, the freshwater cetacean has been documented in the Karnali, Koshi, Narayani, and Mahakali basins. With their population and distribution range in decline, the Ganges River Dolphin (GRD) is no longer found in the Mahakali River system, which demarcates and traverses the Western border of India and Nepal. This study examines the status and distribution of the GRD in the river systems of Nepal during the monsoon of 2016. The national dolphin population survey was conducted in the three largest river basins in Nepal—Karnali, Narayani, and Koshi. Each of the three basins represent the extreme upstream limit of the GRD distribution in Ganges River basin. The national population survey included both a boat-based survey and shore-based synchronized counting in each of the three river systems. Fifty-two (Best-High-Low: 52-61-50) dolphins were counted during the entire nationwide survey, conducted in July–August, 2016. Researchers gathered social-data from locals residing alongside the observed basin, giving priority to artisanal fishers and those subsisting to some degree from the rivers known to host the river dolphin. A questionnaire survey of ninety-two residents from riparian villages adjacent to the GRD hotspots sheds light on the local perspectives towards dolphin conservation coupled with an assessment of their socio-economic status; artisanal fishing practices; and their awareness of dolphin conservation. According to the survey, notable threats to dolphin conservation are prey depletion; non-availability of suitable habitat; habitat fragmentation and a low level of awareness. Based on the counting outcomes and social survey, recommendations have been put forward for the conservation of this species.

Keywords: Conservation, Ganges River Dolphin, large rivers, national survey, Nepal.

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For **Author details** & **Author contribution** see end of this article.

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INTRODUCTION

The Ganges River Dolphin *Platanista gangetica gangetica* is one of the four obligate freshwater dolphin species found in the world. Of all the four obligate species, both the Ganges and Indus River Dolphin species hold the most ancient evolutionary lineage, separated from all other cetaceans by around 30 million years ago (Turvey 2009). The Ganges River Dolphin inhabits the Ganges-Brahmaputra-Meghna River (GBM) and the Karnaphuli-Sangu (KS) River systems of Nepal, India, and Bangladesh (Jones 1982; Mohan 1989; Reeves & Brownell 1989; Shrestha 1989; Reeves et al. 1993).

Historically, water development projects such as construction of over 50 dams and barrages within the historical range of the Ganges River Dolphin (Smith et al. 2000, 2012), toxic contamination (Kannan et al. 1993, 1994, 1997; Senthilkumar et al. 1999; Yeung et al. 2009) and incidental killings by fishing gear (Mohan 1995; Smith & Reeves 2000; Sinha 2002) are considered as the significant reasons for the decline of the species and ecological integrity of its habitats. Moreover, the reduction of prey along with alterations to the physical integrity of the GBM are contributing to the species' decline.

In Nepal, the Ganges River Dolphin is protected by Section 10 of the National Parks and Wildlife Conservation Act 1973 and is among 27 protected mammals in Schedule I (HMGN 1973). Despite the population concentrated in the Karnali and Koshi rivers being classified as Endangered (Baillie & Groombridge 1996), the freshwater cetacean species has received relatively less national attention in comparison to other megafauna casting a shadow over the works by conservation leaders in this specific ecozone (Paudel et al. 2015).

Regular assessments of the dolphin and its habitat by the scientific community are imperative for the implementation, monitoring and evaluation of future river dolphin conservation action plans (Smith & Reeves 2000). In this regard, the International Union for Conservation of Nature (IUCN Nepal), Department of National Parks and Wildlife Conservation (DNPWC) and National Trust for Nature Conservation (NTNC) jointly conducted a nationwide dolphin population survey in Nepal. The major objectives were: (1) to assess status and distribution of dolphins in Nepal during the monsoon season, (2) to assess conservation threats to dolphins, and (3) to assess the socio-economic status, local fishing practices, and awareness and perception on dolphin conservation of the people living in the vicinity of dolphins. This study is unique and first of its kind as it uses standard methodologies and covers all possible dolphin habitats in Nepal during the monsoon season.

MATERIALS AND METHODS

Study sites

The dolphin population survey was conducted in the three largest river basins of Nepal (Figure 1), i.e., Karnali (Figure 2) and its tributary Mohana (Figure 3), Narayani (Figure 4), and Koshi (Figure 5) where the Ganges River Dolphin have been documented till date. These rivers represent the extreme upstream limits of the Gangetic Dolphin distribution in the Ganges basin. These river basins extend from the Tibetan Plateau to the lower Himalayas with rivers sourced from snow packs in the high Himalaya, glaciers, and glacial lakes; and from the Siwalik Hills. As the waters flow southward into the plains of the Terai region, residents of the shared watersheds greatly depend on agriculture and fishing, resulting in an increased spatial overlap between the dolphins and commercial as well as artisanal fishers (Paudel et al. 2015).

Methods

We followed the survey methods recommended by Smith & Reeves (2000) that includes both a boat-based survey and a shore-based synchronized counting in each of the three river systems.

Shore Based Survey: Similar to the methods applied in the past population surveys of the dolphin in Koshi River (Khatri et al. 2010) and Karnali River (WWF 2006), the shore-based synchronized counting-hotspots were identified on the basis of literature reviews coupled with secondary data obtained from key informant interviews and local consultations. The total number of counting hotspots identified within each basin are the following: 15 hotspots in Mohana and its tributaries (Figure 3); 9 in Geruwa and Karnali (Figure 2); 4 in Narayani (Figure 4) and 11 in Koshi (Figure 5). To avoid double counting, the surveys were conducted simultaneously at all hotspots within each basin and lasted for a duration of three hours, sub-divided into six observation times with 30-minute duration each. The population survey took place for two days in each location allowing for greater robustness of data by decreasing error from other factors (including weather, water level/flow, double counting). Observations were repeated on 2016 July 25 and 26 in Mohana and its tributaries; 2016 July 27 and 28 in Geruwa and Karnali in parallel; 2016 August 19 and

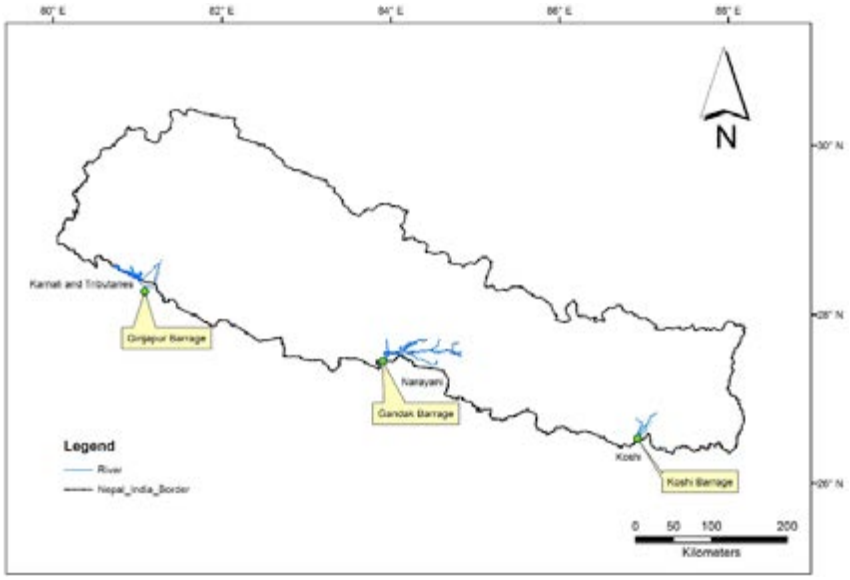

Figure 1. The studied rivers of Nepal namely (from left to right) Mohana, Karnali, Narayani, and Koshi.

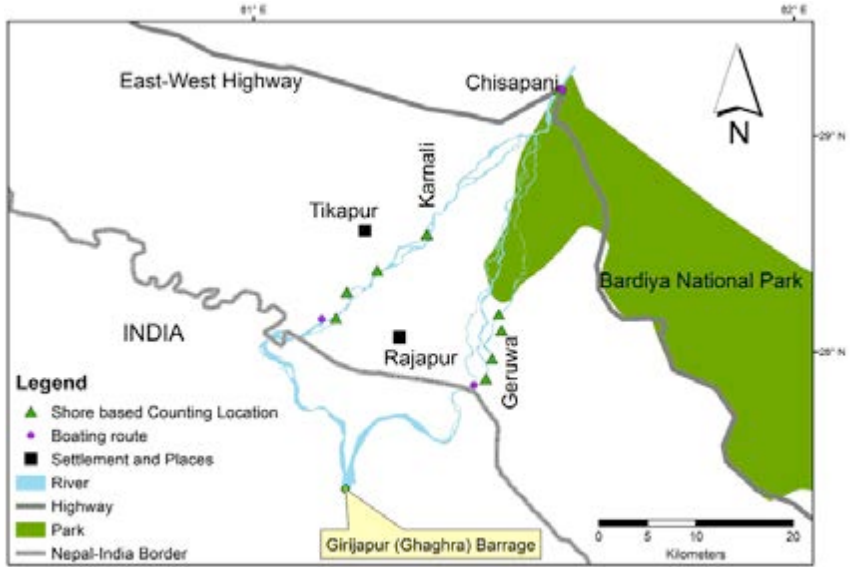

Figure 2. The surveyed areas in Karnali and Geruwa rivers, Nepal.

20 in Koshi; and 2016 August 22 and 23 in the Narayani River.

Boat-based Survey: The boat-based counting was performed in a single rowing boat, travelling approximately 8km/h following a mid-channel route with multiple observers on board (at least two primary observers in the front, two observers in the back and two observers on each side). This allowed counting the dolphins that surfaced at least once within the range of detection and avoided double counting. To minimize the risks of perception-bias, the observers' positions were rotated every two hours.

During boat-based surveys, there are inherent risks of missing a proportion of animals in the observed basin when dolphins are submerged and out of view, resulting in a negative-bias due to the lack of correction factors for availability and perception.

There are also inherent losses of data when national surveys are performed on species that transcend political boundaries. The authors recommend the results be integrated with concurrent data from other survey methods to estimate the abundance of river dolphin in Nepal during the monsoon season as well as those during the dry season. These data will greatly improve our understanding of dolphin populations whose summer home ranges extend across international boundaries

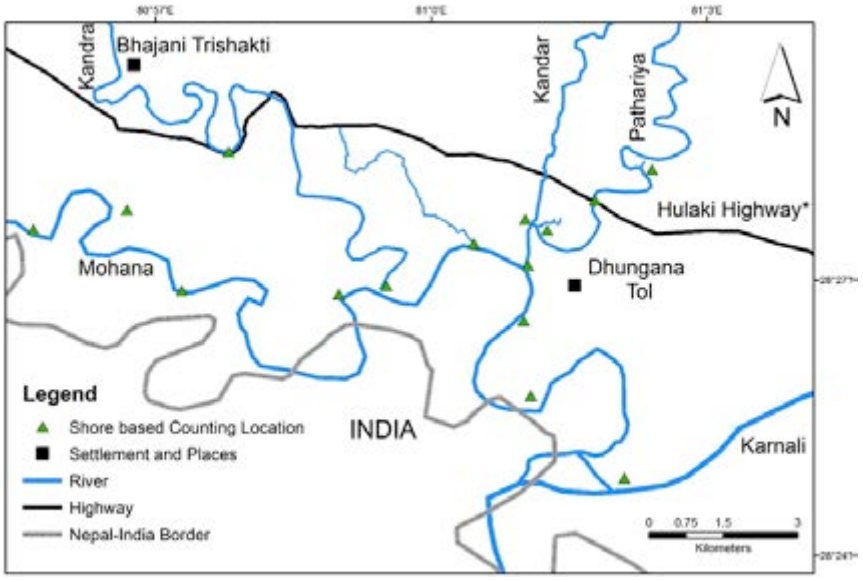

Figure 3. The surveyed areas in Mohana and its tributaries. Mohana is a right tributary of Karnali River. The Nepal-India border shown in this figure is not in scale.

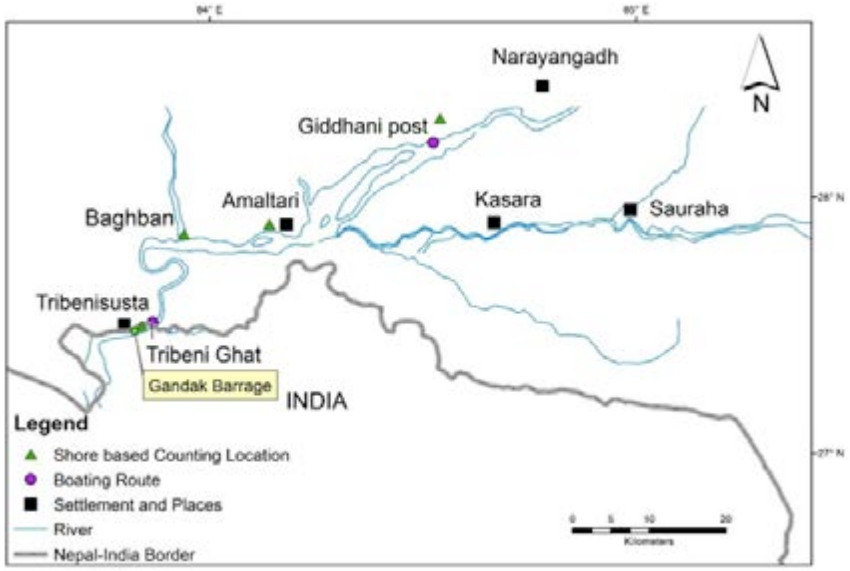

Figure 4. The surveyed areas in Narayani River, Nepal.

into Nepal and improve our ability to provide advice for conservation within Nepal, specifically with regards to proposed development projects in and alongside the rivers.

Social Survey: Altogether 92 respondents were selected at random, based on their dependence on the observed basins that host river dolphin hotspots. In addition, an informal discussion was conducted with the officials of Bardia National Park, Chitwan National Park, Koshi Tappu Wildlife Reserve and with the members of respective buffer zone committees. Respondents were inquired about local fishing practices; their attitudes toward dolphin conservation; historical accounts of dolphin abundance; perceived threats to the dolphins; potential pollution in the area, and basic socioeconomic demographics.

Data Analysis

The dolphin population survey results were made at best, high and low estimates. High and low estimates are used to reflect the confidence of observers coupled with the accuracy of the best estimate. Identical best, high, and low estimates indicate a high level of confidence in the best estimate. The direct count and local sightings of dolphins were mapped using GPS points taken during the survey. Multiple counting of the same individuals was avoided by recording the location and time of sightings and by noting distinctive physical characteristics such as length of the rostrum and body size.

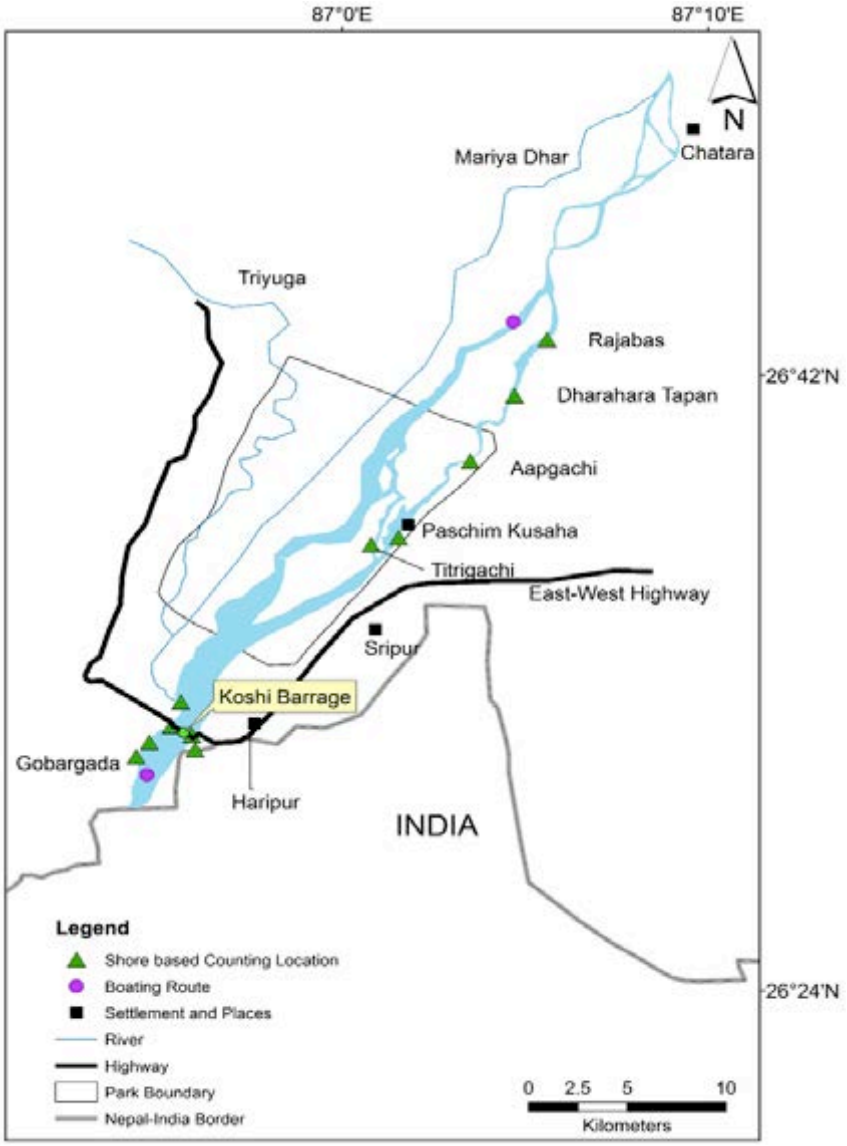

Figure 5. The surveyed areas in Koshi River, Nepal.

RESULTS AND DISCUSSION

The population of Ganges River Dolphin (Image 1) in the Karnali, Narayani, and Koshi rivers of Nepal was estimated at best 52 individuals. The high estimation was 61 and the low was 50 individuals in the three basins observed in Nepal's monsoon season (Table 1). Local sightings of the dolphins have also been made apart from the official population survey. Two local sightings in Mohana at Helauna Baba Ghat, two local sightings in Geruwa, and two local sightings in Narayani were made apart from the official population survey. In Mohana and its tributaries, mostly the mother and calf were observed.

The number of dolphins varied seasonally in relation to the water levels in Mohana and its tributaries. During monsoon the dolphins ascend into the tributaries of Karnali River (Sinha & Kannan 2014). Notably it was seen in Mohana and its tributaries but during dry periods, most of its tributaries dry out causing the dolphins to reside in deeper water of the main channel. In Karnali and Geruwa rivers no dolphins were counted within the surveyed area, however, there were local sightings of two dolphins in Geruwa prior to our population survey. We attributed this to the possibilities of high water levels and turbulent flows to the absence of dolphins in Geruwa as well as Karnali River. Hence, it is important to ensure that threats to dolphins are minimized in the larger main rivers (Karnali and Geruwa) during the dry-season, but for Mohana threats need to be addressed mainly during the monsoon season. No dolphin was

Image 1. Ganges River Dolphin *Platanista gangetica* in Mohana River, Nepal. © Amit Poudyal/ IUCN.

sighted in Narayani River during our survey, however, two dolphins were spotted by other surveyors during April 2016. In Koshi, dolphins were observed both in the upstream and downstream of the Koshi Barrage.

Among the respondents of our household-based survey, about 44 percent were engaged in fishing practices. Indigenous groups such as the Tharu and Magars were mostly engaged in fishing but not the non-ethnic groups like Brahmin and Chettri. A majority of the artisanal fishers used traditional fishing nets like tiyari, balchi (hooks), Chatijaal, Khepnijaal, Haatajaal, Khokrijaal for fishing. About 66 percent of the respondents had a prior knowledge of Mahajaal (large seines). It was, however, not in practice in any of the surveyed areas.

In Karnali, fishing is for both domestic consumption and commercial purpose. While fishing is prohibited within the Bardia National Park boundary and certain sections of Chisapani areas, licenses are provided by the District Development Committee (DDC) for fishing in the river falling outside the national park's jurisdiction. Generally, one person acquires the contract and grants permit to other fishermen by levying a nominal amount. Likewise in Narayani, fishers use a traditional net for catching fish for domestic consumption though fishing is prohibited inside Chitwan National Park. Similarly, in Koshi River, both commercial and domestic fishing is practiced. While fishing is prohibited within the core area of Koshi Tappu Wildlife Reserve, licenses are provided by the Koshi Tappu Wildlife Reserve Office to fish in the river falling within the buffer zone.

Fishing is intense in all the studied rivers. There remains a paucity of scientific evidence with regards to competition between fishers and dolphins for fish, however, there are known negative impacts on dolphins due to specific fishing methods when river depth decreases. Following the flood (2012–2015) of the Karnali Basin, dolphins were seldom seen in the Geruwa channel but one fatality was recorded in 2013. Given that fishing intensity is greater in the Karnali Channel, the population estimated by our team is seen to be in an ecological trap (Khanal et al. 2016). To boost the abundance of dolphin, fishing in preferred channels and hotspots should be restricted or confined to limited periods with respect to river depths. For sustainable conservation practice, the concerned authorities are encouraged to demotivate fishing by supporting alternative livelihood enhancement programs with consideration to the cultural and ethnic needs of the targeted communities.

As stated in the beginning of the paper, this study is unique as this is a nation-wide survey performed during the monsoon season. Flagship species tourism has the potential to raise funds for conservation and improve the economic conditions surrounding the dolphin habitats according to local and conservationists' opinion. Bardia National Park visitation has grown nearly three-fold within two decades (BNP 2018/ 2019).

Table 1. Dolphin counts in different rivers of Nepal during July–August 2016.

	Name of the river	Length of river surveyed (km)	No. of dolphins sighted/best estimate
1	Mohana and its tributaries	26	43
2	Karnali	35	NS
3	Geruwa	37	NS
4	Narayani	57	NS
5	Koshi	49	9

*NS – Not Sighted during the official dolphin population survey, could be due to perception bias and high water levels as the surveys were done during the monsoon season.

Collaboration between scientific bodies and federal government to survey dolphins in the monsoon allows the government to realize the potential in investing in the ecological resilience of such charismatic megafauna during a season that otherwise experiences a decline in tourism throughout the year.

The population reduction of the species' geographical range due to habitat fragmentation (Khanal et al. 2016) and ecological degradation is one of the indispensable characteristics of river dolphin population decline and extinction (Turvey et al. 2010). Anthropogenic activities such as construction of dams/ barrages, irrigation schemes, and intensive and unregulated fishing have invariably harmed aquatic organisms (Smith 1993; Kelkar et al. 2010).

The dearth of riverine conservation policy, its enforcement and local stewardship allows the species' population to continue its decline. Therefore, we see both the formulation and active enforcement of National and Trans-boundary Dolphin Conservation Strategy and Action Plans as imperative for the survival of the species.

The environmental stress affecting the studied basins is not expected to abate in the immediate future. At present, there is no single transboundary, national or inter-province based agreement to regulate basin volume which is threatened by increased agricultural demand for irrigation (Khanal et al. 2016), proposed hydropower in the Karnali Chisapani (10,800 MW); and pollution, rapid sand and rock mining, and fishing practices.

Further investigation into banning the use of chemical fertilizers and pesticides which might negatively affect the aquatic life by way of bioaccumulation is suggested. This coupled with localized enforcement of fishing methods with respect to locations, quantities and season may help conserve the species. With consideration to indigenous subsistence artisanal fishers, the pressure on the shared basins must be monitored and managed by locals, who are incentivized by the notion of co-management or alternative livelihood enhancement programs.

Inter-province collaboration must take place for the enforcement of laws with consideration to the watersheds divided by the provinces of Nepal. Both Koshi and Karnali basins are divided into two separate provinces. The known habitats for the Ganges River Dolphin are provinces one and two of Koshi and six and seven of Karnali.

Lastly, we propose the Government of Nepal to establish a sanctuary for the Ganges River Dolphin for its conservation. The creation of the Vikramshila Sanctuary of Bihar, India has proven beneficial for the survival of the species.

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Author contributions: DNS conceived the project, led the field study and wrote up the paper. DNS and GS designed the field methods. AP and GS joined the survey team in the Karnali River basin. SL edited the manuscript. All authors read and approved the manuscript. The authors declare no conflict of interest.

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COMMUNICATION

Bat (Mammalia: Chiroptera) diversity, dominance, and richness in the southwestern region of Bhutan with three new records for the country

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Abstract: Bats are ecologically crucial as they are good pollinators and pest controllers, but are less known in Bhutan. We investigated bat diversity and richness in broadleaved forests of southwestern Bhutan. Fieldwork was carried out from July 2016 to April 2017 using mist nets and hoop nets. The main objective of the study was to document bat diversity and species richness. We captured 157 bats of 10 species belonging to four families. Two species (*Myotis siligorensis* Horsfield, 1855 and *Rhinolophus affinis* Horsfield, 1823) accounted for almost 52% of the total captures. Species richness of bats differed depending upon habitat types. *Myotis siligorensis* was captured more often from broadleaved forests whereas *Rhinolophus macrotis* Blyth, 1844 and *Rhinolophus affinis* were common around human settlements. The present study contributed three new records for Bhutan which increased the bat diversity from 65 to 68 species. We conclude that the southwestern region, especially Chukha District, could be one of the bat diversity hotspots in Bhutan.

Keywords: Chiroptera, Chukha, Dagana, *Myotis*, *Rhinolophus*, Samtse, species richness.

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Author submission: Hoop nets were used with precaution and extra care not to injure/harm bats during the study. No accidental death occurred during the whole study period. We now understand that the use of hoop nets is unethical. We will not repeat this in future bat studies.

Author Details: Sangay Tshewang's research interests are in bat conservation and environment science. Dr. Dhan Bahadur Gurung's research interests are in the areas of ecotourism and taxonomy with special focus on orchids, reptiles, and fishes. Karma Sherub's research interest includes studies of mammals and birds and he is pursuing a study on bird diversity and behaviour. Dr. Sumit Dookia's current research includes habitat use by bats in urban environments with special reference to metropolitan areas of Delhi as well as the bat fauna of northern India, Rajasthan, Haryana, and Delhi. Kuenzang Dorji is a wildlife biologist with special interest in small mammals. Dr. Pema Choephyel is interested in environment conservation and ecology.

Author Contribution: ST developed the concept, collected data and wrote the draft. DBG improved the draft and finalized the paper. KS, SD, KD and PC provided valuable comments in improving the documents and assisted in species identification.

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INTRODUCTION

Chiroptera are unique and true flying mammals consisting of more than 1,300 species worldwide (Fenton & Simmons 2014). They are divided into 18 families in two unequal suborders–Yinpterochiroptera and Yangochiroptera. The Yinpterochiroptera or Pteropodiformes is a suborder of Chiroptera which includes six families: one family of fruit bats Pteropodidae, formerly known as Megachiroptera and five families comprising of Rhinopomatidae, Rhinolophidae, Hipposideridae, Craseonycteridae, and Megadermatidae. The Yangochiroptera or Vespertilioniformes is a proposed suborder of Chiroptera that includes 12 families, most of which were previously classified as Microchiroptera (Srinivasulu et al. 2010).

Bats constitute the second most diverse order of mammals (Korad et al. 2007). They represent about one-fifth of the 5,418 known mammal species (Lumsden 2004; Rajchal 2007). Bhutan has recorded 65 species which constitutes 33% of all mammal taxa of which nine species are fruit bats and 56 species are insectivorous belonging to five families (Marimuthu 2009). The most common group of bats in Bhutan is the evening bats (Vespertilionidae) with 34 species (Wangchuk et al. 2004; Choden 2009).

Species richness, diversity and distribution of bats have been well studied in many parts of the Indian subcontinent such as in the Western Ghats, Uttarakhand, and parts of Marathwada region of Maharashtra (Korad et al. 2007; Korad 2014; Sayyed 2016; Chakravarty 2017), in Kathmandu Valley of Nepal (Thapa et al. 2012) as well as in Malaysia (Shafie et al. 2011; Hanif et al. 2015). These studies added detailed information about species. In Bhutan, such studies are lacking and absence of baseline data has further impeded our understanding of bat species richness, diversity and ecological benefits. Conservation of small mammals such as bats has gained focus worldwide as they have their own ecological roles to play as pollinators, seed dispersers, and pest controllers.

The surveys by Salvo et al. (2009), Korad et al. (2007) and Raghuram et al. (2014) have added wide information about bat habitat preferences, species richness, and disturbances. Threats to bats have also been studied by Rajchal (2007) and Acharya & Adhikari (2010). In the context of Chukha District, such information is lacking despite the area having undergone rapid socio-economic development due to peoples' choice of modern development projects over biodiversity conservation. The lack of baseline information calls for an urgent need to generate data on bat species richness and diversity.

MATERIALS AND METHODS

Study area

The study area covers the southwestern districts of Samtse and Dagana including Chukha covering an area of about 1,802km^2. The area is predominantly covered by mixed broadleaved forest. It is situated between 27.117^{0}N and 89.783^{0}E (Figure 1) with elevations ranging 200–3,500 m. The landscape comprises of complex geomorphologic features with caves, rocky outgrowths and also man-made tunnels which are ideal roosting habitats for bats.

It was reported that the study area is home to a number of bat species such as Eastern Bent-winged Bat *Miniopterus fuliginosus* Hodgson, 1835, Intermediate Horseshoe Bat *Rhinolophus affinis* Horsfield, 1823, and Blandford's Fruit Bat *Sphaerias blanfordi* Thomas, 1891(Chakraborty 1975; Bates et al. 2008; Chiozza 2008; Hutson et al. 2008; Walston et al. 2008).

Chukha District has undergone rapid land use changes due to peoples' choice of modern development activities resulting in increased threats and disturbances to the bat populations and their habitats. Despite the area having high economic value to the country, it has also major conservation issues and challenges due to ongoing hydropower projects, industries, mining, and other development activities. These projects have huge environmental impacts in terms of habitat disturbance, fragmentation, and environmental pollution.

Field sampling

We divided the region into five major habitat types (forest, cave, settlement, stream, and abandoned house). Further, it was divided into four elevation categories (<1,500, 1,500–2,500m, 2,500–3,000m and >3,000m) to study the presence or absence of bats in different elevation zones. Thirty-four sites were sampled with elevations ranging from 200–3,500 m. The sites were visited twice in each season, i.e., monsoon and winter as it is important to sample same sites in different seasons to assess the bat density and diversity of the region more appropriately.

Species richness and diversity of bats

Mist netting was carried out in sampling sites at various habitat types (forest, streams/water bodies, settlement) to investigate species diversity and habitat use. To avoid injury to bats, mist nets were monitored

Figure 1. Study area.

by the field assistant all the time. Two to three mist nets of 6m and 9m length with 2.5m height of three to five shelves were erected as nets were found more successful in capturing bats in dense forest. Mist nettings began before dusk with the use of bamboo and tree poles. Since bats use vertical stratification and forage at various heights to reduce food competition, finding the right spot for erecting the mist nets was crucial for successful capture.

In general, capture success was enhanced when nets were put at natural flyways such as across forest trails. Since the study area had dense forest cover, there are chances that certain species may not have been captured at all.

Bat trappings were carried out mostly for five hours after dusk depending on capture success and weather conditions. The study was carried out from July 2016 to April 2017 in an effort of 147 trapping nights (768 mistnet hours). Four to five field assistants were involved every night to monitor the mist nets. In addition, a hoop net was used to capture species in habitats such as abandoned houses and caves. To determine bat species richness, dominance and diversity, the following indices were assessed: (1) Shannon-Wiener diversity index (H') (Shannon & Wiener, 1949), (2) Simpson's index (D), (3) Pielou's evenness (J) and (4) Margalef's index for species richness (R) (Margalef 1958).

Shannon index (H') = $-\Sigma Pi \ln Pi$

Where Pi = S/N

S = Number of individual of one species

N = Total number of all individuals in the sample

ln = Logarithm to base e

$$\text{Simpson's index D} = \frac{\sum ni(ni-1)}{N(N-1)}$$

Where N = Total number of all organisms

n_i = Number of individuals of each individual species.

Pielou's evenness (J) compares the actual diversity

value (such as the Shannon-Wiener index, H') to the maximum possible diversity value (when all species are equally common, Hmax=lnS where S is the total number of species). For Shannon-Wiener index, the Pielou's evenness (J) was used:

$$J=H'/Hmax \text{ or } H'/lnS$$

Where H' = Shannon Wiener index value

Hmax = Maximum possible diversity value

S = Total number of species

$$\text{Margalef's index } (R) = S - 1 / \ln (N)$$

Where S = Total number of species in the sample

ln = Logarithm to base e

N = Total number of all individuals in the sample

Morphometric measurement of bats

The live-trapped bats were carefully removed from mist nets and kept in cloth bags for morphometric measurements and identification. Using a Pesola spring balance (100g), weights of each individual were measured. The sex and age group of bats were recorded by classifying into juvenile or adult (Kunz & Parsons 2009; Kangoyé et al. 2015). Measurements were taken to the nearest 0.1mm accuracy using SPI dial calipers (Bates & Harrison 1997; Ith et al. 2015; Chakravarty 2017). Morphometric measurements included: HBL (head body length) following Soisook et al.(2016), Ear length (EL) from lower margin to tip of ear, FA (length of forearm including carpals), Tibia (TIB), and HF (hind foot including claws) as per Kangoyé et al. (2015). The length of metacarpals was taken excluding carpals. Measurements were taken immediately after capture at the study sites to assist identification.

Identification of bats

Bats were identified based on morphological measurements (Table 1) and qualitative characters by comparing photographs taken and using available morphological keys. The majority of the bats were identified based on available reference guides and keys (Bates & Harrison 1997; Csorba et al. 1999; Acharya & Adhikari 2010; Srinivasulu et al. 2010; Menon 2014). For species which could not be identified in the field, photographs were taken for seeking identification assistance from experts.

RESULTS

Species diversity of bats

The bat fauna in southwestern Bhutan is insectivorous as no fruit bats of suborder Yinpterochiroptera belonging to the family Pteropodidae were captured. A total of 157 individuals belonging to 10 species were caught with the use of mist nets and hoopnets (Images 1 & 2). For this study, 17 individuals (10.83%) were captured in hoop nets and the rest in mist nets. The Rhinolophidae was the most diverse family contributing 59% of the bat fauna in Chukha District. The family Vespertilionidae was the second most diverse family with 32% and the least was the Miniopteridae with 0.54%. Following Wangchuk et al. (2004), species that have been reported for the first time for Bhutan are marked with double asterisks (**) and the first time record from Chukha District of the south-western region are marked with a single asterisk (*) (Table 2).

Table 1. Morphological measurement (in range) of bats.

Species	TSS	Measurements (mm)								
		FA	HBL	HF	EL	TIB	3mt	4mt	5mt	BW
Hipposideros armiger	12	88–93.50	90.51–92.31	12.52–16.45	21.34–23.58	42.34–45.78	67–70.24	67.52–68.59	67.54–68.93	48–57.57
Myotis siligorensis	43	34–36.45	38.31–40.12	6.08–7.34	11.05–11.95	14.78–15.50	30.6–31.54	30–30.93	29.5–30.51	4.86–5.94
Myotis longipes	8	35.01–36.74	39.50–41.68	6.81–7.58	10.51–11.47	14–15.46	30–31.24	31–31.50	31.90–40.12	5.23–6.05
Rhinolophus affinis	38	53–55.51	47–49	6–70.81	17–18	24–25.5	36.50–37.83	39–40.54	40–41.71	16.20–17
Rhinolophus luctus	9	68–70.32	81–82.45	11.50–12.65	32–36	37–38.56	50–51	52.50–53.8	55–56.80	31.85–34
Rhinolophus pusillus	7	35–37.83	31–32.70	6–70.32	15.50–16.8	15–16	25–26.40	26.50–27.3	27.50–28	5–6.42
Rhinolophus lepidus	5	40.05–41	32–33.50	6.20–7.08	16–17	16.30–16.9	30.8–31.50	31–31.50	31.40–31.70	5–6.81
Rhinolophus sinicus	13	45–46.52	50.20–52.40	6–7.31	17–17.80	16.80–17.50	36.80–37.90	36–37	35.90–36.40	10.30–11.21
Rhinolophus macrotis	21	41.56–54	50–55.67	10–11.55	17.50–18.50	24–26.34	40–42.35	41–43.90	42.02–43.57	7–8.40
Miniopterus fuliginosus	1	47.85	53.54	7.52	10.32	19.67	40.15	39.51	37.64	13.94

TSS—Total specimen measured in each species |FA—forearm | HBL—head body length | HF—hind foot | EL—ear length| TIB—Tibia | 3mt—third metacarpal | 4mt—fourth metacarpal | 5mt—fifth metacarpal |BW—body weight.

Table 2. Information on the species and number of individuals caught.

Species	NI	NIP (%)	NSC	H'	J	D
*Hipposideros armiger**	12(M:3, F:9)	7.64	1	1.97	0.86	0.17
*Myotis siligorensis**	43(M:17, F:26)	27.39	11			
*Myotis longipes***	8(M:8)	5.10	2			
Rhinolophus affinis	38(M:25, F:13)	24.20	9			
*Rhinolophus luctus**	9(M:6, F:3)	5.73	2			
*Rhinolophus pusillus**	7(M:2, F:5)	4.46	1			
*Rhinolophus lepidus**	5(M:4, Ju:1)	3.18	2			
*Rhinolophus sinicus***	13(M:9, F:4)	8.28	2			
*Rhinolophus macrotis**	21(M:8, F:12, Ju:1)	13.38	5			
*Miniopterus fuliginosus***	1(M:1)	0.64	1			

M—male | F—female |Ju—juvenile| NI—number of individuals | NIP—number of individuals in % | H'—species diversity | J—Pielou's evenness | D—Simpson's index |NSC—number of sites caught.

Myotis siligorensis had the highest overall bat count (NI=43, NIP=27.39%), followed by *Rhinolophus affinis* (NI=38, NIP=24.20%), and lowest for *Miniopterus fuliginosus* (NI=1, NIP=0.64%) (Table 2). Shannon-Wiener diversity index (H') and Pielou's evenness (J) were 1.97 and 0.86 respectively. The capture rate of *M. siligorensis* ranged from two to six individuals per trapping night followed by *R.affinis* with one to five individuals. The family Rhinolophidae contained the maximum number of individuals captured (N=93, NIP=59.24%). The diversity index (H') and Pielou's evenness (J) were 0.90 and 0.78 for the families captured (Table 3).

Occurrence of bats at different elevations

The species richness was comparatively higher between the elevations 1,500–2,500 m and there after it decreased significantly with increasing elevation (Table 4). The majority of species (63%) were captured within the elevation range of <1,000–2,500 m. *Rhinolophus affinis* and *Myotis siligorensis* were the most common species in an elevation range of <1,500–2,500 m. The average species capture rate and richness were highest between elevations of 1,500–2,500 m (μ=6.10, R=1.78, SD=4.53) followed by <1,500m (μ=6.10, R=1.38, SD=6.52) and lowest in >3,000m (μ=0.90, R=0.59, SD=1.28). The maximum total number of individuals captured was highest at elevation <1,500m and 1,500–2,500 m (TNI=61) and lowest at >3,000m (TNI=9).

Table 3. Summary of bat diversity in different family category.

Family diversity	Total no. of individuals (N)	%	H′	J
Hipposideridae	12	7.64	0.90	0.78
Vespertilionidae	51	32.48		
Rhinolophidae	93	59.24		
Miniopteridae	1	0.64		

Table 4. Summary of bat occurrence in different elevation range.

Species	Elevation (in m)			
	<1,500	1,500–2,500	2,500–3,000	>3,000
Rhinolophus luctus	4	5	0	0
Rhinolophus affinis	16	13	6	3
Rhinolophus pusillus	3	3	1	0
Rhinolophus lepidus	2	2	0	1
Rhinolophus sinicus	6	4	3	0
Rhinolophus macrotis	8	6	5	2
Myotis siligorensis	19	12	9	3
Myotis longipes	3	3	2	0
Miniopterus fuliginosus	0	1	0	0
Hipposideros armiger	0	12	0	0
No. of species	8	10	6	4
Average no. of species captured (μ)	6.10	6.10	2.60	0.90
Max (Min)	19(0)	13(1)	9(0)	3(0)
Margalef's index(R)	1.38	1.78	0.99	0.59
SD	6.52	4.53	3.13	1.28
Total no. of individuals (TNI)	61	61	26	9

Diversity of bats by habitat type

From the total of 157 bats captured, 87 (55.41%) were captured from forests followed in order by settlements (N=36, 22.93%), streams (N=19, 12.10%) and abandoned houses (N=3, 1.91%) (Table 5). The Shannon-Wiener diversity index (H'), however, showed that diversity among the different habitats was 1.19 and the overall Pielou's evenness (J) was 1.03.

Bat species richness in relation to habitat types

Margalef's index showed that forest habitat had the highest species richness (R=1.34) followed by settlements (R=1.12) and the least in caves and abandoned houses

Image 1. Bat species recorded in the study area: A—*Rhinolophus luctus* | B—*Myotis longipes* | C—*Miniopterus fuliginosus* | D—*Hipposideros armiger* | E—*Rhinolophus macrotis* | F—*Rhinolophus affinis.*

(R=0) (Table 5). The total number of individuals caught was high for Rhinolophidae family (N=93) followed by other families in decreasing order: Vespertilionidae (N=51), Hipposideridae (N=12), and Miniopteridae (N=1) (Table 3). The capture rate was comparatively higher for Rhinolophidae and Vespertilionidae families.

DISCUSSION

Species diversity of bats

Studies on bats in the landlocked Himalayan country of Bhutan is almost non-existent though it has been well studied in neighboring countries such as Nepal and India (Korad et al. 2007; Thapa et al. 2012; Korad 2014; Sayyed 2016; Chakravarty 2017). This study is the first to assess the bat diversity in southwestern region of Bhutan (Chukha District) in which a total of 10 bat species were documented. All the species captured during the

Image 2. Bat species recorded in the study area: G—*Rhinolophus lepidus* | H—*Rhinolophus sinicus* | I—*Rhinolophus pusillus* | J—*Myotis siligorensis.*

current survey were insectivorous bats.

Considering the reports of bats from Bhutan (Chakraborty 1975; Bates et al. 2008; Chiozza 2008; Walston et al. 2008), all species except *Rhinolophus affinis* and *Miniopterus fuliginosus* are new records for the country and nine species except *Rhinolophus affinis* are recorded for the first time from Chukha District. Following the studies conducted by Wangchuk et al. (2004), however, only three of the 10 species are new to Bhutan. These are *Myotis longipes*, *Rhinolophus sinicus*, and *Miniopterus fuliginosus*. This indicates that the subsequent studies (Bates et al. 2008; Chiozza 2008; Walston et al. 2008) might have over looked the study of Wangchuk et al. (2004).

Occurrence of bats at different elevations

Bat species richness was highest between the elevations 1,500–2,500 m and thereafter decreased with increasing elevation. This finding is in contrast with the report from Kathmandu valley by Thapa et al. (2012) where it is mentioned that bat assemblage was rich at altitudinal range of 1,300–1,500 m. The difference in findings could be due to geographical variation, habitat types and availability of roosting sites besides food availability (moths and insects). However, the similar findings on the difference in distribution of bat species and their richness at different elevations were reported by Thapa et al. (2012) and Raghuram et al. (2014).

In terms of the average number of species captured,

Table 5. Information on bat diversity by habitat type.

