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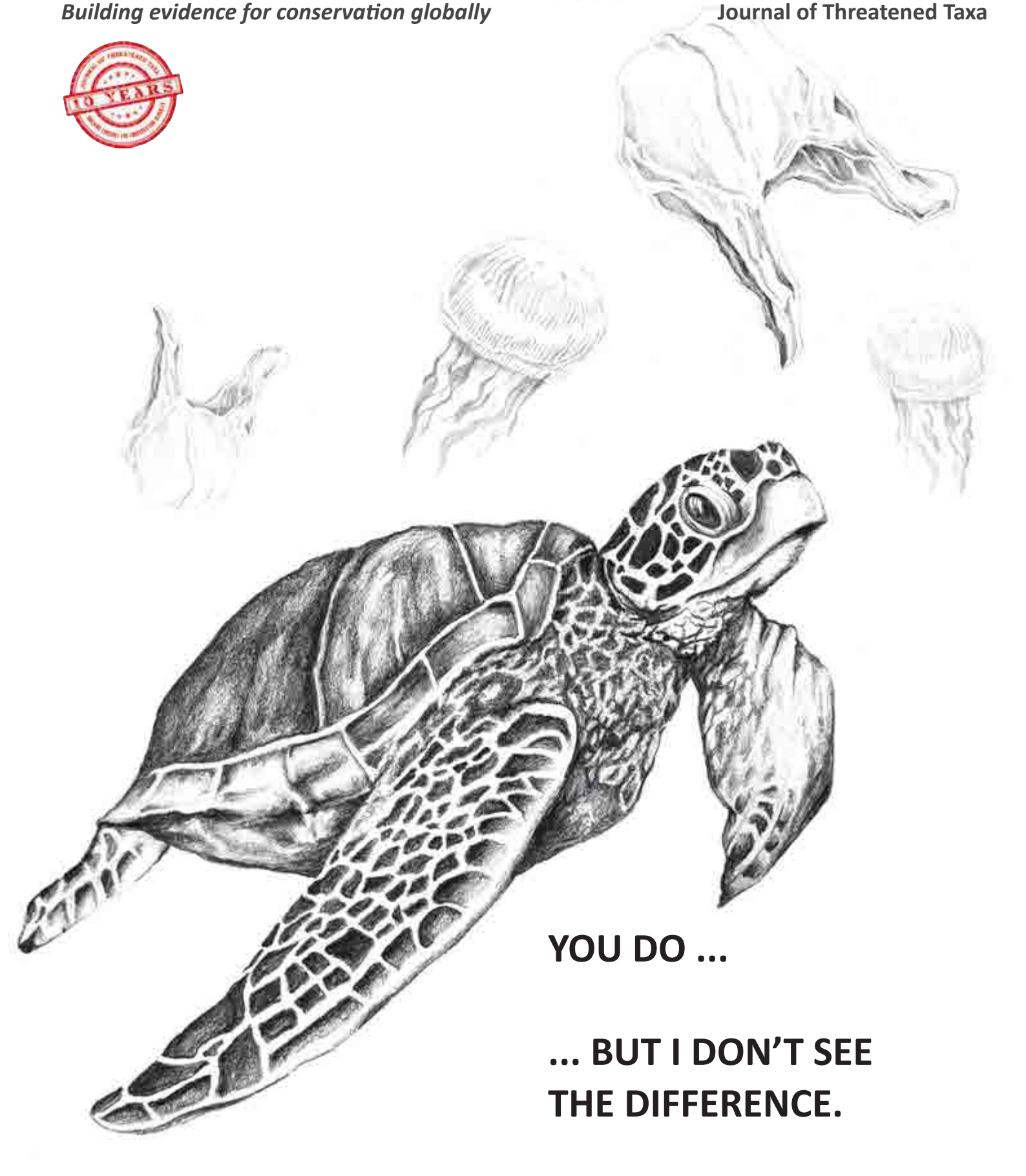

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continued on the back inside cover

Caption: Marine turtles are amazing creatures that feed on jellyfish. But today they are unable to see the difference between floating plastic bags and jellyfish. Eating these bags can result into death of these creatures that have been around since before the dinosaurs. Cover by Sivaprasad Velayudhan, Realworks Studios, Coimbatore.