Habitat	Family	Species	Total (N)	%	H'	R
Forests	Rhinolophidae	*Rhinolophus pusillus*	87	55.41	0.33	1.34
		Rhinolophus lepidus				
		Rhinolophus sinicus				
		Rhinolophus macrotis				
	Vespertilionidae	*Myotis siligorensis*				
		Myotis longipes				
	Hipposideridae	*Hipposideros armiger*				
Caves	Hipposideridae	*Hipposideros armiger*	12	7.64	0.20	0
Settlements	Miniopteridae	*Miniopterus fuliginosus*	36	22.93	0.34	1.12
	Rhinolophidae	*Rhinolophus affinis*				
		Rhinolophus macrotis				
		Rhinolophus lepidus				
	Vespertilionidae	*Myotis longipes*				
Streams	Vespertilionidae	*Myotis siligorensis*	19	12.10	0.26	0.34
	Rhinolophidae	*Rhinolophus lepidus*				
Abandoned houses	Rhinolophidae	*Rhinolophus luctus*	3	1.91	0.08	0

%—percentage | H'—species diversity | R—species richness.

bat assemblage was highest between 1,500–2,500 m and lowest for >3,000m. This finding is consistent with the report of Choden (2009) mentioning bat distribution range 500–3,000 m. A decrease in species density at higher elevation was reported by Martins et al. (2015). Similar findings on different number of individuals confining to different elevation zones such as low or high elevations, some across the elevation gradient was also reported by Raghuram et al. (2014). The difference in capture rate in different elevation zones could be due to variations in habitats as well as climatic influence and disturbance in different elevation gradients.

Diversity of bats by habitat type

The highest bat diversity was from the forest with seven species (*Rhinolophus pusillus*, *R. lepidus, R. sinicus, R. macrotis, Myotis siligorensis, M. longipes*, and *Hipposideros armiger*). A similar finding on abundant bat species composition in the forest was reported from Bolivia (Loayza & Loiselle 2009), Malaysia (Shafie et al. 2011) and southern Western Ghats of India (Deshpande 2012). Korad et al. (2007) and Korad (2014) also reported that bat diversity and distribution is governed by forest types. The reason for the presence of a high diversity of bats in the forest and around human settlement might be due to the availability of more food such as moths and insects. It might also be due to the presence of high number of roosting sites and foraging opportunities in forests compared to other sampling sites. Other preferred habitats are caves, abandoned houses and human settlements (Mickleburgh et al. 2002; Korad et al. 2007; Raghuram et al. 2014). In current study, caves and abandoned houses are seen to prefer as day roosting sites.

In this study, use of acoustic recorders to record the echolocation call of bats was felt important due to the presence of dense forest cover. Acoustic recorder, however, was not available during the field work which is one of the limitations of this study. Further, bats use vertical stratification and forage at various heights to reduce competition for food as well as to detect prey (Plank 2011; Carvalho 2013; Marques 2015). Therefore, there are high chances that certain species may not have been captured at all during the survey.

Hipposideros armiger was observed roosting in caves with large openings. Species such as *Rhinolophus luctus* roosted in abandoned houses near cowsheds while other species such as *Myotis siligorensis* and *Rhinolophus lepidus* were captured near streams. Some species such as *Rhinolophus affinis* and *R.macrotis* were found in disturbed areas as well as in agricultural areas and around human settlements. In Malaysia, Shafie

et al. (2011) found that plantations and agricultural areas provide suitable habitats for bat species. In India and Nepal (Deshpande 2012; Swamidoss et al. 2012; Thapa et al. 2012; Korad 2014) have mentioned that water bodies, farm land, human settlement, hillock, abandoned houses, tree hollows, unused railway tunnels, canal tunnels, caves and forests are some of the most preferred habitats of microchiropteran bats.

Bat species richness in relation to habitat types

In a world where conversion of forest to farmland and pastures is occurring at an accelerating rate (Loayza & Loiselle 2009), a study documenting bat species richness in forest is a critical step for bat conservation. In the current study, bat species richness was highest in forest and least in caves and abandoned houses. The reason for the high bat species richness in forest might be due to the presence of forest clearings, trails and open areas which provide diverse refuge and foraging habitats for bats. The weather condition and forest structure also influenced the capture success within the study areas. Heavy rain affects capture rate as the bats delay their emergence (Hanif et al. 2015). In the current study, the capture rate was higher in the monsoon season and this could be due to more food (insects) availability compared to winter season or we might have captured more migratory bats.

CONCLUSION

With the use of mist nets and hoop nets, a bat survey was conducted in southwestern region, Chukha District of Bhutan. The present study added three new records to the already existing 65 species of bats in Bhutan. The rich diversity of bats from Chukha District in southwestern Bhutan highlights the presence of diverse habitat types. Since bats provide many ecosystem services, it is required to protect their habitats to conserve them. In addition, it is important to expand similar studies to other parts of the country as Bhutan seems to harbor a diverse bat fauna.

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Appendix 1. Individual morphological measurements for all specimens of *Rhinolophus affinis*.

Species	TNS (38)	Measurements (mm)								
		FA	HBL	HF	EL	TIB	3mt	4mt	5mt	BW
Rhinolophus affinis	1	54.31	48	6.21	17	25.11	36.9	39.8	41	16.3
	2	53	47.34	6.83	17.5	24.6	37	40	40.4	16.5
	3	55	48.42	7	18	25	37.4	39.8	40.35	17
	4	54.2	47.9	6.61	17.21	24.33	36.67	39	40	16.75
	5	53	47.11	6.54	17	24.05	36.6	39	40.5	16.25
	6	55	48.54	7.32	17.87	24.98	37	40.03	41	16.85
	7	53.33	47	6.04	17.51	24.66	36.77	39.22	40.56	16.43
	8	53	47	6	17.06	24	36.61	39	40.01	16.4
	9	54	48	7.55	17.4	24.76	36.99	40	40.5	16.77
	10	54	48.03	7.6	17.8	24.91	37	40.3	40.55	17
	11	55	48	7.6	17.5	25	37.22	40.4	40.7	16.2
	12	53.5	47.3	6.8	17	24	36.7	39	40	16.5
	13	55.43	48.6	7.35	17.78	25.04	37	40	41	17
	14	55	49	7.71	18	25	37.76	40.44	41.31	16.2
	15	55.51	49	7.8	17.92	25.44	37.83	40.5	41.65	17
	16	53	47.21	6.33	17	24.03	36.5	39.04	40.12	16.32
	17	54	47.5	6.5	17.5	24.5	36.8	39.5	40.75	16.55
	18	54.06	47	6.66	17.2	24.71	37	40	41	17
	19	54.21	47.91	7	17	24.96	36.99	39.62	40.84	16.45
	20	54	47.5	6.65	17.43	24.61	37	40	41	17
	21	53	47	6.3	17.32	24	36	39	40	17
	22	55	48.76	7.54	18	25	37.67	40	41	16.5
	23	54.2	47.9	6.61	17.21	24.33	36.67	39.12	40	16.75
	24	54	48	7.55	17.4	24.76	36.99	40	40.5	16.77
	25	55.43	48.6	7.35	17.92	25.44	37.83	40.5	41.65	17
	26	54.31	48	6.21	17	25.11	36.9	39.8	41	16.3
	27	53.5	47.3	6.8	17	24	36.7	39	40	16.5
	28	55	48.42	7	18	25	37.4	39.8	40.35	17
	29	54	47.66	7.55	17.45	24.89	37	40	41	17
	30	53.55	48	6.98	17.67	24.81	36.86	39.34	40.56	16.71
	31	55.51	48.91	7.81	18	25.5	37.76	40.54	41	16.85
	32	54	48	7	17.45	25.5	37.83	40	41.34	17
	33	53.33	47	6.04	17.51	24	36.61	39	40.01	16.4
	34	55	48.54	7.32	18	25	37.67	40	41	17
	35	54.2	47.9	7.55	17.4	24.89	37	39	40	16.5
	36	53.5	47.3	6.3	17.32	24.05	36.5	39.04	40.12	16.32
	37	55.51	49	7.78	17.89	25.53	37.83	40.54	41.71	16.92
	38	53	47	6.05	17.45	24	37	39.18	40.05	16.45

TSN—Total number of specimen of *Rhinolophus luctus* |FA—forearm | HBL—head body length | HF—hind foot | EL—ear length| TIB—Tibia | 3mt—third metacarpal | 4mt—fourth metacarpal | 5mt—fifth metacarpal |BW—body weight.

Appendix 2. Individual morphological measurements for all specimens of *Rhinolophus luctus*.

Species	TNS (9)	Measurements (mm)								
		FA	HBL	HF	EL	TIB	3mt	4mt	5mt	BW
Rhinolophus luctus	1	69	81.56	11.6	34	37.58	50.51	52.86	55.5	32.62
	2	70.32	82	12.45	36	38.52	51	53	56.80	33
	3	68.59	81.78	12	33.85	37.42	50	52.04	55.42	31.85
	4	68	81.09	11.76	32	37	50	53.15	55	32
	5	70	82.45	12.65	36	38.56	50.98	53.8	56.57	34
	6	70.06	82	12.79	35.73	38	50.06	53.47	56.09	32.85
	7	69.57	81	11.95	33.65	37.98	50.75	52.86	55.76	33.62
	8	68.34	81.05	11.50	32.09	37.54	50.12	52.5	55.62	31.91
	9	70.22	82	12.64	35.52	38	50.96	53	55.69	31.98

TSN—Total number of specimen of *Rhinolophus luctus* |FA—forearm | HBL—head body length | HF—hind foot | EL—ear length| TIB—Tibia | 3mt—third metacarpal | 4mt—fourth metacarpal | 5mt—fifth metacarpal |BW—body weight.

Appendix 3. Individual morphological measurements for all specimens of *Rhinolophus pusillus*.

Species	TNS (7)	Measurements (mm)								
		FA	HBL	HF	EL	TIB	3mt	4mt	5mt	BW
Rhinolophus pusillus	1	36.76	31.81	6.5	16	15.34	25.56	26.89	27.52	5.43
	2	35	31	6.23	15.5	15	25	26.59	27.5	5.98
	3	37.83	32.5	7.32	16.8	16	26.34	27.3	28	6.32
	4	36	31	6.23	15.95	15.81	25.54	26.5	27.59	5.87
	5	35	31.11	6	15.56	15.32	25.21	26.51	27.5	5.45
	6	37	32.7	7.30	16.56	15.98	26.4	27.12	27.97	6.42
	7	35.06	31.21	6.09	15.9	15.11	25.54	26.5	27.32	5

TSN—Total number of specimen of *Rhinolophus pusillus* |FA—forearm | HBL—head body length | HF—hind foot | EL—ear length| TIB—Tibia | 3mt—third metacarpal | 4mt—fourth metacarpal | 5mt—fifth metacarpal |BW—body weight.

Appendix 4. Individual morphological measurements for all specimens of *Rhinolophus lepidus*

Species	TNS (5)	Measurements (mm)								
		FA	HBL	HF	EL	TIB	3mt	4mt	5mt	BW
Rhinolophus lepidus	1	40.54	32.41	6.4	16.43	16.5	30.95	31.05	31.40	5.52
	2	41	33.23	7	16.98	16.9	31.45	31.34	31.52	6
	3	40.05	32	6.2	16.34	16.3	30.8	31	31.45	5
	4	40.98	33.50	7.08	17	16.78	31.5	31.5	31.7	6.81
	5	40.76	32.94	7.03	16.85	16.65	31	31.23	31.54	6.41

TSN—Total number of specimen of *Rhinolophus lepidus* |FA—forearm | HBL—head body length | HF—hind foot | EL—ear length| TIB—Tibia | 3mt—third metacarpal | 4mt—fourth metacarpal | 5mt—fifth metacarpal |BW—body weight.

Appendix 5. Individual morphological measurements for all specimens of *Rhinolophus sinicus.*

Species	TNS (13)	Measurements (mm)								
		FA	HBL	HF	EL	TIB	3mt	4mt	5mt	BW
Rhinolophus sinicus	1	45.34	51	6.5	17.45	16.98	36.9	36.56	35.98	10.54
	2	45	50.2	6.23	17	16.8	36.8	36	35.91	10.3
	3	46	51.5	7	17.6	17.45	37.23	37	36	11
	4	45	50.66	6	17.09	16.95	36.87	36.54	35.9	10.55
	5	45.87	51	6.88	17.31	17.11	36.96	36.35	36.09	10.61
	6	46.52	52.4	7.31	17.67	17.5	37.9	37	36.4	11.21
	7	45.09	50.35	6.23	17.72	16.86	37.21	36.89	36.35	10.83
	8	45	50.23	6	17	17.09	37	36.86	36.12	11.05
	9	45.9	51	6.55	17.06	17.12	36.98	36	35.96	10.89
	10	46	52	7.03	17.8	17.45	37.7	36.85	36.38	10.57
	11	45.86	50.2	6.23	17.6	17.45	36.88	36.73	35.99	10.85
	12	46.34	52	7	17.69	17.34	37.56	36.98	36.05	10.38
	13	46	52.4	7.31	17.06	17.12	37.9	37	36	11

TSN—Total number of specimen of *Rhinolophus sinicus* |FA—forearm | HBL—head body length | HF—hind foot | EL—ear length| TIB—Tibia | 3mt—third metacarpal | 4mt—fourth metacarpal | 5mt—fifth metacarpal |BW—body weight.

Appendix 6. Individual morphological measurements for all specimens of *Rhinolophus macrotis*.

Species	TNS (21)	Measurements (mm)								
		FA	HBL	HF	EL	TIB	3mt	4mt	5mt	BW
Rhinolophus macrotis	1	50.53	53	11.05	17.85	25	41.5	42.53	42.65	7.5
	2	45.65	50.53	10.87	17.5	24.86	41	41.57	41.98	7
	3	41.56	50	10	17.59	24	40.98	41.23	42.06	7.56
	4	53	54.23	11.26	18	25.45	42	43	43.51	8.40
	5	54	55.67	11.55	18.5	26	42.08	43.23	43.45	7.98
	6	47	53.34	10.67	17.89	25.53	41.98	42.56	43	8
	7	46.91	52	11	17.78	24,96	41.90	42.45	42.97	7.40
	8	53.76	54.98	11.56	17.9	25	42	43	43.43	8.40
	9	50.55	51	10.87	17.83	24.97	41	41.78	42.8	7.76
	10	41.56	50	10	17.5	24	40	41	42.02	7.56
	11	48	51.56	11.05	17.9	25.01	41.05	42.31	42.59	8
	12	54	55.67	11.55	18.5	26.34	42	43.47	43.57	8.09
	13	51.89	52.87	11.48	17.97	25.67	41.67	42	42.96	7.78
	14	45.65	50.53	11	17.78	24,96	41	41.57	41.98	8
	15	50.53	53.76	11.25	17.83	24.97	41	42.31	42.59	7.77
	16	41.56	50	10.55	17.59	24.06	41.5	42.23	42.65	8.03
	17	46	51.89	53.67	17.5	24.86	41.90	42.45	42.97	7.78
	18	53.80	54.98	11.46	18.06	25.65	42.35	43.90	43.45	8.04
	19	43.59	50.78	10.56	17.87	24,36	41.03	41.55	42	8
	20	46.11	51.43	10.98	17.58	24,26	41.62	42.15	42.58	7.01
	21	51.55	51.34	10.97	17.98	24.99	41.34	41.68	42.89	8.26

TSN—Total number of specimen of *Rhinolophus macrotis* |FA—forearm | HBL—head body length | HF—hind foot | EL—ear length| TIB—Tibia | 3mt—third metacarpal | 4mt—fourth metacarpal | 5mt—fifth metacarpal |BW—body weight.

Appendix 7. Individual morphological measurements for all specimens of *Myotis siligorensis*.

Species	TNS (43)	Measurements (mm)								
		FA	HBL	HF	EL	TIB	3mt	4mt	5mt	BW
Myotis siligorensis	1	35	39.05	6.35	11.23	14.90	30.78	30.45	29.95	5.06
	2	34	38.56	6.19	11.23	14.93	30.65	30.34	29.85	4.89
	3	34.91	38.31	6.08	11.05	14.78	30.63	30.43	29.50	5.01
	4	35.67	40.04	7	11.45	15.32	31.45	30.13	30.86	5.75
	5	36.45	40.12	7.24	11.85	15.40	31.54	30.83	30.51	5.64
	6	34	38.75	6.39	11.43	14.85	30.75	30.54	29.66	5.03
	7	35.56	40.05	6.75	11.83	14.95	30.98	30.75	29.99	5.66
	8	34.12	38.31	6.08	11.09	14.59	30.60	30.06	29.5	4.86
	9	36.33	40	7.34	11.95	15.50	31.44	30.93	30.32	5.34
	10	36.42	40.08	7.26	11.87	15.43	31.49	30.76	30.42	5
	11	34	38	6.13	11.14	14.78	30.6	30.23	29.34	4.98
	12	35.45	39.45	6.35	11.44	14.81	30.95	30.75	29.88	5.93
	13	34.09	38.65	6.29	11.63	14.82	30.75	30.54	29.78	5.50
	14	36.35	40.10	7.17	11.65	15.23	31.39	30.83	30.11	4.98
	15	35.86	40.04	7	11.34	15.22	31.45	30.23	30.46	5
	16	36.44	40.11	7.24	11.88	15.50	31.35	30.90	30.50	5.45
	17	35.45	39.46	6.16	11.23	14.79	30.85	30.66	29.81	5.09
	18	34	38.45	6.41	11.43	14.91	30.75	30.44	29.85	5.56
	19	35.27	40.10	7.23	11.45	15.45	31.35	30.03	30.48	4.9
	20	35.81	40.01	6.21	11.61	14.79	30.76	30.25	29.95	4.88
	21	36.42	40.03	7.06	11.91	15.42	31.18	30.64	30.44	5.39
	22	35.78	40.12	7.24	11.23	15.32	31.28	30.19	30.39	5
	23	34.23	38.45	6.5	11.43	14.84	30.65	30.04	29.85	4.96
	24	35	38.42	6.14	11.21	14.81	30.61	30.16	29.48	4.95
	25	36.35	40.12	7.08	11.55	15.12	31.29	30.73	30.22	5.34
	26	34.25	38.56	6.19	11.20	14.92	30.65	30.34	29.89	5
	27	35.08	39.96	7.09	11.39	15.38	31.49	30.21	30.46	5.65
	28	34	38.05	6.24	11.14	14.93	30.41	30	29.77	5.07
	29	35.77	40.12	6.40	11.61	14.79	30.76	30.33	29.87	5.85
	30	35.70	40	6.27	11.55	14.83	30.76	30.43	29.55	5.09
	31	36.32	40.10	7.14	11.87	15.43	31.49	30.76	30.42	5.34
	32	35.45	39	6.49	11.34	14.80	30.71	30.54	29.66	5.81
	33	36	39.54	7.24	11.49	15.5	31.87	30.43	30.41	5.34
	34	36.22	40.11	7.04	11.77	15.45	31.23	30.76	30.31	5
	35	35	38.85	6.98	11.87	14.92	30.84	30.24	29.68	4.92
	36	35.34	40.00	7.23	11.42	15.43	31.35	30.08	30.40	5.08
	37	35.82	39.53	7.08	11.45	15.44	31	30.13	30.32	4.96
	38	35.32	39.15	6.22	11.42	14.82	30.66	30.42	29.87	5.94
	39	34.88	38.77	6.45	11.29	14.91	30.88	30.65	29.69	4.87
	40	35.67	39	7.23	11.52	15.11	31.76	30.42	30.51	5.23
	41	34.65	38.90	6.88	11.73	14.98	30.81	30.55	29.89	4.95
	42	36.04	40.12	7.16	11.75	15.21	31.22	30.74	30.25	5.79
	43	34.90	38.68	6.39	11.47	14.79	30.97	30.45	29.86	5.42

TSN—Total number of specimen of *Myotis siligorensis* |FA—forearm | HBL—head body length | HF—hind foot | EL—ear length| TIB—Tibia | 3mt—third metacarpal | 4mt—fourth metacarpal | 5mt—fifth metacarpal |BW—body weight.

Appendix 8. Individual morphological measurements for all specimens of *Myotis longipes*.

Species	TNS (8)	Measurements (mm)								
		FA	HBL	HF	EL	TIB	3mt	4mt	5mt	BW
Myotis longipes	1	35.46	40.07	6.89	10.85	14.97	30.45	31.08	31.98	5.56
	2	36.54	41.26	7.31	11.06	15.35	31	31.24	40.10	6.01
	3	35.01	39.50	6.81	10.56	14	30.5	31	31.95	5.23
	4	35.23	39.58	6.97	10.51	14.27	30	31.34	31.90	5.98
	5	36.41	41.55	7.32	11.09	15.32	31.21	31.33	40.03	6
	6	36.74	41.68	7.58	11.32	15.36	31.24	31.50	40	6.05
	7	35.95	39.89	6.92	10.88	14.56	30.96	31.08	31.99	5.86
	8	36.65	41.59	7.52	11.47	15.46	31.09	31.45	40.12	6.04

TSN—Total number of specimen of *Myotis longipes* |FA—forearm | HBL—head body length | HF—hind foot | EL—ear length| TIB—Tibia | 3mt—third metacarpal | 4mt—fourth metacarpal | 5mt—fifth metacarpal |BW—body weight.

Appendix 9. Individual morphological measurements for all specimens of *Miniopterus fuliginosus*.

Species	TNS (1)	Measurements (mm)								
		FA	HBL	HF	EL	TIB	3mt	4mt	5mt	BW
Miniopterus fuliginosus	1	47.85	53.54	7.52	10.32	19.67	40.15	39.51	37.64	13.94

TSN—Total number of specimen of *Miniopterus fuliginosus* |FA—forearm | HBL—head body length | HF—hind foot | EL—ear length| TIB—Tibia | 3mt—third metacarpal | 4mt—fourth metacarpal | 5mt—fifth metacarpal |BW—body weight.

Appendix 10. Individual morphological measurements for all specimens of *Hipposideros armiger*.

Species	TNS (12)	Measurements (mm)								
		FA	HBL	HF	EL	TIB	3mt	4mt	5mt	BW
Hipposideros armiger	1	90.09	91.32	14.55	22.51	43.86	69.32	67.86	67.91	55.75
	2	89.45	90.85	13.21	22.13	42.94	68.06	67.93	67.58	53.74
	3	88.38	90.51	13	21.86	41.24	67.34	67.59	67.55	49.51
	4	91.76	91.84	14.76	22.69	44.01	69.53	67.91	67.95	55.82
	5	88.41	90.51	12.52	21.85	42.64	67	67.83	67.54	48
	6	92.09	91.89	15.17	23	45.05	69.56	68.55	68.78	57.42
	7	88	90.59	12.52	21.34	42.34	67.06	67.52	67.59	50.59
	8	90.56	91	14.88	22.34	44.07	69.14	68.09	68.23	56
	9	93.50	92.31	16.45	23.41	45.67	70.24	68.39	68.52	57.09
	10	93.49	92.30	16.38	23.58	45.78	70.21	68.59	68.93	57.57
	11	89.01	91.19	12.87	21.59	42.83	67.59	67.58	67.64	49.67
	12	92.54	91.98	16.32	23.09	45.12	69.95	68.81	68.90	54.71

TSN—Total number of specimen of *Hipposideros armiger* |FA—forearm | HBL—head body length | HF—hind foot | EL—ear length| TIB—Tibia | 3mt—third metacarpal | 4mt—fourth metacarpal | 5mt—fifth metacarpal |BW—body weight.

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COMMUNICATION

The pattern of waterbird diversity of the trans-Himalayan wetlands in Changthang Wildlife Sanctuary, Ladakh, India

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Abstract: Ladakh lies on an important bird migratory route between the Palearctic and the Indian sub-continent, and the high altitude migratory species utilise Ladakh frequently as a stopover site. The trans-Himalayan landscape in Ladakh also serves as a breeding site for many water birds species including the globally threatened Black-necked Crane *Grus nigricollis*. Yet, only sporadic information is available on the status and diversity of waterbirds here. In a landscape-level assessment study spanning over 27,000km^2 area, we surveyed 11 major high-altitude wetlands of Changthang Wildlife Sanctuary, Ladakh during the pre-winter season of the year 2013. We recorded a total of 38 waterbird species belonging to 10 families, including one species in Vulnerable and two species in Near Threatened categories of IUCN Red List. We calculated species diversity and richness indices to compare the wetlands. Statapuk Tso and Tsokar were the most diverse wetlands of the sanctuary (Shannon diversity 2.38 and 2.08, respectively). We used principal component analysis to find out the wetlands with unique species assemblage and identify the sites with high conservation value. We also observed a directional pattern of diversity among the wetlands of Ladakh. We provide a reminder that wildlife even in protected areas should be surveyed regularly with the sources of threats to their conservation documented carefully.

Keywords: Black-necked Crane, conservation management, migratory birds, point count survey, species assemblage, tourism.

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Author details: Pushpinder Singh Jamwal is working on the ecology of otters along Indus River and its tributaries in Ladakh region of India. Shivam Shrotriya's research focuses on Himalayan Wolf along with other large mammals in the Trans-Himalayan landscape of Ladakh. Jigmet Takpa undertook several initiatives on biodiversity conservation, rural development and renewable energy in Ladakh.

Author contribution: PSJ and JT conceptualised and designed the study. PSJ and SS collected the data, analysed and wrote the manuscript. All the authors reviewed the final manuscript.

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INTRODUCTION

Waterbirds are an essential component of wetland ecosystems and serve as bio-indicators and models to monitor the health of wetlands (Urfi et al. 2005). Aquatic birds function at multiple trophic levels in the wetland food webs, thus reflecting the changes in different ecosystem components (Custer & Osborne 1977; Grimmett et al. 2011). The Convention on wetlands or the Ramsar Convention stresses the importance of waterfowl habitats. Conserving and managing wetlands over vast landscapes, however, requires extensive resources, is cumbersome and often difficult to achieve. For practical reasons, it is important that wetlands supporting important species assemblages are identified and protected (Young et al. 2014). Avifauna diversity parameters such as species richness, diversity and density of the birds frequently provide information on habitat quality and are crucial to wetland management (Nilsson & Nilsson 1978; Sampath & Krishnamurthy 1990; Colwell & Taft 2000).

India harbours more than 4,000 high altitude lakes, and most of those are situated in the trans-Himalayan Ladakh region (Space Applications Centre 2011). Ladakh is the westward extension of the Tibetan Plateau. The Indus Valley in Ladakh is a crucial bird migratory route between the Palearctic and the Indian sub-continent (Williams & Delany 1986; Ali & Ripley 1988). As many as 319 bird species, making about 26% of Indian avifauna, are reported from Ladakh; and out of these 44 species are waterbirds (Pfister 2004; Chandan et al. 2008; Hussain et al. 2008). Ladakh is the only known breeding ground of Black-necked Crane *Grus nigricollis* in India (Chandan et al. 2006). Other waterbird species that breed in Ladakh are Bar-headed Goose *Anser indicus*, Brown-headed Gull *Chroicocephalus brunnicephalus*, Common Merganser *Mergus merganser*, Common Redshank *Tringa totanus*, Common Tern *Sterna hirundo*, Great Crested Grebe *Podiceps cristatus*, Ruddy Shelduck *Tadorna ferruginea*, and Lesser Sand Plover *Charadrius mongolus* (Prins & Wieren 2004; Chandan et al. 2008; Hussain et al. 2008; Humbert-Droz 2011).

Only a few sporadic scientific studies on waterbirds in the Indian trans-Himalaya have been conducted so far, leaving a significant information gap. Except for a few studies on waterbirds at specific high altitude wetlands (Mishra & Humbert-Droz 1998; Hussain & Pandav 2008; Namgail et al. 2009; Chandan 2015), there has been no attempt made to study waterbirds of Ladakh at the landscape level. We surveyed 11 major high-altitude wetlands of Ladakh during the pre-winter season from 15 September to 15 November 2013, when bird migration towards India takes place. Here, we provide an inventory of migratory waterbirds of Ladakh and report on the species richness and diversity of the wetlands. We also highlight the critical wetlands that support a high diversity and threatened bird species.

MATERIAL AND METHODS

Study area

Ladakh constitutes the trans-Himalayan landscape bordering Tibet (China). A high number of wetlands including 22 lakes and Indus river catchment are located in Changthang Wildlife Sanctuary (CWS) in eastern Ladakh (Chandan et al. 2006). CWS spans about 27,000km^2 between 32.317–34.583 ^{0}N and 77.750–79.300 ^{0}E at an average altitude of 4,000m. CWS is an important highland grazing system in the cold desert biotope with a short summer and Arctic-like winter. Powerful and unpredictable winds make the area highly inhospitable; temperature ranges from 0°C to 30°C during summer and from -10°C to -40°C during winter (Mishra & Humbert-Droz 1998; Chandan 2015). Most of the wetlands in Ladakh are of glacial origin and remain frozen from December to March. Several brackish and freshwater wetlands here are home to a wide variety of flora and fauna. We surveyed 11 major wetlands (>0.4 km^2) in CWS: Pangong Tso, Puga, Rongo, Sato-Harong Marshes, Statapuk Tso, Tashi Chuling, Thasangkaru Tso, Tsigul Tso, Tsokar, Tsomorirri, and YayaTso (Figure 1, Table 1).

Data collection

We conducted field surveys from 15 September to 15 November 2013 following point count survey method (Bibby et al. 1992). The points were placed on the shores of the wetlands keeping the inter-point distance of at least 1km. A total of 59 points were surveyed and repeated fortnightly four times each (Table 1). Observations were aided by binoculars and carried out early in the morning during the first three hours after sunrise at 06.30h when the bird activity is at its peak. Each survey consisted of three 10-minute scans with a break of one hour in between. All the corresponding points for a wetland were surveyed simultaneously at the same time. Each of the wetlands was surveyed by a different team of authors, wildlife department guards and volunteers ranging 6–22 members. The checklist of species was prepared following (Grimmett et al. 2011). The conservation status of species was assigned using

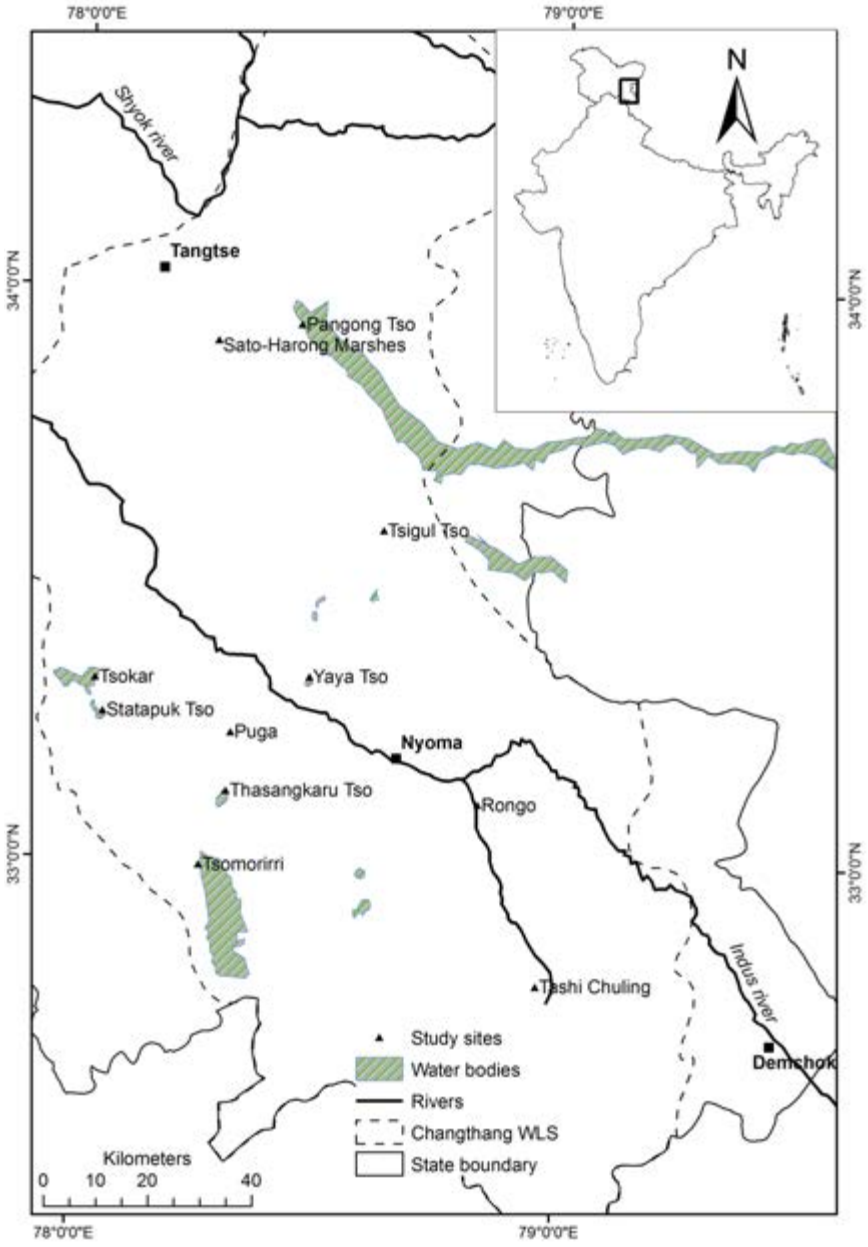

Figure 1. Location of the study area and surveyed high altitude wetlands of Changthang Wildlife Sanctuary, Ladakh.

the Red List classification of IUCN (IUCN 2019).

Data analysis

We calculated Shannon-Weiner diversity index SDI (Hutchison 1970), Margalef's richness index MRI (Margalef 1958), Pielou's evenness index PEI (Pielou 1966), and McNaughton's community dominance index CDI (McNaughton 1968) to compare the species richness and diversity across the sites. We performed principal component analysis with Bray-Curtis distances on the species assemblage to develop a minimum spanning tree of the surveyed wetlands (Bray & Curtis 1957; Gower 1966). Minimum spanning tree is closely related to single linkage clustering. All the analyses were performed in statistical program R, version 3.4.4 (R Core Team 2018) using the package "vegan", version 2.4-6 (Oksanen et al. 2018).

RESULTS

We recorded 38 water-bird species belonging to 10 families in 11 high altitude wetlands of Ladakh, India (Images 1–15). Anatidae accounted for 34% species followed by Scolopacidae (21%), Charadriidae and Laridae (11% each), Podicipedidae, Rallidae, and

Table 1. Location, size and survey effort of the high altitude wetlands of Ladakh in Changthang Wildlife Sanctuary.

Wetland	Location	Size (Km^2)	Survey Points
Pangong Tso	N 33.936°, E 78.447°	26.99	4
Puga	N 33.223°, E 78.318°	0.84	4
Rongo	N 33.105°, E 78.835°	1.66	3
Sato-Harong Marshes	N 33.905°, E 78.274°	6.34	4
Statapuk Tso	N 33.256°, E 78.052°	6.09	8
TashiChuling	N 32.789°, E 78.962°	0.44	4
Thasangkaru Tso	N 33.121°, E 78.311°	5.48	4
Tsigul Tso	N 33.579°, E 78.627°	0.89	3
Tsokar	N 33.314°, E 78.035°	21.53	11
Tsomorirri	N 32.991°, E 78.258°	22.19	9
Yaya Tso	N 33.323°, E 78.479°	1.55	5

Recurvirostridae (5% each), and Ardeidae, Gruidae and Motacillidae (2.6% each). Bar-headed Goose, Common Merganser, Common Sandpiper *Actitis hypoleucos*, Northern Pintail *Anas acuta*, and Ruddy Shelduck *Tadorna ferruginea* were the most abundant species, while less than five individuals were recorded for Black-winged Stilt *Himantopus himantopus*, Kentish Plover *Charadrius alexandrinus*, Pacific Golden Plover *Pluvialis fulva*, Pallas's Gull *Ichthyaetus ichthyaetus*, Red-crested Pochard *Netta rufina*, and Water Rail *Rallus aquaticus*. Bar-headed Goose, Black-necked Crane *Grus nigricollis*, Brown-headed Gull *Chroicocephalus brunicephalus*, Common Sandpiper *Actitis hypoleucos*, Great Crested Grebe, Northern Pintail *Anas acuta* and Ruddy Shelduck were the most well distributed species, recorded at more than five wetlands (Table 2).

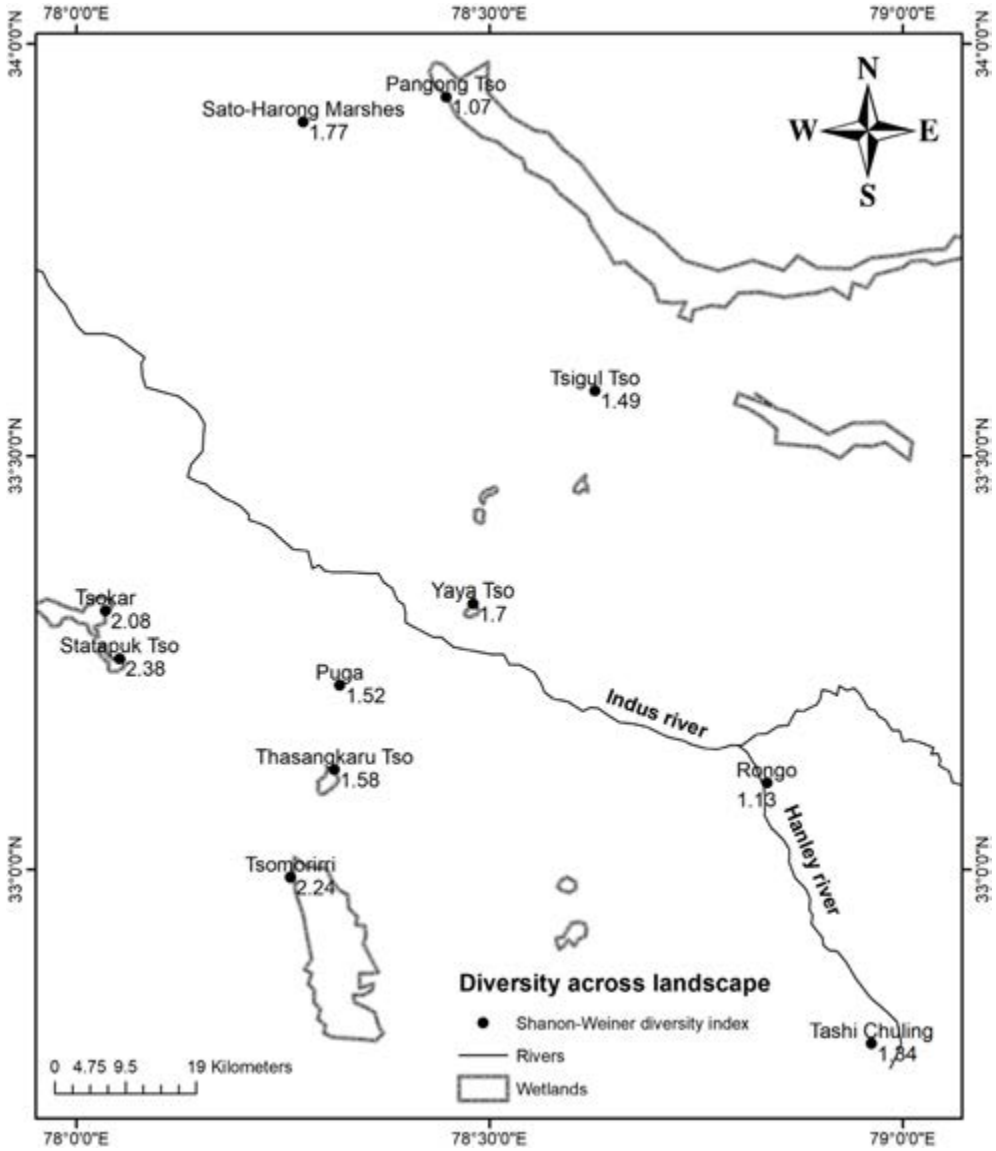

Figure 2. Pattern of Shannon-Weiner diversity across the high altitude wetlands of Changthang Wildlife Sanctuary, Ladakh.

Table 2. List of waterbird species recorded at the high altitude wetlands of Changthang Wildlife Sanctuary, Ladakh.

Family	Common name	Scientific name	IUCN status*	Recorded at wetlands#	Abundance†
Anatidae	Bar-headed Goose	*Anser indicus*	LC	2,3,4,5,6,8,9,10,11	1298–1717
Anatidae	Common Merganser	*Mergus merganser*	LC	5,10,11	1573–1806
Anatidae	Common Pochard	*Aythya ferina*	LC	4	44–61
Anatidae	Eurasian Wigeon	*Anas penelope*	LC	5,10	20–48
Anatidae	Ferruginous Duck	*Aythya nyroca*	NT	1,5,10,11	40–56
Anatidae	Gadwall	*Anas strepera*	LC	5	29–56
Anatidae	Garganey	*Anas querquedula*	LC	5,11	58–105
Anatidae	Mallard	*Anas platyrhynchos*	LC	5,8	55–76
Anatidae	Northern Pintail	*Anas acuta*	LC	1,2,3,4,5,6,7,8,9,10,11	1341–1571
Anatidae	Northern Shoveler	*Anas clypeata*	LC	5,10,11	48–68
Anatidae	Red-crested Pochard	*Netta rufina*	LC	5	4
Anatidae	Ruddy Shelduck	*Tadorna ferruginea*	LC	2,3,4,5,6,7,8,9,10,11	943–1526
Anatidae	Tufted Duck	*Aythya fuligula*	LC	5,11	31–48
Ardeidae	Grey Heron	*Ardea cinerea*	LC	4,5,11	7–8
Charadriidae	Kentish Plover	*Charadrius alexandrinus*	LC	5,9	2–4
Charadriidae	Lesser Sand Plover	*Charadrius mongolus*	LC	5,9	146–210
Charadriidae	Pacific Golden Plover	*Pluvialis fulva*	LC	5	2
Gruidae	Black-necked Crane	*Grus nigricollis*	VU	2,3,4,5,6,8,9,11	29–35
Laridae	Brown-headed Gull	*Chroicocephalus brunnicephalus*	LC	1,3,4,5,7,9,10	563–699
Laridae	Common Tern	*Sterna hirundo*	LC	2,5	8–11
Laridae	Little Gull	*Hydrocoloeus minutus*	LC	5	12–56
Laridae	Pallas's Gull	*Ichthyaetus ichthyaetus*	LC	3	2–4
Motacillidae	Citrine Wagtail	*Motacilla citreola*	LC	5	15–18
Podicipedidae	Black-necked Grebe	*Podiceps nigricollis*	LC	5,9	10–25
Podicipedidae	Great Crested Grebe	*Podiceps cristatus*	LC	1,5,7,9,10,11	520–860
Rallidae	Eurasian Coot	*Fulica atra*	LC	5	7
Rallidae	Water Rail	*Rallus aquaticus*	LC	5	2
Recurvirostridae	Black-winged Stilt	*Himantopus himantopus*	LC	5	4
Recurvirostridae	Pied Avocet	*Recurvirostra avosetta*	LC	9	21–23
Scolopacidae	Common Redshank	*Tringa totanus*	LC	5,10	71–101
Scolopacidae	Common Sandpiper	*Actitis hypoleucos*	LC	2,3,4,5,6,7,8,9,10,11	1469–1854
Scolopacidae	Common Snipe	*Gallinago gallinago*	LC	5	73–90
Scolopacidae	Eurasian Curlew	*Numenius arquata*	NT	5,9	3–9
Scolopacidae	Green Sandpiper	*Tringa ochropus*	LC	5,9	104–131
Scolopacidae	Little Stint	*Calidris minuta*	LC	5,9	17–26
Scolopacidae	Little Ringed Plover	*Charadrius dubius*	LC	2,5,9	282–486
Scolopacidae	Ruff	*Philomachus pugnax*	LC	5	6
Scolopacidae	Temminck's Stint	*Calidris temminckii*	LC	5,9	453–566

LC—Least Concern | NT—Near Threatened | VU—Vulnerable | 1—Pangong Tso | 2—Puga | 3—Rongo | 4—Sato-Harong Marshes | 5—Statapuk Tso | 6—TashiChuling | 7—Thasangkaru Tso | 8—Tsigul Tso | 9—Tsokar | 10—Tsomorirri | 11—Yaya Tso | †—Range from minimum to maximum number of individuals counted.

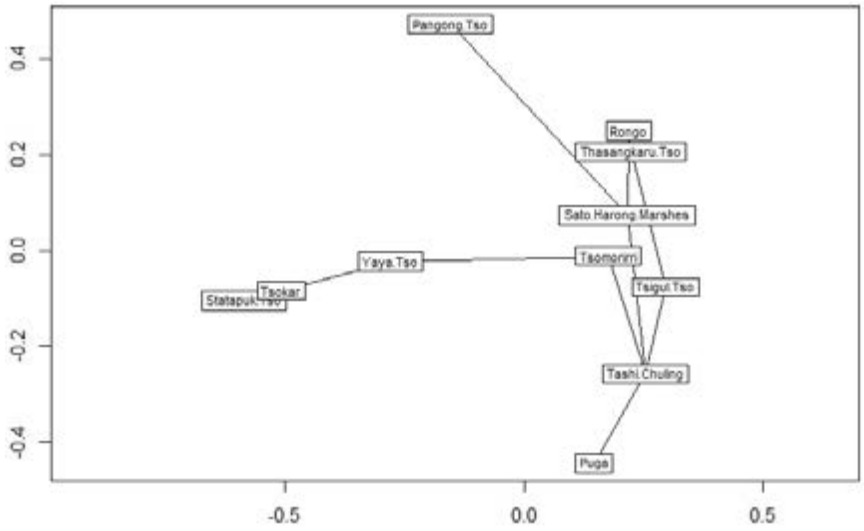

Figure 3. Minimum spanning tree based on principal coordinate analysis of the bird assemblage at the high altitude wetlands of Changthang Wildlife Sanctuary, Ladakh.

Statapuk Tso was the most diverse and species-rich wetland (SDI 2.38, MRI 3.91) with 35 species recorded there. Diversity and richness were higher at Tsokar (n=16, SDI 2.08, MRI 1.93), Yaya Tso (n=12, SDI 1.7, MRI 1.58) and Tsomoriri (n=11, SDI 2.24, MRI 1.79) as well. Pangong Tso had the lowest number of species (n=4, SDI 1.07, MRI 0.54). PEI was the highest at Thasangkaru Tso (0.98) and the lowest at Rongo (0.58), while CDI was the highest at Pangong Tso, Rongo and Tashi Chuling (0.8) and the lowest at Statapuk Tso and Tsomoriri (0.4) (Table 3). We also observed that the western wetlands held comparatively higher waterbird diversity than the eastern wetlands, revealing a directional pattern (Figure 2). We tested the hypothesis if the species diversity was affected by the size of the wetlands using paired Mann-Whitney-Wilcoxon test; and we found that wetland size does not relate with Shannon diversity (V= 53, p=0.083). Following the species assemblage, studied sites aligned into two main groups. Statapuk Tso, Tsokar, and Yaya Tso formed one group and Rongo, Thasangkaru Tso, Sato-Harong Marshes, Tsomoriri, Tsigul Tso, and Tashi Chuling formed another group. Species assemblage at Pangong Tso and Puga were distinct from each other and all other wetlands as well (Figure 3).

DISCUSSION

Measures of diversity are frequently seen as indicators of the wellbeing of ecological systems (Magurran 1988). The presence of an endangered species, however, can add to the conservation importance of a site. For effective conservation, wetlands supporting important species, diversity and unique assemblages should be identified and protected (Young et al. 2014). Black-necked Crane was the most threatened waterbird species in our checklist, categorised as Vulnerable in the IUCN Red List (Rahmani 2012; Rahmani et al. 2015; IUCN 2019). Ladakh is the only known breeding ground of Black-necked Crane in India (Chandan et al. 2006). The species was present at all wetlands but Thasangkaru Tso, Tsomoriri and Pangong Tso. Although widespread among the surveyed wetlands, its abundance was very low (Table 2). Seasonality might have affected its sighting as the species is reported to begin migrating at the beginning of the winter season (Chandan 2015). Eurasian Curlew *Numenius arquata* and Ferruginous Duck *Aythya nyroca*, categorised as Near Threatened in the IUCN Red List (IUCN 2019), were also sighted infrequently (Table 2). Eurasian Curlew was present at Statapuk Tso and Tsokar, whereas Ferruginous Duck was present at Statapuk Tso, Tsomoriri, Yaya Tso and Pangong Tso. We did not sample a large number of the smaller wetlands (<0.4 km^2) during the present study, where a few species and individuals of threatened species might find refuge. Principal coordinates analysis of the wetlands based on their species composition indicated that Statapuk Tso, Puga and Pangong Tso are unique, falling on the farthest edges of the minimum spanning tree (Figure 3). Statapuk Tso and Tsokar hold most of the waterbird diversity and are situated together forming a complex (Chandan et al. 2014). Tsomoriri and Tsigul Tso are located at the centre of the minimum spanning tree (Figure 3), suggesting that the water-bird communities of these wetlands share common species with other wetlands as well. Tsomoriri is a high altitude Ramsar

Table 3. Measurements of waterbird diversity and richness at the high altitude wetlands of Changthang Wildlife Sanctuary, Ladakh.

Wetland	Total Species	Shannon-Weiner diversity index (SDI)	Margalef's richness index (MRI)	Pielou's evenness index (PEI)	Community dominance index (CDI)
Pangong Tso	4	1.07	0.54	0.77	0.8
Puga	7	1.52	1.06	0.78	0.6
Rongo	7	1.13	1.25	0.58	0.8
Sato-Harong Marshes	8	1.77	1.26	0.85	0.5
Statapuk Tso	35	2.38	3.91	0.67	0.4
Tashi Chuling	5	1.34	0.76	0.83	0.8
Thasangkaru Tso	5	1.58	1.07	0.98	0.5
Tsigul Tso	6	1.49	1.03	0.83	0.6
Tsokar	16	2.08	1.93	0.75	0.5
Tsomorirri	11	2.24	1.79	0.93	0.4
YayaTso	12	1.7	1.58	0.68	0.7

site, while Tsokar and Tsomoriri are also identified as 'Important bird areas' in India (Rahmani et al. 2013).

The wetlands with the highest Shannon diversity and Margalef's richness, namely, Statapuk Tso, Tsokar, and Tsomoriri, were all situated in the southwestern region of CWS (Figure 2, Table 3). Other wetlands in this region, such as Yaya Tso, Puga, and Thasangkaru Tso, also hold comparatively higher diversity than that of the wetlands situated in the eastern part of the sanctuary, e.g., Tashi Chuling and Rongo (Figure 2, Table 3). Our results show that wetland size did not affect waterbird diversity. We, however, observed a directional pattern in the species diversity of wetlands of the eastern Ladakh landscape (Figure 2). In general, wetlands on the western part were comparatively more diverse than the eastern wetlands. Wetlands in the south-west seem to offer suitable habitat for the majority of waterbird species. The landscape in Ladakh opens towards Tibetan Plateau in the east, which is comparatively much drier and colder habitat. Moreover, the wetlands in the north such as Pangong Tso have steep shores, providing less area for waterbirds to establish. Therefore, geo-climatic factors might be the reason for a directional pattern of species diversity.

Worldwide more than 50% of natural wetland areas have been lost due to human activities. This has adversely affected the hydro system, plant growth and avian communities that depend on wetland habitats directly and indirectly for various activities (Fraser & Keddy 2005; Coleman et al. 2008; Zakaria & Rajpar 2014). Ladakh is facing similar threats owing to growing tourism close to many of the wetlands (Chandan et al. 2006). Pangong Tso, Tsokar and Tsomoriri, three crucial wetlands for waterbirds, are also among the prime tourist places during the summer season. Global population trend of the waterbird species recorded in Ladakh shows that 20 species (53%) are declining in number, three species (8%) have a stable population, three species (8%) are increasing, and the status of 13 species (34%) is unknown (Wetlands International 2012; Gopi et al. 2014). As much as nine waterbird species are known to breed in the area (Prins & Wieren 2004; Hussain et al. 2008; Humbert-Droz 2011). Therefore, wetlands of Ladakh hold a high conservation value. We recommend that critical areas around the wetlands need to be mapped where tourist routes and waterfowl habitats overlap, and protective measures such as restriction of access to key waterfowl habitats especially during their breeding time could be applied.

Knowledge of the spatiotemporal distribution of biodiversity is still quite incomplete in several parts of the world. It is one of the major problems preventing the assessment and effectiveness of conservation actions (de Carvalho et al. 2017). Our study provides an assessment of the water-bird diversity of the eastern Ladakh during the pre-winter season. We also highlighted the critical wetlands that support a high diversity and threatened bird species. Future assessment surveys can use this study as a baseline and expand the survey effort to include smaller wetlands. We provide a reminder that wildlife even in protected areas should be studied regularly, with the sources of threats to their conservation documented carefully.

Image 1. Bar-headed Goose *Anser indicus*

Image 2. Ruddy shelduck *Tadorna ferruginea*

Image 3. Black-necked Crane *Grus nigricollis*

Image 4. Black-winged Stilt *Himantopus himantopus*

Image 5. Brown-headed Gull *Chroicocephalus brunnicephalus*

Image 6. Common Pochard *Aythya ferina*

Image 7. Common Redshank *Tringa totanus*

Image 8. Common Snipe *Gallinago gallinago*

Image 9. Common Tern *Sterna hirundo*

Image 10. Eurasian Coot *Fulica atra*

Image 11. Eurasian Curlew *Numenius arquata*

Image 12. Great-crested Grebe *Podiceps cristatus*

Image 13. Little Ringed Plover *Charadrius dubius*

Image 14. Northern Shoveler *Anas clypeata*

Image 15. Bar-headed Goose *Anser indicus* and Ruddy Shelduck *Tadorna ferruginea*

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COMMUNICATION

Composition, diversity and foraging guilds of avifauna in agricultural landscapes In Panipat, Haryana, India

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Abstract: Avian communities are very good indicators of integrity and stability of ecosystem structure and functions. Assessment of bird assemblages in different landscapes is therefore emphasized from an environmental monitoring viewpoint. Bird surveys were carried out from April 2015 to March 2016 to document the avian species assemblage of agricultural landscapes in Panipat, Haryana, India. Point-transect in amalgam with opportunistic encounter methods were used to collect data. A total of 101 bird species under 44 families and 15 orders were recorded from the study area. The bird species richness was highest for the order Passeriformes (48), followed by Pelecaniformes (15), Charadriiformes (6), and the remaining 12 orders. Ardeidae was the most diverse bird family in the study area. Among the recorded avifauna, 77 species were residents, 18 species were winter migrants and six species were summer migrants. Species richness was recorded to be highest in the month of January compared to the remaining months. Species richness, abundance, diversity and evenness differed significantly ($P < 0.05$) between seasons as well as among the agricultural landscapes. Most bird species were insectivorous (36) followed by carnivorous (26), omnivorous (24), granivorous (9), frugivorous (5) and nectarivorous (1). Painted Stork *Mycteria leucocephala*, Black-necked Stork *Ephippiorhynchus asiaticus*, Black-headed Ibis *Threskiornis melanocephalus*, and Alexandrine Parakeet *Psittacula eupatria* are four Near Threatened species found in this region. Interestingly, five species having globally declining population trends are still common in the study area. The observed richness of avian species in the study area calls for further studies on habitat preference, seasonal changes, nest ecology, and breeding biology to understand species specific roles of birds in agro-ecosystems.

Keywords: Agroecosystem, avian communities, ecosystem structure, point-transect, species diversity.

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Author details: Dr. Parmesh Kumar is Associate Professor of Zoology, Institute of Integrated & Honors Studies, Kurukshetra University. He has published dozens of papers in the national and international journals and few book chapters on biodiversity specifically on avifauna of Haryana. His field of research includes wildlife ecology and animal behaviour. Sharmila Sahu is a research scholar and pursuing her PhD from Department of Zoology, Kurukshetra University.

Author contribution: PK conceived and designed the study as well as wrote the final draft of the manuscript. SS performed the field surveys, analysed the data and prepared rough draft of the manuscript. Both authors read and approved the final manuscript.

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INTRODUCTION

Agroecosystems are among the most productive ecosystems on earth, occupying 38% of the earth's terrestrial area (Foley et al. 2011). In addition to various ecosystem services, agricultural landscapes serve as unique habitats for a huge diversity of wildlife including invertebrates, amphibians, reptiles, birds, and mammals (Bambaradeniya et al. 1998). Birds constitute an important component of the biotic community in the agro-ecosystems and execute varied functional roles as seed dispensers, pollinators, scavengers, nutrient depositors, predators of insect pests and rodents (Dhindsa & Saini 1994; Whelan et al. 2008; Sekercioglu 2012). Because of the variety of ecological functions performed by birds, they are generally recognised as valuable indicators of the overall biodiversity in agricultural landscapes (Malhi 2006).

Birds are known to play a dual role as pests and as biological control agents of insect pests in agroecosystems (Dhindsa & Saini 1994; Bianchi et al. 2006; Narayana et al. 2019). The agricultural landscapes provide a concentrated and highly predictable source of food to many bird species in the form of grains, seeds, fruits, green vegetation of the crop plants, grasses, weeds, insects, other invertebrates, and rodents (O'Connor & Shrubb 1986; Dhindsa & Saini 1994; Asokan et al. 2009). In agro-ecosystems, most bird species are insectivorous and play an important role in maintaining the population of insect pests and thereby are beneficial to farmers (Asokan et al. 2009). Studies of avian diversity in agricultural landscapes of India, however, are very limited compared to natural and protected ecosystems (Dhindsa & Saini 1994; Hossain & Aditya 2016; Narayana et al. 2019).

In the past few decades, Haryana State has witnessed tremendous changes in its agroecosystem owing to intensive agriculture and its mechanization, excessive use of pesticides and fertilizers along with rapid urbanization and industrial growth. All these developmental activities have resulted in several ecological changes in the agroecosystems, and consequently affected the avifauna of the state. As a result, documentation of bird assemblages in agroecosystems need priority to assess the impact of changing natural habitat and agricultural practices (Mallik et al. 2015; Hossain & Aditya 2016; Mukhopadhyay & Mazumdar 2017; Narayana et al. 2019). Information on species richness and community structure of birds will help in developing suitable conservation strategies for sustaining birds without interfering with the objective of intensive agricultural practices in heterogeneous agricultural landscapes (Dhindsa & Saini 1994; Sundar & Kittur 2013; Hossain & Aditya 2016). Panipat is one of the agriculturally advanced districts of Haryana, India. Till date no data is available on the bird diversity in agricultural landscapes of the district. In this context, the present study made an attempt to record species composition and diversity of avian fauna in agricultural landscapes of the district Panipat, Haryana.

MATERIALS AND METHODS

Study area

The study was conducted in all five development blocks (Panipat, Samalkha, Israna, Bapoli and Madlauda) of district Panipat, Haryana, India, taking at least two study sites in each development block. Panipat, is situated between 29.150–29.450 ^{0}N and 76.633–77.150 ^{0}E at an elevation of 244.5m and has an area of 1,268km^2 (Figure 1). A brief description of the selected agricultural landscapes is given in Table 1. Net area sown in the district is 93,000ha which constitutes 71% of the total area. Agricultural activities of the district are dependent on tube wells and canals. The district is mainly drained by the river Yamuna and its tributaries. Rice-wheat cropping system dominates with the consequent marginalization of pulses and oilseed. Sugarcane is also being grown in the study area as a cash crop. The district forms a part of the Indo-Gangetic alluvial plain with flat terrain. The study area experiences sub-tropical climate with three major seasons, i.e., rainy (July to September), a cool dry (October to February) and the hot dry season (March to June). Temperature is as high as 45^0 C in summer and as low as 3^0 C in winter. The average annual rainfall in the district is 467mm and generally increases from south-west to north-east. Most of the precipitation is received during the monsoon and some rain is also received during the cold season in association with passing western disturbances.

Data collection

Bird surveys were conducted in selected sites on a fortnightly basis from April 2015 to March 2016. Point-transect method was used to record bird species (Sutherland 2006; Narayana et al. 2019). One-km transect was laid at each study site and a point was marked at every 200m distance and the birds species were recorded in 20m radius. On arrival at a survey point, an initial 5min settling-down period was used prior to counting the birds and 15min were spent at each

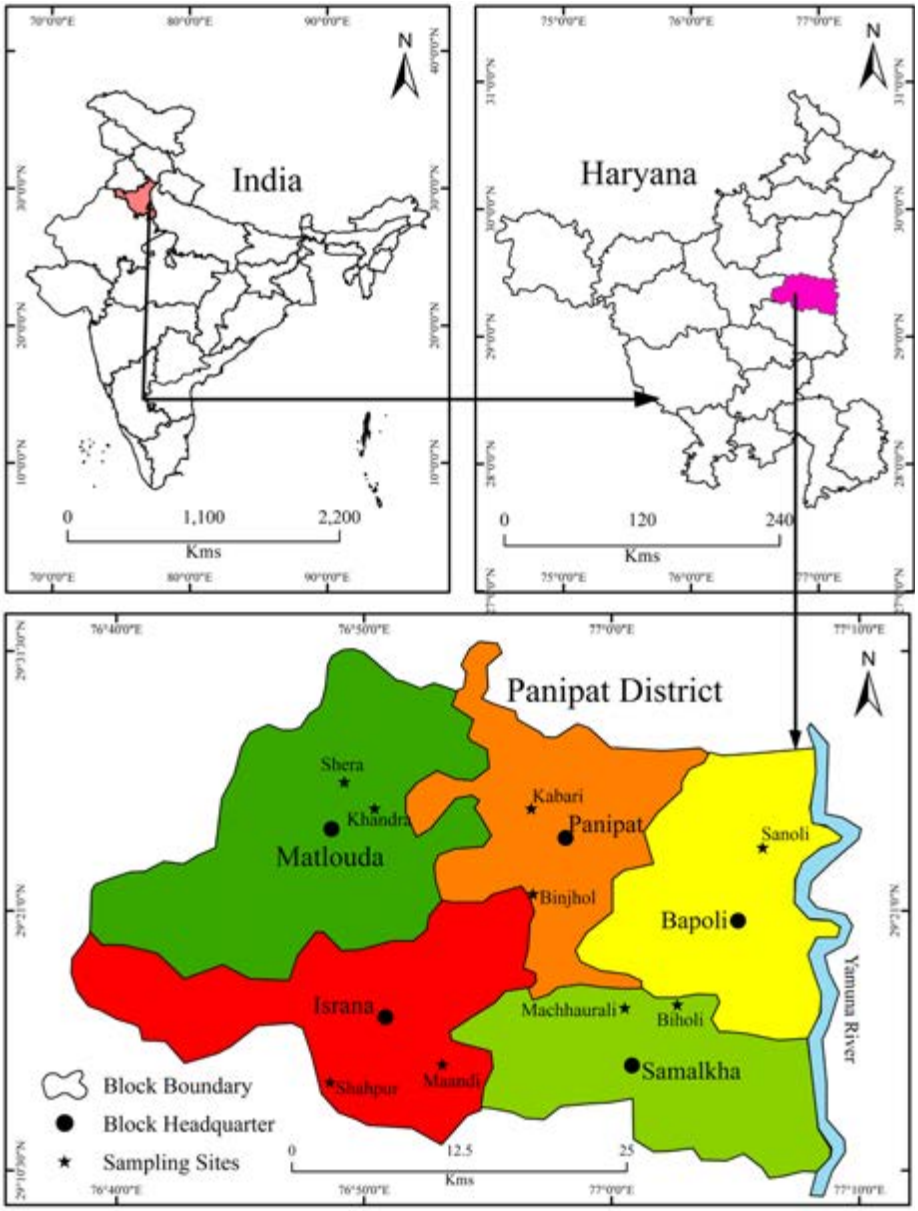

Figure 1. Panipat, Haryana, India with location of study sites.

Table 1. Summary of general characteristics of the selected agricultural landscapes.

Agricultural Landscape/ Block	Co-ordinates	Elevation (m)	General features
Panipat	29.395^{0}N & 76.968^{0}E	219	Rice-wheat cropping system dominates with the consequent marginalization of pulses and oilseed. Sugarcane is also being grown in the study area as cash crop. Agricultural activities are dependent on tube wells and on western Jamuna canal (WJC). Panipat Museum with dense vegetation is located in the vicinity of the selected agricultural landscape.
Samalkha	29.238^{0}N & 77.014°E	227	Rice-wheat cropping system along with sugarcane dominates in the landscape. The selected agricultural landscape is surrounded by the wetland (river Yamuna).
Israna	29.276^{0}N & 76.851^{0}E	231	Wheat and paddy are the main crops in the area. Agricultural activities are mainly dependent on tube wells and distributaries of WJC. Educational Institutions, temples and ponds are located in the vicinity of selected agricultural landscape.
Bapoli	29.360^{0}N & 77.057^{0}E	234	Wheat, paddy and sugarcane are the main agricultural crops grown in the area. The patches of tall wooded trees, orchards, dense vegetation, grasses and the wetlands (river Yamuna) surrounding the selected agricultural fields added to the rich habitat heterogeneity of the selected area.
Madlauda	29.401^{0}N & 76.801^{0}E	236	Paddy, wheat, sugarcane, mustard, jowar, bajra are the crops grown in the area. Selected agricultural landscape is irrigated by tube wells. The selected site was located in the vicinity of industrial area (Thermal Power Plant of Panipat) with enhanced anthropogenic activities.

point to count and record all birds observed. Each point location on transect was surveyed as many as 24 times during the entire study period. Birds were counted at their point of first detection and care was taken to ensure that the same birds were not counted again. Birds were counted directly, aided by a pair of field binoculars (Nikon 8 x 40), during hours of peak activity 06.00–10.00 h or 16.00–18.00 h. Bird species, number of individuals and habitat were recorded. Overpasses except for habitually aerial bird species such as swallows and swifts were not recorded. Call notes of birds were also used for locating the birds. Field visits were carried out on foot only on days with suitable weather conditions (i.e., in the absence of rain or strong wind). The direction of point-transects and the timing of observations was alternated during every subsequent visit. In addition, opportunistic observations of birds at other times were also included to document a comprehensive checklist. Identification of birds was done following Grimmett et al. (2011). Taxonomic position (order and family), common, and scientific names of recorded bird species were assigned following Praveen et al. (2016). For residential status, birds were categorised as resident, winter visitor and summer visitor on the basis of presence or absence in the study area (Kumar et al. 2016). We also assigned a local status to each species on the basis of the percentage of frequency of sightings following Mackinnon & Phillipps (1993) as common (C)—sighted on 80–100% of field visits, fairly common (FC)—sighted on 60–79.9% of field visits, uncommon (UC)—sighted on 20–59.9% of field visits, and rare (RA)—sighted on less than 19.9% of field visits. For determination of the feeding guilds, foraging birds were observed by focal sampling method using field binoculars and data were obtained on the type of food taken by the species. The probable food items collected from the feeding sites further helped in substantiating the observations and in evaluating the availability of food. On the basis of direct observations and description given by Ali & Ripley (1987), recorded bird species were categorized into six major feeding guilds (Figure 2): insectivorous (species that feed exclusively on insects), carnivorous (species that feed mainly on non-insect invertebrates and vertebrates), granivorous (species that feed on grains/seeds), frugivorous (species that feed predominantly on fruits), nectarivorous (species that feed on floral nectar), and omnivorous (species that feed on both plant parts and other animals).

Species richness was calculated as total number of bird species observed in the study area. The relative diversity (RDi) of bird families was calculated using the following formula (Torre-Cuadros et al. 2007):

$$RDi = \frac{\text{Number of bird species in a family}}{\text{Total number of species}} \times 100$$

Species similarity between any two agricultural landscapes was measured by Jaccard's similarity index as

Jaccard's similarity index (C_j) = a / (a + b + c)

where a is number of species common to both the landscapes, b is number of the species unique to the first landscape and c is the number of the species unique to the second landscape. Shannon–Wiener's diversity and species evenness indices of birds were estimated using PAST version 3.26 software. We pooled the recorded field data corresponding to two seasons, i.e., summer (April–September) and winter (October–March) to test the seasonal variation of bird assemblages in the study area. Two way ANOVA Tukey HSD test were used to analyse difference in the values of diversity and other indices of bird population between seasons and among the five selected agricultural landscapes at 5% level of significance (SPSS 24.0 version). The conservation status of recorded bird species and their global population trend (decreasing, increasing, stable or unknown) were compiled from the Red List of IUCN (2019).

RESULTS AND DISCUSSION

A total of 101 species of birds belonging to 82 genera, 44 families, and 15 orders were recorded during the study period (Table 2). The study area supports about 8% of the total avian species found in India (Praveen et al. 2016) and this richness of avifauna is comparable with reports of earlier studies carried out in agricultural landscapes in different parts of India. For instance, Abdar (2014) recorded 97 species from agricultural habitats of the Western Ghats, Maharashtra; Hossain & Aditya (2016) encountered 144 bird species from Burdwan, West Bengal; and Narayana et al. (2019) recorded 128 species of birds belonging to 59 families and 19 orders from agricultural landscapes of Nalgonda District in Telangana State. A maximum number of bird species belonged to the order Passeriformes (48), followed by Pelecaniformes (15), Charadriiformes (6), and the remaining, 12 orders. More than half (68.3%) of the species recorded during the study belonged to one of three orders (Passeriformes, Pelecaniformes, and Charadriiformes). These results are in agreement with previous records that order Passeriformes constitutes the most predominant avian taxa in India (Praveen et al. 2016).

Table 2. List of bird species recorded from agricultural landscapes of the district Panipat, Haryana, India together with their respective taxonomic positions, residential status, feeding guild, local status, landscape, IUCN Red List status, and global population trend.

	Order/family /common name	Scientific name	Residential status	Feeding guild	Local status	Agricultural landscape					Red List status	Global population trend
						PA	SA	IS	BA	MA		
	Order: GALLIFORMES Family: Phasianidae											
1	Indian Peafowl	*Pavo cristatus*	R	O	CO	✓	✓	✓	✓	✓	LC	→
2	Black Francolin	*Francolinus francolinus*	R	O	UC	✓	✓	×	×	✓	LC	→
3	Grey Francolin	*Francolinus pondicerianus*	R	O	FC	✓	✓	✓	×	×	LC	→
	Order: PHOENICOPTERIFOMES Family: Podicipedidae											
4	Little Grebe	*Tachybaptus ruficollis*	R	C	UC	×	×	×	✓	×	LC	↓
	Order: COLUMBIFORMES Family: Columbidae											
5	Rock Pigeon	*Columba livia*	R	G	CO	✓	✓	✓	✓	✓	LC	↓
6	Eurasion Collared Dove	*Streptopelia decaocto*	R	G	FC	×		×	✓	×	LC	↑
7	Spotted Dove	*Spilopelia chinensis*	R	G	FC	✓	✓	✓	✓	✓	LC	↑
8	Laughing Dove	*Streptopelia senegalensis*	R	G	CO	✓	✓	✓	✓	✓	LC	→
9	Yellow-legged Green Pigeon	*Treron phoenicopterus*	R	F	UC	✓	✓	×	✓	×	LC	↑
	Order: CAPRIMULGIFORMES Family: Apodidae											
10	Indian House Swift	*Apus affinis*	R	I	UC	×	×	×	✓	×	LC	↑
	Order: CUCULIFORMES Family: Cuculidae											
11	Greater Coucal	*Centropus sinensis*	R	O	CO	✓	✓	✓	✓	✓	LC	→
12	Pied Cuckoo	*Clamator jacobinus*	S	I	UC	✓	×	×	✓	×	LC	→
13	Asian Koel	*Eudynamys scolopaceus*	R	O	FC	✓	✓	×	✓	×	LC	→
14	Drongo Cuckoo	*Surniculus lugubris*	S	I	RA	×		×	✓	×	LC	↓
15	Common Hawk Cuckoo	*Hierococcyx varius*	S	I	RA	×	✓	×	×	×	LC	→
	Order: GRUIFORMES Family: Rallidae											
16	White-breasted Waterhen	*Amaurornis phoenicurus*	R	O	CO	✓	✓	✓	✓	✓	LC	?
17	Purple Swamphen	*Porphyrio porphyrio*	R	O	FC	×	×	×	×	✓	LC	?
	Order: PELECANIFORMES Family: Ciconiidae											
18	Painted Stork	*Mycteria leucocephala*	W	C	RA	×	×	×	✓	×	NT	↓
19	Asian Openbill	*Anastomus oscitans*	W	C	RA	×	✓	×	×	×	LC	?
20	Black-necked Stork	*Ephippiorhynchus asiaticus*	W	C	RA	×	✓	×	×	×	NT	↓

	Order/family /common name	Scientific name	Residential status	Feeding guild	Local status	Agricultural landscape					Red List status	Global population trend
						PA	SA	IS	BA	MA		
	Family: Ardeidae											
21	Black-crowned Night Heron	*Nycticorax nycticorax*	R	C	UC	×	×	×	✓	×	LC	↓
22	Indian Pond Heron	*Ardeola grayii*	R	C	CO	✓	✓	✓	✓	✓	LC	?
23	Cattle Egret	*Bubulcus ibis*	R	C	CO	✓	✓	✓	✓	✓	LC	↑
24	Grey Heron	*Ardea cinerea*	R	C	RA	×	×	×	✓	×	LC	?
25	Purple Heron	*Ardea purpurea*	R	C	RA	×	✓	×	×	×	LC	↓
26	Great Egret	*Ardea alba*	W	C	UC	×	✓	×	✓	×	LC	?
27	Intermediate Egret	*Ardea intermedia*	W	C	UC	✓	✓	✓	✓	✓	LC	↓
28	Little Egret	*Egretta garzetta*	R	C	UC	×	✓	×	✓	×	LC	↑
	Family: Threskiornithidae											
29	Black-headed Ibis	*Threskiornis melanocephalus*	R	C	UC	✓	×	✓	✓	×	NT	↓
30	Indian Black Ibis	*Pseudibis papillosa*	R	C	C	✓	✓	✓	✓	✓	LC	↓
31	Glossy Ibis	*Plegadis falcinellus*	R	C	UC	✓	✓	✓	✓	✓	LC	↓
	Family: Phalacrocoracidae											
32	Little Cormorant	*Microcarbo niger*	R	C	FC	✓	✓	×	✓	×	LC	?
	Order: CHARADRIIFORMES Family: Recurvirostridae											
33	Black-winged Stilt	*Himantopus himantopus*	R	C	CO	✓	✓	✓	✓	✓	LC	↑
	Family: Charadriidae											
34	Little Ringed Plover	*Charadrius dubius*	W	C	UC	×	×	×	✓	×	LC	→
35	Red-wattled Lapwing	*Vanellus indicus*	R	C	CO	✓	✓	✓	✓	✓	LC	?
	Family: Jacanidae											
36	Pheasant-tailed Jacana	*Hydrophasianus chirurgus*	S	O	RA	×	×	×	✓	×	LC	↓
	Family: Scolopacidae											
37	Common Sandpiper	*Actitis hypoleucos*	W	I	CO	✓	×	✓	×	×	LC	↓
38	Common Redshank	*Tringa totanus*	W	C	FC	×	×	✓	✓	✓	LC	?
	Order: ACCIPITRIFORMES Family: Accipitridae											
39	Black-winged Kite	*Elanus caeruleus*	R	C	UC	×	×	×	×	✓	LC	→
40	Shikra	*Accipiter badius*	R	C	FC	✓	✓	✓	✓	✓	LC	→
41	Brahminy Kite	*Haliastur Indus*	R	C	RA	×	×	×	✓	×	LC	↓
42	Black Kite	*Milvus migrans*	R	C	FC	✓	×	✓	×	✓	LC	?
	Order: STRIGIFORMES Family: Strigidae											
43	Spotted Owlet	*Athene brama*	R	C	FC	✓	✓	✓	✓	✓	LC	→

	Order/family /common name	Scientific name	Residential status	Feeding guild	Local status	Agricultural landscape					Red List status	Global population trend
						PA	SA	IS	BA	MA		
	Order: BUCEROTIFORMES Family: Bucerotidae											
44	Indian Grey Hornbill	*Ocyceros birostris*	R	O	FC	✓	✓	✓	✓	×	LC	→
	Family: Upupidae											
45	Common Hoopoe	*Upupa epops*	R	O	CO	✓	✓	✓	✓	✓	LC	↓
	Order: PICIFORMES Family: Picidae											
46	Lesser Golden-Backed Woodpecker	*Dinopium benghalense*	R	I	RA	×	×	×	✓	×	LC	→
	Family: Ramphastidae											
47	Brown-headed Barbet	*Psilopogon zeylanicus*	R	F	FC	✓	✓	✓	✓	×	LC	→
48	Coppersmith Barbet	*Psilopogon haemacephalus*	R	F	FC	✓	✓	✓	✓	×	LC	↑
	Order: CORACIIFORMES Family: Meropidae											
49	Green Bee-eater	*Merops orientalis*	R	I	CO	✓	✓	✓	✓	✓	LC	↑
	Family: Coraciidae											
50	Indian Roller	*Coracias benghalensis*	R	I	FC	×	✓	×	×	×	LC	↑
	Family: Alcedinidae											
51	White-throated Kingfisher	*Halcyon smyrnensis*	R	C	CO	✓	✓	✓	✓	✓	LC	↑
	Order: PSITTACIFORMES Family: Psittaculidae											
52	Alexandrine Parakeet	*Psittacula eupatria*	R	F	RA	✓	×	×	✓	×	NT	↓
53	Rose-ringed Parakeet	*Psittacula krameri*	R	F	CO	✓	✓	✓	✓	✓	LC	↑
	Order: PASSERIFORMES Family: Campephagidae											
54	Long-tailed Minivet	*Pericrocotus ethologus*	W	I	UC	✓	×	×	×	×	LC	↓
	Family: Oriolidae											
55	Eurasian Golden Oriole	*Oriolus oriolus*	S	O	RA	✓	×	×	×	×	LC	→
	Family: Dicruridae											
56	Black Drongo	*Dicrurus macrocercus*	R	I	CO	✓	✓	✓	✓	✓	LC	?
	Family: Laniidae											
57	Bay-backed shrike	*Lanius vittatus*	R	I	FC	×	✓	✓	✓	✓	LC	→
58	Long-tailed Shrike	*Lanius schach*	R	I	FC	×	×	✓	✓	✓	LC	?
	Family: Corvidae											
59	RufousTreepie	*Dendrocitta vagabunda*	R	I	CO	✓	✓	✓	✓	×	LC	↓

	Order/family /common name	Scientific name	Residential status	Feeding guild	Local status	Agricultural landscape					Red List status	Global population trend
						PA	SA	IS	BA	MA		
60	House crow	*Corvus splendens*	R	O	CO	✓	✓	✓	✓	✓	LC	→
61	Large-billed Crow	*Corvus macrorhynchos*	W	O	UC	✓	✓	✓	✓	✓	LC	→
	Family: Nectariniidae											
62	Purple Sunbird	*Cinnyris asiaticus*	R	N	FC	✓	✓	✓	✓	✓	LC	→
	Family: Ploceidae											
63	Black-breasted Weaver	*Ploceus benghalensis*	R	G	UC	×	×	×	✓	×	LC	→
64	Streaked Weaver	*Ploceus manyar*	R	G	UC	×	×	✓	×	×	LC	→
65	Baya Weaver	*Ploceus philippinus*	R	G	FC	×	✓	✓	✓	✓	LC	→
	Family: Estrildidae											
66	Indian Silverbill	*Euodice malabarica*	R	G	FC	×	✓	×	✓	×	LC	→
67	Scaly-breasted Munia	*Lonchura punctulata*	R	G	FC	✓	✓	✓	✓	✓	LC	→
	Family: Passeridae											
68	House Sparrow	*Passer domesticus*	R	O	UC	✓	✓	✓	✓	✓	LC	↓
	Family: Motacillidae											
69	Paddyfield Pipit	*Anthus rufulus*	R	I	UC	×	✓	×	×	✓	LC	→
70	Western Yellow Wagtail	*Motacilla flava*	W	I	UC	✓	✓	✓	✓	×	LC	↓
71	Grey Wagtail	*Motacilla cinerea*	W	I	FC	✓	✓	✓	✓	✓	LC	→
72	Citrine Wagtail	*Motacilla citreola*	W	I	FC	✓	×	✓	✓	×	LC	↑
73	White-browed Wagtail	*Motacilla maderaspatensis*	R	I	FC	✓	✓	✓	✓	✓	LC	→
74	White Wagtail	*Motacilla alba*	W	I	FC	✓	✓	×	✓	×	LC	→
	Family: Alaudidae											
75	Crested Lark	*Galerida cristata*	R	O	RA	×	×	×	×	✓	LC	↓
	Family: Cisticolidae											
76	ZittingCisticola	*Cisticola juncidis*	R	I	FC	×	✓	×	✓	×	LC	↑
77	Ashy Prinia	*Prinia socialis*	R	I	FC	✓	✓	✓	✓	✓	LC	→
78	Plain Prinia	*Prinia inornata*	R	I	FC	✓	×	✓	✓	✓	LC	→
79	Common Tailorbird	*Orthotomus sutorius*	R	I	FC	✓	✓	✓	✓	✓	LC	→
	Family: Acrocephalidae											
80	Paddyfield Warbler	*Acrocephalus agricola*	S	O	RA	×	×	✓	×	✓	LC	↓
	Family: Hirundinidae											
81	Red-rumped Swallow	*Cecropis daurica*	R	I	UC	✓	×	×	×	×	LC	→
82	Wire-tailed Swallow	*Hirundo smithii*	R	I	C	✓	✓	✓	✓	✓	LC	↑
83	Barn Swallow	*Hirundo rustica*	R	I	RA	×	✓	×	✓	×	LC	↓
84	Plain Martin	*Riparia paludicola*	R	I	RA	✓	✓	×	×	×	LC	↓

	Order/family /common name	Scientific name	Residential status	Feeding guild	Local status	Agricultural landscape					Red List status	Global population trend
						PA	SA	IS	BA	MA		
	Family: Pycnonotidae											
85	Red-vented Bulbul	*Pycnonotus cafer*	R	O	CO	✓	✓	✓	✓	✓	LC	↑
	Family: Sylviidae											
86	Lesser Whitethroat	*Sylvia curruca*	W	O	UC	×	×	×	✓	×	LC	→
	Family: Zosteropidae											
87	Oriental White-eye	*Zosterops palpebrosus*	R	I	UC	×	✓	×	✓	×	LC	↓
	Family: Leiothrichidae											
88	Large Grey Babbler	*Argya malcolmi*	R	O	FC	✓	✓	✓	✓	✓	LC	→
89	Common Babbler	*Argya caudata*	R	O	FC	×	✓	✓	×	×	LC	→
90	Jungle Babbler	*Turdoides striata*	R	O	FC	×	×	×	×	✓	LC	→
	Family: Sturnidae											
91	Asian Pied Starling	*Gracupica contra*	R	O	FC	✓	×	✓	✓	✓	LC	↑
92	Brahminy Starling	*Sturnia pagodarum*	R	O	UC	✓	×	×	✓	✓	LC	?
93	Common Myna	*Acridotheres tristis*	R	O	C	✓	✓	✓	✓	✓	LC	↑
94	Bank Myna	*Acridotheres ginginianus*	R	I	FC	✓	×	✓	✓	×	LC	↑
	Family: Muscicapidae											
95	Indian Robin	*Saxicoloides fulicatus*	R	I	FC	✓	✓	×	×	✓	LC	→
96	Oriental Magpie Robin	*Copsychus saularis*	R	I	FC	✓	✓	✓	✓	×	LC	→
97	Verditer Flycatcher	*Eumyias thalassinus*	W	I	RA	×	×	×	✓	×	LC	→
98	Bluethroat	*Cyanecula svecica*	W	I	RA	✓	✓	×	×	×	LC	→
99	Black Redstart	*Phoenicurus ochruros*	W	I	UC	✓	✓	×	×	×	LC	↑
100	Pied Bushchat	*Saxicola caprata*	R	I	CO	✓	✓	✓	✓	✓	LC	→
101	Brown Rock Chat	*Oenanthe fusca*	R	I	CO	✓	✓	✓	✓	✓	LC	→

R—Resident | S—Summer migrant | W—Winter migrant | I—Insectivore | C—Carnivore | O—Omnivore | G—Granivore | F—Frugivore | N—Nectarivore | CO—Common | FC—Fairly common | UC—Uncommon | RA—Rare | PA—Panipat | SA—Samalkha | IS—Israna | BA—Bapoli | MA—Madlauda | IUCN—International Union for Conservation of Nature | LC—Least Concern | NT—Near Threatened | →—Stable | ↓—Decreasing | ↑—Increasing | ?—Unknown.

Analysis of data on relative diversity revealed that Ardeidae was the most diverse bird family in the study area (8 species, RDi = 7.92) followed by Muscicapidae (7 species, RDi = 6.93), Motacillidae (6 species, RDi = 5.94), while 22 families, Podicipedidae, Apodidae, Phalacrocoracidae, Recurvirostridae, Jacanidae, Strigidae, Bucerotidae, Upupidae, Picidae, Meropidae, Coraciidae, Alcedinidae, Campephagidae, Oriolidae, Dicruridae, Nectariniidae, Passeridae, Alaudidae, Acrocephalidae, Pycnonotidae, Sylviidae, and Zosteropidae, were poorly represented in the study area with a single species in each (RDi= 0.99; Table 3). Muscicapidae is the largest family of birds in India (Manakadan & Pittie 2001). In the study area, however, Ardeidae showed the highest diversity of species, followed by Muscicapidae. Nevertheless, several other studies have also found Ardeidae to be the most diverse avian family, particularly in agricultural habitats, urban areas, and wetlands in India (Basavarajappa 2006; Kumar 2006; Vijayan et al. 2006; Dal & Vaghela 2015; Mukhopadhyay & Mazumdar 2017). Of the total species identified, 35 species (34.65%) were recorded from all the five selected agricultural landscapes, but 66 species (65.34%) were spotted at some specific agricultural landscapes only. The similarity in species composition of birds as measured by Jaccard's index, between the five selected agricultural landscapes is shown in Table 4. These results revealed that Panipat and Israna blocks (0.685) showed a maximum similarity in bird communities, while species' similarity of Samalkha with Madlauda was recorded to be the minimum (0.487). The highest species similarity recorded between Panipat and Israna block might be attributed to landscape characteristics. Habitats with greater structural similarity tended to present similar bird communities (Tubelis & Cavalcanti 2001; Andrade et al. 2018).

In the study area, 77 species (76.23%) were residents, 18 (17.82%) were winter migrants, and 6 (5.94%) were summer migrants. The spotting of a considerable number of winter visitors can be attributed partly to the study area being on the Central Asian Flyway and serving as a wintering site for migratory birds that breed in the Palearctic region (Kumar et al. 2016). The highest number of bird species was recorded at Bapoli block (77), followed by Samalkha block (68), Panipat block (62), Israna block (56), and Madlauda block (51) as shown in Table 2. During the summer and winter seasons, 83 and 95 bird species were recorded respectively. Seventy-seven bird species were common to both seasons but six and 18 were exclusive to summer and winter seasons, respectively. The species richness of birds during summer and winter was significantly different ($F_{1, 50}$ = 93.35, $P < 0.05$) and also varied significantly among the five agricultural landscapes ($F_{4, 50}$ = 86.09, $P < 0.05$, Table 5). Average species richness of Bapoli block (65.50 ± 7.29) was significantly higher (Tukey's HSD test, all $P < 0.05$) than that of the remaining four agricultural landscapes. Species richness at Samalkha block (58.42 ± 5.81), however, showed non-significant differences ($P > 0.05$) with that of Panipat block (54.67 ±4.94). The species diversity of birds also varied significantly between the seasons ($F_{1,50}$ = 93.70, $P < 0.05$) as well as among the five landscapes ($F_{4,50}$ =126.29, $P < 0.05$). Mean species diversity of Bapoli block (3.78 ±0.04) was significantly higher than in the other four agroecosystems (Tukey's HSD test, all $P < 0.05$). But the average species diversity at Panipat block (3.58 ±0.05) did not differ significantly ($P > 0.05$) from that of Israna block (3.57 ±0.04) and Madlauda block (3.56 ±0.05). Species evenness differed significantly between the summer and winter seasons ($F_{1, 50}$ = 65.35, $P < 0.05$) and also among the five agroecosystems ($F_{4,50}$ =85.15, $P < 0.05$). Average species evenness at Madlauda block (0.95 ±0.01) was registered significantly higher than the remaining agroecosystems

Table 3. Relative diversity index (RDi) of various avian families in agricultural landscapes of district Panipat, Haryana, India.