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ARTICLE

The terrestrial life of sea kraits: insights from a long-term study on two *Laticauda* species (Reptilia: Squamata: Elapidae) in the Andaman Islands, India

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Abstract: Sea kraits forage in water and return to land to digest their prey, mate, slough, and lay their eggs. The temporal terrestrial patterns in encounter rate and behaviour of two species of sea kraits *Laticauda colubrina* and *L. laticaudata* were studied over four years at the New Wandoor beach in the southern Andaman Islands. The encounter rate of *L. colubrina* was found to be 20 times higher than *L. laticaudata*, and sea kraits were observed to prefer the natural refuge that the microhabitat of uprooted trees provide. Additionally, nesting observations are presented that emphasize the need to promote the conservation of these crucial terrestrial habitats.

Keywords: Andaman Islands, encounter rate, habitat use, India, *Laticauda colubrina*, *Laticauda laticaudata*, nesting behaviour, sea snake, terrestrial pattern.

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Author Contribution: TK and EY conceived the idea; TK and ZT collected the data; NPM performed the analysis; ZT and NPM led the writing, all authors contributed to the writing.

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INTRODUCTION

Sea snakes of the genus *Laticauda*, most commonly known as banded sea snakes or sea kraits, are amphibious in nature (Shine 2003; Heatwole et al. 2005). They rely entirely on aquatic prey and display adaptations to marine life such as a flattened paddle-like tail, salt-excreting glands, and enlarged lungs (Heatwole 1999; Shine & Shetty 2001; Brischoux & Shine 2011). Unlike the other lineages of marine snakes, however, sea kraits retain an oviparous mode of reproduction and hence must return to land to lay their eggs. They also mate, digest their prey, and slough their skins on land (Heatwole 1999; Greer 1997). They possess large ventral scales that help them move efficiently on land (Bonnet et al. 2005; Shine & Shetty 2001). Acquiring fresh water is crucial for sea kraits (Lillywhite et al. 2008; Kidera et al. 2013) and a combination of availability of fresh water on land and low salinity at sea may determine the sea kraits' geographic distributions and indicate their environmental tolerances (Brischoux et al. 2012, 2013). Sea snakes may also act as indicators of climate change effects (Lillywhite et al. 2008, 2014), thus heightening the interest in their ecology, behaviour, and conservation (Brischoux et al. 2009a; Bonnet 2012; Elfes et al. 2013).

Sea kraits are widely distributed in the tropical and subtropical coastal waters of the eastern Indian Ocean, southeastern Asia, and archipelagoes of the western Pacific Ocean (Heatwole et al. 2005). Of the eight *Laticauda* spp., Yellow-lipped Sea Krait *L. colubrina* and Blue-lipped Sea Krait *L. laticaudata* have the largest range, extending throughout the southeastern Asian islands and seas. Comparatively, the distribution of *L. laticaudata* is fragmented with a smaller extent of occurrence than *L. colubrina* (Gherghel et al. 2016). *Laticauda colubrina* grow to an avergae total length of 100cm with females growing larger than males, whereas *L. laticaudata* grow to an average length of 80cm (Shetty 2000). While *L. colubrina* are considered to be more terrestrial, *L. laticaudata* are considered to be intermediate, using both terrestrial and aquatic phases equally (Heatwole 1999; Greer 1997; Bonnet 2012). Juveniles of both species rarely venture far from water but stay close to its edge, whereas adults move inland (Shetty & Shine 2002a,b). Mate-searching males move about much more actively on land than do females (Shine & Shetty 2001).

In the Andaman Islands, *L. colubrina* and *L. laticaudata* are known to occur throughout the archipelago (Bhaskar 1996; Shetty & Sivasundar 1997, 1998). On South Reef Island off North Andaman, the relative abundance of *L. colubrina* with respect to *L. laticaudata* was found to be 200:1 (Bhaskar 1996). Preliminary studies on the behaviour of sea kraits, conducted in the late 1990s at South Reef Island (Bhaskar 1996; Shetty & Prasad 1996), show that sea kraits restrict their terrestrial activities between 1800 and 0400 hr. During the day, they take shelter in the cool microclimatic conditions provided by the crevices of live and dead trees (Shetty & Prasad 1996). Terrestrial activities such as digesting of prey and sloughing have been encountered with one record of copulation (Bhaskar 1996; Shetty & Prasad 1996). The reproductive behaviour of these two species in the archipelago is not well known, with no nesting observations apart from one record of egg laying in captivity (Bhaskar 1996; Shetty & Prasad 1996). In addition, sea kraits are known to exhibit positive phototaxis on land at night, making them extremely vulnerable to anthropogenic activities (Bhaskar 1996). Therefore, there is a necessity for a contemporary study to observe the terrestrial behaviour of sea kraits, specifically of reproduction and habitat use.

In this context, a long-term study was carried out to investigate the temporal patterns in abundance and behaviour of two species of sea kraits *L. colubrina* and *L. laticaudata* in the Andaman Islands. The relative abundance of sea kraits was primarily investigated with respect to ambient climatic and tidal conditions, along with the sea kraits' behaviour and substrate use. In addition, incidental natural history observations were documented.

METHODS

The study was carried out at the New Wandoor beach, located between 11.594°N & 92.607°E and 11.600°N & 92.608°E, in the southwestern corner of the South Andaman Island (Fig. 1a,b). The study area lies adjacent to the Mahatma Gandhi Marine National Park and Lohabarrack Crocodile Sanctuary and is lined with fringing reefs (Raghuraman & Raghunathan 2013). The islands are significantly influenced by the southwestern and northeastern monsoons from May to December, receiving up to 3,500mm of rainfall annually (Andrews & Vasumati 2002). The site experiences high anthropogenic activity as it is within the boundaries of Wandoor Village that is used for tourism and a part of the location lies in front of the Sea Princess Hotel, a tourist resort.

The study was conducted as a volunteer program to introduce groups of laypersons to conservation-related experiential learning and all groups were led and monitored by the Andaman Nicobar Environment Team (ANET) staff. As part of the ANET volunteering program,

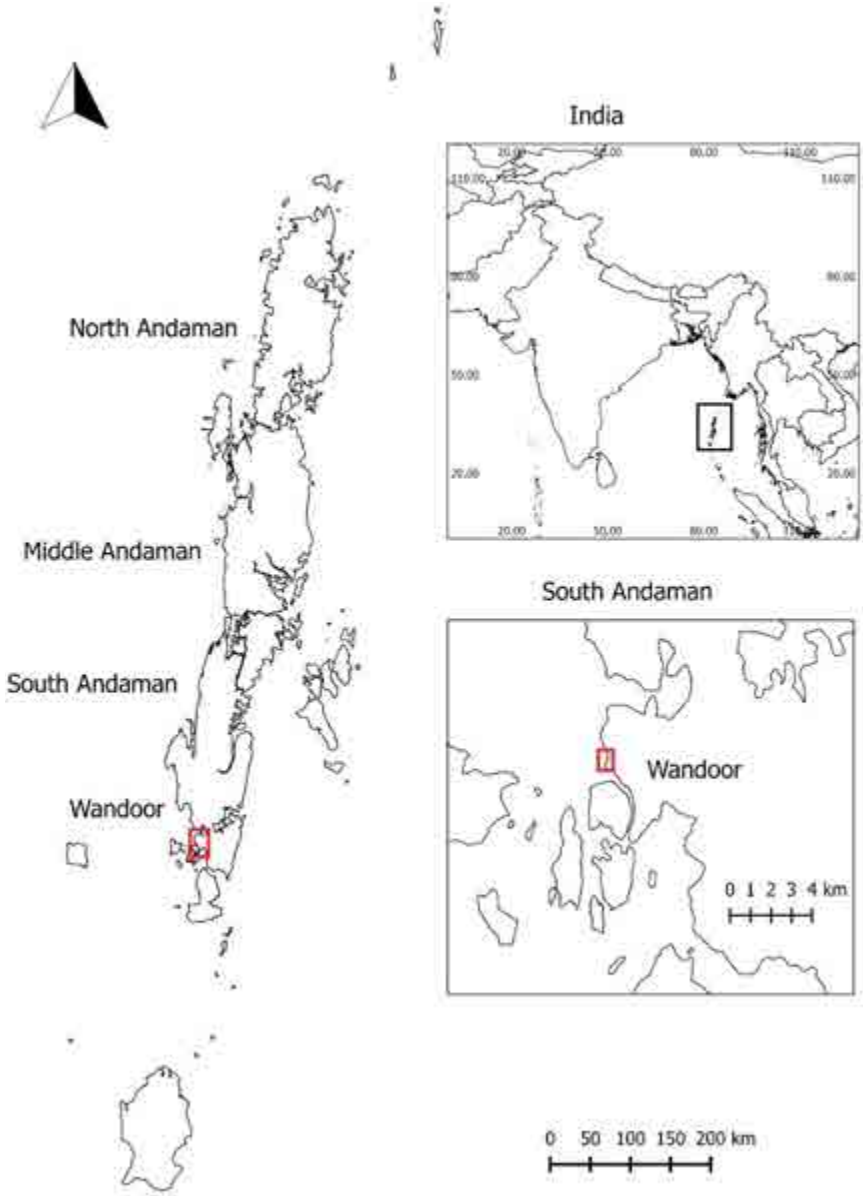

Figure 1a. Study area map showing the Andaman Islands. Inset top - the location of Andaman & Nicobar Islands in India, inset bottom - the location of the study area at the New Wandoor Beach, South Andaman Island