Avian families	Number of recorded species	Relative diversity index (RDi)
Ardeidae	8	7.92
Muscicapidae	7	6.93
Motacillidae	6	5.94
Columbidae, Cuculidae	5	4.95
Accipitridae, Cisticolidae, Hirundinidae, Sturnidae	4	3.96
Phasianidae, Ciconiidae, Threskiornithidae, Corvidae, Ploceidae, Leiothrichidae	3	2.97
Rallidae, Charadriidae, Scolopacidae, Ramphastidae, Psittaculidae, Laniidae, Estrildidae	2	1.98
Podicipedidae, Apodidae, Phalacrocoracidae, Recurvirostridae, Jacanidae, Strigidae, Bucerotidae, Upupidae, Picidae, Meropidae, Coraciidae, Alcedinidae, Campephagidae, Oriolidae, Dicruridae, Nectariniidae, Passeridae, Alaudidae, Acrocephalidae, Pycnonotidae, Sylviidae, Zosteropidae	1	0.99

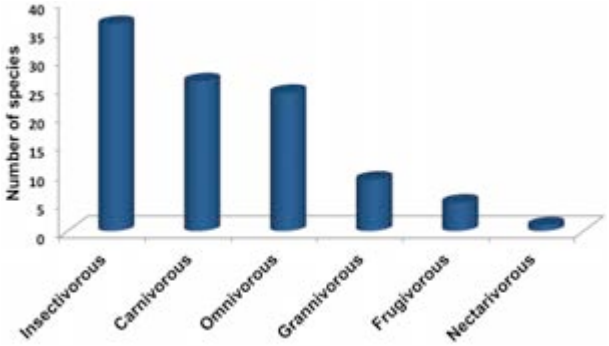

Figure 2. Feeding guilds of bird species recorded in agricultural landscapes of district Panipat, Haryana, India.

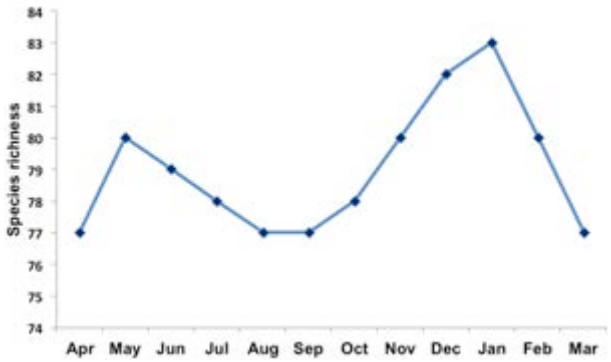

Figure 3. Monthly variations in overall species richness in all the selected agricultural landscapes of the study area during 2015–16.

(Tukey's HSD test, all $P < 0.05$). The average species evenness at Samalkha block (0.90 ±0.01) did not differ significantly ($P > 0.05$) from that of Bapoli block (0.90 ±0.02) and Panipat block (0.90±0.01). This relatively higher species richness, diversity and abundance of birds recorded during the winter (as compared to summer) might be due to the arrival of more migratory species during the winter season, and variation in habitat conditions (Kumar et al. 2016; Rajashekara & Venkatesha 2017). Bird species richness and community structure differ from region to region (Karr & Roth 1971; Pearson 1975; Richards 1996). From the observations it is evident that species richness and diversity of birds varied within the geographical area considered in the present study. This difference in bird diversity among the selected agroecosystems might be associated with availability of food, roosting and nesting sites, predation pressure and human disturbance (Hossain & Aditya 2016; Narayana et al. 2019). Crop composition and farming intensity also determine the species richness and abundance of birds in the agricultural landscapes (Cunningham et al. 2013). In the Bapoli block, the selected agricultural landscape was surrounded with patches of tall wooded trees, scrub and bushy type stumpy vegetation, grasses and the wetlands (river Yamuna) which provided a mosaic of habitats, leading to multiple and variety of the alternative food resources, and opportunities for microhabitat segregation for the birds and, thus, registered highest species richness and diversity (Hossain & Aditya 2016; Narayana et al. 2019). In contrast, agricultural landscape of Madlauda block being located in the vicinity of an industrial area (Thermal Power Plant of Panipat) was exposed to enhanced anthropogenic activities and adjacent land use alteration thus had the lowest species richness and diversity (Hossain & Aditya 2016). Human activities and their direct interference strongly disturb the avifauna (Hossain & Aditya 2016). This reflects that the basic requirements such as food, shelter, roosting and nesting sites for bird communities are not equally available in the different agricultural landscapes.

Monthly variations in species richness of birds in the study area are depicted in Figure 3. Overall, a maximum number of bird species was recorded in January (83 species), and minimum in August and September (77 species each). The variation in species richness could be related with the arrival of migratory species. It is evident from the figure that species richness of birds at study area begins to increase with the arrival of winter visitors. The winter migratory birds started appearing at study sites in October, gradually increased from November, reached a peak in the month of January, then started declining and leave the agricultural fields by April, flying back to their breeding grounds. Resident species were present throughout the year and showed no seasonal variation, but the migratory species (winter visitors and summer visitors) showed a definite species-specific pattern of arrival and departure from the study area. We observed that the majority of the winter migrants stayed in the agricultural fields from November to March. The summer visitors, including Pied Cuckoo, Drongo Cuckoo, Common Hawk Cuckoo, Pheasant-tailed Jacana, Eurasian Golden Oriole, and Paddy field Warbler were spotted during summer season (April–August) in the study area.

In this study, the recorded bird species were categorized into six major feeding guilds (Figure 2). This representation of major trophic guilds in the area indicated that the agricultural landscapes hold a wide variety of food resources for birds. The insectivore guild was the most abundant one with 36 species followed by carnivore (26), omnivore (24), granivore (9), frugivore (5) and nectarivore (1) guild. The results of the present study are consistent with the previously studied - that insectivore is the dominant feeding guild in agricultural

Table 4. Jaccard's similarity index (C_j) of bird species between selected agricultural landscapes of the study area.

Agricultural landscape	Panipat	Samalkha	Israna	Bapoli
Madlauda	0.547	0.487	0.671	0.488
Bapoli	0.616	0.611	0.602	
Israna	0.685	0.569		
Samalkha	0.604			

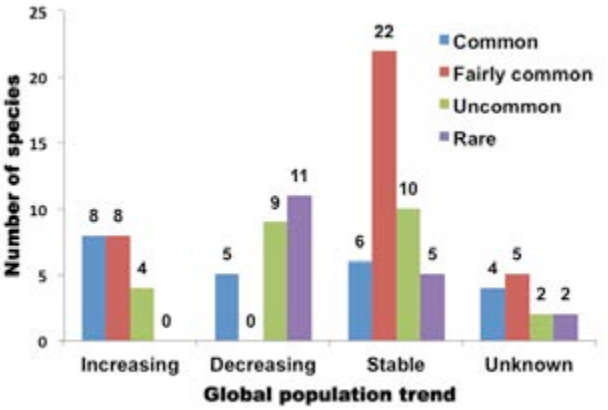

Figure 4. Comparison of local status of avifaunal species recorded in selected agricultural landscapes of the district Panipat, Haryana with its IUCN global population trend.

ecosystems in India (Dhindsa & Saini 1994; Narayana et al. 2019). Maximum insectivorous bird species belonged to Muscicapidae (7 species) and Motacillidae (6 species). The results of the current study also reflect possible variation in functional roles, feeding habits and resource utilization pattern of birds in the agricultural landscapes. Most bird species within the study area were insectivorous, indicating a rich abundance of insects here. Insectivorous birds play a crucial role in biological control of various insect pests thriving in agriculture, horticulture, floriculture, and forests (Mahabal 2005; Thakur et al. 2010). Indiscriminate use of chemical pesticides in the agricultural fields may have severe ecological consequences and a grave effect on the birds of the selected area. Insectivorous birds often consume insects contaminated with pesticides (Sánchez-Bayo et al. 1999), and thus these birds, being at a higher trophic level in food chain, are at a high risk of suffering from the toxic effects of bioaccumulation of such chemical pesticides (Sánchez-Bayo 2011).

Among the recorded avifauna, four species namely, Painted Stork *Mycteria leucocephala*, Black-necked Stork *Ephippiorhynchus asiaticus*, Oriental White Ibis *Threskiornis melanocephalus* and Alexandrine Parakeet *Psittacula eupatria* are Near Threatened species, while the remaining species are categorized as least concern species in the Red List of IUCN (2019). Assessment of local abundance revealed that 23 species were common, 35 species were fairly common, 25 species were uncommon and 18 species were rare in the study area (Table 2). When this local abundance status was compared with the global population trend of the species (Figure 4), we found that some species having a globally declining population trend were still common in the study area. Five species with globally declining population trends, Rock Pigeon *Columba livia*, Indian Black Ibis *Pseudibis papillosa*, Common Sandpiper *Actitis hypoleucos*, Eurasian Hoopoe *Upupa epops*, and Rufous Treepie *Dendrocitta vagabunda* were found to be common in our study area, which indicates that suitable resources for these avian species are still available in these agricultural landscapes. Hence, these species must be prioritized for regular and long-term monitoring from a global bird conservation perspective.

Birds are a good agency for dispersing seeds, pollinating plants, biological control of pests, and thus have a vital role in continuing the ecological cycle (Lawson et al. 1998; Gregory et al. 2008). Hence a decline in the diversity of birds may induce a cascading effect on the food chain, affecting multiple species and subsequently disrupting the species interactions and integrity of ecosystem functions (Whelan et al. 2008; Sekercioglu et al. 2012). Regular and long-term monitoring of avifauna is, therefore, an excellent means of keeping watch on ecosystem health. Assessment of the species richness and composition of birds in a particular landscape is a prerequisite to assess their ecological importance (Sekercioglu et al. 2012; Hossain & Aditya 2016; Mukhopadhyay & Mazumdar 2017). In this context the present study is the first scientific documentation of avifaunal diversity in the agricultural landscapes of the district Panipat, Haryana, India. The findings of the present study can be used as a baseline for further research on conservation and management of existing bird species in the agricultural landscapes. Regular and long-term monitoring of bird assemblages should be continued in the study area, emphasizing seasonal abundance, habitat use, nesting, feeding and breeding ecology to supplement a holistic approach to conservation and management strategies for sustenance of ecosystem services derived from the agricultural birds.

Table 5. Species richness, abundance, species diversity and species evenness of avifauna in the selected agricultural landscapes of the district Panipat, Haryana

Agricultural landscape		Diversity indices(mean± SE)									
		Species richness			Number of birds			Species diversity			Species evenness		
		Summer	Winter	Both	Summer	Winter	Both	Summer	Winter	Both	Summer	Winter	Both
Panipat		51.00 ±2.19	58.33 ±4.08	54.67^{bc} ±4.94	200.17 ±34.08	234.67 ±26.56	217.42^{abc} ±34.25	3.54 ±0.02	3.62 ±0.04	3.58^{c} ±0.05	0.90 ±0.00	0.89 ±0.01	0.90^{cde} ±0.01
Samalkha		54.00 ±2.00	62.83 ±4.83	58.42^{b} ±5.81	210.83 ±33.23	246.83 ±20.43	228.83^{ab} ±32.33	3.63 ±0.02	3.71 ±0.04	3.67^{b} ±0.05	0.91 ±0.00	0.90 ±0.01	0.90^{c} ±0.01
Israna		44.17 ±2.86	51.33 ±2.66	47.75^{d} ±4.58	164.17 ±23.96	205.17 ±23.27	184.67^{d} ±31.07	3.54 ±0.02	3.61 ±0.02	3.57^{cd} ±0.04	0.93 ±0.01	0.92 ±0.01	0.92^{b} ±0.01
Bapoli		59.50 ±3.02	71.50 ±4.64	65.50^{a} ±7.29	230.83 ±25.21	265.67 ±18.12	248.25^{a} ±27.73	3.75 ±0.02	3.81 ±0.03	3.78^{a} ±0.04	0.92 ±0.01	0.89 ±0.01	0.90^{cd} ±0.02
Madlauda		39.67 ±2.58	45.83 ±3.06	42.75^{e} ±4.20	155.50 ±36.78	209.50 ±25.17	182.50^{de} ±41.21	3.53 ±0.03	3.60 ±0.04	3.56^{cde} ±0.05	0.96 ±0.01	0.94 ±0.01	0.95^{a} ±0.01
ANOVA F-value	Season			93.35			32.30			93.70			65.35
	Landscape			86.09			13.05			126.29			85.15
P-value	Season			0.00*			0.00*			0.00*			0.00*
	Landscape			0.00*			0.00*			0.00*			0.00*

*-significant differences were found at 5% level of significance. Results in a column under various indices followed by different letters indicate significant differences among different agricultural landscapes at $P < 0.05$. Results in a column followed by same letters indicate non-significant differences among different agricultural landscapes at $P > 0.05$ (Two-way ANOVA and Tukey's HSD post-hoc test).

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COMMUNICATION

An overview of fishes of the Sundarbans, Bangladesh and their present conservation status

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Abstract: Sundarbans, the largest mangrove forest of the world is located in Bangladesh and India. Studies done on the diversity of fish fauna in the Sundarbans mangrove forest of Bangladesh are sparse and patchy. Here we take the opportunity to provide an updated checklist of the fishes of the Sundarbans, Bangladesh based on primary and secondary data. Field surveys were undertaken in the aquatic habitat of Sundarbans core area along with its adjacent marine habitat from June 2015 to July 2017. Based on published information and primary observations the updated list of fishes covers a total of 322 species belonging to 217 genera, 96 families, and 22 orders. Additionally, four species of fishes, are newly reported in Bangladesh waters, viz., *Mustelus mosis* Hemprich & Ehrenberg, 1899; *Lagocephalus guentheri* Miranda Ribeiro, 1915; *Carangoides hedlandensis* Whitley, 1934; *Uranoscopus cognatus* Cantor, 1849. The global IUCN Red List status of each species has been enlisted. The updated checklist will constitute the reference inventory of fish biodiversity for the Sundarbans, a natural world heritage site.

Keywords: Bangladesh, checklist, fish, mangroves, Sundarbans, World Natural Heritage Site.

Abbreviations: Dorsal fin D_1—1st Dorsal fin | D_2—2nd Dorsal fin | P_1—Pectoral fin| P_2—Pelvic fin| A—Anal fin.

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INTRODUCTION

Mangroves are intertidal forested wetlands confined to the tropical and subtropical regions (Tomlinson 1986). The total area of the mangroves in the globe is an estimated 18.1 million ha (Spalding et al. 1997). The Sundarbans, the single largest tract of mangrove forest in the world covers about 1 million hectares in the delta of the river Ganges, Brahmaputra, and Meghna. Among the total area 60% lies in Bangladesh and the rest in India. This transboundary ecosystem is extremely important both ecologically and economically as it provides a nursery and breeding area for key fishes including those of the Bay of Bengal. The Sundarbans in Bangladesh covers an area of 6,017km^2 along its southwestern part sharing 4,143km^2 of land and 1,874km^2 of water bodies comprising of hundreds of creeks, canals, small and large rivers, and estuaries. This mangrove forest was declared a Ramsar site by the Convention of Wetlands of International Importance in 1992 and declared as a Natural World Heritage Site by UNESCO in 1997 (Figure 1). Despite continued degradation, the Sundarbans contributes 3% to the country's gross domestic product out of 5% contribution of the country's forestry sector (Roy & Alam 2012).

The fish diversity of the brackish water ecosystem of the Sundarbans is usually associated with tolerance to a wide range of salinity fluctuation and migration. The freshwater fish species having low salinity tolerance enter into upper estuarine zone mainly in the period of ebb tide, while marine fishes are usually confined to the lower zone. Though some species travel freely in the whole salinity area for a major part of the year, very few can be considered as 'native' (Mishra 2017). Basically, most of the fish species enter into the brackish waters of the Sundarbans and spend for a certain period of their life cycle there either for shelter and feeding or for spawning purposes. The major threat to fishes of the Sundarbans region are environmental changes, reduction of freshwater discharge during lean seasons, increased salinity, use of destructive fishing gear (e.g., set bag net, small mesh size gill net), over exploitation, extraction of resources, and pollution.

Information regarding the diversity of fish in the Sundarbans of Bangladesh is scattered. Fishes of the Sundarbans were first described in the study of Hamilton (1822). He described about 71 fish species in the Gangetic estuaries and 51 of them occurred from the Sundarbans. After the independence of Bangladesh in 1971, several researchers and authors published different scientific and conference papers, project reports, guides and books on fish faunal diversity especially since 1978. Only some of them can be considered as valid references on the species availability in the Sundarbans waters such as Seidensticker & Hai (1983), Rahman (1989), Acharya & Kamal (1994), Chantarasri (1994), Bernacsek (2001), Bernacsek & Haque (2001), Shah & Hossain (2006), and Rahman et al. (2009). The main objective of the present study is to assess the existing fish fauna of Sundarbans and accumulate all fish species from the valid records made so far. Additionally, we have reviewed the present fishing practices in the Sundarbans detrimental to fish biodiversity, and the national policies made for fisheries management and conserving fish diversity.

METHODS

We consulted the primary and previously published articles, records, and books on ichthyological studies in the Sundarbans to build this checklist. These collections are mainly taken for preparing the list of the fishes known to occur in the Sundarbans and their valid identification and confirmation. Unbiased and sincere efforts were made in accumulating such a valuable treasure.

In the present survey, specimens of fishes were sampled between June 2015 and July 2017 from the major rivers of the Sundarbans, viz., Baleswar, Shibsa, Passur, Shela, Kobadak, Kalindi, Kholpetua, and a few of the tidal estuaries, and adjacent marine habitat in the Sundarbans, with the help of local fishermen during fishing (Figure 1). The fishes were also collected from the fish markets inside or near the Sundarbans of Khulna, Bagherhat, and Satkhira districts. The spellings of scientific names and species validity were checked following Fishbase (Froese & Pauly 2018) and the California Academy of Sciences Catalog of Fishes (Eschmeyer et al. 2018). The arrangement of families and order are made according to Nelson (2006) and Laan et al. (2014). The identification was made by using FAO fish species catalogues which present detailed taxonomic accounts of all known species of individual families. As the checklist is intended to be a master reference for the Sundarbans habitat conservation and management, we consulted the latest global IUCN Red List status of each species (IUCN 2018). For habitat preference, we consulted previous data, our primary observation, reference website (Froese & Pauly 2018) and different reference books (Siddiqui et al. 2007; Rahman et al. 2009). DNA barcoding through mitochondrial COI gene sequencing was done for the newly recorded species during the present survey and the sequence was submitted to GenBank.

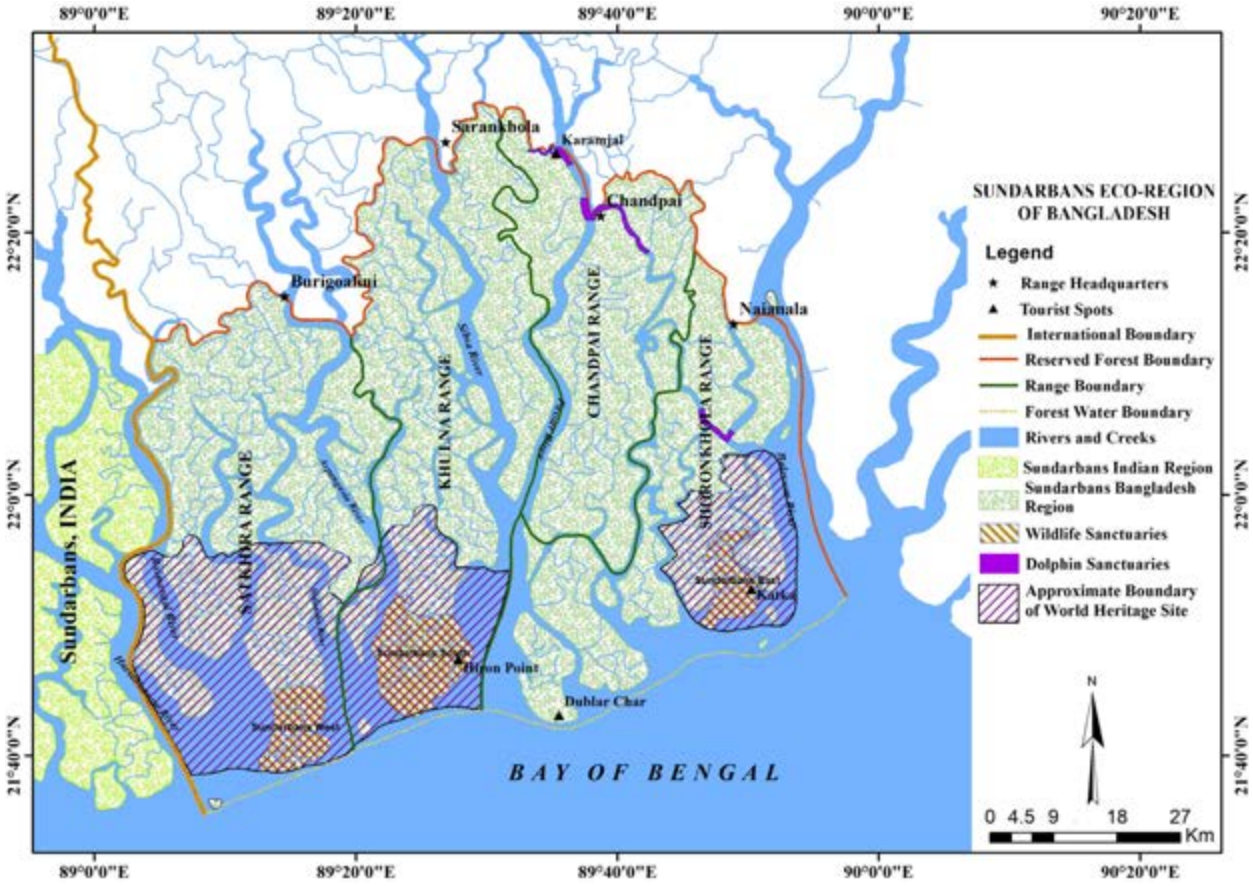

Figure 1. Map showing the location of Sundarbans, Bangladesh where the fishes were recorded from June 2015 to July 2017.

RESULTS

Based on the previously published information, specimens housed in the Aquatic Bioresource Research Lab., SAU and observations in the present study, the updated list of fishes of Sundarbans, Bangladesh provides information of 322 species belonging to 217 genera of 96 families and 22 orders (Table 1). In the present checklist, we have not considered any description. The column named as "present study" of Table 1, signifies our primary data collected between July 2015 and June 2017 and "previous literature" signifies the names which were enlisted in previous work on Sundarbans conducted by different scholars. Among the enlisted fish, Chondrichthyes (cartilaginous fish) contains 23 genera, 11 families and six orders whereas bony fish (Osteichthyes) covers 194 genera, 85 families and 16 orders. Maximum numbers of fishes (165 species, 50.24%) were recorded from order Perciformes in Sundarbans, Bangladesh. The number of fish species recorded under 22 orders is given at Figure 2.

In the present article, we report four new distributional records of fishes from the Sundarbans region of Bangladesh, viz., *Mustelus mosis* Hemprich & Ehrenberg, 1899; *Lagocephalus guentheri* Miranda Ribeiro, 1915; *Carangoides hedlandensis* Whitley, 1934; *Uranoscopus cognatus* Cantor, 1849 (Image 1).

Order Carcharhiniformes

Family Triakidae

Genus *Mustelus* Linck 1790

***Mustelus mosis* Hemprich & Ehrenberg, 1899**

Materials examined: Specimens collected from Bangladesh: Sundarbans: Dubla: Alorkol; coordinate 21.71N, 89.59E (Image 1A); coll. Habib and Neogi, 03.ii.2016; one specimen (Specimen voucher F1602sb-73). GenBank accession number MF588562.

Identification: Body color reddish-grey above and dull white ventrally. Small sized shark, with an elongate and slender body; snout markedly pointed and long. Mouth triangular, with well-developed labial folds. Skin fairly smooth.

Order Tetraodontiformes
Family Tetraodontidae
Genus *Lagocephalus* Swainson, 1839
***Lagocephalus guentheri* Miranda Ribeiro, 1915**

Materials examined: Specimens collected from Bangladesh: Sundarbans: Dubla: Alorkol; coordinate 21.71N, 89.59E (Image 1B); coll. K.A. Habib, 03.ii.2016; three specimens (Specimens voucher F1602sb-65-2, F1602sb-64, F1602sb-65-3). GenBank accession numbers MF588654, MF588655, MF588656.

Identification: Fin formula D 22-23; P_1 14; P_2 6; A 19-21. Color of dorsal side of the body is brown with several dark bands crossing over the back; a silver-white band running on the side of the body was found in the holotype. The dorsal fin dusky. The caudal fin dark brown or almost black with the dorsal and ventral white tips. The pectoral and anal fins pale. Body stout and small sized fishes, covered with small spinules on back, abdomen and throat; caudal fin rounded.

Order Perciformes
Family Carangidae
Genus *Carangoides* Bleeker, 1851
***Carangoides hedlandensis* Whitley, 1934**

Materials examined: Specimens collected from Bangladesh: Sundarbans: Dubla: Alorkol; coordinate 21.71N, 89.59E (Image 1C); coll. Habib and Neogi, 16.xii.2016; two specimens (Specimens voucher F1612sb-69, F1612sb-66). GenBank accession numbers MF588553, MF614771.

Identification: Fin formula D_1 VIII; D_2 I/22 $P_1$19; P_2 I/5; A II+I/17. Body color bluish-green above and silvery white below; dorsal fin dusky; filamentous soft rays black, soft dorsal fin yellow; pectoral and anal fins silvery; caudal fin yellowish green; pectoralfin dusky. A black opercular spot present. Body strongly compressed and very deep. Eye diameter about equal to or larger than snout length. Central rays of dorsal and anal fins elongated. Scales small; breast naked. Lateral line anteriorly with a moderate regular arch.

Order Perciformes
Family Uranoscopidae
Genus *Uranoscopus* Linnaeus, 1758
***Uranoscopus cognatus* Cantor, 1849**

Materials examined. Specimens collected from Bangladesh: Sundarbans: Dubla: Alorkol; coordinate 21.71N; 89.59E (Image 1D); coll. Habib and Neogi, 21.ii.2017; three specimens (Specimens voucher F1702sb-29, F1702sb-30, F1702sb-31).

Identification. Fin formula D_1 IV; D_2 I/8; $P_1$14; P_2 I/5; A III/8. Body color grayish above and minute black dots on upper third body; sivery below; opercle golden. Body compresses; anterior moderately and posterior deeply.

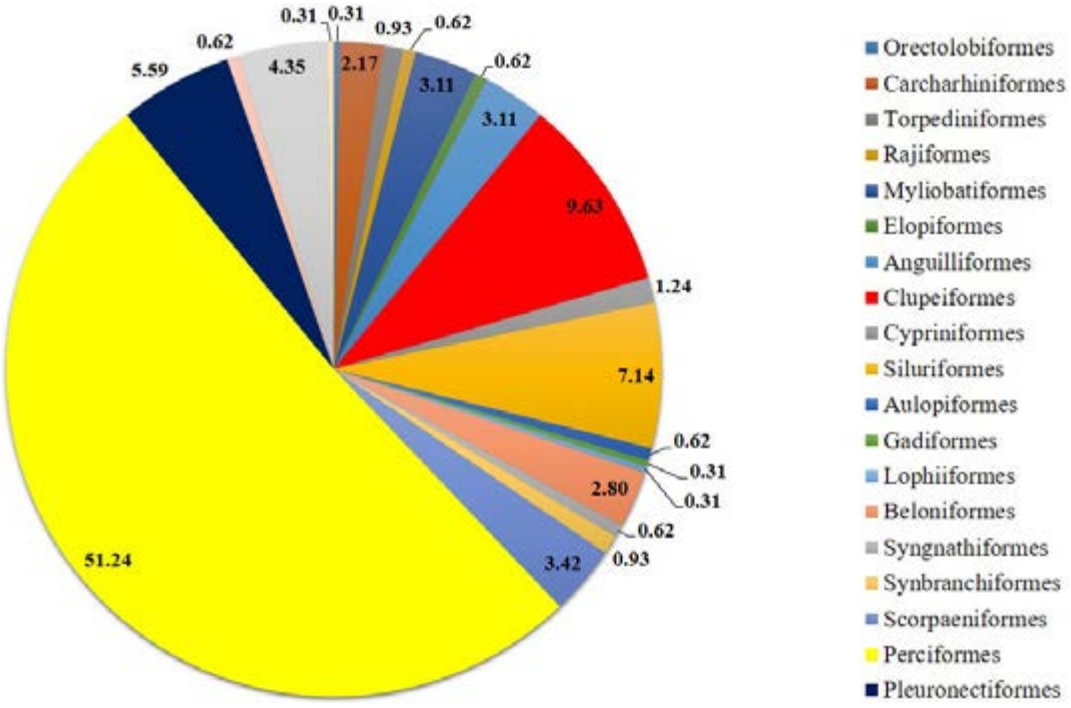

Figure 2. Order-wise distribution of listed fishes of the Sundarbans, Bangladesh.

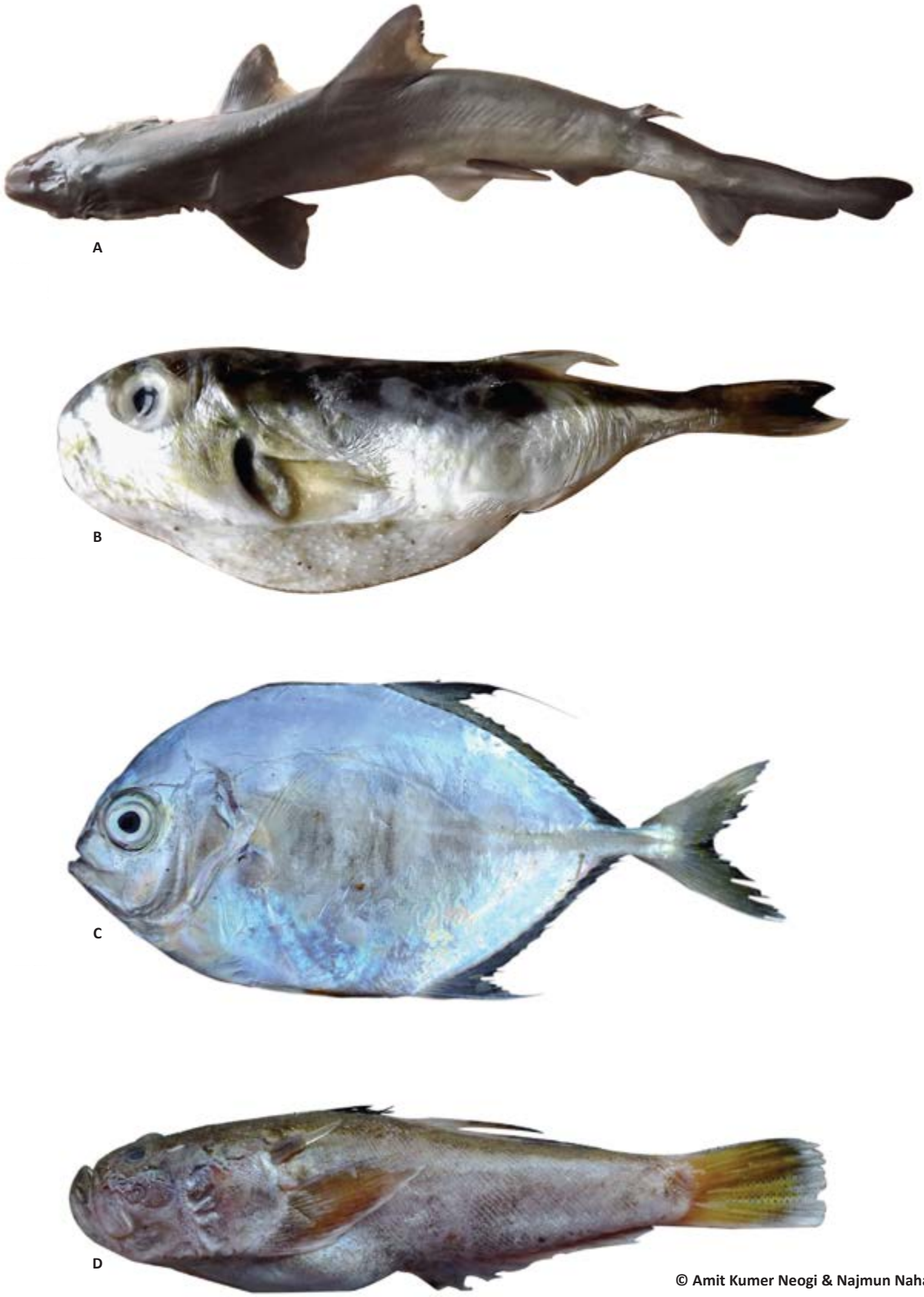

Image 1. Four new country records from the Sundarbans, Bangladesh: A—*Mustelus mosis* Hemprich & Ehrenberg, 1899 | B—*Lagocephalus guentheri* Miranda Ribeiro, 1915 | C—*Carangoides hedlandensis* Whitley, 1934 | D—*Uranoscopus cognatus* Cantor, 1849.

Table 1. List of fish species from the Sundarbans including their order and family status, english name, local name, scientific name, Global IUCN Red List status, earlier literature record and their habitats (Abbreviations: EN—Endangered | VU—Vulnerable | NT—Near Threatened | LC—Least Concern | DD—Data Deficient | NE—Not Evaluated | F—Freshwater | B—Brackish | M—Marine).

	Order/ Family	English name	Scientific name	Red List status	Present study	Previous literature	Habitat
1	**Orectolobiformes Hemiscylliidae**	Grey Bamboo Shark	*Chiloscyllium griseum*	NT	√		M,B
2	**Carcharhiniformes Carcharhinidae**	Dog Shark	*Scoliodon laticaudus*	NT	√		M,B
3		Shark	*Glyphis glyphis*	EN		Bernacsek 2001a	M,F,B
4		Scoliodon Walbeehmii	*Rhizoprionodon acutus*	NE	√		M,F,B
5		Blacktip Reef Shark	*Carcharhinus melanopterus*	NT		Bernacsek 2001a	M,B
6	**Carcharhiniformes Sphyrnidae**	Scalloped Hammerhead Shark	*Sphyrna lewini*	EN	√		M,B
7		Hammerhead Shark	*Eusphyra blochii*	EN		Bernacsek 2001a	M,B
8	**Carcharhiniformes Triakidae**	Hardnose Smoothhound	*Mustelus mosis*	DD	√		M
9	**Torpediniformes Narkidae**	Brown Spotted Numbfish	*Narcine brunnea*	NE	√		M
10	**Torpediniformes Narcinidae**	Electric Ray	*Narcine timlei*	DD		Bernacsek 2001a	M
11		Spottail Sleeper Ray	*Narke dipterygia*	DD	√		M
12	**Rajiformes Rhinobatidae**	Gulter Fish	*Rhynchobatus djiddensis*	VU		Bernacsek 2001a	M,B
13		Sharpnose Guiterfish, Shovelnose	*Glaucostegus granulatus*	VU	√		M
14	**Myliobatiformes Dasyatidae**	Scaly Whipray	*Brevitrygon imbricata*	DD	√		M,F,B
15		Dwarf Whipray	*Brevitrygon walga*	NT	√		M
16		Stingray	*Himantura undulata*	VU		Bernacsek 2001a	M
17		Leopard Stingray, Reticulate Whipray, Honeycomb Stingray	*Himantura uarnak*	VU	√		M,B
18		Cowtail Stingray	*Pastinachus sephen*	NE		Bernacsek 2001a	M,F,B
19		Bleeker's Whipray	*Pateobatis uarnacoides*	VU		Bernacsek 2001a	M
20		White Spotted Stingray	*Maculabatis gerrardi*	VU		Bernacsek 2001a	M,B
21		Cowtail Stingray	*Pastinachus sephen*	NT		Bernacsek 2001a	M,F,B
22		Sharp Snout Stingray	*Telatrygon zugei*	NT	√		M,B
23	**Myliobatiformes Gymnuridae**	Longtail Butterfly Ray, Butterfly Ray	*Gymnura poecilura*	NT	√		M
24	**Elopiformes Elopidae**	Tenpounder,Tarpon	*Elops machnata*	LC		Bernacsek 2001a	M,B
25	**Elopiformes Megalopidae**	Indo-Pacific Tarpon	*Megalops cyprinoides*	DD	√		M,F,B
26	**Anguilliformes Muraenidae**	Red Sea White-Spotted Moray	*Gymnothorax punctatus*	NE	√		M
27		Moray Eel	*Gymnothorax tile*	NE	√		M,F,B
28		Moray Eel	*Gymnothorax sp.*	NE	√		M,B
29		Slender Giant Moray	*Strophidon sathete*	NE	√		M,B
30	**Anguilliformes Muraenesocidae**	Yellow Pike Conger	*Congresox talabonoides*	NE		Huda et al. 2003	M,B
31		Eel	*Congresox talabonoides*	NE		Bernacsek 2001a	M,B
32		Daggertooth Pike Conger	*Muraenesox cinereus*	NE		Bernacsek 2001a	M,F,B
33	**Anguilliformes Ophichthidae**	Boro Snake Eel	*Pisodonophis boro*	LC	√		M,F,B

	Order/ Family	English name	Scientific name	Red List status	Present study	Previous literature	Habitat
34	Anguilliformes Anguillidae	Purple Spaghetti Eel	*Moringua raitaborua*	NE	√		F,B
35		Giant Mottled Eel	*Aquilla bengalensis*	NT	√		M,F,B
36	Clupeiformes Clupeidae	Chacunda Gizzard Shad, Shortnodse Gizard Shad	*Anodontostoma chacunda*	NE	√		M,F,B
37		Indian River Shad	*Gudusia chapra*	LC	√		F,B
38		Kelee Shad	*Hilsa kelee*	NE	√		M,F,B
39		Bloch's Gizzard Shad, Longfinned Gizzard Shad	*Nematalosa nasus*	LC	√		M,F,B
40		White Sardine	*Escualosa thoracata*	NE	√		M,F,B
41		Gold Stripe Sardine	*Sardinella gibbosa*	NE		Bernacsek 2001a	M
42		Sardine	*Sardinella fimbriata*	NE	√		M,B
43		Indian Oil Sardine	*Sardinella longiceps*	NE	√		M
44		Blacktip Sardinella	*Sardinella melanura*	NE	√		M
45		River Shad, Hilsa Shad	*Tenualosa ilisha*	LC	√		M,F,B
46		Toli Shad, Shad	*Tenualosa toli*	NE	√		M,F,B
47	Clupeiformes Engraulidae	Goldspotted Grenadier Anchovy	*Coilia dussumieri*	NE	√		M,F,B
48		Neglected Grenadier Anchovy	*Coilia neglecta*	LC	√		M,B
49		Ramcarat Grenadier Anchovy	*Coilia ramcarati*	NE	√		M,B
50		Gangetic Hairfin Anchovy	*Setipinna phasa*	NE		Bernacsek 2001a	F,B
51		Scaly Hairfin Anchovy	*Setipinna taty*	NE	√		M,B
52		Indian Anchovy	*Stolephorus indicus*	NE	√		M,B
53		Common Hairfin Anchovy	*Setipinna tenuifilis*	NE	√		M,B
54		Spined Anchovy	*Stolephorus tri*	NE	√		M,B
55		Anchovy	*Thryssa dussumieri*	LC		Bernacsek 2001a	M,B
56		Hamilton's Thryssa	*Thryssa hamiltonii*	NE	√		M,B
57		Oblique Jaw Thryssa, Gangetic Anchovy	*Thryssa purava*	NE	√		M,B
58	Clupeiformes Chirocentridae	Wolf Herring	*Chirocentrus nudus*	LC		Bernacsek 2001a	M
59		Dorab Wolf-Herring	*Chirocentrus dorab*	NE	√		M,B
60	Clupeiformes Dussumieriidae	Rainbow Sardine	*Dussumieria acuta*	LC		Bernacsek 2001a	M,F,B
61	Clupeiformes Pristigasteridae	Smooth Back Herring	*Raconda russeliana*	NE		Bernacsek 2001a	M,B
62		Indian Pellona Herring	*Pellona ditchela*	LC		Bernacsek 2001a	M,F,B
63		Indian Ilisha	*Ilisha melastoma*	LC		Bernacsek 2001a	M,B
64		Bigeye Herring	*Ilisha megaloptera*	LC		Bernacsek 2001a	M,F,B
65		Coromandal Ilisha	*Ilisha filigera*	DD		Huda & Haque 2003	M,F,B
66		Long Finned Herring	*Opisthopterus tardoore*	NE	√		M,B
67	Cypriniformes Cobitidae	Guntea Loach	*Lepidocephalichthys guntea*	LC	√		F,B
68	Cypriniformes Cyprinidae	Swamp Barb	*Puntius chola*	LC	√		F
69		Barb	*Puntius terio*	LC		Bernacsek 2001a	F
70		Gangetic Scissortail Rasbora	*Rasbora rasbora*	LC	√		F,B

	Order/ Family	English name	Scientific name	Red List status	Present study	Previous literature	Habitat
71	Siluriformes Plotosidae	Canine Catfish Eel	*Plotosus canius*	NE	√		M,F,B
72		Striped Ell Tail Catfish	*Plotosus lineatus*	NE		Bernacsek 2001a	M,B
73	Siluriformes Schilbeidae	Gagra	*Clupisoma garua*	LC	√		F,B
74	Siluriformes Ailiidae	Gangetic Ailia	*Ailia coila*	NT	√		F,B
75		Silond Catfish, Silondia Vacha	*Silonia silondia*	LC	√		F,B
76	Siluriformes Pangasiidae	Fatty Catfish	*Pangasius pangasius*	LC		Bernacsek 2001a	F,B
77	Siluriformes Bagridae	Tengara Catfish	*Mystus tengara*	LC	√		F,B
78		Catfish	*Mystus bleekeri*	LC		Bernacsek 2001a	F,B
79		Long-Whiskered Catfish	*Mystus gulio*	LC		Bernacsek 2001a	F,B
80	Siluriformes Clariidae	Walking Catfish	*Clarias batrachus*	LC		Huda et al. 2003	F,B
81	Siluriformes Sisoridae	Gangetic Goonch, Devil Catfish	*Bagarius bagarius*	LC	√		F,B
82	Siluriformes Ariidae	Gagora Catfish	*Arius gagora*	NT	√		M,F,B
83		Spotted Catfish, Sea Catfish	*Arius maculatus*	NE	√		M,F,B
84		Yellow Sea Catfish, Marine Catfish	*Arius venosus*	NE	√		M,B
85		Threadfin Sea Catfish	*Arius arius*	LC	√		M,B
86		Blacktip Sea Catfish	*Plicofollis dussumieri*	LC		Bernacsek 2001a	M,F,B
87		Flatmouth Sea Catfish	*Plicofollis platystomus*	LC		Bernacsek 2001a	M,B
88		Dusky Catfish, Sona Sea Catfish	*Sciades sona*	NE	√		M,B
89		Engraved Catfish	*Nemapteryx nenga*	NE	√		M,B
90		Engraved Catfish	*Nemapteryx caelata*	NE		Huda & Haque 2003	M,B
91		Giant Sea Catfish	*Netuma thalassina*	NE		Bernacsek 2001a	M,F,B
92		Bronze Catfish	*Netuma bilineata*	NE	√		M,F,B
93	Siluriformes Heteropneustidae	Stinging catfish	*Heteropneustes fossilis*	LC	√		F,B
94	Aulopiformes Synodontidae	Bombay Duck	*Harpadon nehereus*	NE	√		M,B
95		Greater Lizard Fish	*Saurida tumbil*	LC	√		M
96	Gadiformes Bregmacerotidae	Unicorn Cod	*Bregmaceros mcclellandi*	NE	√		M,B
97	Lophiiformes Antennariidae	Shaggy Angler, Zebra Frogfish	*Antennarius hispidus*	NE	√		M
98	Beloniformes Belonidae	Banded Needle Fish, Square Tail Alligator Gar	*Strongylura leiura*	NE	√		M,B
99		Spottail Needle Fish	*Strongylura strongylura*	NE		Bernacsek 2001a	M,B
100		Needle Fish	*Tylosurus crocodilus*	NE		Bernacsek 2001a	M,B
101		Silver Needle Fish	*Xenentodon cancila*	LC	√		M,F,B
102	Beloniformes Hemiramphidae	Congaturi Halfbeak	*Hyporhamphus limbatus*	LC		Bernacsek 2001a	M,F,B
103		Georges Halfbeak, Longbilled Halfbeak	*Rhynchorhamphus georgii*	NE	√		M,F,B
104	Beloniformes Zenarchopteridae	Buffon's Halfbeak, Buffon's Garfish	*Zenarchopterus buffonis*	NE	√		M,B
105		Ectuntio Halfbeak	*Zenarchopterus ectuntio*	NE	√		F,B

	Order/ Family	English name	Scientific name	Red List status	Present study	Previous literature	Habitat
106	**Beloniformes Exocoetidae**	Tropical Two-Winged Flying Fish	*Exocoetus volitans*	LC	√		M
107	**Syngnathiformes Fistulariidae**	Red Cornetfish, Flute-Mouth	*Fistularia petimba*	LC	√		M,B
108	**Syngnathiformes Syngnathidae**	Sea Horse, Smooth Seahorse	*Hippocampus kuda*	VU	√		M,B
109	**Synbranchiformes Synbranchidae**	Cuchia, Gangetic Mud Eel	*Monopterus cuchia*	LC	√		F,B
110	**Synbranchiformes Mastacembelidae**	Lesser Spiny Eel	*Macrognathus aculeatus*	NE	√		F,B
111		Striped Spiny Eel	*Macrognathus pancalus*	LC	√		F,B
112	**Scorpaeniformes Scorpaenidae**	Plaintail Turkeyfish, Russell`S Firefish	*Pterois russelii*	NE	√		M,B
113		Miles Lion Fish	*Pterois miles*	NE		Bernacsek 2001a	M
114	**Scorpaeniformes Synanceiidae**	Grey Stingfish	*Minous monodactylus*	NE	√		M
115		Painted Stringer	*Minous pictus*	NE	√		M
116	**Scorpaeniformes Platycephalidae**	Rough Flathead	*Grammoplites scaber*	NE	√		M,B
117		Flathead	*Cociella punctata*	LC		Bernacsek 2001a	M
118		Spiny Flathead	*Kumococius rodericensis*	NE	√		M
119		Spotted Flathead	*Cociella crocodilus*	NE		Bernacsek 2001a	M,B
120		Thorny Flathead	*Rogadius asper*	LC		Bernacsek 2001a	M
121		Flathead	*Rogadius pristiger*	LC		Bernacsek 2001a	M
122		Bartail Flathead	*Platycephalus indicus*	NE	√		M,B
123	**Perciformes Epinephelidae**	Cloudy Grouper, Cloudy Rock Cod	*Epinephelus erythrurus*	VU	√		M,B
124		Orangespotted Grouper	*Epinephelus coioides*	NT	√		M,B
125		Blacktip Grouper	*Epinephelus fasciatus*	LC		Bernacsek 2001a	M,B
126		Grouper	*Epinephelus tauvina*	DD		Bernacsek 2001a	M
127		Vermillion Grouper	*Cephalopholis miniata*	LC		Bernacsek 2001a	M
128		Gaint Gruper	*Epinephelus lanceolatus*	VU	√		M,B
129	**Perciformes Terapontidae**	Terapon Perch, Three-striped Tiger Fish	*Terapon jarbua*	LC	√		M,F,B
130		Big Eye	*Terapon theraps*	LC	√		M,F,B
131	**Perciformes Priacanthidae**	Moontail Bulls Eye	*Priacanthus hamrur*	LC	√		M
132		Purple Spotted Big Eye	*Priacanthus tayenus*	LC			M
133	**Perciformes Apogonidae**	Broad-banded Cardinalfish	*Ostorhinchus fasciatus*	NE	√		M
134		Three Striped Cardinalfish	*Apogon septemstriatus*	NE	√		M
135	**Perciformes Sillaginidae**	Gangetic Sillago	*Sillaginopsis panijus*	NE	√		M,F,B
136		Silver Sillago	*Sillago sihama*	LC	√		M,B
137	**Perciformes Channidae**	Asiatic Snakehead	*Channa orientalis*	NE		Bernacsek 2001a	F,B
138		Striped Snakehead	*Channa striata*	NE		Bernacsek 2001a	F,B
139		Spotted Snakehead	*Channa punctata*	LC		Bernacsek 2001a	F,B
140	**Perciformes Rachycentridae**	Cobia, Black King Fish	*Rachycentron canadum*	LC	√		M,B
141	**Perciformes Echeneidae**	Common Remora	*Remora remora*	LC	√		M

	Order/ Family	English name	Scientific name	Red List status	Present study	Previous literature	Habitat
142	Perciformes Carangidae	Razorbelly Scad	*Alepes kleinii*	LC	√		M
143		Shrimped Scad	*Alepes djedaba*	LC		Bernacsek 2001a	M
144		Black-Fin Scad	*Alepes melanoptera*	LC	√		M,B
145		Threadfin Trevally	*Alectis indica*	LC		Huda & Haque 2003	M,B
146		Threadfin Trevally	*Alectis ciliaris*	LC		Bernacsek 2001a	M
147		Black-Fin Jack	*Atropus atropos*	LC	√		M
148		Oxeye Scad	*Selar boops*	LC		Bernacsek 2001a	M
149		Bigeye Scad	*Selar crumenophthalmus*	NE		Bernacsek 2001a	M
150		Longfin Trevally	*Carangoides armatus*	NE	√		M,B
151		Bigeye Trevally	*Caranx sexfasciatus*	LC	√		M,B
152		Bumpnose Trevally	*Carangoides hedlandensis*	NE	√		M
153		Trevally	*Carangoides malabaricus*	LC		Bernacsek 2001a	M
154		Giant Trevally, Giant Kingfish	*Caranx ignobilis*	LC	√		M,B
155		Red Tailed Mackerel Scad	*Decapterus kurroides*	NT	√		M
156		Torpedo Scad	*Megalaspis cordyla*	LC	√		M,B
157		Black Promfet	*Parastromateus niger*	NE	√		M,B
158		Double Spotted Queenfish	*Scomberoides commersonnianus*	LC	√		M,B
159		Queen Fish	*Scomberoides tol*	NE	√		M,B
160		Black Banded Trevally	*Seriolina nigrofasciata*	LC	√		M,B
161		Longrakered Trevally	*Ulua mentalis*	LC	√		M
162	Perciformes Menidae	Moon Fish	*Mene maculata*	NE	√		M,B
163	Perciformes Leiognathidae	Orangefin Ponyfish	*Photopectoralis bindus*	NE	√		M,B
164		Shortnoso Ponyfish	*Leiognathus brevirostris*	NE	√		M,B
165		Striped Ponyfish	*Leiognathus fasciatus*	LC		Bernacsek 2001a	M,B
166		Common Ponyfish	*Leiognathus equulus*	NE	√		M,F,B
167		Deep Pugnose Pony Fish	*Secutor ruconius*	NE		Bernacsek 2001a	M,F,B
168		Pugnose Pony Fish	*Secutor insidiator*	NE	√		M,B
169		Tooth Pony	*Gazza minuta*	NE	√		M,B
170	Perciformes Lactariidae	False Trovally	*Lactarius lactarius*	NE		Bernacsek 2001a	M,B
171	Perciformes Lutjanidae	John`S Snapper, Red Snapper	*Lutjanus johnii*	LC	√		M,B
172		Malabar Red Snapper	*Lutjanus malabaricus*	NE		Huda & Haque 2003	M,B
173		Pinjalo Snapper	*Pinjalo pinjalo*	LC		Bernacsek 2001a	M
174		Blood Snapper	*Lutjanus sanguineus*	NE		Bernacsek 2001a	M
175	Perciformes Uranoscopidae	Stargazer	*Astroscopus guttatus*	LC		Bernacsek 2001a	M
176		Dollfus' Stargrazer	*Uranoscopus guttatus*	NE		Huda & Haque 2003	M
177		Stargazer	*Ichthyscopus inermis*	NE		Bernacsek 2001a	M
178		Stargazer	*Ichthyscopus lebeck*	NE		Bernacsek 2001a	M
179	Perciformes Datnioididae	Four Barred Tigerfish	*Datnioides polota*	NE	√		F,B

	Order/ Family	English name	Scientific name	Red List status	Present study	Previous literature	Habitat
180	Perciformes Gerreidae	Whiptail Silverbiddy	*Gerres filamentosus*	LC	√		M,F,B
181		Silverbiddy	*Gerres sp.*	NE	√		M,B
182	Perciformes Haemulidae	Silver Grunt	*Pomadasys argenteus*	LC	√		M,F,B
183		Blotched Grunt	*Pomadasys maculatus*	LC	√		M,B
184	Perciformes Sparidae	Ongspine Seabream	*Argyrops spinifer*	NE		Bernacsek 2001a	M
185		Yellow Seabrem	*Acanthopagrus latus*	DD		Bernacsek 2001a	M,F,B
186		River Bream	*Acanthopagrus berda*	LC	√		M,F,B
187	Perciformes Nemipteridae	Double Whip Threadin Bream	*Nemipterus nematophorus*	NE		Bernacsek 2001a	M
188		Pink Perch	*Nemipterus japonicus*	NE	√		M
189	Perciformes Sciaenidae	Goatee Croaker	*Dendrophysa russelii*	NE	√		M,F,B
190		Croaker	*Chrysochir aureus*	NE		Bernacsek 2001a	M,B
191		Blackmouth Croaker	*Atrobucca nibe*	NE		Bernacsek 2001a	M
192		Sharpnose Hammer Croaker	*Johnius borneensis*	NE	√		M,F,B
193		Silver Croaker	*Pennahia argentata*	NE	√		M
194		Large-Eye Croaker	*Johnius plagiostoma*	NE	√		M,F,B
195		Coitor, Crocker	*Johnius coitor*	LC	√		M,F,B
196		Large Fined Croaker	*Johnius macropterus*	NE	√		M,F,B
197		Black Croaker	*Johnius dussumieri*	NE		Bernacsek 2001a	M
198		Gangetic Bola, Croaker	*Johnius gangeticus*	NE		Bernacsek 2001a	M,B
199		Kathala Croaker	*Kathala axillaris*	NE	√		F,B
200		Cuja Croaker	*Macrospinosa cuja*	NE	√		M
201		Pama Croaker	*Otolithes parna*	NE		Bernacsek 2001a	M,F,B
202		Lesser Tiger Toothed Croaker	*Otolithes cuvieri*	NE		Bernacsek 2001a	M
203		Tiger Toothed Croaker	*Otolithes ruber*	NE	√		M
204		Pama Croaker	*Otolithoides pama*	NE	√		M,B
205		Bronze Croaker	*Otolithoides biauritus*	NE	√		M,B
206		Panna Croaker	*Panna microdon*	NE	√		M,F,B
207		Donkey Croaker	*Pennahia anea*	NE	√		M,B
208		Spindle Croaker	*Pseudotolithus elongatus*	LC		Bernacsek 2001a	M
209		Spotted Croakor	*Protonibea diacanthus*	NE	√		M,F,B
210		Blotched Tiger-Toothed Croaker	*Pterotolithus maculatus*	LC	√		M,B
211	Perciformes Polynemidae	Fourfinger Threadfin	*Eleutheronema tetradactylum*	NE	√		M,B
212		Indian Threadfin	*Leptomelanosoma indicum*	NE	√		M,F,B
213		Blackspot Threadfin	*Polydactylus sextarius*	NE	√		M,F,B
214		Golden Threadfin	*Polydactylus sexfilis*	NE		Bernacsek 2001a	M,B
215		Paradise Threadfin	*Polynemus paradiseus*	NE	√		M,F,B
216	Perciformes Mullidae	Red Sea Goatfish	*Parupeneus forsskali*	NE	√		M,F,B
217		Goatfish	*Parupeneus heptacanthus*	LC		Bernacsek 2001a	M,B
218		Goldband Goatfish	*Upeneus moluccensis*	LC	√		M,B
219		Sulphur Goatfish	*Upeneus sulphureus*	LC	√		M,B
220		Finstripe Goatfish	*Upeneus taeniopterus*	LC	√		M,B

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221	Perciformes Toxotidae	Largescale Archerfish	*Toxotes chatareus*	NE	√		M,B
222		Banded Archerfish	*Toxotes jaculatrix*	LC		Bernacsek 2001a	F,B
223	Perciformes Drepanidae	Spotted Sickle Fish	*Drepane punctata*	NE		Bernacsek 2001a	F,B
224		Spadefish	*Ephippus orbis*	NE		Bernacsek 2001a	M,F,B
225		Banded Drepane	*Drepane longimana*	NE	√		M,B
226	Perciformes Mugilidae	Longarm Mullet	*Osteomugil cunnesius*	NE	√		M,B
227		Striped Mullet	*Mugil cephalus*	LC	√		M,F,B
228		Greenback Mullet	*Planiliza subviridis*	NE	√		M,F,B
229		Corsula Mullet	*Rhinomugil corsula*	LC	√		M,F,B
230		Mullet	*Valamugil speigleri*	NE		Bernacsek 2001a	F,B
231		Yellowtail Mullet	*Sicamugil cascasia*	LC	√		M,F,B
232		Goldspot Mullet	*Liza parsia*	NE		Bernacsek 2001a	F
233		Tade Grey Mullet	*Chelon planiceps*	NE		Bernacsek 2001a	M,F,B
234		Goldspot Mullet	*Chelon parsia*	NE	√		M,F,B
235	Perciformes Uranoscopidae	Stargazer	*Uranoscopus guttatus*	NE		Huda & Haque 2003	M,F,B
236		Stargazer	*Ichthyscopus lebeck*	NE		Huda & Haque 2003	M
237		Two Spined Yellowtail Stargazer	*Uranoscopus cognatus*	NE	√		M
238	Perciformes Eleotridae	Duckbill Sleeper	*Butis butis*	LC	√		M
239		Black Spot Sleeper Goby	*Butis humeralis*	NE	√		M,F,B
240		Sleeper Goby	*Butis melanostigma*	NE		Huda & Haque 2003	M,F,B
241		Dusky Sleeper	*Eleotris fusca*	LC	√		M,F,B
242	Perciformes Gobiidae	Mudskipper	*Boleophthalmus boddarti*	LC	√		M,F,B
243		Tank Goby	*Glossogobius giuris*	NE	√		M,F,B
244		Goby	*Apocryptes bato*	NE		Bernacsek 2001a	M,F,B
245		Bearded Worm Goby	*Taenioides cirratus*	DD		Rahman 1989	M,F,B
246		Bumblebee Goby	*Brachygobius nunus*	NE		Bernacsek 2001a	M,F,B
247		Goby	*Zappa confluentus*	NE		Bernacsek 2001a	F,B
248		Goby	*Pogonogoibius planiformes*	NE		Huda & Haque 2003	M,F,B
249		Mudskipper	*Periophthalmodon schlosseri*	NE		Bernacsek 2001a	M,B
250		Mudskipper	*Periophthalmus barbarus*	LC		Bernacsek 2001a	M,F,B
251		Rubicundus Eelgoby	*Odontamblyopus rubicundus*	NE	√		M,F,B
252		Pointed-Tailed Goby	*Pseudapocryptes elongatus*	LC	√		M,F,B
253		Walking Goby	*Scartelaos histophorus*	NE	√		F,B
254		Knight Goby	*Stigmatogobius sadanundio*	NE	√		M,B
255		Eel Goby	*Taenioides buchanani*	NE		Bernacsek 2001a	F,B
256		Burrowing Goby	*Trypauchen vagina*	NE	√		M,B
257	Perciformes Callionymidae	Arrow Dragonet	*Callionymus sagitta*	NE	√		M,B
258	Perciformes Ephippidae	Spadefish	*Ephippus orbis*	NE	√		M

	Order/ Family	English name	Scientific name	Red List status	Present study	Previous literature	Habitat
259	Perciformes Ambassidae	Elongate Glassy Perchlet	*Chanda nama*	LC	√		M
260		Himalayan Glassy Perchlet	*Parambassis baculis*	LC		Bernacsek 2001a	F,B
261		Glassy Fish	*Parambassis ranga*	LC	√		F
262	Perciformes Scatophagidae	Spotted Scat, Spotted Butterfish	*Scatophagus argus*	LC	√		F,B
263	Perciformes Siganidae	Streaked Rabbitfish	*Siganus javus*	LC		Huda & Haque 2003	M,F,B
264		White-Spotted Spinefoot	*Siganus canaliculatus*	LC	√		M,B
265	Perciformes Sphyraenidae	Bigeye Barracuda	*Sphyraena forsteri*	NE	√		M,B
266		Barracuda	*Sphyraena barracuda*	LC		Bernacsek 2001a	M
267		Yellowstripe Barracuda	*Sphyraena chrysotaenia*	NE	√		M
268		Banded Or Indian Barracuda	*Sphyraena jello*	NE	√		M,B
269	Perciformes Trichiuridae	Smallhead Ribbon Fish	*Eupleurogrammus muticus*	NE	√		M,B
270		Large Head Ribbon Fish	*Trichiurus lepturus*	NE		Bernacsek 2001a	M,B
271		Savalani Ribbon Fish	*Lepturacanthus savala*	NE	√		M,B
272	Perciformes Scombridae	Mackerel Tuna	*Euthynnus affinis*	LC	√		M,B
273		Island Mackerel	*Rastrelliger faughni*	DD	√		M
274		Indian Mackerel	*Rastrelliger kanagurta*	LC	√		M
275		Indian Mackerel	*Rastrelliger brachysoma*	DD		Bernacsek 2001a	M
276		Striped Bonito	*Sarda orientalis*	LC		Bernacsek 2001a	M,B
277		Buulet Tuna	*Auxis rochei*	NE		Huda & Haque 2003	M
278		Seer Fish	*Scomberomorus lineolatus*	LC		Bernacsek 2001a	M,B
279		Barred Mackerel	*Scomberomorus commerson*	NT	√		M
280		Indo-Pacific King Mackerel	*Scomberomorus guttatus*	DD	√		M
281	Perciformes Stromateidae	Silver Pomfret	*Pampus argenteus*	NE	√		M,B
282		Chinese Pomfret	*Pampus chinensis*	NE	√		M
283	Perciformes Lethrinidae	Ornate Emperor	*Lethrinus ornatus*	LC		Bernacsek 2001a	M,B
284	Perciformes Lobotidae	Tripletail	*Lobotes surinamensis*	LC		Bernacsek 2001a	M
285	Perciformes Kurtidae	Indian Lamphead	*Kurtus indicus*	NE		Bernacsek 2001a	M,B
286	Perciformes Latidae	Barramundi	*Lates calcarifer*	NE	√		M,F,B
287	Perciformes Anabantidae	Climbing perch	*Anabas testudineus*	DD	√		F,B
288	Pleuronectiformes Soleidae	Javanese Flounder	*Pseudorhombus javanicus*	NE	√		M,F,B
289		Commerson`S Sole	*Synaptura commersonnii*	NE	√		M
290		Zebra Sole	*Zebrias altipinnis*	NE		Bernacsek 2001a	M,B
291		Oriental Sole	*Brachirus orientalis*	NE	√		M,F,B
292		Sole	*Brachirus pan*	LC		Bernacsek 2001a	M,F,B
293	Pleuronectiformes Paralichthyidae	Malayflounder	*Pseudorhombus malayanus*	NE		Bernacsek 2001a	M,B
294		Large Tooth Flounder	*Pseudorhombus arsius*	NE		Bernacsek 2001a	M
295		Deep Flounder	*Pseudorhombus elevatus*	NE		Bernacsek 2001a	M,B

	Order/ Family	English name	Scientific name	Red List status	Present study	Previous literature	Habitat
296	Pleuronectiformes Psettodidae	Indian Hailbut	*Psettodes erumei*	NE		Huda & Haque 2003	M
297		Halibut	*Psettodes belcheri*	DD		Bernacsek 2001a	M
298	Pleuronectiformes Cynoglossidae	Fourlined Tongueso'le	*Cynoglossus bilineatus*	NE		Bernacsek 2001a	M,B
299		Gangetic Tonguesole	*Cynoglossus cynoglossus*	NE		Bernacsek 2001a	M,B
300		Long Tonguesole	*Cynoglossus kopsii*	NE		Bernacsek 2001a	M
301		Tongusole	*Symphurus trifasciatus*	NE		Bernacsek 2001a	M
302		Tongusole	*Paraplagusia bilineata*	NE		Bernacsek 2001a	M
303		Double Lined Tonguesole	*Cynoglossus lingua*	NE		Bernacsek 2001a	M,F,B
304		Speckled Tonguesole	*Cynoglossus puncticeps*	NE		Bernacsek 2001a	M,F,B
305		Largescale Tonguesole	*Cynoglossus arel*	NE	√		M,B
306	Pristiformes Pristidae	Saw Shark	*Anoxypristis cuspidata*	EN		Huda & Haque 2003	M,F,B
307		Large Tooth Saw Fish	*Pristis microdon*	NE		Bernacsek 2001a	M,F,B
308	Tetraodontiformes Triacanthidae	Short-Nosed Tripod Fish	*Triacanthus biaculeatus*	NE	√		M,F,B
309		Tripod Fish	*Pseudotriacanthus strigilifer*	NE		Bernacsek 2001a	M
310	Tetraodontiformes Balistidae	Triggerfish	*Abalistes stellaris*	NE		Bernacsek 2001a	M
311	Tetraodontiformes Ostraciidae	Yellow Box Fish	*Ostracion cubicus*	NE	√		M
312	Tetraodontiformes Tetraodontidae	Gangetic Pufferfish	*Chelonodontops patoca*	LC	√		M,F,B
313		Bengal Reticulated Puffer	*Chelonodontops bengalensis*	NE	√		M,B
314		Puffer Fish	*Arothron stellatus*	LC		Bernacsek 2001a	M,B
315		Puffer Fish	*Leiodon cutcutia*	NE		Bernacsek 2001a	F,B
316		Puffer Fish	*Carinotetraodon travancoricus*	VU		Bernacsek 2001a	F
317		Diamond-Back Puffer	*Lagocephalus guentheri*	LC	√		M
318		Green Pufferfish	*Lagocephalus lunaris*	LC	√		M
319		Lattice Blaasop	*Takifugu oblongus*	LC	√		M,B
320		Green Pufferfish	*Dichotomyctere fluviatilis*	LC	√		F,B
321	Tetraodontiformes Diodontidae	Spoted Porcupine Fish	*Diodon hystrix*	LC	√		M
322	Batrachoidiformes Batrachoididae	Grunting Toadfish	*Allenbatrachus grunniens*	NE	√		M,B

Head flat above. Caudal fin slightly emarginated. Lateral line absent. Scales ctenoid.

DISCUSSION

In Bangladesh, Acharya & Kamal (1994) first made a list of fishes from a portion of the Sundarbans where 53 species of pelagic and 124 species of demersal fishes were included. Afterward, another list of finfishes has been compiled by Bernacsek & Haque (2001) where the fishes were basically gathered from the baseline study of Chantarasri (1994) under a project of Food and Agriculture Organization (FAO) and this study contained a list of 196 species reported from the Sundarbans of Bangladesh. This baseline survey on the fishes of the Sundarbans reproduced many subsequent reports on fish biodiversity in the 1980s. After that no significant study on fish diversity has been conducted on the Sundarbans region of Bangladesh. Further, no conservation status was assessed by IUCN locally in Bangladesh for Sundarbans'

marine and brackish water fishes. In the present study, we have categorized all of the compiled fishes according to the Global IUCN status, which is given in the Table 1.

About 54.35% species of enlisted fishes belongs to the category of "Not Evaluated" and only 4.04% of fishes are in "Data Deficient" (Figure 3). Around 33.23% of species are categorized as "Least concern", some of which are exploited for commercial purposes such as *Elops machnata* Forsskal, 1775; *Gudusia chapra* Hamilton, 1822; *Coilia* sp., *Thryssa* sp., *Ilisha* sp., *Arius arius* Hamilton, 1822; *Sillago sihama* Forsskal, 1775; *Alepes* sp. Among the fishes of the Sundarbans of Bangladesh enlisted in the present study 4.04% (13 species) of the species are "Near Threatened" and 10 species (3.11%) species are "Vulnerable" viz. *Rhynchobatus djiddensis* Forsskal, 1775, *Glaucostegus granulatus* Cuvier, 1829, *Himantura undulata* Bleeker, 1852, *Himantura uarnak* Gmelin, 1789, *Pateobatis uarnacoides* Bleeker, 1852, *Maculabatis gerrardi* Gray, 1851, *Hippocampus kuda* Bleeker, 1852, *Epinephelus erythrurus* Valenciennes, 1828, *Epinephelus lanceolatus* Bloch, 1790 and *Carinotetraodon travancoricus* Hora & K.K. Nair, 1941. Four (1.24%) species viz. *Glyphis glyphis* Müller & Henle, 1839, *Sphyrna lewini* Griffith & Smith, 1834, *Eusphyra blochii* Cuvier, 1816, and *Anoxypristis cuspidata* Latham, 1794 are listed as "Endangered" based on the global Red List status. Based on our observations, *Himantura uarnak, Glyphis glyphis, Sphyrna lewini* and *Eusphyra blochii* that are frequently found in the Sundarbans though the Red List mentions these as threatened globally.

Most of the shark, skates, and rays (Elasmobranchs) are usually over-exploited for their fins and skins. Dried fins are used for the shark fin trade and other parts of the shark body are used for other purposes. Sharks are sold through an open bidding system. Before selling, the fishes are graded species-wise and sometimes lengthwise. We recorded a good number of *Chiloscyllium griseum* Muller & Henle, 1838 of the order Orectolobiformes which was previously overlooked in the Elasmobranchs checklist of the Sundarbans. A total of 10 species of rays under the order Myliobatiformes are enlisted here, among them *Brevitrygon imbricata* Bloch & Schneider, 1801 and *Telatrygon zugei* Müller & Henle, 1841 are new reports from the Sundarbans area of Bangladesh.

Eels are usually a less studied group in Bangladesh. *Anguilla bengalensis* Gray, 1831 which is locally named as Bamosh, is a known commercially valuable species. In this present checklist, we list 10 species of the order Anguilliformes. Among them *Gymnothorax punctatus* Bloch & Schneider, 1801, *Gymnothorax tile* Hamilton, 1822, and *Moringua raitaborua* Hamilton, 1822 are newly reported from the Sundarbans area.

Recent taxonomic studies of the family Leiognathidae (Pony fishes) suggest several changes; however, a total of seven species have been recorded in this family from the Sundarbans. Among them we found four species where *Leiognathus brevirostris* Valenciennes, 1835 was newly recorded in the Sundarbans. Pony fishes are small fishes and commercially not valuable. Those species are usually exploited for dried fish.

Puffer fishes belong to the family Tetraodontidae. A total of 13 species of puffer fish has been listed in this checklist from previous literature and the present study whereas Shamsuzzaman et al. (2015) recorded nine marine puffer fish species from Cox's Bazar located on the eastern coast. Among 13 species of puffer fish reported in the Sundarbans until now, we documented four new records of which three species, viz., *Triacanthus biaculeatus* Bloch, 1786; *Diodon hystrix* Linnaeus, 1758, and *Ostracion cubicus* Linnaeus, 1758 are locally new and the species *Lagocephalus guentheri* Miranda Ribeiro, 1915 is the first record in the country. This study also added a new described species, *Chelonodontops bengalensis* Habib et al., 2018 from the same family.

The Sundarbans is where mainland Bangladesh meets the Bay of Bengal, making the area a globally unique ecological niche. In the Indian part, 34 elasmobranchs under 10 families and 271 bony fishes belonging to 61 families are known from the Sundarbans (Pal et al. 2014). In the present checklist, 36% species have been found as the habitants of both marine and brackish water followed by 26% as exclusively marine, 25% as marine, freshwater & brackish, 11% freshwater and brackish, and 2% exclusively as freshwater fish (Figure 4).

Among the bony fishes a few rare species of fishes are also reported from the Sundarbans of Bangladesh in this updated check list, viz., *Rhizoprionodon acutus*, *Himantura uarnak*, *Gymnura poecilura, Epinephelus coioides* Hamilton, 1822, *Glaucostegus granulatus*, *Antennarius hispidus* Bloch & Schneider, 1801, *Bregmaceros mcclellandi* Thompson, 1840, *Ostracion cubicus* Linnaeus, 1758, *Allenbatrachus grunniens* Linnaeus, 1758, and *Chelonodontops bengalensis* (Image 2). After the previous report by Hussain (1969), we report *Antennarius hispidus* from the Bay of Bengal coast of Bangladesh.

To the best of our knowledge, no study has been performed to assess diversity and breeding status of fish exclusively for three protected wildlife sanctuaries in the Sundarbans. In the present study, we have tried to cover the sanctuaries to assess its existing species composition of fishes; however, detailed and year-round study is necessary. One of the major limitations in a year-round

survey is the lack of a vessel suitable to go downstream of rivers and canals during the monsoon season due to the strong current of the heavy downwards water flow.

Kobadak, Kholpetua, Rupsa, Shibsa, Pashur, Baleshwar, Raimangal, Arpangasia, Sakbaria are the main rivers passing through the Sundarbans which constitute about 2,000km^2 of waterways (Khan 2011), in addition to numerous small rivers, canals and creeks. The Sundarbans in Bangladesh has been divided into northeastern freshwater, middle to southern moderately saline and western saline zones (Chaffey et al. 1985). Therefore, it has brackish water as well as fresh water fish available in the labyrinth of water bodies. The government made some regulations and passed acts to protect and maintain sustainable production of fish in the Sundarbans area which are executed and enforced by the Bangladesh Forest Department (BFD). For example, 18 'khals' (canals) in the buffer zone of the Sundarbans have been permanently closed for fishing to ensure natural breeding of fish under Khal Closure Regulation (1989). Further, canals of less than 25 feet width have been banned for fishing throughout the Sundarbans. Entire fish of these small canals can be caught easily using poison and trapping fish setting net from two ends. Fishing is prohibited in three wildlife sanctuaries of Sundarbans by Wildlife Sanctuary Regulations (1999). Close Season Regulation (2000) banned catching of three finfish species, viz., *Pangasius pangasius*, *Plotosus canius*, *Lates calcarifer*, from 1 May to 30 June every year inside the Sundarbans to ensure natural breeding. BFD also implements the banning of Hilsa fishing each year imposed by Bangladesh Government's Department of Fisheries during peak breeding season during a certain time of the month between September and October every year (e.g., 9–30 October in 2019).

Fishers of the Sundarbans use different kinds of harmful nets and gear for catching fish which cause damage to aquatic lives, such as monofilament gill nets (called current Jal) are responsible for the killing of different aquatic animals and small sized fishes. Fine-meshed set bag nets (locally called Behundi Jal), pull and push nets (Thela Jal), fine-mesh mosquito nets (Chingri Pona Jal), long shore nets (Khuti Jal) have been identified as the most destructive among all the fishing gears in the Sundarbans. Catch mortality is very high for these nets. Set bag nets used for collecting shrimp fry in the estuary and rivers of the Sundarbans also catch eggs, spawn, and larvae of all species along with adult fish. It is highly detrimental for declining fish diversity. Local fishers also use pull nets to catch post larvae (PL) of shrimps which also hampers fishery growth. In such cases they dispose unwanted larvae onto land rather than being freed into water, resulting in wastage. Thus, these larvae do not get the opportunity to mature into fish. It has been observed that about 99 fin fish and fry of other shrimp species are discarded for collecting a single shrimp post larva (Rashid 2000; Azad et al. 2017). Considering such a detrimental effect, the Government of Bangladesh declared a regulation in 2000 where it was stated that "no person shall catch or cause to be caught fry or post larvae of fish, shrimp and prawns of any kind in any form and in any way in the estuary and coastal waters of Bangladesh" (MoFL 2000). Unfortunately, thousands of people still catch post larvae of fish, shrimps and prawns and market their catch.

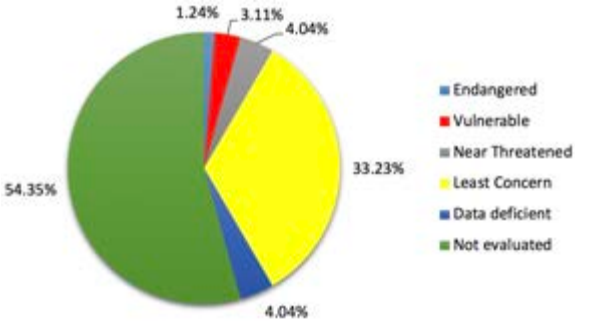

Figure 3. Global IUCN Red List status of the fishes recorded from the Sundarbans, Bangladesh.

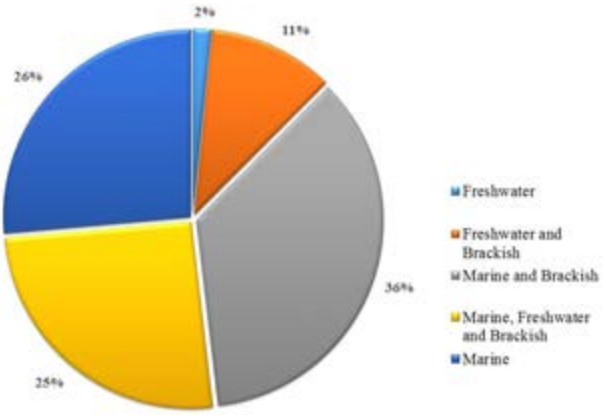

Figure 4. Habitat-wise distribution of listed fishes of the Sundarbans, Bangladesh.

Poison fishing is another ecosystem threatening practice of the locals. It is very alarming that some fishermen are illegally using lethal poison to catch fish including crabs and shrimps in the Sundarbans canals. They release poison into the water and collect the dying fish. The poison is so deadly that a few drops of it are sufficient to kill a large amount of fish. It also contaminates the water, planktons, and mangrove tree roots. As toxic water flows into the large rivers from canals, it is not only the fish species that are being destroyed, but the entire

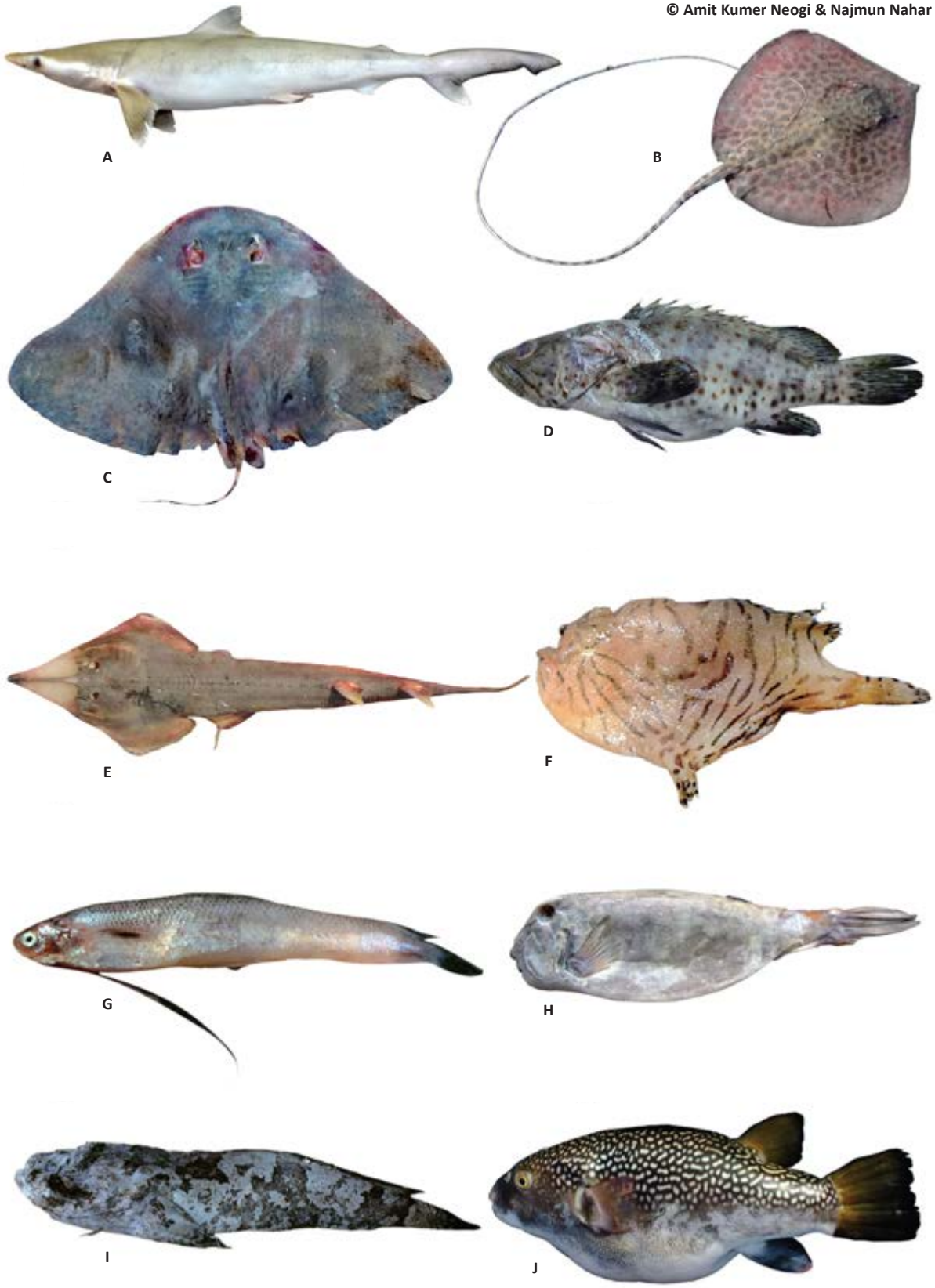

Image 2. Pictures of some rare species recorded during the present study: A—*Rhizoprionodon acutus* Ruppell, 1837 | B—*Himantura uarnak* Gmelin, 1789 | C—*Gymnura poecilura* Shaw, 1804 | D. *Epinephelus coioides* Hamilton, 1822 | E—*Glaucostegus granulatus* Cuiver, 1829 | F—*Antennarius hispidus* Bloch & Schneider, 1801 | G—*Bregmaceros mcclellandi* Thompson, 1840 | H—*Ostracion cubicus* Linnaeus, 1758 | I—*Allenbatrachus grunniens* Linnaeus, 1758 | J—*Chelonodontops bengalensis* Habib, Neogi, Oh, Lee & Kim, 2018.

aquatic ecosystem is also under threat. Such dangerous practices cause a great risk to the flora and fauna of the Sundarbans and may create long-term negative effects on its ecology. This illegal practice needs a close watch to stop it. Increased and regular patrolling inside the forests and, motivation and engaging fishers against this is under way to stop this practice.

Mangrove forest is the breeding and nursery ground of many fish species. In a prohibitive order, the BFD had banned fishing in all of the canals (around 450) in the Sundarbans for the two months of July and August in 2019 for ensuring safe breeding and for conservation. It has been also observed that the intensity of poison fishing is higher in these two months; however, more studies need to be carried out to accurately identify the canals and creeks where breeding of fish occurs and which fish breed especially in the downstream with their specific breeding seasons. Netting of fish was also banned in the beels (e.g., Andaria beel) and chatals of the Sundarbans from February to March in 2019 for smooth breeding as proposed in IRMP (2010). The beels and chatals are lake-like wetlands with static water but chatals are relatively smaller. Further, a chatal gets totally dried out in the late winter but a beel does not. Some chatals are located between Chandpai and Sharankhola range of the Sundarbans. Both of the wetlands are reservoirs of freshwater. Both waterbodies are the source of many small indigenous freshwater fish species such as *Anabas testudineus*, *Clarias batrachus*, *Heteropneustes fossilis*, *Channa* sp. etc. The actions taken by the Government of Bangladesh to protect the availability and diversity of fish in Sundarbans have been shown in Table 2. This table has been prepared based on UNESCO (2016) along with different acts and regulations made by Bangladesh Government. Besides, to prevent over fishing, the number of boat license certificates (BLC) provided by BFD to allow fishermen for catching fish inside Sundarbans were limited. The maximum number of annual BLC issuance has been 12,000. The first priority in issuing BLC is given to those boat owners who live within 5km area around the Sundarbans. The maximum limit of permits for a month is given for three times and 5–7 days fishing is allowed under one permit (UNESCO 2016).

This article is primarily aimed to compile the information generated by authors and previous workers on the occurrence of total fish species from the past to the present in the core and adjacent marine areas of the Sundarbans, Bangladesh. This checklist should be considered as a working document and several additions of records of fish species for Sundarbans are added with survey work, particularly in the unique aquatic ecosystem.

Table 2. Current monitor and conservation measures taken by Bangladesh Forest Department.

Measures taken	Implementation periods (month)											
	J	F	M	A	M	J	J	A	S	O	N	D
Fishing ban in waterbodies of wildlife sanctuaries.	■	■	■	■	■	■	■	■	■	■	■	■
Fishing ban in specific 18 declared canals in the buffer zone	■	■	■	■	■	■	■	■	■	■	■	■
Fishing ban canals less than 25 feet wide throughout the Sundarbans	■	■	■	■	■	■	■	■	■	■	■	■
Fishing ban in all canals							■	■				
Fishing ban in beels and chatals		■	■									
Complete ban of using monofilament gill net (current jal), set bag net (behundi jal), push net (thela jal), channel stake net (khalpata jal)	■	■	■	■	■	■	■	■	■	■	■	■
No fishing by poison, insecticide and de-watering	■	■	■	■	■	■	■	■	■	■	■	■
No fishing by the net with mesh size more than 01 inch or 15 mm (knot to knot at stretch condition).	■	■	■	■	■	■	■	■	■	■	■	■
Fishing ban three finfish species viz. Pangas (*Pangasius pangasius*), Sea bass (*Lates calcarifer*) and Kain magur (*Plotosus canius*)					■	■						
Ban on Hilsa (*Tenualosa ilsha*) fishing for 22 days (a total of 4 days before and 17 days after the full moon in October i.e. the month of Ashwin in Bangla calendar)										■		
Catching of Hilsa (*Tenualosa ilsha*) and Pangus (*Pangasius pangasius*) below 23 cm	■	■	■	■	■	■					■	■
Boal (*Wallago attu*) lower than 12 inch.				■	■	■	■	■				
Ban on fishing of the species Shilon (*Silonia silondia*), Vola (*Johnius argentatus*) and Air (*Bagarius bagarius*) lower than 12 inch.		■	■	■	■	■						
Ban on fingerling and fish fry collection	■	■	■	■	■	■	■	■	■	■	■	■

More studies should be conducted on the Sundarbans fishes to known the total scenario of this unique ecological niche. Based on the study further management measures can be taken with the forest department to protect fisheries. Lastly, awareness campaigns need to be carried out on a larger scale for fish conservation.

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COMMUNICATION

Digital image post processing techniques for taxonomic publications with reference to insects

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Abstract: There exists substantial literature for capturing digital images of insect specimens for taxonomy purposes but very few papers are available on post processing of these images. We present a few techniques for editing digital images of insects using Adobe® Photoshop® which can be performed in a relatively short amount of time. The results clearly show that techniques using a combination of options like Curves, Dodge/Burn, Hue/Saturation and Lab Color mode in the software, enhance the quality of the original image without changing any taxonomic information. These methods applied in different combinations can be used for taxonomy of any insect taxon. We also caution the readers of the abuse of such techniques in context of taxonomy.

Keywords: Adobe® Photoshop®, beetles, insects, lab color, purple fringing.

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Author contribution: SP and HG conceptualized the idea. HG and SP carried out photography. NJ and SP carried out the post-processing of images. All authors contributed to writing the manuscript.

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INTRODUCTION

Insect taxonomy using some/any kind of illustrations to support descriptions has always made it easier for the reader to comprehend those descriptions. The form of illustrations has evolved from simple drawings used in early studies to the use of digital imaging via confocal microscopy, scanning electron microscopy, dual beam scanning electron microscopy, and micro-CT (among others) for studying and describing specific aspects of their morphology (Wipfler et al. 2016).

By and large though, images (and drawings) taken by digital cameras with/without use of stereomicroscopes and/or bright field compound microscopes are widely used in insect taxonomy currently (Buffington et al. 2005; Holzenthal 2008). Digital imaging systems and techniques such as the 'Auto Montage' (hardware and software) (Azorsa & Sosa-Calvo 2008; Jansen & Halbert 2016; Otto 2016), 'Dome lighting' (hardware) (Kerr et al. 2008) and 'Natural color 3D models' (hardware and software) (Nguyen et al. 2014) are now utilized for documentation and taxonomic studies of various insects.

Subsequently, many softwares are available to cater to the processing of such captured images (e.g., Adobe® Photoshop® and GIMP). These provide a plethora of tools and techniques for different aspects of image editing. Using these tools, Jakubec et al. (2018) have provided an excellent and less time consuming method which is used for background isolation of the entomological digital illustrations. While literature exists detailing various methods of photo documentation for different insect groups (Häuser et al. 2005; Riedel 2005; Buffington & Gates 2008), to our knowledge, not much literature exists for the image processing details in context of taxonomy. The best example we know of are the image editing procedures explained on the journal, 'Zootaxa' website (http://mapress.com/zootaxa/imaging/index.html).

With this background, we present a few digital image processing techniques by using Adobe® Photoshop® which can be done in a relatively less amount of time using Coleoptera (images) as a model system.

MATERIALS AND METHODS

Material studied

Species from four families of Coleoptera, viz., Cerambycidae, Chrysomelidae, Dytiscidae, and Endomychidae were used for standardizing the different image editing processes. Selection of the insect group was based solely on the availability of specimens, no other selection criterion was used.

Methods

Multiple images were taken either via 1) Canon 400D SLR camera with a 100mm macro lens and/or 2) Stereo Binocular Microscope (Leica MZ6 with attached Canon PowerShot S50). Multiple images were taken and digitally stacked using COMBINE ZP (http://www.hadleyweb.pwp.blueyonder.co.uk/), a freeware. The photo processing techniques were standardized on Adobe® Photoshop® CS5 student version on Windows 10.

We have explained some of the basics before the actual procedures (given below), though, absolute essentials of Adobe® Photoshop® are beyond the scope of this work and hence, not covered here. Readers who wish to learn about it can visit the official site for help. Terms and terminologies are as per Adobe® Photoshop® CS5 software.

We have used only a single representative image of a cerambycid beetle while describing the processes for consistency.

Some pre-requisite basics are first explained below before the actual methods.

1) New Layer

New layer creates a blank space where in additional colors and vectors can be put and later merged/blended with the image to be processed. New layer can be created by pressing the 'Create New Layer' icon on the bottom right of the main window (Image 1a 'circle') or by going to the 'Layers' drop down menu, selecting 'New' followed by 'Layer'. New layer can also be created by pressing Shift+Ctrl+N.

2) Duplicate Layer

Duplicate Layer makes a copy of the original image/Layer. This is made so that the original image is not changed or processed in any way. A Duplicate Layer can be created by going to the 'Layers' drop down menu and selecting 'Duplicate Layer'. Duplicate Layer can also be made by pressing Ctrl + J.

3) Adjustment Layer

Adjustment Layers are used to edit the images and using them is more advantageous as they can be switched on/off and/or modified later. Adjustment Layers can be created by pressing the 'Create Adjustment Layer' icon located on the bottom right of the main window (Image 1a 'square') or going to the 'Layers' drop down menu and selecting 'New Adjustment Layer'.

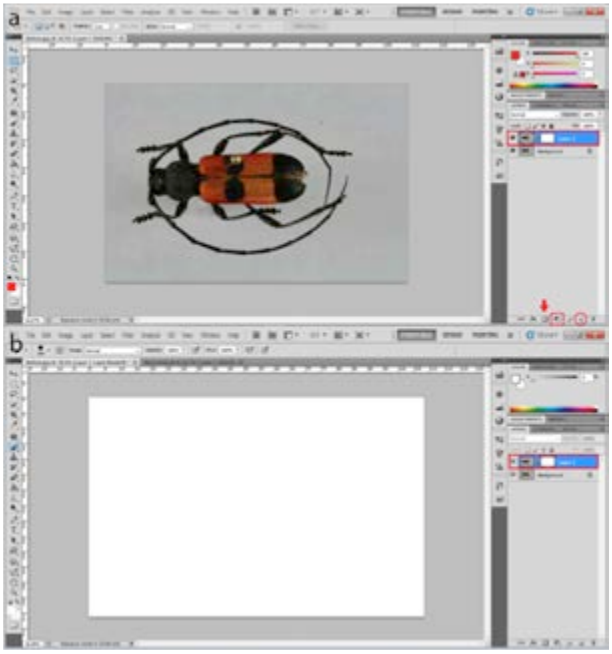

Image 1. Display window showing main window of Adobe® Photoshop® and its Layer Mask options. a—Layer Mask option – thick arrow; New layer – circle; Adjustment layer – square; Layer Mask applied – rectangle | b—Layer mask specifically selected – rectangle.

4) Layer Mask

A layer mask is created in Adobe® Photoshop® to either reveal or hide all the details of the image. A white layer implies all the details are revealed while a black layer means that all the details are hidden (Image 1b 'rectangle'). Layer mask can be made by selecting the 'Create Layer Mask' icon on the bottom right of the main window (Image 1a 'thick arrow') or going to the 'Layers' drop down menu, selecting 'Layer Mask' and further selecting either 'Reveal All' or 'Hide All'. Pressing Alt on the mask displays the actual layer mask (Image 1a & b).

Image processing techniques

1) Aligning the image (Image 2a)

Generally, while making scientific illustrations, it is important to have well aligned images in 90° or 180°. Hence, when the captured image is not at a desirable position, it can be aligned using the Image Rotation option.

The image can be aligned as per user specification.

- Duplicate the layer
- Go to Image > Image Rotation (Image 2a 'square') (Extent of rotation is determined by the user).

2) Lightening or darkening parts of the image (Image 2b).

Overexposure and/or under exposure in portions of the images is edited by two tools namely, 'Burn' (darkens overexposed parts of the image) and 'Dodge' (lightens the dark parts of the image) respectively (Image 2b 'Rectangular box').

- Select the option as per the image exposure
- Select the 'Shadows' part in the dropdown menu after selecting 'Dodge' (Image 2b 'thick arrow') so that only the darkest parts of the image are highlighted and mid tones are left in their natural state. Similarly, select the 'Highlights' parts in the drop down menu after selecting Burn so that only the white parts (overexposed) are darkened.
- Brush size is selected as per the area of the image which needs either of the two tools (Image 2b 'circle')
- Exposure (intensity) of the brush is selected as per the requirement for the image (Image 2b 'thin arrow'). A value between fifty to seventy percent usually works.

3) Adjusting the Levels (Image 3a & b)

The lighting levels of the photo can be quickly edited by using 'Curves' in the 'Adjustment Layer' menu. Levels can also be adjusted by using the option 'Levels' in the 'Adjustment Layer' (not explained here).

- Select the 'Curves' option (Image 3a 'arrow') in the 'Adjustment Layer'.
- This will open a graph of the composition of the image (Image 3b 'square box')
- Adjust by moving the slider (via mouse) either in the X or Y axis as required (Image 3b thin and thick arrows', respectively)

4) Sharpening (Image 4a & b; Image 5a & b)

This tool is used when the details within the image come out soft and need to be emphasized more. Basic sharpening includes using Sharpen tools in Filter menu (not explained here).

One way of doing effective sharpening of the image is by a combination of a) Lab color mode and b) High pass filter

- Duplicate the layer
- Go to Image pull down menu and select 'Mode' followed by 'Lab color' (Image 4a 'square box & arrow'). A message will follow this selection for which Don't flatten should be chosen (Image 4b)
- Duplicate this layer again (and this layer should be selected)
- Go to 'Filter' and select 'Other' followed by 'High Pass' (Image 5a 'square box')

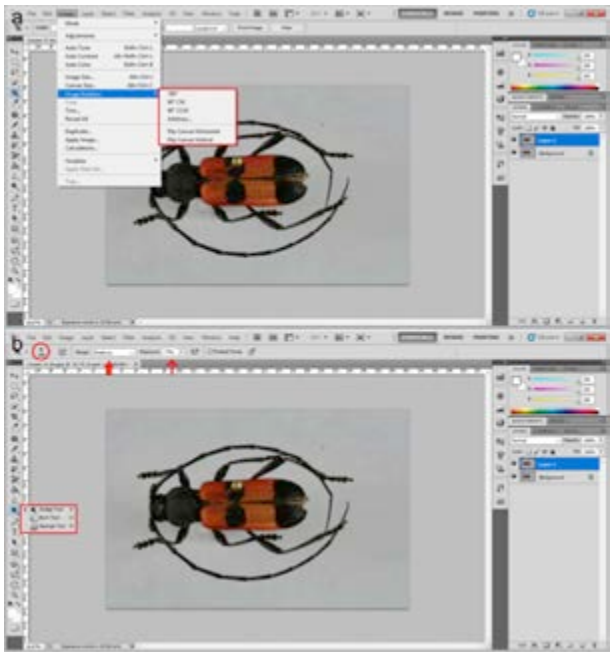

Image 2. Display windows showing 'Image Alignment' and 'Dodge/ Burn' tools. a—Image Alignment option – rectangle | b—Dodge/ Burn tool - rectangle; Brush size - circle; Range selection (for either Shadows, Highlights or Midtones) - thick arrow; Exposure (intensity) - thin arrow.

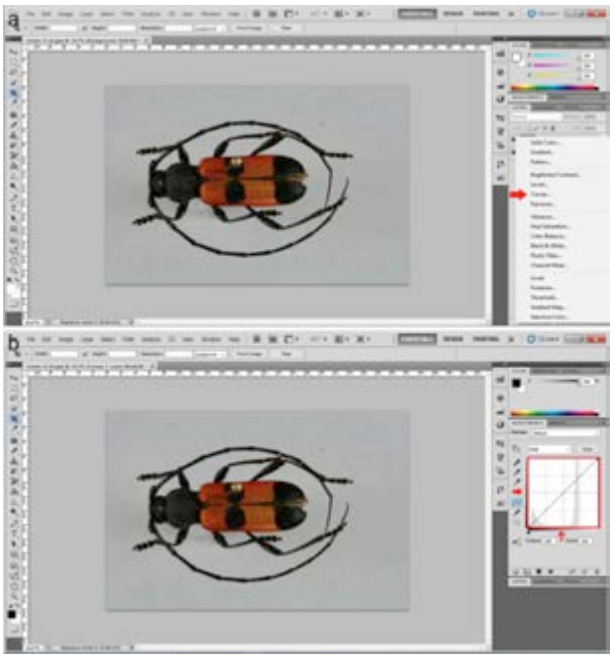

Image 3. Display window showing process for altering the 'Curves'. a—Curves option in Adjustment Layer - thick arrow | b—a graph for changing the Curves settings - square; The Y and X axes respectively - thick and thin arrows.

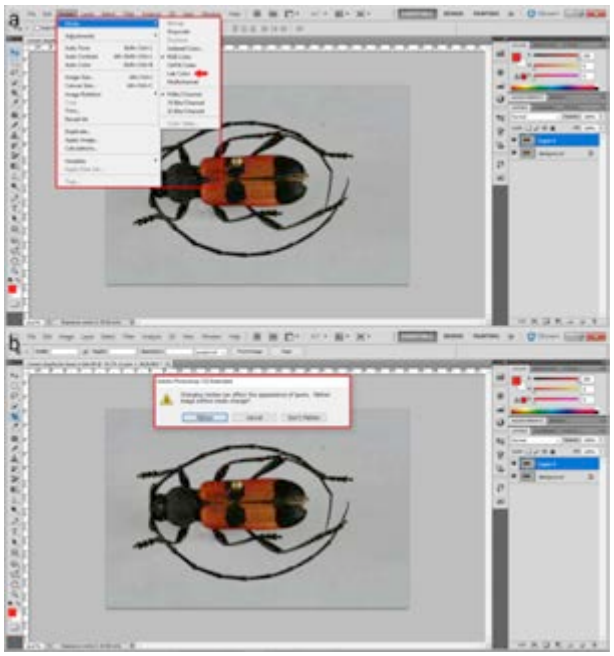

Image 4. Display window showing the process selecting the Lab color mode. a—panel for selecting Lab color option - square; Lab color option - thick arrow | b—window showing the option of 'Flatten Image' – rectangle.

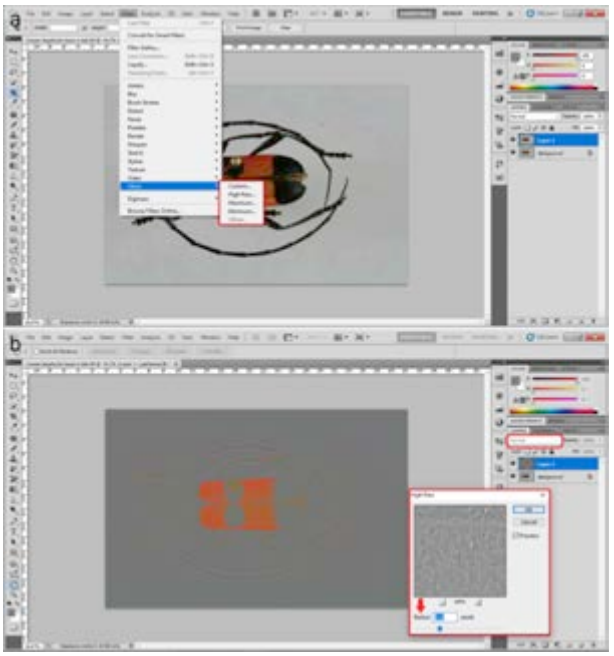

Image 5. Display window showing the process of image sharpening by using Lab color mode. a—High Pass option – rectangle | b—High Pass option window - square; Blend mode drop down menu - rectangle; Slider for the radius - thick arrow.

- In the 'High Pass' window (Image 5b 'square'), select the radius; optimum value ranges between 2 and 6 (Image 5b 'arrow'). Exact value has to be selected as per the image requirement. Click OK.
- Select the 'Soft Light' or 'Overlay' Blending mode (In the drop down menu below Layers on the Right Hand) (Image 5b 'round edged rectangle')
- The two layers should then be merged (this can be done by selecting the two layers and then pressing Ctrl + E).

5) Color artifacts (Image 6 a,b)

The captured image sometimes contains color artifacts which alters its original color. Many times, images also have purple fringing (PF), a chromatic aberration occurring at the edges of the image (especially when the microscope does not have achromatic lenses). These can be edited by making use of 'Hue/Saturation' option in the Adjustment layer in Adobe® Photoshop®

- Image must be in RGB mode (if it has been earlier converted to Lab color)
- Duplicate the layer (Ctrl + J)
- Go to the 'Adjustments Layer' on the bottom right of the main window (Image 1 'square') and select 'Hue/Saturation' (Image 6a 'rectangle' & 'thick arrow')
- In the 'Adjustment Layer' window click on the second drop down menu (Image 6b 'circle') and select Magenta/Blue (for PF) (or the color of the aberration/ artifact)
- After selecting the color, a Dropper Tool icon will be active located below the 'Lightness' slider (Image 6b 'thick arrow'). Select the dropper tool and move it to the part on the image which has the artifact/s. After selecting it, Photoshop will give a color range of that color (located below the dropper tool) (Image 6b 'thin arrow') (Re-check if it is the right shade).
- Drag the Saturation slider to the left-hand side till the point the color artifact is not seen anymore (Image 6b 'rectangle')

In many cases, it also affects the natural coloration of animals

What can be done for this?

- Make a 'Layer Mask' (Image 1a)
- Hold the 'Alt' key and left click on the Layer mask to select it (Image 1b)
- Press Ctrl + I to convert the white layer to black (thus hiding all the desaturation done)
- Select the Paint brush tool with white color followed by stroking on the parts which have purple fringing so that only those parts are edited and show up while the original color is retained for the rest of the image.

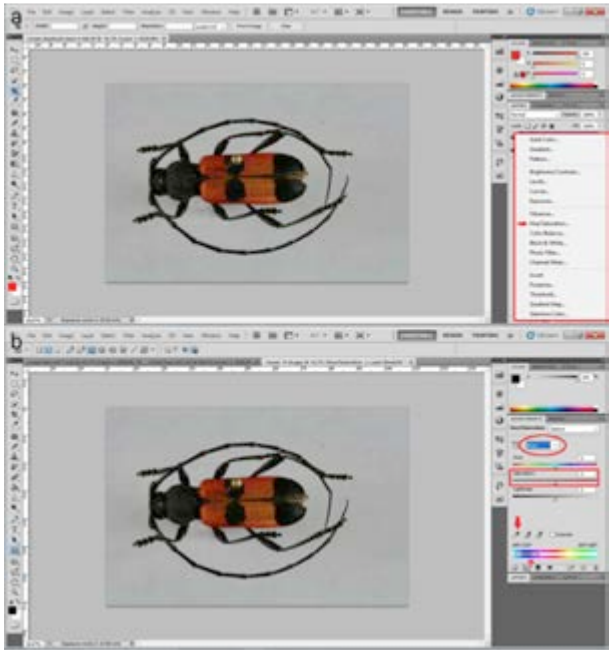

Image 6. Display window showing the process of removing color artifacts. a—Adjustment Layer - rectangle; Hue/Saturation option - thick arrow | b—Hue/Saturation slider - rectangle; Color shade option - circle; Dropper tool for selecting the specific type of color (to be altered) - thick arrow ; color range provided by Photoshop for selected color - thin arrow.

6) Background color (Image 7 a,b)

This tool is used to get a uniform background color of choice for any image. It is ideal for photos taken with any uniform background.

Please note: For using this tool, the original background should have fewer colors to begin with and it is not recommended when the image contains complex backgrounds (e.g., Live animal in its natural habitat). Chroma+ method can also be used for unifying background if you have images with chroma background and neutral background. This method is surely less time consuming when you have images with both chroma+ and neutral backgrounds. If time for capturing image is also considered, then both chroma+ and below mentioned method consumes equal amount of time with similar final results.

- Create an empty Layer (Image 7a 'square') below your image and fill it with White (or the background color of your choice) (Take care that the color selected should not be the same shade of the new intended color for this method to work. E.g., If the background color of the original image is green, refrain using any shades of green for the new intended background) (Image 7a 'thin

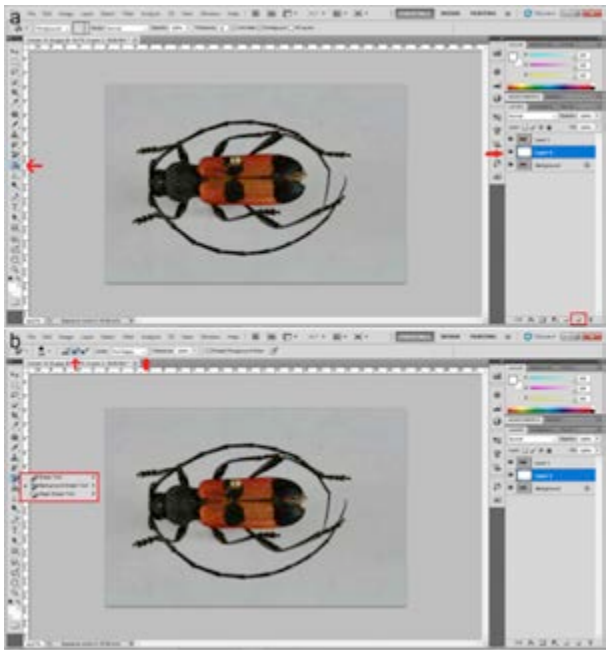

Image 7. Display window showing the process of removing the background color. a—New Layer option - rectangle; New Layer in the Layers menu - thick arrow; Paint Bucket tool - thin arrow | b—Background eraser tool option - rectangle; Limits option - thick arrow; Type of background erasing - thin arrow.

and thick arrows')

- Right click on the 'Eraser' tool on the left-hand side panel of Photoshop and select 'Background Eraser Tool' (Image 7a 'rectangle')
- Select 'sampling once' from the sampling tool bar, which is placed next to the 'brush preset picker' (Dropper icon with a bullseye mark) (Image 7b 'thin arrow')
- Select the 'Limits' (for selecting type of background erasing) as 'Find Edges' from the drop down and set the tolerance between 50–70 % (this value will change as per the image) (Image 7b 'thick arrow')
- Start erasing the background. Just make sure the plus mark seen in the Brush pointer should be always placed on the background while clicking not on the image (otherwise any colors resembling the background in the specimen will also be erased).

RESULTS AND DISCUSSION

The processed images showed a marked improvement without any loss of taxonomic information. Details which were hidden due to insufficient light were highlighted clearly using Curves (Image 8a & b) and Dodge tools (Image 8c & d). The soft parts of the images

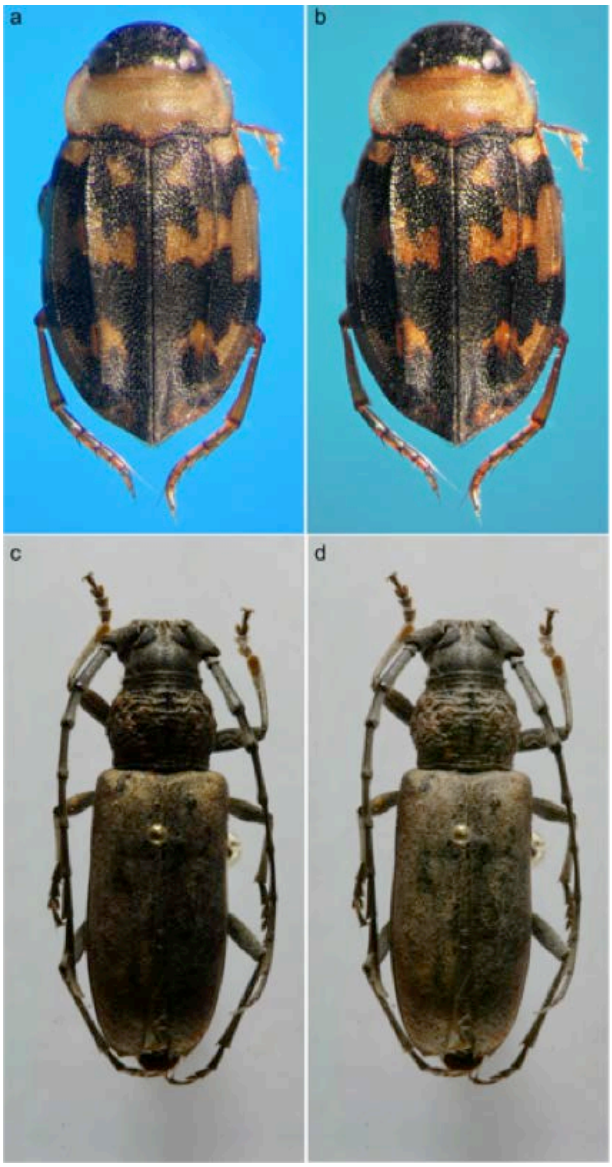

Image 8. Images showing a change in contrast due to altering Curves. a—(Dytiscidae) before | b—after | c—image showing a change in highlights using Dodge tool (Cerambycidae) – before | d—after.

were refined noticeably after sharpening, (Image 9a & b) while the color artifacts were completely nullified thereby revealing the true color of the specimen (Image 9c-f). The background of the image was completely changed bringing more contrast to the image (Image 10a & b). The photos then become very suitable for taxonomy publications as shown here.

The aforementioned techniques can be used singly or in combination (E.g., Image 10c & d) as per the researcher's requirement for any insect taxon (with slight alterations), though, image capture techniques need to be selected appropriately beforehand given the taxa under consideration; for example, the number of images

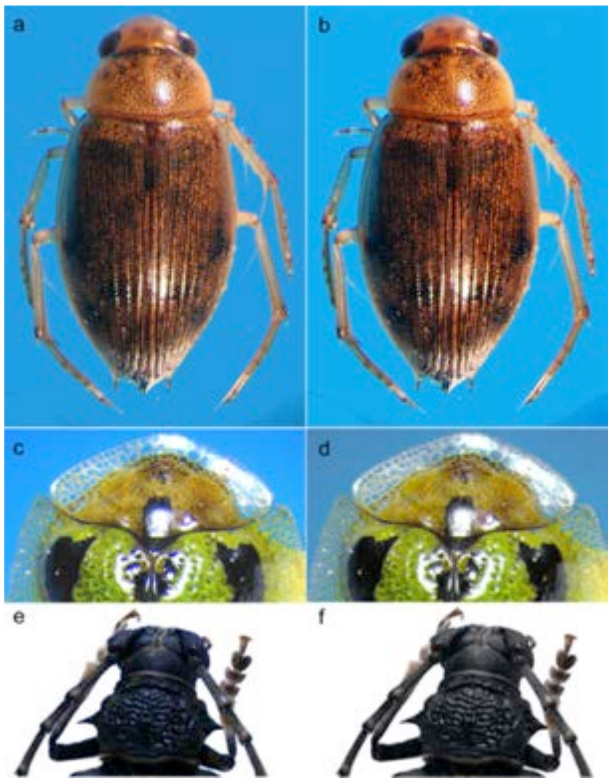

Image 9. Image showing a change in sharpness using Lab color mode and High Pass filter: a—(Hydrophilidae) before | b—after | Image showing removal of Purple fringing due to altering Magenta color using Hue/Saturation tool – (Cassidinae): c—before | d—after | (Cerambycidae): e—before | f—after.

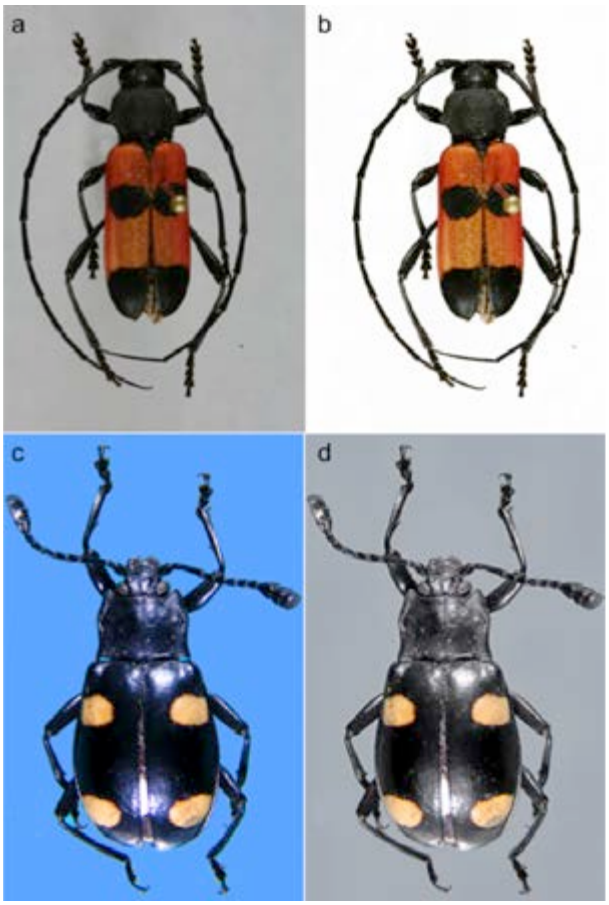

Image 10. Image showing a change in background color using Background Eraser tool: a—(Cerambycidae) before | b—after | Image showing a composite editing (using Curves, Sharpening and Color artifacts removal) (Endomychidae): c—before | d—after.

required for stacking for a beetle would be different than that for a butterfly given their body convexity (Riedel 2005).

An ideal image is the one which does not require any or very little processing but that does not happen in many cases. Many laboratories do not have the necessary infrastructure due to financial and/or logistical constraints. Capturing high resolution images optimally in an affordable way poses a challenge which needs to be tackled (Buffington & Gates 2008). Still, good images can be taken by adjusting conditions such as correct and/or additional lighting, use of correct lenses (if using SLR or micro 4/3rd), finest use of manual Mode in digital cameras and making adequate (not excessive) use of photo processing tools (as is shown through this study). Simple tools such as 'Unsharp Mask' can help sharpening the image in Adobe Photoshop (R) as suggested by Zootaxa (see guidelines for preparing images).

Images or line drawings considerably improve the contents of the taxonomy papers and providing such illustrations gives valuable information while describing and/or revising new species, genera or families; e.g., assassin bugs (Weirauch et al. 2014), tiger beetles (Moravec 2016), and scarab beetles (Rossini & Vaz-de-Mello 2017). In spite of the availability of the latest technology people are still using poor quality images in biology papers in many instances. Preparing good images or drawings is an important issue in taxonomy and our paper assists in this issue to a certain extent. This article focuses on post processing techniques of already existing image while earlier work cited here, mainly describes procedures for obtaining good quality images. We understand that software would be updated frequently but all the protocols provided here are basic and would be functional in the updated versions. There is a high chance that, all these editing processes will be automated with the progress in the technology.

We would like to caution the readers that our aim here was to present ways to process only properly taken digital images where in altering few aspects such as orientation, background color and exposure betters the

already good quality of the image. These techniques are not meant for enhancing or editing poorly captured images. We would also like to point out that, even though the use of good photographs are extremely beneficial and could be used as substitutes for the type specimens in some cases, they should never replace actual type specimens (Rogers et al. 2017). Actual specimens act as replicable datasets and a single image would not be able to capture this entire data contained in an actual specimen (Ceriaco et al. 2016; Rogers et al. 2017).

CONCLUSION

Our work shows that digital images used for insect taxonomy can be edited to an extent which doesn't alter the image properties and thereby morphological characters altogether but, enhances it enough so that it can be used in taxonomical research. These methods are quite easy to perform as well. We also stress on the fact that a poor image with heavy editing is no substitute for a properly taken one with less editing or no editing.

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SHORT COMMUNICATION

Description of a new species of the genus *Lampropsephus* Fleutiaux, 1928 (Coleoptera: Elateridae: Elaterinae: Dicrepidiini) from Konkan, Maharashtra, India

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Abstract: *Lampropsephus sulcatus* sp. nov. is described from the Konkan region of Maharashtra, India. A note to transfer *Propsephus assamensis* from *Propsephus* Candeze, 1859 to *Sephilus* Candeze, 1878 is included.

Keywords: Coastal lateritic outcrops, Elateridae, *Lampropsephus, Propsephus, Sephilus,* Western Ghats.

ZooBank: urn:lsid:zoobank.org:pub:54E5A22C-1657-44CF-935C-08D0B713A0C3

Candeze (1859) erected *Psephus* with *P. beniniensis* as a type species. Later on Hyslop (1921) erected a new genus *Propsephus* to put all known *Psephus* under it because *Psephus* was already preoccupied by *Psephus* Kirby, 1826 in Ochodaeidae (Scaraboidea). Fleutiaux (1935) proposed *P. eliminatus* Candeze, 1859 as type species. Casari (2008) retained Hyslop's assumption of *P. beniniensis* as type species. Fleutiaux (1928) erected monobasic *Lampropsephus* for *Propspehus cyaneus* Candeze (1878).

So far only one species *L. cyaneus* Candeze (1878) is before reported from India with a type locality as 'Himalaya'.

Materials and Methods

The specimen was collected from a coastal lateritic outcrop near Bakale Village, Rajapur Taluk, Ratnagiri District in Maharashtra State. The holotype is a female and is deposited in the museum of The Bombay Natural History Society, Mumbai. The identification is based on Candeze (1859, 1878), Schwarz (1905), Fleutiaux (1928, 1935), and Casari (2008). The treatment given by Casari (2008) was the latest and most comprehensive. The morphological terminology was also consulted from Leschen et al. (2010).

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Results

Lampropsephus (Fleutiaux, 1928)

Type species: *Psephus cyaneus* Candeze, 1878, by monotypy

Fleutiaux erected *Lampropsephus* for *Propsephus* based on brilliant colors (brilliant is *lampros* in Greek) and a combination of the following characters. Body oblong, convex with bristly pubescence. Frontal carina complete between eyes. Antennae not reaching the base of the pronotum. Second and third antennomeres small and globular and the others serrate. Elytra punctate-striate. Prosternum with indistinct chin piece. Notosternal sutures furrowed in the anterior. Elytral epipleurae wide and large, wider near anterior angles of elytra. Metacoxal plate narrow and posterior margin sinuate. Metatarsi slightly shorter than metatibia.

Lampropsephus sulcatus sp. nov.

(Images 1–6,7D)

urn:lsid:zoobank.org:act:835A11B1-B8D6-4978-96F3-3A0F0AE27EF6

Type examined: Holotype: BNHS 302, female, 10.vii.2012, Bakale, Ratnagiri District, Maharashtra, India 16.57°N & 73.34°E, on the flowers of *Antidesma acidum* Retz. leg. R. Khot (Image 1)

Diagnosis: The new species can be differentiated from *L. cyaneus* Candeze, 1878 by having a distinct groove in the posterior half of prothorax which is absent in the latter; prosternal margins distinctly concave in *L. cyaneus* Candeze, 1878 where as they are subparallel in the new species; prosternal projection stouter than the latter; body multi-coloured in the new species where as it is monochrome cyan in *L. cyaneus* Candeze, 1878.

Description

Habitus (Image 2)

Female: Total length 18.3mm from anterior margin of frontal carina to the tip of the elytra. Maximum breadth 5.57mm at the broadest part of elytra. Integument tricoloured; prothorax including hypomera rufous; head, antennae, proventrite, mesoventrite and metaventrite black; scutellar shield and elytra shining and deep blue. Punctures round, deep and dense. Pubescence yellow ochre.

Head (Image 3): Width (2.86mm) including eyes, slightly more than half of the prothorax width (5.32mm). Anterior margin broadly rounded. Frons broad, squarish, flat, inclined anteriorly, entirely carinate along its width (between eye to eye). Labrum bulging, anterior margin rounded. Mandibles with glabrous tip, bluntly truncate.

Image 1. *Lampropsephus sulcatus* sp. nov. on the flowers of *Antidesma acidum* Retz.

Image 2. Dorsal habitus of *Lampropsephus sulcatus* sp. nov. (Holotype: female. Registration #BNHS 302).

Image 3. Head of *Lampropsephus sulcatus* sp. nov.

Image 4. Antenna of *Lampropsephus sulcatus* sp. nov.

Image 5. Ventral view of *Lampropsephus sulcatus* sp. nov.

Image 6. Abdominal ventrites of *Lampropsephus sulcatus* sp. nov.

Antenna (Image 4): Serrate, reaching beyond middle of the prothorax. Antennomere 4–11 with rami. First segment more than the double the length of second. Second and third antennomeres small and subequal. Fourth antennomere the broadest. Antennomere 5–10 distinctly serrate. Eleventh antennomere longer than the preceding, blunt, with broadly rounded apex, lateral sides constricted in the distal half.

Prothorax (length 4.82mm; breadth 5.32mm near the base of the posterior angles) with a distinct shallow grove in the posterior half. Anterior margin darker, slightly rounded in the middle with anterior angles which cover eyes partially. Lateral margin completely carinate from posterior to anterior, narrowing in the anterior half. Posterior angles long with black borders and blunt apex; with distinct, black single carina from the tip to the base of the angle. Posterior margin black, glabrous. Sublateral incision along the posterior margin distinct, broad, squarish. Prescutal notch broad. Hypomeral margin along the pronotosternal sutures angulate.

Scutellum strongly declivous anteriorly with margins as follows: anterior margin carinate and broadly arcuate, lateral margins arcuate and in posterior two third and straight in the anterior third, posterior margin with broadly arcuate apex.

Elytra (length 11.6mm; breadth 5.57mm) with sides parallel tapering posteriorly to broadly rounded apex. Anterior angles indistinct. Striae with distinct and deep punctures which are separated by more than two diameters of punctures. Striae 2,3 and 4 slightly depressed on either side of the scutellum. Interstriae flat.

Prosternum (Image 5) with anterior margin slightly arcuate. Lateral margins slightly tapering

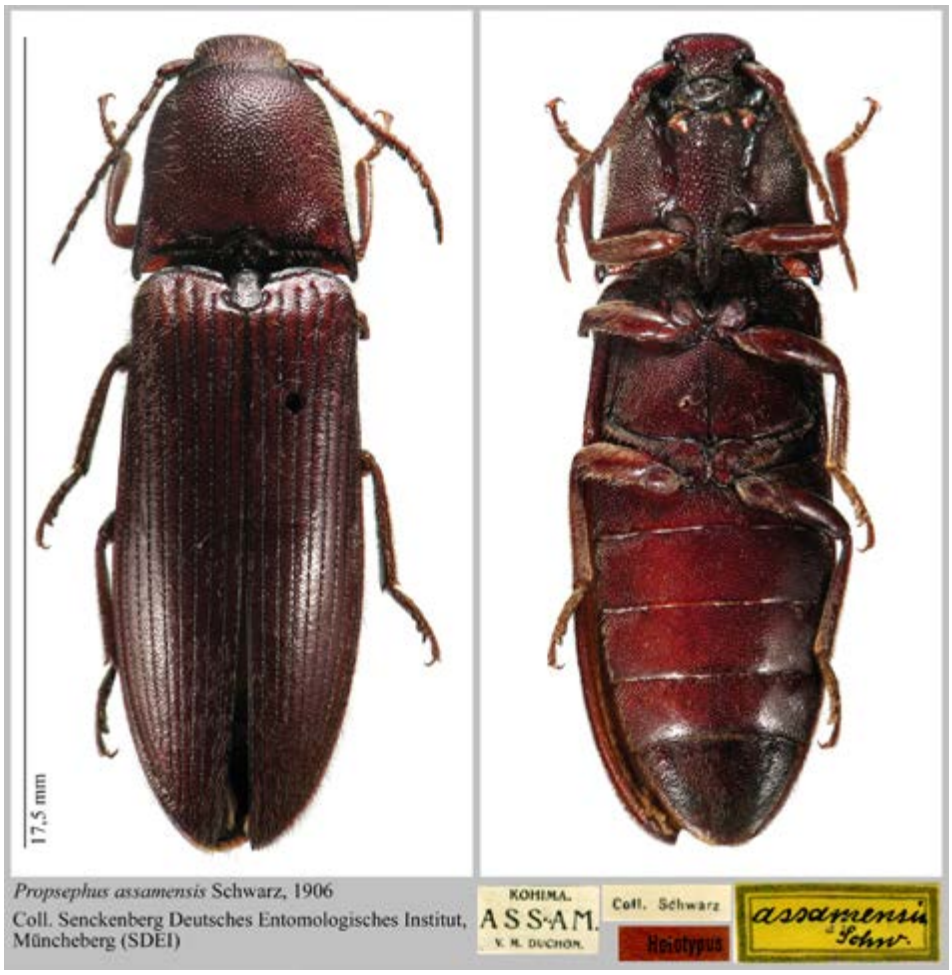

Image 7. ***Sephilus assamensis*** **(Schwarz, 1905). syn. nov.**

posteriorly. Notosternal sutures broad. Mesoventrite declivous anteriorly with an area on either sides of the mesoventral cavity depressed. Mesoventral cavity vertical in the middle with posterior end broadly rounded with thick margins, reaching beyond middle of mesocoxae. Metaventrite (Image 5) truncate between mesocoxae, distinctly separated from the mesosternum by deep suture. Metaventral discrimen distinct, entire. Metasternum slightly projecting between metacoxal plates.

Metacoxal plates (Image 5) broadly rounded along midline of body. Posterior margin sinuate as for the genus with posterior angle distinct and broad.

Legs: Mesocoxal margin formed by mesoventrite, metaventrite, mesepimeron, and mesanepisternum. Mesofemur the broadest. Posteriorly femora with a grove. Tibia long, thin, parallel sided, outer margin with a row of spinose hairs. Distal end of tibia with a row of spiniform hairs and short tibial spurs. Tarsomere 1–3 broad; 4–5 tarsomere thin and glabrous. First tarsomere with band of golden hairs near the apex appearing like a lamella. Second and third tarsomere lamellate. Claw blade without basal seta arising from the outer surface of the blade.

Abdominal ventrites (Image 6) convex. Pygidium or abdominal process longer than the previous ventrites and with rounded apex.

Etymology

The species is named indicating the groove or sulcus present on prothorax. Masculine.

Note on transfer of *Propsephus assamensis* (Schwarz, 1905) (Image 7)

Sephilus assamensis (Schwarz, 1905) syn. nov.

Psephus assamensis Schwarz, 1905 (Deut. Entomo. Zeit. 260–261)

Propesphus assamensis: Hyslop, 1921 (Proc. of the Unit. St. Nat. Mus. 58: 621–680)

Type locality: Kohima, Nagaland (then Assam)

By examining high resolution photographs of the holotype of *Propsephus assamensis* and the description

Image 8. Five species of psephid genera.
A—*Sephilus assamensis* (Schwarz, 1905) syn. nov. | B—*Propsephus thanensis* (Patwardhan & Athalye, 2010) | C—*Neopsephus assamensis* (Schimmel, 2007) | D—*Lampropsephus cyaneus* (Candeze, 1878) | E—*Lampropsephus sulcatus* sp. nov.

by Schwarz (1905) the following characters are clearly seen. Antennae reaching beyond the base of prothorax. The terminal antennomere slender, long with pointed apex, as long as the previous two together. Head with complete carina on the frons. Prothorax wider than long, slightly narrowing anteriorly with margins entirely carinate. Notosternal sutures broad and deepened almost entire length. Prosternal process with narrowed apex. Metatarsi distinctly shorter than the metatibia. Based on these characters *Propsephus assamensis* Schwarz, (1905) can be transferred to *Sephilus* Candeze, 1878 as *Sephilus assamensis* (Schwarz) syn. nov.

Discussion

Four psephid species (Image 8) have been described from India previously as follows – *Lampropsephus cyaneus* Candeze (1878), *Propsephus assamensis* Schwarz (1905), *Neopsephus assamensis* Schimmel (2007) and *Propsephus thanensis* Patwardhan & Athalye (2010). The first three species are from northeastern India and the last is from northern Western Ghats.

P. cyaneus described by Candeze (1878) with the type locality as 'Himalaya' of which Fleutiaux (1928) and Casari (2008) mention the type locality as 'Tonkin' which is outside Himalayan boundaries. *P. assamensis* was described by Schwarz (1905) from 'Kohima, Assam'. Kohima is now the capital of Nagaland State. *Neopsephus assamensis* Schimmel (2007) was reported from south of Shillong, Meghalaya. *P. thanensis* was described by Patwardhan & Athalye (2010) from Thane, Maharashtra.

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SHORT COMMUNICATION

Spiders (Arachnida: Araneae) from the vicinity of Araabath Lake, Chennai, India

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Abstract: This study documents the spider fauna in the vicinity of a suburban lake (Araabath Lake) in Chennai. A total of 70 species of spiders belonging to 58 genera and 21 families were recorded. Seven species are endemic to India and six are endemic to India and Sri Lanka. Salticidae was the most dominant with 24 species belonging to 19 genera. Guild structure analysis revealed seven feeding guilds of which, stalkers and orb-web weavers were the dominant feeding guilds followed by ground runners and ambushers, respectively.

Keywords: Diversity, guild structure, spiders, Suburban Lake, Thirumullaivoyal.

Spiders are hyper diverse arthropods and are represented by 48,365 described species under 4,145 genera in 120 families worldwide (World Spider Catalog 2019). In India, 1,799 species under 448 genera and 59 families (World Spider Catalog 2019) are known. Not many studies have been made on the spider diversity from Chennai City (erstwhile Madras) and its suburbs except for those done in the earlier half of the 20th century by Sherriffs (1919, 1927), Gravely (1921, 1924, 1931, 1935) and one study by Phanuel in 1963.

The aim of the present paper is to present compiled information on the diversity of spiders particularly from the surroundings of a water body called 'Araabath Lake'. Recently, several studies were conducted from the region (Caleb 2016a,b, 2017; Caleb & Mathai 2014; Caleb et al. 2015) contributing considerably to the knowledge of the group.

Study area

The study was conducted around Araabath Lake and neighboring areas during 2014–2017. The water body lies between (13.129–13.120 ^{0}N & 80.138–80.136 ^{0}E) (Figure 1). It is about 1km long and 115m wide and covers a total area of 7.75ha. The area falls under the 'Coastal Area Ecosystem' with average temperature ranging from 23–40 ^{0}C. The region receives the north-west monsoon and occasional rainfall resulting from depressions in the Bay of Bengal with a mean annual rainfall of 135cm (Raghavan & Narayan 2008).

Methods

Spiders were collected and preserved in 70% alcohol. Specimens were photographed using a Nikon D60 DSLR camera. Adult specimens were identified up to species level with the help of available literature and keys

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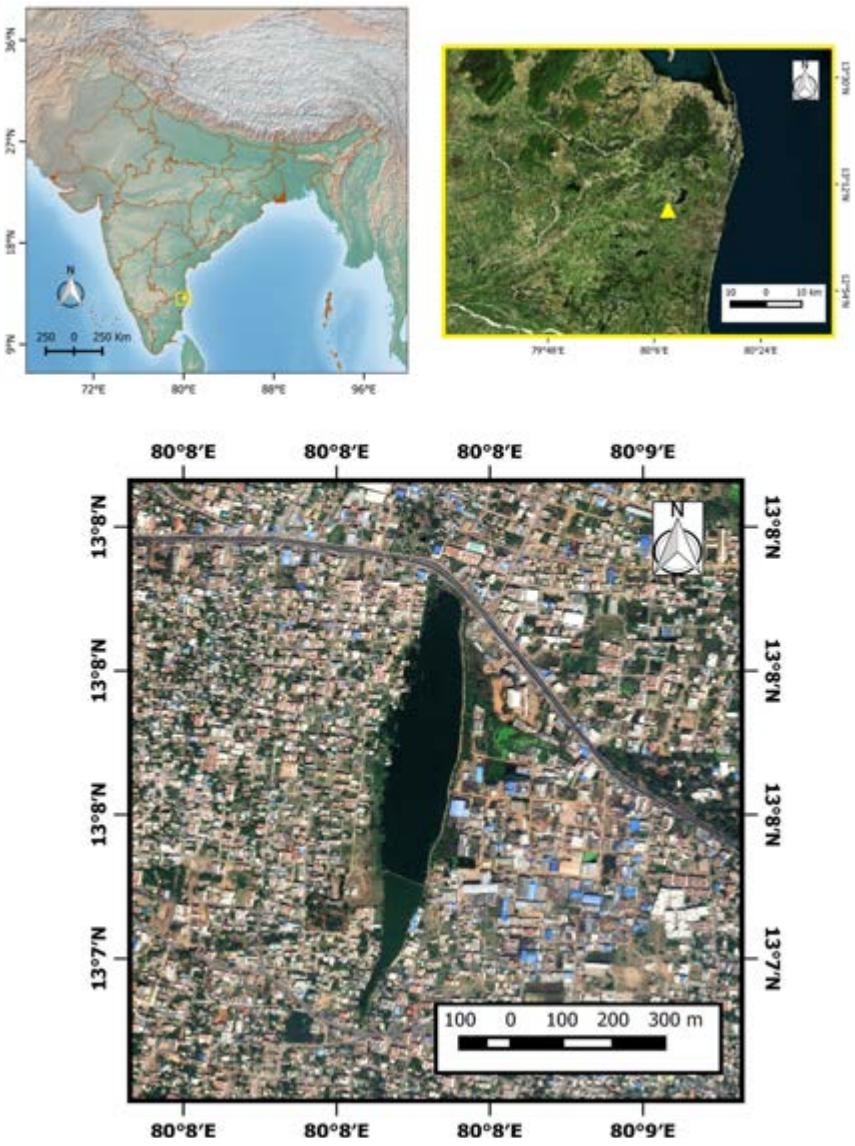


Figure 1. Location map of Araabath Lake and its neighborhood.

(Tikader & Malhotra 1980; Tikader 1982; Pocock 1901; Gravely 1921, 1924; Proszynski & Caleb 2015). The nomenclature follows the World Spider Catalog (2019).

Results and Discussion

Spiders representing 21 families, 58 genera and 70 species (Table 1, Figure 3) were recorded from around Araabath lake, Thirumullaivoyal. Salticidae was the dominant family constituting 24 species under 19 genera and followed by Araneidae with 12 species under seven genera. Guild structure analysis revealed seven feeding guilds: orb-web weavers, stalkers, ground runners, foliage hunters, sheet web builders, scattered line weavers and ambushers (Table 1) (Uetz et al. 1999). Stalkers (38%) and orb-web weavers (26%) constitute the dominant feeding guild. They are followed by ground

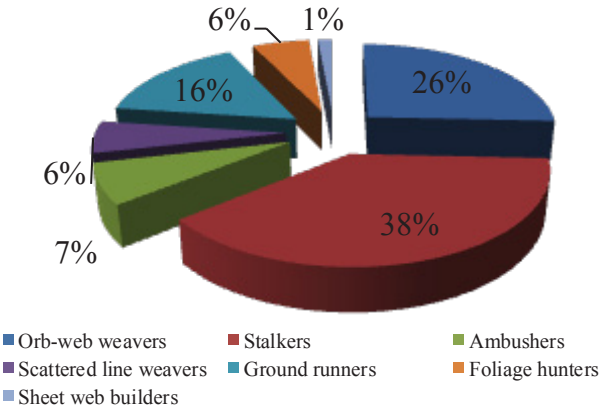


Figure 2. Guild structure of spiders collected from Araabath Lake, Chennai.

Table 1. Total number of families, genera, species composition and functional guilds of spiders from the vicinity of Araabath Lake.

	Family	No. of genera	No. of species	Guild
1	Araneidae	7	12	Orb-web weavers
2	Cheiracanthiidae	1	1	Foliage hunters
3	Clubionidae	1	1	Foliage hunters
4	Corinnidae	1	1	Ground runners
5	Ctenidae	1	1	Ground runners
6	Eresidae	1	1	Sheet web builders
7	Gnaphosidae	3	3	Ground runners
8	Hersiliidae	1	1	Ambushers
9	Idiopidae	1	1	Ground runners
10	Liocranidae	1	1	Ground runners
11	Lycosidae	4	4	Ground runners
12	Oecobiidae	1	1	Scattered line weavers
13	Oxyopidae	3	3	Stalkers
14	Philodromidae	2	2	Ambushers
15	Pholcidae	1	1	Scattered line weavers
16	Salticidae	19	24	Stalkers
17	Sparassidae	2	2	Foliage hunters
18	Tetragnathidae	3	5	Orb-web weavers
19	Theridiidae	2	2	Scattered line weavers
20	Thomisidae	2	2	Ambushers
21	Uloboridae	1	1	Orb-web weavers
	Total	**58**	**70**	

runners (16%), ambushers (7%), foliage hunters (6%), scattered line weavers (6%), sheet web builders (1%) (Figure 2). Seven of the recorded species are endemic to India and six are endemic to India and Sri Lanka (Table 2). The spider diversity is rich in this region and there is an urgent need for preserving this lake from an ecological and biodiversity perspective.

Araabath Lake is a small suburban lake located in Thirumullaivoyal, Chennai. The lake serves as a ground water reservoir and supports a wide variety of flora and fauna, including migratory birds. Anthropogenic activities like encroachment, drainage of untreated sewage, open defecation, dredging of mud for urban construction projects and utilization of the lake as a dumping ground has resulted in deterioration of habitat and water quality (Caleb pers. obs. 2017). This lake is in dire need for proper restoration, maintenance and conservation efforts.

Recent work from this region led to the discovery of three new species, *Icius alboterminus* Caleb, *Icius kumariae* Caleb and *Pellenes iva* Caleb (Caleb 2017; Caleb & Kumar 2018) along with the discovery of five species, *Aelurillus kronestedti* Azarkina, *Chrysilla volupe* (Karsch), *Curubis erratica* Simon, *Micaria dives* (Lucas) and *Myrmarachne kuwagata* Yaginuma newly recorded in India (Caleb 2016a,b, 2018; Caleb et al. 2015) and the redescription of species discovered over a century since their original description (*Curubis erratica* Simon

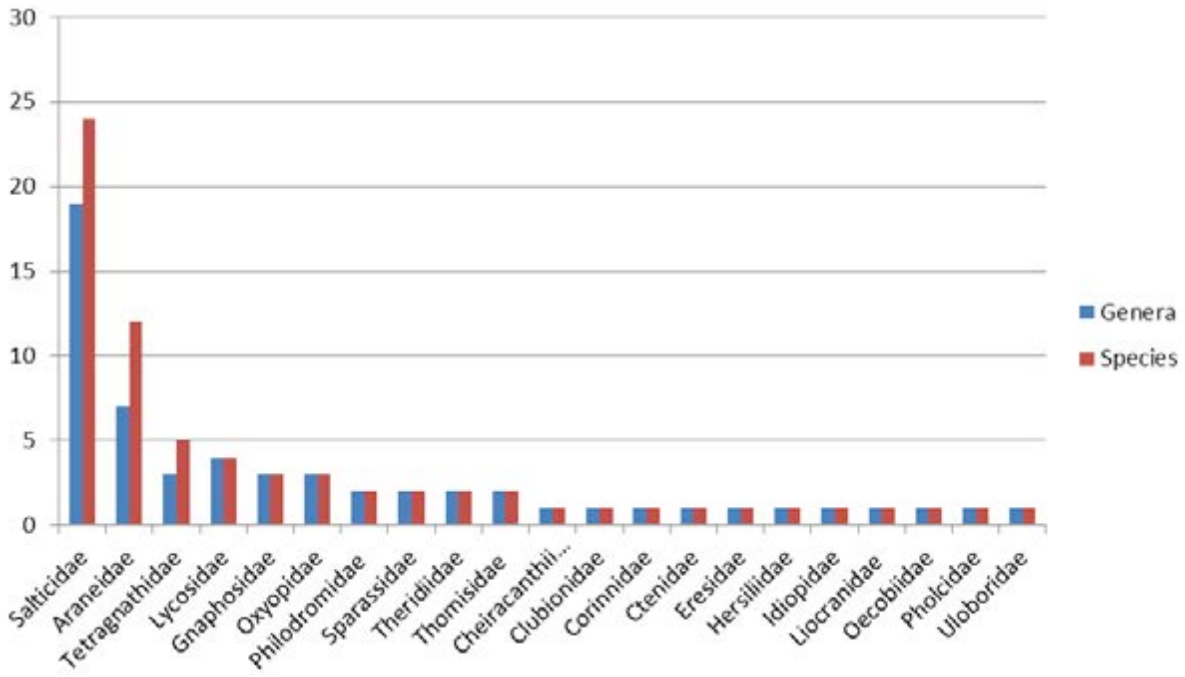
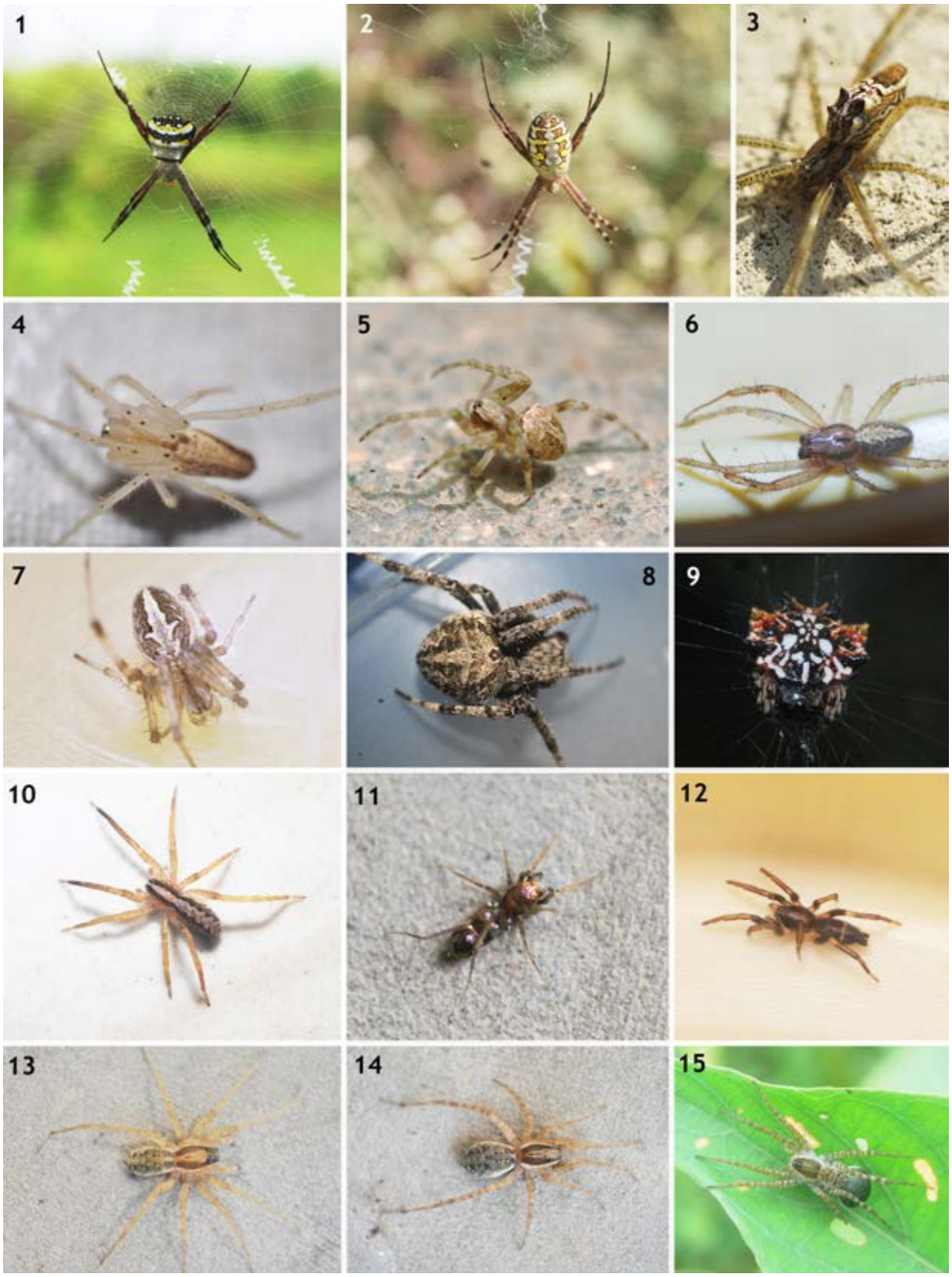


Figure 3. Diversity of spiders from Araabath Lake, Chennai.

Table 2. List of spiders collected from the vicinity of Araabath Lake.

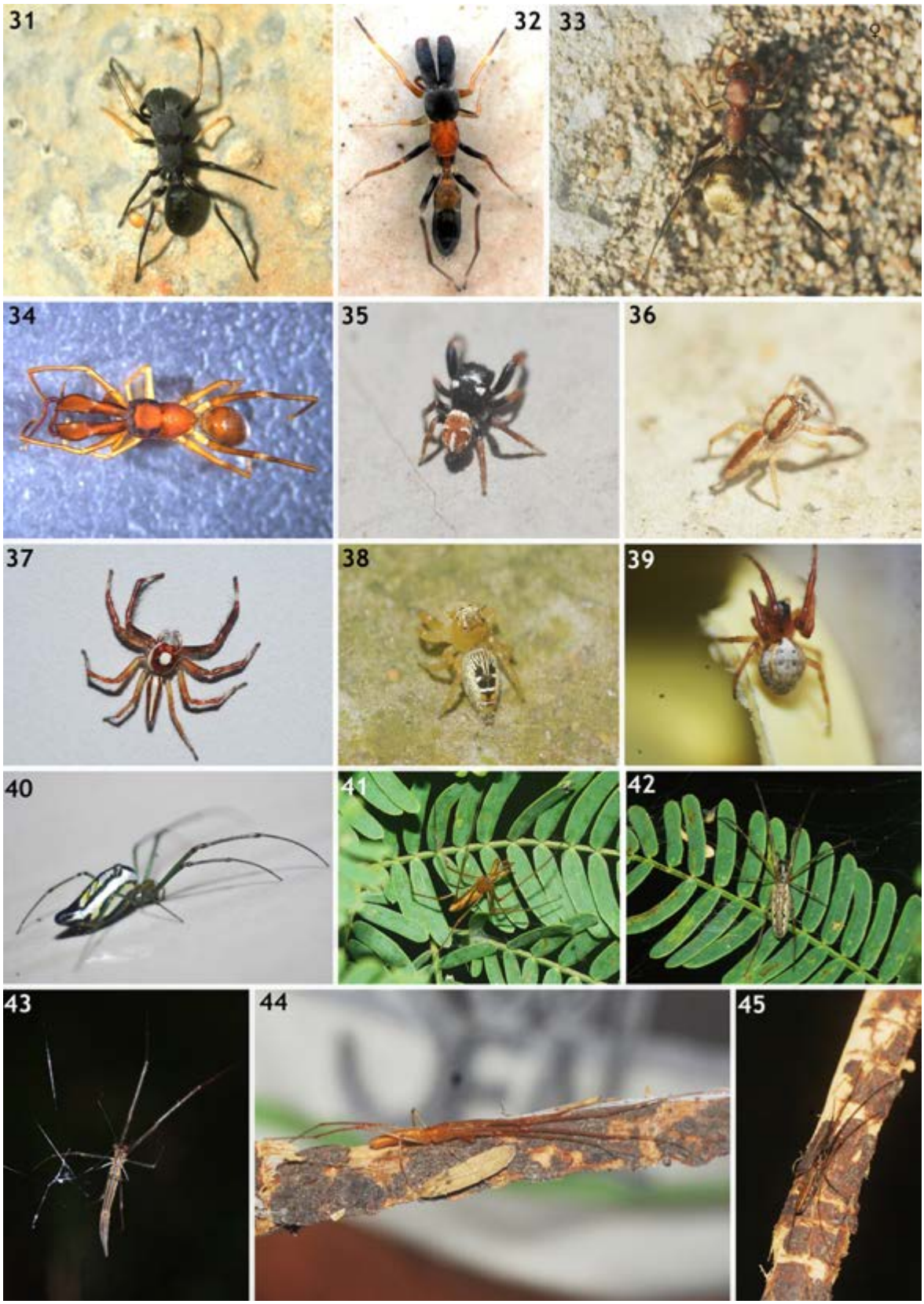
	Family	Genus/Species
1	Araneidae	*Argiope aemula* (Walckenaer, 1841)
2		*Argiope pulchella* Thorell, 1881
3		*Argiope catenulata* (Doleschall, 1859)
4		*Cyrtophora cicatrosa* (Stoliczka 1869)
5		*Gasteracantha geminata* (Fabricius, 1798)
6		*Larinia* sp.
7		*Neoscona bengalensis* Tikader & Bal, 1981
8		*Neoscona nautica* (L. Koch, 1875)
9		*Neoscona theisi* (Walckenaer, 1841)
10		*Neoscona vigilans* (Blackwall, 1865)
11		*Poltys nagpurensis* Tikader, 1982
12		*Thelacantha brevispina* (Doleschall, 1857)
13	Cheiracanthiidae	*Cheiracanthium* sp.
14	Clubionidae	*Clubiona* sp.
15	Corinnidae	*Castianeira* sp.
16	Ctenidae	*Anahita* sp.
17	Eresidae	*Stegodyphus sarasinorum* Karsch, 1892
18	Gnaphosidae	*Drassodes luridus* (O. Pickard-Cambridge, 1874)*
19		*Micaria dives* (Lucas, 1846)
20		*Poecilochroa* sp.
21	Hersiliidae	*Hersilia savignyi* Lucas, 1836
22	Idiopidae	*Idiops constructor* (Pocock, 1900)*
23	Liocranidae	*Oedignatha microscutata* Reimoser, 1934*
24	Lycosidae	*Draposa lyrivulva* (Bösenberg & Strand, 1906)
25		*Hippasa greenalliae* (Blackwall, 1867)
26		*Pardosa pseudoannulata* (Bösenberg & Strand, 1906)
27		*Wadicosa fidelis* (O. Pickard-Cambridge, 1872)
28	Oecobiidae	*Oecobius putus* O. Pickard-Cambridge, 1876
29	Oxyopidae	*Oxyopes hindostanicus* Pocock, 1901#
30		*Hamataliwa* sp.
31		*Peucetia viridana* (Stoliczka, 1869)
32	Philodromidae	*Philodromus* sp.
33		*Psellonus planus* Simon, 1897*
34	Pholcidae	*Crossopriza lyoni* (Blackwall, 1867)
35	Salticidae	*Aelurillus kronestedti* Azarkina, 2004#
36		*Bianor balius* Thorell, 1890
37		*Bristowia gandhii* Kanesharatnam & Benjamin, 2016#
38		*Chrysilla volupe* (Karsch, 1879)
39		*Carrhotus viduus* (C.L. Koch, 1846)
40		*Curubis erratica* Simon. 1902#
41		*Cyrba ocellata* (Kroneberg, 1875)
42		*Hasarius adansoni* (Audouin, 1826)
43		*Hyllus semicupreus* (Simon, 1885)
44		*Icius alboterminus* (Caleb, 2014)*
45		*Icius kumariae* Caleb, 2017*
46		*Menemerus bivittatus* (Dufour, 1831)
47		*Myrmarachne kuwagata* Yaginuma, 1969
48		*Myrmarachne melanocephala* MacLeay, 1839
49		*Myrmarachne prava* (Karsch, 1880)#
50		*Myrmarachne ramuuni* Narayan, 1915
51		*Pellenes iva* Caleb, 2018*
52		*Phintella vittata* (C.L. Koch, 1846)
53		*Plexippus paykulli* (Audouin, 1826)
54		*Plexippus petersi* (Karsch, 1878)
55		*Proszynskia diatreta* (Simon, 1902)#
56		*Rudakius ludhianaensis* (Tikader, 1974)
57		*Telamonia dimidiata* (Simon, 1899)
58		*Thyene imperialis* (Rossi, 1846)
59	Sparassidae	*Heteropoda venatoria* (Linnaeus, 1767)
60		*Olios* sp.
61	Tetragnathidae	*Guizygiella* sp.
62		*Leucauge decorata* (Blackwall, 1864)
63		*Tetragnatha ceylonica* O. Pickard-Cambridge, 1869
64		*Tetragnatha javana* (Thorell, 1890)
65		*Tetragnatha mandibulata* Walckenaer, 1841
66	Theridiidae	*Argyrodes argentatus* O.P. Cambridge, 1880
67		*Chikunia* sp.
68	Thomisidae	*Thomisus* sp.
69		*Xysticus* sp.
70	Uloboridae	*Uloborus* sp.

*Endemic to India | #Endemic to India and Sri Lanka



Images 1–15. 1—*Argiope aemula* | 2—*Argiope catenulata* | 3—*Cyrtophora cicatrosa* | 4—*Larinia* sp. | 5—*Neoscona nautica* | 6—*Neoscona theisi* (male) | 7—*Neoscona theisi* (female) | 8—*Neoscona vigilans* | 9—*Thelacantha brevispina* | 10—*Anahita* sp. | 11—*Micaria dives* | 12—*Poecilochroa* sp. | 13—*Draposa lyrivulva* (male) | 14—*Draposa lyrivulva* (female) | 15—*Pardosa pseudoannulata*. © John Caleb.

Images 16–30. 16—*Oxyopes hindostanicus* Pocock, 1901 | 17—*Philodromus* sp. | 18—*Psellonus planus* | 19—*Aelurillus kronestedti* | 20—*Bianor balius* (male) | 21—*Bianor balius* (female)| 22—*Carrhotus viduus* (male) | 23—*Carrhotus viduus* (female) | 24—*Chrysilla volupe* | 25—*Curubis erratica* | 26—*Cyrba ocellata* | 27—*Hasarius adansoni* | 28—*Icius alboterminus* (male) | 29—*Icius alboterminus* (female) | 30—*Icius kumariae*. © John Caleb.



Images 31–45. 31—*Myrmarachne kuwagata* | 32—*Myrmarachne melanocephala* | 33—*Myrmarachne prava* | 34—*Myrmarachne ramuuni* | 35—*Pellenes iva* | 36—*Rudakius ludhianaensis* | 37—*Telamonia dimidiata* | 38—*Thyene imperialis* | 39—*Guizygiella* sp. | 40—*Leucauge decorata* | 41—*Tetragnatha ceylonica* (male)| 42—*Tetragnatha ceylonica* (female) | 43—*Tetragnatha javana* | 44—*Tetragnatha mandibulata* (male) | 45—*Tetragnatha mandibulata* (female). © John Caleb.

and *Proszynskia diatreta* (Simon)) (Caleb & Mathai 2014; Caleb 2016a).

In view of the above mentioned remarkable discoveries from this area, restoration and management actions need to be planned to curb anthropogenic pressures affecting the lake and its surroundings. Conservation of this particular region which may harbor many more undiscovered life forms is the need of the hour. The lacuna of data for other animal groups needs to be recompensed by more extensive eco-biological studies in the region.

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SHORT COMMUNICATION

Two new records of gilled mushrooms of the genus *Amanita* (Agaricales: Amanitaceae) from India

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Abstract: Two new records of *Amanita constricta* and *Amanita velosa* from India are reported for the first time from sal *Shorea robusta* forest of central India. Earlier *Amanita constricta* was reported from USA and Canada, while *A. velosa* was reported from USA and Mexico. The reported species are edible but they should be taken with caution as at least two deadly *Amanitas* with saccate type volvas are known. *A. velosa* grows in open areas.

Keywords: Amanitaceae, distribution, new record, sal forest.

The genus *Amanita* belongs to family Amanitaceae, order Agaricales, class Agaricomycetes of Basidiomycetous fungi. The family contains of eight genera, namely, *Amanita, Amanitopsis, Amarrendia, Catatrama*, *Limacella, Saproamanita* and *Torrendia* (Verma & Pandro 2018a). This group of mushroom comprises of edible as well as deadly poisonous species. Mushroom poisoning is a perennial problem in India where mushroom collection from the wild is common. The majority of mushroom poisoning occurs due to misidentification of edible variety. Recently, diversities of macro-fungi were studied and many fungi were reported from central Indian region including two new records of *Amanita bisporigera* and *A. pantherina* from sal *Shorea robusta* forests (Verma & Pandro 2018a). Some other edible macro-fungi, *Astraeus hygrometricus, Auricularia auricular-judae, Calvatia cyathiformis*, *C. pyriformis, Laetiporus sulphureus, Macrocybe crassa*, *Macrocybe lobayensis*, and *Schizophyllum commune* were reported from central India (Verma & Verma 2017a,b; Verma et al. 2017a,b,c). In addition, six species each of *Boletus* and *Russula* namely: *Boletellus ananas, B. chrysenteroides, B. corneri*, *B. dissiliens, Boletus edulis, B. pseudochrysenteroides, R. adusta, R. cinerella, R. congoana, R. delicula, R. leelavathyi*, and *R. michiganensis*) were also reported (Verma & Pandro 2018b). A total of 81 species of mushrooms of the family Amanitaceae were recorded from different parts of India including 73 species of *Amanita*, where maximum number of species were reported from Himachal Pradesh, Uttarakhand, and Kerala and the list includes both poisonous and edible mushrooms (Bhatt et al. 1999, 2017; Vrinda et al. 2005a,b; Semwal et al. 2005, 2007, 2014; Verma & Pandro 2018).

The present article reports two new records of amanitaceous mushrooms, *Amanita constricta* and *Amanita velosa*, from sal forests of Dindori (Madhya Pradesh) of central India.

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Competing interests: The authors declare no competing interests.

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Materials and Methods

Study site

Sal forest of Dindori District of Madhya Pradesh (22.569^{0}N and 81.371^{0}E) was selected for study of *Amanita* mushrooms. In addition, sal forest of Bajag forest range (Chada Road) of Madhya Pradesh was also surveyed for amanitaceous mushrooms.

Collection and processing of mushroom

Specimens of mushrooms were collected from selected forests of Madhya Pradesh during rainy season (July 2018). Collected samples were preserved immediately in 70% alcohol after collection for microscopic study. The fruit bodies of fungi were dried under the sun or in wooden box lit with 100W electric bulb.

Identification of mushroom

Microscopic slides were prepared by using stain, mountant, clearing and softening chemicals. Slides were observed under advanced research microscope (Leica, Germany). Observations under phase contrast and dark field were also carried out whenever necessary. Photomicrography of specimens was prepared with the help of a digital camera (Leica, Germany) attached to the advanced microscope. Identification of *Amanita* was possible with the help of published literature, monographs, books, and keys. (Roy & Samajpati 1978; Sathe et al. 1980; Bhatt & Lakhanpal 1988; 1989; Abraham & Kachroo 1989; Das & Simha 1990; Bhatt & Bhatt 1996; Bhatt et al. 1999, 2003, 2007, 2017; Vrinda et al. 2005a,b; Semwal et al. 2005, 2007, 2014; Semwal 2006a,b; Pradeep & Vrinda 2007; Mohanan 2011; Farook et al. 2013; Singh & Kaur 2016).

Results

Taxonomic Description

1. *Amanita constricta* Thiers & Ammirati, Mycotaxon, 1982 (Images 1–2)

The cap 5–7.5cm wide, convex when young, becoming plano-convex to plane, eventually subumbonate to umbonate in old age, strongly sulcate to tuberculate striate margin. Cap brownish-gray, often with inconspicuous dark radial streaks. Flesh usually white, sometimes becoming faintly pinkish with exposure. Volva mainly present as a membranous fibrillose patch over the umbo; white to buff to smoke gray-brown-salmon color. Gills are close to crowded, adnate to decurrent by a short hook when young, becoming free, white at first, becoming gray, and drying tan to sordid tan to brownish gray. Gills are moderately broad with the edge usually gray and fibrillose. The stipe is 6–9cm long x 1–1.5cm wide, white, cylindric or narrowing upward, and exannulate. Hyphae 2.5–7.5µm wide. Basidia 37–

Image 1. *Amanita constricta*: A– habits | B– details of sporophore.

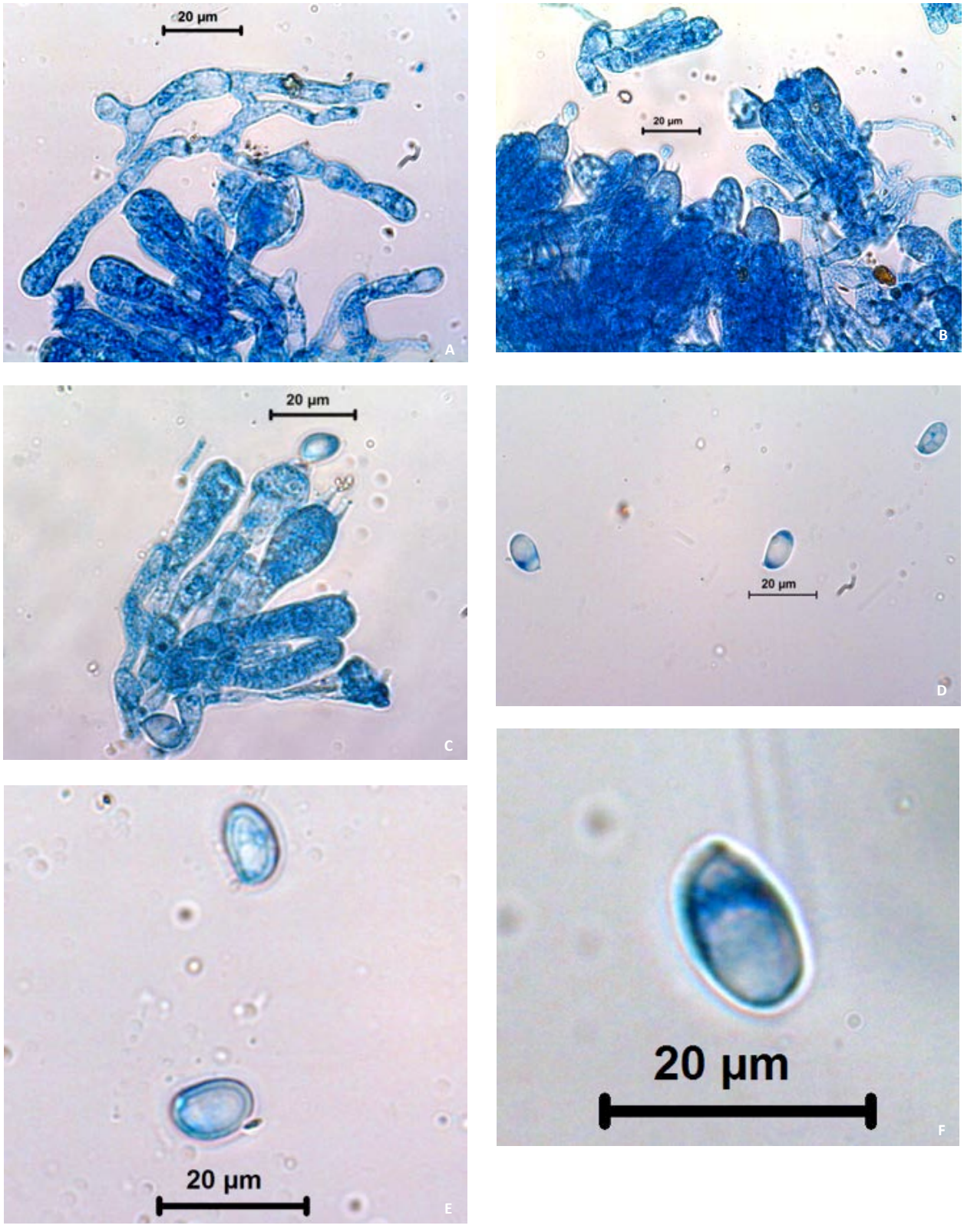

Image 2. ***Amanita constricta*****: A–B—pileial element and basidia | C—basidia with sterigmata | E–F—basidiospores.**

60 x 10–12.5 µm, sterigmata, 4 measuring 2.5–3.7µm. Basidiospores measure 10–13.7 × 5.0–8.7µm, inamyloid, globose to subglobose to broadly ellipsoid. Pileial element cells 10–20µm wide.

Collection examined: TF- 4060, 19.vii.2018 on soil surface in sal forest, Bajag forest range, Chada Road, Dindori, Madhya Pradesh. Specimen deposited in Mycology Herbarium, Tropical Forest Research Institute, Jabalpur.

2. *Amanita velosa* (Peck) Lloyd,
Mycol. Writ., 1898 (Images 3–4)
≡ *Amanitopsis velosa* Peck

The cap is 3–7cm which is pale yellowish-orange to pale orangish, pale orange or yellowish-orange to brownish orange, sometimes becoming paler toward margin; margin conspicuously grooved or striate, surface viscid when moist, smooth, pinkish-buff to orange-buff, fading with age, white, without staining. The pigment is sometimes washed out entirely by heavy rain; the fleshy cap lacks an umbo. The stipe is 2–8 × 1.5–2.0cm white to pale orange-white above, white below; it bears a robust, white, membranous, sack-like volva with pointed scales, tapering to an enlarged base; surface white, smooth to pruinose above, sometimes scaly below, universal veil forming a membranous, white cup-like volva at the base. The gills are free to narrowly adnate, crowded, off-white to pale cream to pale orangish cream in mass, with some reverse forking and anastomosing present; the short gills are more or less truncate, plentiful, unevenly distributed, of diverse lengths, occasionally adjacent to the stipe as well as to the margin. Gills close, white, sometimes with pinkish tones in age, attachment variable: free to slightly adnate or adnexed. Basidia 37.5–40.0 x 7.5–12.5 µm, sterigmata 3.7–5.0 µm, clamps are not present at bases of basidia. Basidiospores, sub-globose to broadly ellipsoid, smooth-walled, inamyloid, hyaline, measuring 7.5–12.5 x 6.2–8.5µm; spore print white.

Collection examined

TF – 4059, 19.vii.2018 on soil surface in sal forest, Bajag forest range (Chada Road), Dindori, Madhya Pradesh. Specimen deposited in Mycology Herbarium, Tropical Forest Research Institute, Jabalpur.

Discussion

Amanita constricta was earlier recorded on the Pacific coastal hardwood species such as oak, arbutus or madrone (family Ericaceae) and Douglas fir, *Pseudotsuga* sp.), it grows singly or in scattered form during December–January. The species is distributed in California and extends into southwestern Canada (Thiers & Ammirati 1982). *A. velosa* was recorded earlier from oak *Quercus agrifolia* and coast live oak from Oregon and California (USA) and Baja, California Peninsula, Mexico (Lloyd 1898). Other species of *Amanita* reported from India and recorded in sal forests are: *A. banningiana, A. bisporigera*, *A. chepangiana, A. ocreata, A. pantherina, A. populiphila, A. shorea* and *A. vaginata*. Among them *A. bisporigera* and *A. pantherina* were distributed in sal forest of Dindori, Madhya Pradesh (Verma & Pandro 2018). *A. chepangiana* is recorded from forests dominated by *Shorea robusta* and *Tectona grandis* and oak from Uttarakhand and Himachal Pradesh (Semwal et al. 2014), *A. shorea* was grown in pure sal forest of Himachal Pradesh (Singh & Kaur 2016). *A. banningiana, A. ocreata* and *A. vaginata* form ectomycorrhizal association with sal trees of Gidhani, Birbhum, Ilambazar (West Midnapur) and Kailibandh, Bishnupur (Bankura) sal forests of West Bengal (Pradhan et al. 2012). *Amanita velosa* is an edible mushroom (Boa 2004). Other edible *Amanita* spp. reported include *Amanita fulva* (Bhatt & Lakhanpal 1988), *A. rubescens* (Bhatt & Lakhanpal 1989), *A. chepangiana, A. hemibapha* and *A. vaginata* (Semwal et al. 2014; Vrinda et al. 2005a). *Amanita constricta* and *Amanita velosa* were collected from sal forest of Bajag, Dindori, Madhya Pradesh (India) in the present study. *A. ceciliae* and *A. pachycolea, A. submembranacea* and *A. vaginata* are comparable to *A. constricta. A. constricta* showed some similarity with *A. ceciliae* but the latter has bigger caps (5–12 cm) with grayish patches and longer stipe (7–18 cm). *A. pachycolea* also has bigger caps (7–18 cm), longer stipe (10–25 cm) and broader spores (9–14 x 9–12 µm). *A. submembranacea* differed in cap size (11.5cm) with olivaceous-pallid margin and roughly spherical spores. *A. vaginata* differ with *A. constricta* in having longer stipe (7–15 cm) with subglobose spores (8–12 µm).

Amanita velosa is an edible mushroom grows solitary to scattered during rainy season (collected on 19 July 2018) and fruit bodies were recorded in open areas of sal forest. About 20–25 fruit bodies were recorded in 25m squire area on forest ground. *A. velosa* showed some *similarity with deadly poisonous mushroom, A. ocreata, but it* differed in cap size (*A. ocreata* cap reach up to 12cm in diameter). The stipe in *A. ocreata* are *also longer (*8–20 cm) with relatively broader spores (9–14 x 7–10 µm).

So far, a total of 73 species of *Amanita* are recorded from India (Verma et al 2018b) whereas 1,550 names were proposed under the genus *Amanita* from the world as indicated in the index fungorum. (http://www.indexfungorum.org).

Image 3. ***Amanita velosa***: **A–C—fruit bodies emerging in sal forest on open area | D—fruit body with fallen gill cover after sloughing off | E—fruit body eaten by some insect | F–G—fruit body showing volva, stipe and gills.**

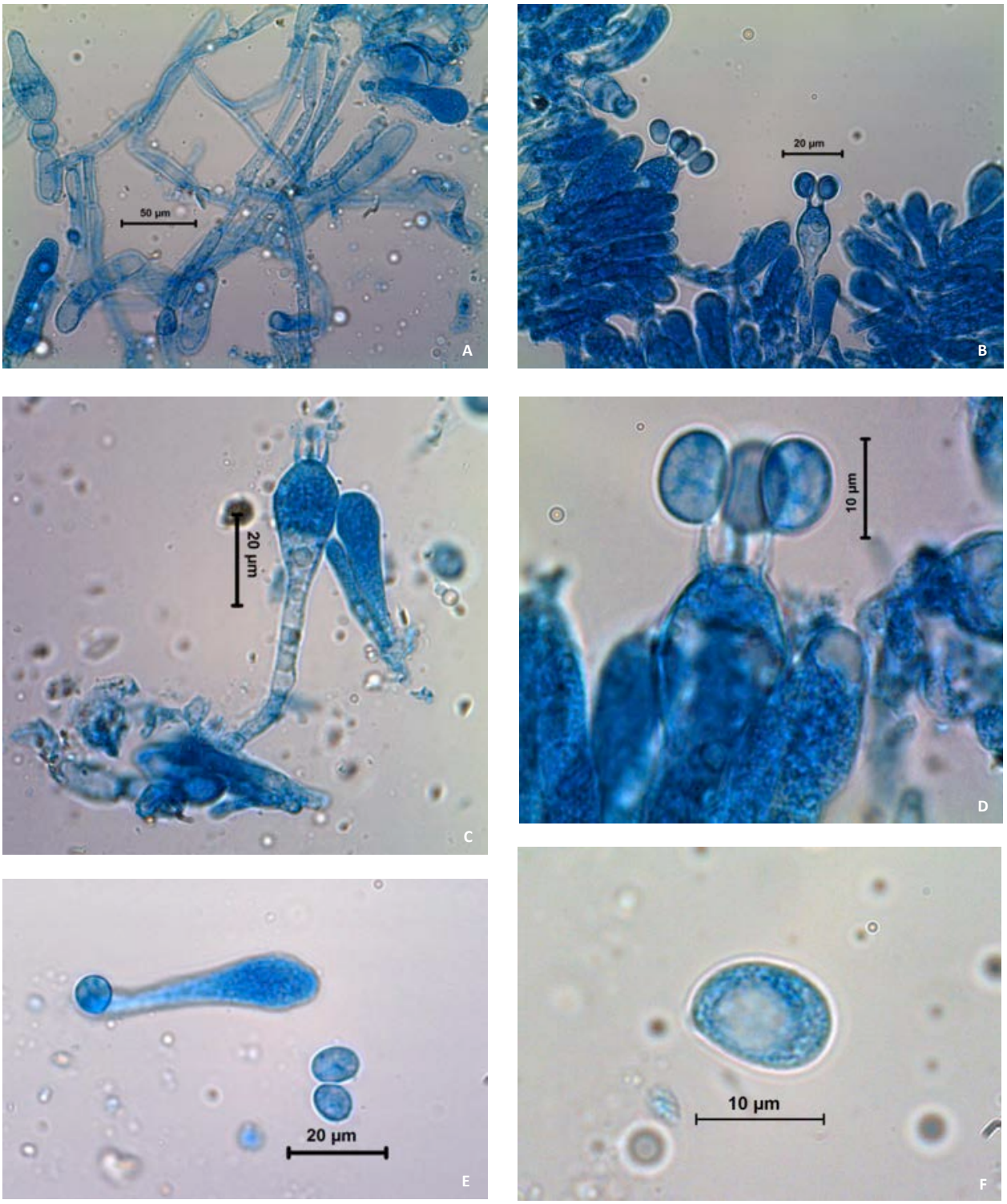

Image 4. ***Amanita velosa*****: A—mycelium networks | B—basidia with attached developing basidiospores| C—basidium showing detail | D—basidium and developing spores attached on sterigmata | E—basidiospores | F—a single basidiospores (enlarged).**

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NOTE

A first record of oviposition of Common Onyx *Horaga onyx* Moore, 1857 (Insecta: Lepidoptera: Lycaenidae) in Sri Lanka and its importance in conserving a highly threatened butterfly

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Horaga onyx (Moore 1857) commonly known as the Common Onyx or Blue Onyx is a Lycaenid butterfly found in Sri Lanka. The Sri Lankan population was described as *Horaga onyx cingalensis by* Moore (1884); it is also found in India. Adult butterflies are very seldom seen, and have been historically recorded very infrequently and in very low numbers. The biology of this butterfly in Sri Lanka is unknown and was placed under the Data Deficient category in IUCN Red List in Sri Lanka in 2007 (IUCN & MOENR 2007). In 2012 it was declared critically endangered in the National Red List (MOE 2012).

H. onyx was reported to occur mainly in the hills, up to an elevation of about 760m (d'Abrera 1998). It has been historically recorded from Kandy, Rathnapura, Deniyaya, Kottawa and a few other locations in the Galle District (Ormiston 1924; Woodhouse 1949) (Figure 1). Recently it was recorded from the Sinharaja Forest Reserve at Kudawa and Deniyaya (van der Poorten & van der Poorten 2018) and at Pallekele (Moditha Kodikara Arachchi pers. obs. 27.vii.2018) (Figure 1). The larval food plant of *H. onyx* in India has been recorded as *Coriaria nepalensis* (Coriariaceae) (MacKinnon & de Nicéville 1898; Chandrasekharan 2019). *Glochidion rubrum* (Phyllanthaceae) has been reported as a larval food plant in Taiwan and *Litsea rotundiflora* (Lauraceae) in Hong Kong (Igarashi & Fukuda 2000). Kasambe (2016) reported oviposition on *Crassocephalum crepioides* (Asteraceae) in southern Western Ghats of India and suggested it being a potential larval food plant. No information on the early stages or oviposition behavior of *H. onyx* has been previously recorded in Sri Lanka, and the observations from this location are the first.

Observations of the oviposition behavior was recorded using two binoculars; a Bushnell 8x42 and Swarovski 10x56. All images were taken with a Canon 7D Mark II DSLR camera with 100–400 mm lens.

Observations were carried out at Enasalwatta, situated about 7km (aerial distance) northeast of Deniyaya Town, in southern Sri Lanka. It is a part of the Sinharaja Forest Reserve with elevation ranging 800–1,200 m. Lower

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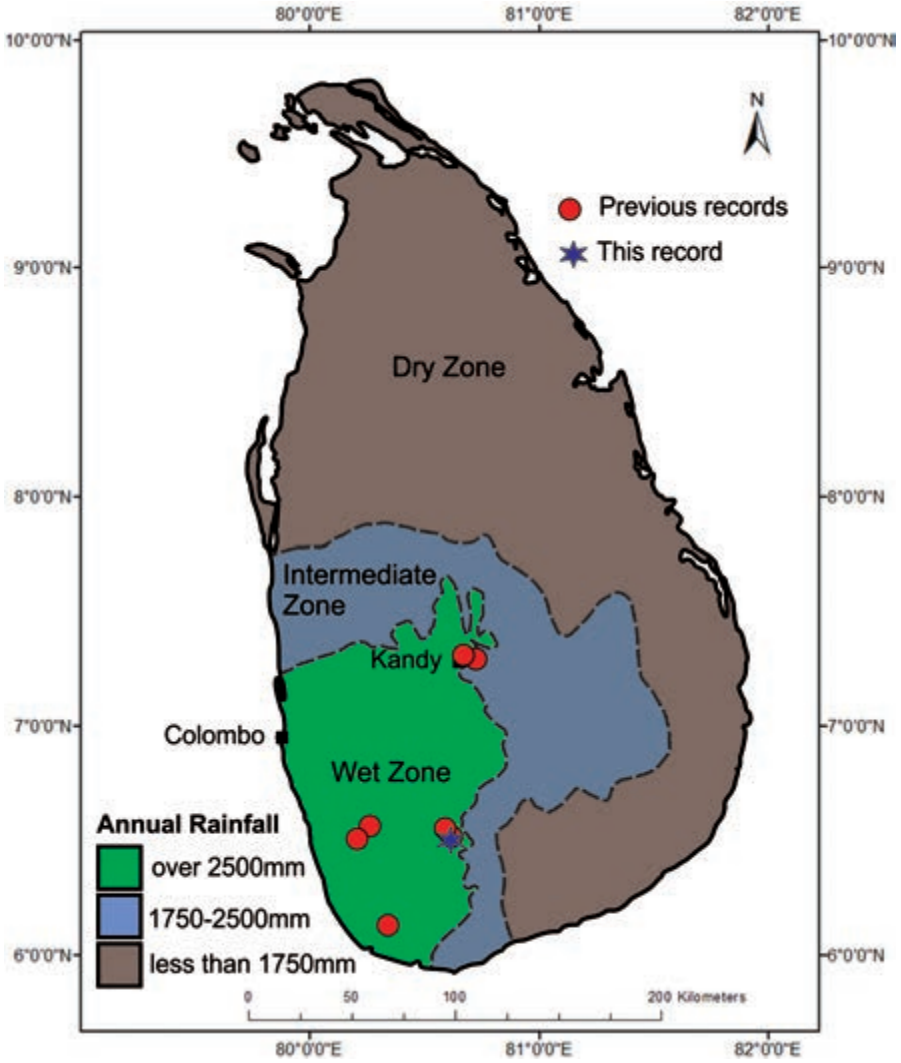

Figure 1. Records of *Horaga onyx* in Sri Lanka (modified after van der Poorten & van der Poorten (2018)).

montane evergreen forests are observed in this area (Image 4) with layering of the forest vegetation typical to that of primary rainforests (Gunatilleke et al. 2008). Average annual rainfall of this area is 5,000–6,000 mm, with most precipitation during the southwest monsoon between May and September, followed by the inter-monsoon rains and the northeast monsoon (Department of Meteorology, Sri Lanka 2019)

On 14 July 2019, a female *H. onyx* was observed flying around a *Macaranga indica* (Euphorbiaceae) tree in Sinharaja Forest Reserve at Enasalwatta, Deniyaya, Sri Lanka (6.391^{0}N & 80.604^{0}E). The elevation of the site is 1,024m. Relative humidity at the time of observation was around 65% with varying cloud cover of 20–70 %. The observations recorded here were made adjacent to a stream near a roadside tree that was about six meters in height. *M. indica* Wight, 1852, is native to Sri Lanka, occurring from wet lowlands to montane forests (Dassanayake 1997) and can be seen regularly on roadsides and forest edges in this area. It was identified with its characteristic leaves, which are large, with slender petioles; 6–18 cm, blades ovate, papery, base broadly rounded and peltate, apex acute, numerous palmate secondary nerves arising from petiole insertion, few conspicuous elongate glands on main nerves beside petiole insertion of which two were most prominent and was used to separate this species from *Macaranga peltata* (Euphorbiaceae) which is the only confusion species and lacks these glands. The tree was at the flowering stage with its flower panicles formed along the branches.

The butterfly was identified by its characteristic white band on the underwing which was broad over both fore- and hind-wings (Image 1), distinguishing it from

Image 1. *Horaga onyx* female perched on *Macaranga indica* leaf.

Image 2. *Horaga onyx cingalensis* egg on the base of a developing inflorescence of *Macaranga indica.*

Image 3. *Horaga onyx cingalensis* egg on a branchlet of *Macaranga indica*.

Image 4. Lower montane forest habitat in the area.

the similar Brown Onyx (*H. albimacula*). Less extensive and less intense blue on upper wings implied that it was a female (Woodhouse 1949; d'Abrera 1998; van der Poorten & van der Poorten 2018). The butterfly flew around the periphery of the tree, seldom moving away. It flew over the entire canopy crown which ranged from three to six meters high from ground level, but favored the sun-lit side. It perched on leaves to sun bathe several times but seldom remained for more than about 40 seconds on a leaf, before flying off again. In one instance it flew down and perched briefly on a bush near the ground.

From time to time the female flew from its perch on to the peduncle of an inflorescence with developing flower buds. On one occasion, it perched near the base of the inflorescence, moved to the developing floral buds, curved its abdomen and placed a single egg on it (Image 2). In some instances, although it flew on to a branchlet or a flower panicle, no ovipositing was observed. Just after ovipositing, the butterfly was seen flying over the canopy and was not seen again on that day. These observations were made from 12.25h to 12.40h during which time the sky was clear with intermittent clouds; a slight drizzle occurred in the morning.

The next day, on 15 July 2019, we observed a female flying around the same tree between 09.20h and 09.30h but were unable to confirm whether or not it was the same individual seen the day before. During the short period observed, it oviposited once. This time the egg was laid directly on a branchlet, close to a flower panicle (Image 3). In other respects its behavior was similar to that seen the day earlier. It appears, judging from its oviposition behavior and the location where eggs were

laid, that the larvae feed on flowers and flower buds.

The current information obtained from this site is crucial for gathering further information on the biology of this species and paves the way to understand its restricted distribution and scarcity. This is particularly relevant because of the dearth of information on the biology of the species, which has been a drawback to the development of a conservation strategy to protect this highly threatened subspecies. Further, *M. indica* must be confirmed as the larval host plant of this species by rearing larvae to successful emergence of adults. Until such time, the suggested larval food plant here must be considered tentative, since it is well known that some species sometimes oviposit on plants that are not used as larval food plants.

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Additions to known larval host plants of butterflies of the Western Ghats, India

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The Western Ghats is rich in butterfly diversity, consisting of 336 species in six families (Nitin et al. 2018). Butterfly diversity largely depends on host plants and their supporting habitat (Knops et al. 1999). Host plants are essential for the butterfly's lifecycle because caterpillars usually feed on a narrow set of plants that are acceptable based on nutritional and chemical requirements. Documentation of larval host plants is essential for conservation management and ecological studies of butterfly diversity. Compared to other parts of India, the larval host plants of Western Ghats butterflies are well documented (Gunathilagaraj et al. 1998; Kunte 2000, 2006; Kalesh & Prakash 2007; Kehimkar 2008; Nitin et al. 2018). In addition, a recent survey showed that there are 834 plant species used as hosts by 320 species of butterflies in the Western Ghats (Nitin et al. 2018). Even though host plants are well documented for the Western Ghats, knowledge of site-specific preferences still needs to be investigated.

Our previous studies documented 172 species of butterflies and recorded host plants from southwestern Western Ghats located in Dakshina Kannada, Karnataka (Naik & Mustak 2015, 2016). Besides these studies, there are no reports of host plants from the study region. Our current study observed four new host plants in the families Poaceae, Rhamnaceae, and Fabaceae**,** which are used by four different species in three butterfly families**,** namely Hesperiidae, Pieridae, and Lycaenidae**.**

From 2016–2018**,** we recorded the host plants of butterflies by observing their early stages and successfully rearing caterpillars in the lab to confirm plant identifications. Butterflies were determined by using field guides (Kunte 2000; Kehimkar 2008; Kunte et al. 2018), while plants were identified by using the floras of Udupi and Dakshina Kannada (Bhat 2003, 2014) and confirmed with the help of experts.

Family Hesperiidae

Pelopidas agna agna **(Moore, 1866) Bengal Obscure Branded Swift:** *Pennisetum* sp. Rich. (Poaceae) (Image 1) is a new record for the Western Ghats. Perennial or annual grass, tall, erect with narrow, flat or convolute leaves, commonly seen in cultivated land, reported in Kollamogaru, Sullia, in September 2016. Studies by Kalesh & Prakash (2015) and Nitin et al. (2018) earlier reported *Axonopus compressus* (Sw.) P. Beauv. (Poaceae) as a host plant.

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Image 1 - *Pennisetum* sp. (Rich.)

Image 2 - *Ventilago maderaspatana* (Gaertn.)

Family Pieridae

***Eurema andersonii shimai* (Yata & Gaonkar, 1999) Sahyadri One-spot Grass Yellow:** *Ventilago maderaspatana* (Gaertn.) (Rhamnaceae) (Image 2) is a new record for the Western Ghats. It is a large woody climber often seen in moist mixed deciduous and semi-evergreen forests, reported in Bantaje Reserve Forest, Puttur, and Kollamogaru, Sullia, in October 2017. In addition to the above species, previous studies reported *Ventilago goughii* Gamble (Rhamnaceae) (Yata & Gaonkar 1999; Nitin et al. 2018) as the host plant in the Western Ghats.

Family Lycaenidae

***Rapala manea schistacea* (Moore, 1879) Bengal Slate Flash:** *Senna tora* (L.) Roxb. [syn. *Cassia tora* L.] (Fabaceae) (Image 3) is a new host-plant record for the Western Ghats. An annual herb with yellow flowers, leaves up to 10cm long with 2–4 leaflets, it was a common weed in Kudremukh Wildlife Sanctuary, Belthangady, in November 2018. Numerous other reported host plants include *Mangifera indica* L. (Anacardiaceae) (Robinson et al. 2010), *Combretum indicum* (L.) DeFilipps (Combretaceae), *Acacia caesia* (L.) Willd., *A. megaladena* (Desv.), *A. pennata* (L.) Willd., *A. torta* Craib (Roxb.) (Fabaceae), *Averrhoa bilimbi* L. (Oxalidaceae), *Antidesma acidum* (Retz.), *A. ghaesembilla* (Gaertn.) (Phyllanthaceae), *Ziziphus* sp. (Mill.) (Rhamnaceae), *Sorbaria sorbifolia* (L.) A.Braun (Rosaceae), *Camellia sinensis* (L.) Kuntze (Theaceae) (Wynter-Blyth 1957; Kunte 2000), *Mimosa invisa* (Mart.), *Saraca asoca* (Roxb.) de Wilde (Fabaceae), *Clerodendrum infortunatum* L. (Lamiaceae), *Urena lobata* L. (Malvaceae), *Lepisanthes tetraphylla* (Vahl) Radlk (Sapindaceae) (Saji et al. 2018), and *Lantana camara* L. (Verbenaceae) (Nitin et al. 2018) from various parts of the Western Ghats.

***Cheritra freja butleri* (Cowan, 1965) Sahyadri Common Imperial:** *Bauhinia phoenicea* Wight &Arn. (Fabaceae) (Image 4) is a newly reported host plant for the Western Ghats. Large climbing shrub, leaves orbicular and deeply bifid, lobes acute, often seen in semi-evergreen forests, reported in Thodikana, Sullia, in December 2017 and Someshwara Wildlife Sanctuary, Karkala. In addition to the above new host plant, *Saraca asoca* (Roxb.) de Wilde (Fabaceae) (Bell 1919; Wynter-Blyth 1957), *Xylia xylocarpa* (Roxb.) Taub. (Fabaceae), (Davidson et al. 1896; Bell 1919; Wynter-Blyth 1957; Robinson et al. 2010), *Cinnamomum camphora* (L.) J.Presl, *C. macrocarpum* (Hook.F.), *C. verum* (J.Presl) (Lauraceae), *Ixora* sp. L. (Rubiaceae) (Wynter-Blyth 1957), and *Lepisanthes tetraphylla* (Vahl) Radlk. (Sapindaceae) (Saji & Ogale 2018) were reported as host plants in the Western Ghats.

Image 3 - *Senna tora* (L.) Roxb.

Image 4 - *Bauhinia phoenicea* Wight &Arn.

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NOTE

Rhynchotechum parviflorum Blume (Gesneriaceae): a new record to mainland India

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The genus *Rhynchotechum* Blume is a group of understory shrubs distributed in southeastern and eastern Asia, from India to Japan (Odyuo & Roy 2017). It is characterised by having opposite to alternate leaves, pink flowers arranged in cymose inflorescences and white indehiscent berries. It has recently been revised by Anderson & Middleton (2013) who recognized a total of 16 species, of which nine are distributed in India namely (*R. alternifolium* C.B.Clarke, *R. calycinum* C.B.Clarke, *R. ellipticum* (Wall. ex D.Dietr.) A.DC., *R. gracile* B.M. Anderson, *R. hookeri* (C.B.Clarke) B.M.Anderson, *R. obovatum* (Griff.) B.L.Burtt, *R. parviflorum* Blume, *R. permolle* (Nees) B.L.Burtt, and *R. vestitum* (Griff.) Wall. ex C.B.Clarke) from which seven (with the exception of *R. parviflorum* and *R. permolle*) are from northeastern India.

Arunachal Pradesh, the largest state in northeastern India covering an area of 83,743km^2, has the second largest forest cover (67,248km^2) in the country (Gurung et al. 2003). The state falls under the continuous belt of Himalaya extending from the plains of Assam to the steppe rugged alpine mountainous belts neighbouring Tibet and Bhutan. Recent studies on the family Gesneriaceae of the state have led to the publication of several new species such as *Boeica clarkei* Hareesh et al. (2018), *Didymocarpus moellerii* A. Joe et al. (2016: 57), *Lysionotus bijantiae* D. Borah & A. Joe (2018: 232), and *L. gamosepalus* W.T. Wang (1983) var. *biflorus* A. Joe et al. (2017: 337). *Rhynchotechum* is known in the state by all the five species present in northeastern India except for *R. hookeri* (distributed in Assam, in almost opposite boundary neighbouring West Bengal and Bangladesh) and *R. gracile* (known from previous Assam, which consisted most of the northeastern states also Arunachal Pradesh, the locality of the type collection is unknown, and hence its distribution in Arunachal Pradesh is doubtful) (Anderson & Middleton 2013). Even a new species of *Rhynchotechum* (under press) is also found from the state. The genus has very little economic importance owing to its congeners in the family, though plants under this genus are known to have some ethnobotanical uses (Kayang 2007). Considering the richness in diversity, the state has high potential for discovery of both new species and records for the region.

On recent studies conducted on the ethnobotany of

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Image 1. ***Rhynchotechum parviflorum*** **Blume: A—habit | B—inflorescence | C—inflorescence branch | D—part of calyx.**

Adi-Komkar tribe in Upper Siang District of Arunachal Pradesh, an interesting specimen of *Rhynchotechum* was collected. After study of different literature (Clarke 1874, 1884; Wang et al. 1998; Anderson & Middleton 2013; Sinha & Datta 2016; Odyuo & Roy 2017; Roy et al. 2019), and consultation of herbarium specimen housed at different herbaria (CAL, ARUN, ASSAM, K, E, PE), it was identified as *R. parviflorum*, the type species of the genus known previously from Myanmar, Thailand, Vietnam, China, Sumatra, Kalimantan, Sulawesi, Indonesian New Guinea, Papua New Guinea, Philippines, and Nicobar Islands of India. The presence of this species in the state is not unexpected, considering its distribution in the neighbouring countries. As there is no record of this species from mainland India, the authors hereby report the newly collected specimen as the first authentic distribution record of *R. parviflorum* in mainland India.

***Rhynchotechum parviflorum* Blume,**

Bijdr. Fl. Ned. Ind. 775 (1826); C.B.Clarke in Hook.f., Fl. Brit. India 4: 373 (1884); Vietnam 3(1): 25 (1993); B.L.Burtt, Thai Forest Bull., Bot. 29: 107 (2001) (Image 1 & 2).

Subshrubs, branched or unbranched; stems 30–150 cm tall, 0.5–1.2 cm diameter. Leaves opposite, to sub-opposite; petiole 1.9–5 cm long, glabrous, green; blade broadly elliptic to obovate, 16–27 cm × 8–13 cm, apex acute, base narrowly cuneate to cuneate, margin crenate, adaxially dark green glabrescent, abaxially pale yellow, rusty woolly at young stage, glabrescent when mature, brown pubescent on veins; mid vein channelled, impressed above, raised below, lateral veins opposite to sub-opposite, 12–24 pairs. Inflorescence green to rusty brown, 1.5–3 cm long, 1–2 branched, rusty villous; bracts widely subulate, pinkish, slightly membranous, rusty pubescent to glabrous; pedicel 4–7 mm, villous; calyx greenish to pinkish-brown, lobes triangular with apices rounded 6–8 mm × 1–1.5 mm, villous; corolla glabrous, pink, zygomorphic with a dark purple spot in the base, tube short upper lobes 1–1.2 × 0.8–1 mm, oblong, apex rounded, lower lobes 1–1.5 × 1–1.2 mm, stamens inserted at the base of the tube, filaments 0.5–1 mm, anthers 1 mm across, ovary 1 × 1 mm, shortly puberulent; style white, 3–5 mm long, stigma white, truncate. Berries not seen.

Phenology: Flowering May–June

Note: *Rhynchotechum parviflorum* is nearly similar to *R. calycinum* and *R. hookeri* in having oblanceolate to elliptic ovate leaves, short fascicled inflorescence and sericeous pedicel whereas differs in having villous calyx lobes (vs. glabrous in *R. calycinum*), puberulent and shorter style (vs. glabrous to pubescent and longer style in *R. hookeri*).

Image 2. *Rhynchotechum parviflorum* Blume: A—habitat | B—showing the reduced inflorescence with green calyx parts.

Ethnobotany: Tender shoots are eaten raw; Jongkot (Adi-Komkar)

Ecology and distribution: It usually prefers cliffs near perennial streams in primary forests as well as in secondary forests and damp groves near roadsides. It grows in association with *Diplazium esculentum, Lysionotus bijantiae, Henckelia pumila, Boeica clarkei, Rhynchotechum vestitum, Pilea insolens, Pilea umbrosa, Mycetia mukerjiana, Cyclosorus parasiticus, Strobilanthes hamiltoniana, Justicia* sp. etc.

Conservation status: Least Concern.

Specimen examined: 5068 (HAU), 18.vi.2018, Sikem, Upper Siang District, Arunachal Pradesh, India, 28°21'39"N, 95°4'17"E, 300m, coll. M. Taram and O. Taku (Image 3).

Type: Java, Seribu mountains, Blume s.n. [barcode: 0834014]

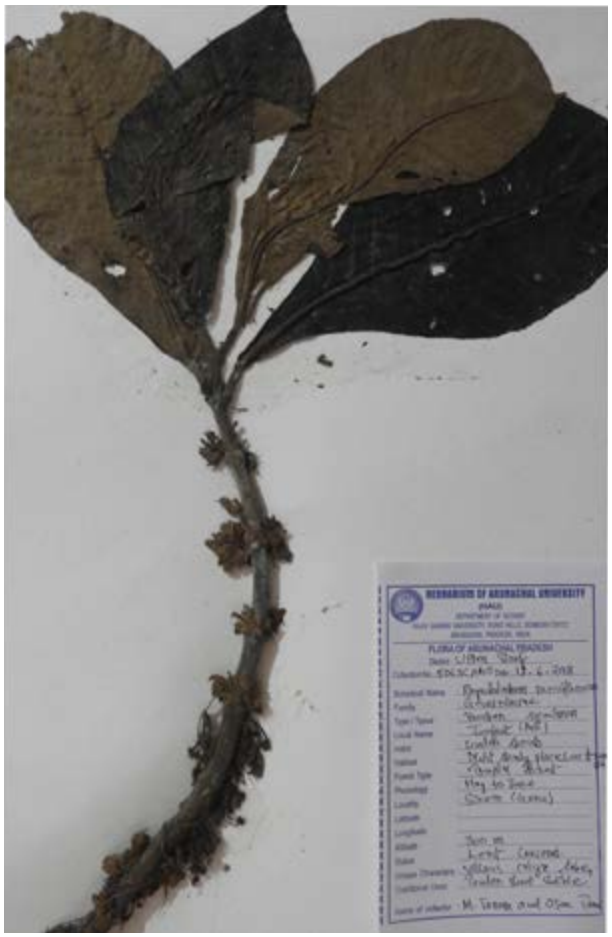

Image 3. Herbarium sheet of *Rhynchotechum parviflorum* Blume (5068 (HAU)).

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NOTE

Re-collection of the Luminous Lantern Flower *Ceropegia lucida* Wall. (Apocynaceae) from Assam, India

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Ceropegia lucida Wall. was first described by Wallich from Terrya Ghat, Sylhet, Bangladesh in the year 1831. Following that, the plant was also reported from the Khasia Hills, Meghalaya by Hooker & Thomson and by Wallich from Prome, Burma. It was also reported from China, Malaysia and Thailand (Siam). King collected this species from Sikkim in 1874 which was considered as the last collection of the century making it endangered or possibly extinct in India as stated by Nayar & Sashtry until its rediscovery and new distribution record from the Namdapha National Park, Arunachal Pradesh in 2017. Nautiyal's record from Sikkim in 2009 is considered as a misidentification of *Ceropegia longifolia* (Khandal et al. 2017).

During a recent floristic survey to the Golaghat District, Assam during the period from August to October, 2018, the authors came across many interesting plant specimens. On consultation with the existing literature (Wallich 1831; Hooker 1883; Kanjilal et al. 1939; Ansari 1984; Kambale 2015) and herbarium specimens deposited at KEW and CAL, this specimen was confirmed as *Ceropegia lucida* Wall.

Ceropegia lucida Wall.

Pl. Asiat. Rar. 2:33, t.139. 1831; Hook.f., Fl. Brit. India 4: 73. 1883; P.C. Kanjilal et al., Fl. Assam 3: 309. 1939; H. Huber, Mem. Soc. Brot; 12, 1-203. 1957; Ansari, Fasc. Fl. India 16: 22. 1984; M.P. Nayar & Sastry (eds.), Red Data Book Indian Pl. 2: 44. 1988; A.P. Jagtap & N.P. Singh, Fasc. Fl. India 24: 229. 1999.

According to the protologues and the existing literature, *Ceropegia lucida* Wall. is a perennial twiner with glabrous stems (Image 1). The leaves are bright green, glabrous, simple, opposite and decussate with elliptic to oblong leaf lamina, 5–11cm x2.3–4.9 cm, petiole 1.4-1.6 cm. The apex is acute to acuminate and base is narrower. Inflorescence axillary with 2-6 flowered umbellate cymes, peduncle 1.5cm (Image 2). Flowers are 1.2–3.2 cm long, greenish or yellowish-white with purple spots, pedicel 1–1.5 cm. Calyx five partite, linear to subulate. Corolla tube cylindrical with a funnel shaped throat and rings of hairs in the wider part. Corolla lobes are greenish-white with purple spots on it, connate at the apex margined by long translucent hairs (Image 3). Corona is biseriate with five bifid deltoid

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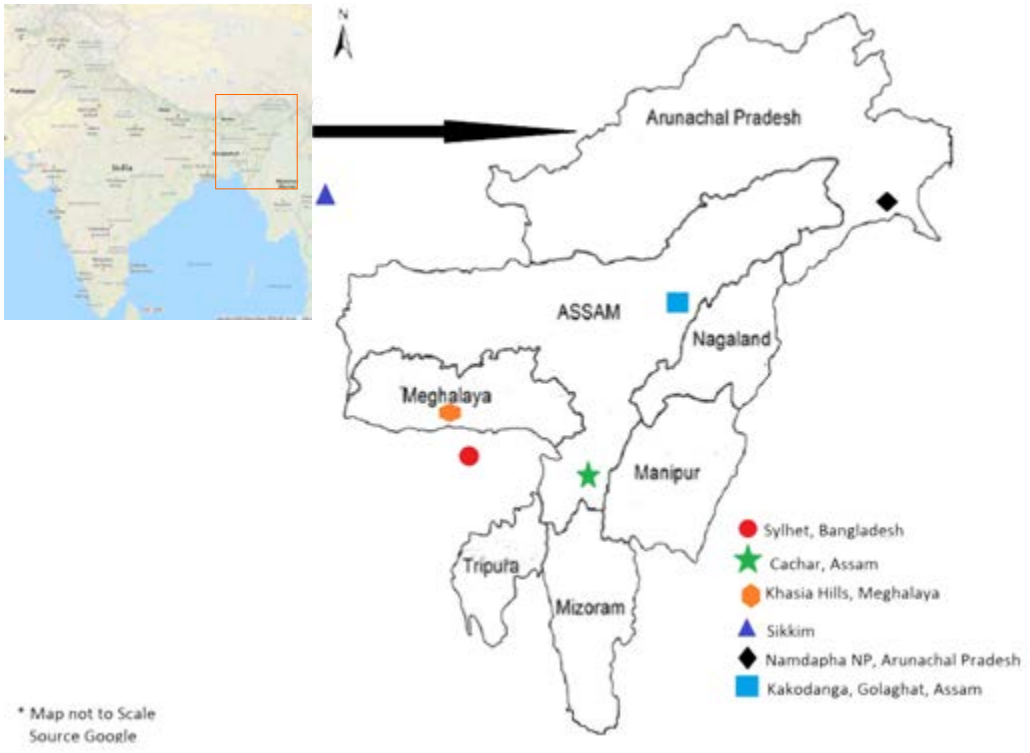

Figure 1. Known locations of *Ceropegia lucida* Wall. in northeastern India.

Image 1. Habit of *Ceropegia lucida* Wall.

Image 2. Inflorescence with leaves of *Ceropegia lucida* Wall.

lobes on the outside and five erect linear to clavate lobes on the inside.

Flowering: September to November; fruits not seen.

Specimen examined: Bangladesh, Sylhet, N. Wallich (K001129042, image!); INDIA. Cachar, Assam, June 1874, R. L. Keenan s.n. (K001325174, image!); Sikkim 1874, G. King s.n. (CAL0000031920, image!); Kakodanga, Golaghat, Assam, 25.xi.2018, D. Dey & M. Baruah, DDM01 (GUBH).

Distribution: India (Arunachal Pradesh (Namdapha National Park), Assam (Cachar, Golaghat), Meghalaya (Khasia Hills), Sikkim), Bangladesh (Sylhet), Myanmar (Prome), Thailand, Malaysia, China.

Population and habitat: The authors came across the plant twining on an abandoned streamside land mass from the Golaghat District of Assam. The twiner grew in close association with bamboos, ferns and other climbers like pipers, *Paederia foetida* etc. Since only 5–6

Table 1. A comparative analysis of *Ceropegia lucida* Wall. with other closely related species of northeastern India.

Attributes	*Ceropegia macrantha* Wight (Kambale & Yadav 2019).	*Ceropegia longifolia* Wall. (Kambale & Yadav 2019).	*Ceropegia lucida* Wall. (Kambale & Yadav 2019; present study).
Leaves	Ovate to lanceolate, 4.5–14 x 2–7 cm.	Lanceolate to linear, 5.7–20.3 x 0.4–3.8 cm.	Elliptic to oblong, 5–11 x 2.3–4.9 cm.
Petiole	1.2–2.4 cm long.	0.5–0.8 cm long.	1.4–1.6 cm long.
Inflorescence	4–5 flowered, subumbellate cymes, peduncle 1.2–2.7 cm long, hairy in rows.	5–12 flowered, umbellate cymes, peduncle 1.8–4 cm long.	2–6 flowered, umbellate cymes, peduncle c. 2cm long, fleshy.
Pedicel	*c.* 0.8cm long, glabrous.	0.5–1.2 cm long, puberulous.	1–1.5 cm long, glabrous
Corolla	2.5–7.6 cm long with pink spots throughout, tube cylindrical, 1.8–3.2 cm long.	1.6–3.8 cm with dark purple spots restricted to the funnel shaped throat only, tube curved, 0.5–2.5 cm long.	1.8–2.7 cm long with purple spots throughout, tube cylindrical, 1.2–2.5 cm long.
Lobes	2.4–2.8 cm long, yellow at lower and dull green at upper half, linear to lanceolate.	0.5–1 cm long, yellowish-green with dark purple spots, elliptic to ovate.	0.7–2.5 cm long, greenish white with purple spots, broadly or elliptic oblong.
Corona	Outer of 5 deeply bifid, pink coloured densely haired lobes, inner of 5 linear lobes.	Outer of 5 deeply bifid deltoid lobes, ciliate along and within margins, inner of 5 linear sub-spathulate lobes.	Outer of 5 shortly bifid- deltoid lobes, ciliate along margins, inner of linear-clavate lobes.

Image 3. A single flower of *Ceropegia lucida* Wall.

number of individuals were observed growing in a single population, only a single plant with a single matured flower was collected for preservation and herbarium making. The voucher specimen has been deposited at the GUBH, Gauhati University, Guwahati (DDM01).

Discussion: According to the Flora of British India, Vol. IV. 73pp. and herbarium specimen (K001325174, image!); R.L. Keenan had collected this plant from the Cachar District of Assam in June, 1874 after which it was neither collected nor reported from anywhere within the state. Barbhuiya in 2013 categorized it as "Regionally Extinct" after being unable to locate it in its site of occurrence. In a significant finding, the authors came across this plant in Golaghat District of Assam after a gap of 145 years. A few photographs of the plant as well as the herbarium specimen DDM01 (Image 4) along with a map (Figure 1) are provided to aid in its proper identification. Also, a comparative analysis of *Ceropegia lucida* Wall. with other closely related species of northeastern India (viz., *C. macrantha* Wight and *C. longifolia* Wall.) is given in Table 1.

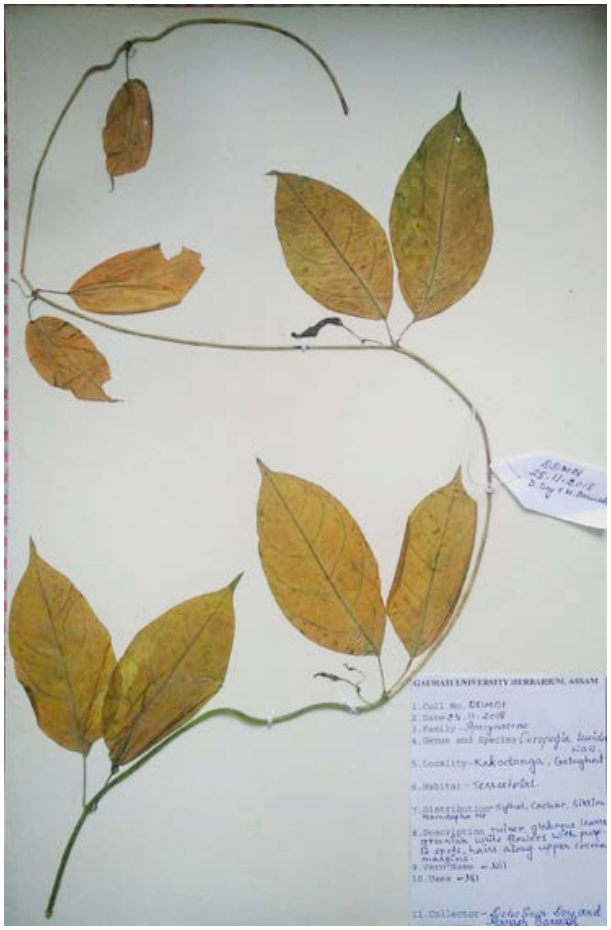

Image 4. Herbarium of *Ceropegia lucida* Wall. Photographed by Manash Baruah.

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NOTE

Tetrasporidium javanicum Möbius (Chlorophyta), a rare species recorded from Arpa River in Bilaspur, Chhattisgarh, India

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Chhattisgarh State is located in the central eastern part of India, a part of the central highlan. The state is well known for its unexplored and rich biodiversity and its mineral resources like iron, coal and limestone. The weather is hot and humid due to its proximity to the Tropic of Cancer (21.295^{0}N and 81.828^{0}E). Mahanadi is the largest river of the state and it is fed by the numerous tributaries including the river Arpa. The river originates from the Maikal range near the Kodari-Khongsara Village of Bilaspur District. It flows southwards to meet with Seonath River which in turn meets with the Mahanadi. Once perennial, now the river is mainly rain fed due to the formation of various check dams (Bhat & Geelani 2013). The riverbed is sandy at most of the places having an average height of about 1.5m and is rocky at some places. Arpa is considered as the lifeline for Bilaspur City as it flows through the middle of the city and is the major source of water. The present study deals with the algal flora of Arpa River near Koni, Bilaspur.

Epilithic algal samples were collected in different seasons by random sampling method between 2012 and 2018. They were collected from the submerged pebbles as epilithic algal thalli attached to the pebbles in the riverbed with the help of scalpel. The collected samples were kept in plastic bottles with river water and 4% formaldehyde. Samples were observed under the microscope and photographs were taken with the help of a Leica DM 2000 microscope at Department of Botany, Guru Ghasidas Vishwavidyalay, Koni, Bilaspur. Identification of the taxon was done by referring to standard research papers (Iyengar 1932; Sarma & Suryanarayana 1969; Pandey et al. 1980).

Samples collected in December 2012 (accession number Bsp/Arpa/14; collection date 23.xii.2012) and December 2013 (accession number Bsp/Arpa/02 collection date 22.xii.2013) were identified as *Tetrasporidium javanicum* Möbius (Chlorophyta, Chlorophyceae, Palmellopsidaceae).

The thalli under lower magnification (4x) appear net-like with many round perforations having smooth margins. Each thallus is multicellular, colonial, ranged between 10–30 cm in length, numerous cells are embedded into a common gelatinous matrix which are attached to the substratum with the help of an attachment disc. The cells are spherical to ellipsoidal, 5–12 µm in diameter. Each cell is uninucleate, with a single cup shaped chloroplast and a single, prominent pyrenoid.

Tetrasporidium javanicum Möbius was first reported from Java (Moebius 1893), and subsequently from other

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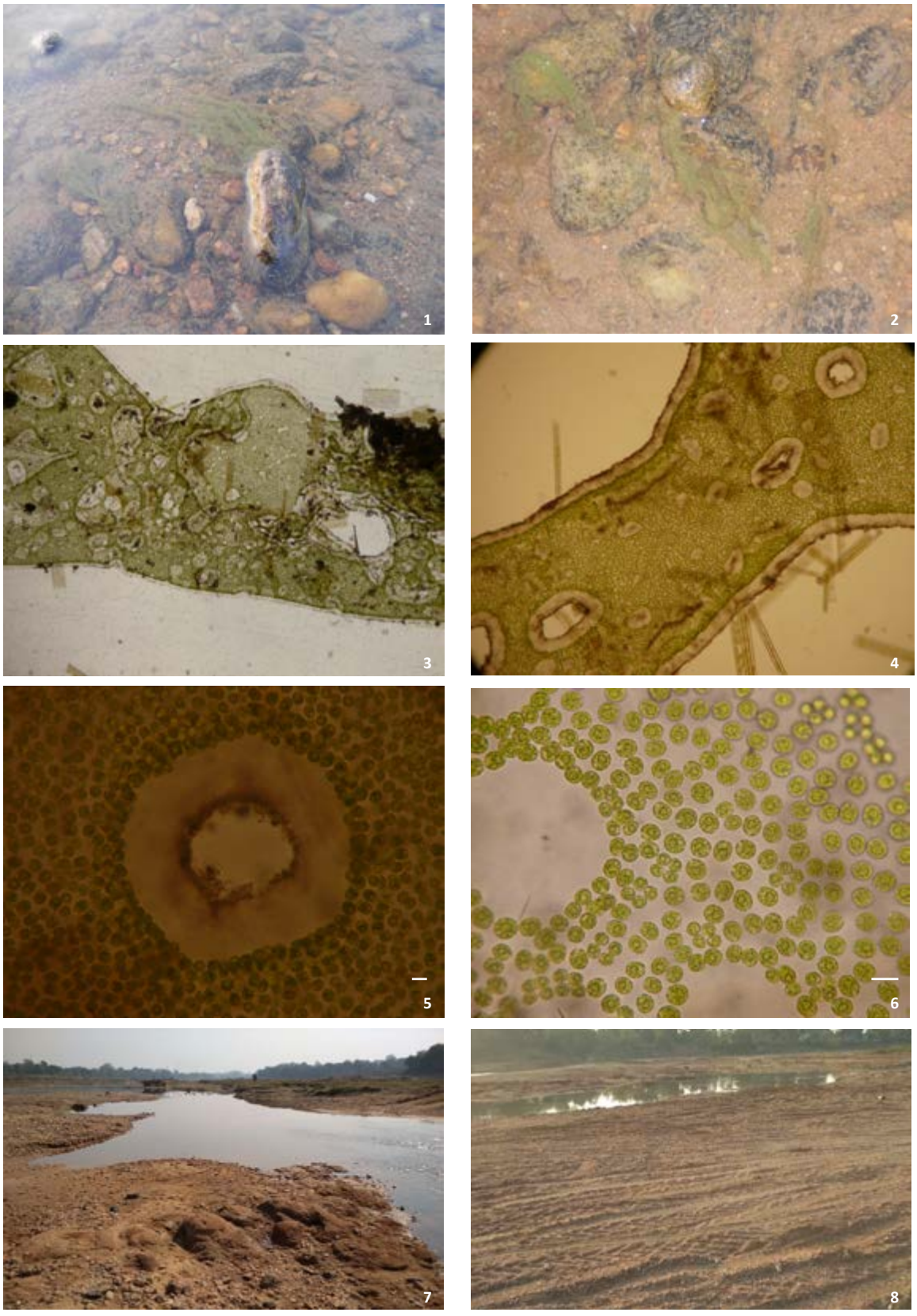

Image 1–8. *Tetrasporidium javanicum* and destruction of the habitat.
1,2—*T. javanicum* attached to the pebbles submerged in Arpa River | 3—*T. javanicum* in 4x magnification of objective lens (not to scale) | 4—*T. javanicum* in 10x magnification of objective lens (not to scale) | 5,6—thallus of *T. javanicum* in 40x and 100x magnifications of objective lens (scale bar is equal to 10µm) | 7,8—sand mining at the collection site. © Rakesh Kumar Dwivedi.

parts of the world such as Czech Republic (Fott et al. 1965), China (Jao 1947; Hu & Wei 2006), Bangladesh (Islam 1970), France (Coute &Tracanna 1981), Portugal (Calado & Rino 1992), Australia (Entwisle & Skinner 2002), the Hawaiian Islands (Sherwood 2004), and Spain (Tomas et al. 2012; Alcaraz et al. 2013). In India, *T. javanicum* was documented for the first time from the pools of Madras (Chennai) and the river Nagari in southern India (Iyengar 1932). Later it was reported from different parts of the country like Ravi River at Chamba in Himachal Pradesh (Singh 1941), Pallar River in Kerala (Randhawa 1962), Vallabha Vidyanagar in Gujarat (Sarma & Suryanarayana 1969), and Allahabad in Uttar Pradesh (Pandey et al. 1980).

The taxon has its distribution in both tropical and temperate regions growing in shallow, slow flowing oligo-mesotrophic to eutrophic river water attached to siliceous substratum, (Calado & Rino 1992; Entwisle & Skinner 2002; Sherwood 2004; Tomas et al. 2012; Alcaraz et al. 2013) which is also confirmed by the present report. Some reports of occurrence of *T. javanicum*, however, are also available from pools as epiphyte, epipelic in river and shallow water channels (Iyengar 1932; Pandey et al. 1980), fishponds as epiphyte on *Potamogeton crispus*, *Elodea canad*, and *Batrachium aquatile* (Fott et al. 1965). The present report of *T. javanicum* confirms its presence in Arpa River in the years 2012 and 2013 but when checked again in December 2014 and 2017 at the study site, the species, however, could not be located. The main reason for the disappearance of the rare alga might be sand mining at the riverbed using tractors and bulldozers. This may have destroyed the substratum and water quality required by this species.

The status of rare and endangered algae is poorly known across the world and India as well. Very few countries like Australia, Britain, Japan, and Germany have tabulated the list of endangered algae and offered legal protection to them (Brodie et al. 2008). Among all groups of algae, the freshwater benthic and periphytons are most vulnerable to extinction. This is because water bodies are used for sewage discharge, coolants for various industries and mixing of the hot water effluent, and sand mining. Sand mining is supposed to be the reason for missing *T. javanicum* in Arpa River at Bilaspur since 2014. For the protection of this rare and endangered alga, conservation of the habitat, mainly the stone substrates, is needed. Authorities providing concessions for sand mining should take this into consideration.

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