Figure 1b. Transect sampled at the New Wandoor Beach for the study

27 surveyors participated in the overall monitoring and walked one transect of 680m parallel to the sea 181 times between 2012 and 2016. The transect lies within the intertidal region, consisting of a sandy shoreline with rocky outcrops at the start and a small estuarine inlet at the end. *Ipomea pes-caprae*, a pantropical salt tolerant creeper (Devall 1992), lines the supratidal zone. During the 2004 tsunami, many littoral trees (e.g., Sea Mohwa *Manilkara littoralis*) were uprooted in the region; in the study area, there were 19 such uprooted trees that were sparsely distributed on the beach.

The transect was walked between 1830 and 2130 hr as sea kraits are known to restrict their terrestrial activities between 1800 and 0400 hr with a peak in activity between 1800 and 2300 hr (Bhaskar 1996). An average of two people wearing headlamps actively searched for sea kraits on the intertidal area, scanning from the sea up to the sandy vegetation (*Ipomea* sp.) lining the supra-tidal zone. At the start of each transect, the time, moon phase, weather conditions (clear, cloudy, or rainy), and ambient climatic variables (sand temperature & humidity, atmospheric temperature & humidity) were recorded using a pocket weather meter (Kestrel 3000).

Upon encountering a sea krait, the following data were recorded: i) species – *L. colubrina* or *L. laticaudata*, ii) activity when sighted — moving, resting, mating, or dead, iii) behaviour/condition — sloughing, gravid, and cluster size, and iv) substrate — *Ipomea* sp., sand, or wood. The microclimatic factors of the sea kraits were not recorded to avoid disturbing them and all participants were instructed not to handle any specimens as part of the study. In addition to these parameters, natural history observations were recorded ad libitum.

Analyses

Since the same transect of a fixed distance was walked by the surveyors on all occasions, the number of encounters of individuals reported are as such and not as a time-constrained encounter rate. Further analyses of data on *L. laticaudata* were not performed as the number of encounters was low. The influence of microclimatic variables and moon phase on the number of encounters of *L. colubrina* was tested using univariate linear regressions. A one way-ANOVA was performed to evaluate the differences between tide categories based on time to the nearest high tide (0–2 h, 2–4 h, >4h) coupled with the direction of the tide (Shetty & Shine 2002a) on the number of encounters in the case of *L. colubrina.* Additionally, effect sizes-η^2 in percentage for one-way ANOVA (Zar 2010) are reported.

RESULTS

Encounter rate

Eight-hundred-and-five individuals of *L. colubrina* and 39 individuals of *L. laticaudata* were encountered during the surveys. The number of encounters of *L. colubrina* per transect was 4.45 ± 0.21 and that of *L. laticaudata* was 0.22 ± 0.04. The average encounter rate for *L. colubrina* ranged from 2.93 in October to 7.6 in August, whereas for *L. laticaudata* it ranged from 0 in June to 0.55 in May (Fig. 2). The number of encounters for *L. colubrina* had a statistically significant correlation with atmospheric temperature ($R^2 = 0.072$, $\beta = 0.387$, SE = 0.018, $p < 0.001$), sand temperature ($R^2 = 0.066$, $\beta = 0.368$, SE = 0.108, $p < 0.001$), atmospheric humidity ($R^2 = 0.024$, $\beta = -0.099$, SE = 0.046, $p = 0.032$), and sand humidity ($R^2 = 0.022$, $\beta = -0.096$, SE = 0.046, $p = 0.039$). These relationships, however, had poor model fit values. The phase of moon did not influence the number of encounters in the case of *L. colubrina* ($R^2 = 0.01$, $\beta = 0.04$, SE = 0.03, $p = 0.185$). Tide categories based on time to high tide did not correlate with the number of encounters for *L. colubrina* ($F = 1.68$, $p = 0.14$, $\eta^2 = 4.86$).

Behaviour

Sloughing of *L. colubrina* was encountered on six separate occasions, more frequently in August to December; sloughing of *L. laticaudata*, however, was not observed (Table 1). Gravid females of *L. colubrina* were observed throughout the year on 37 separate occasions, with the maximum number of observations in April, whereas only one gravid female of *L. laticaudata* was observed, in February (Table 1). Clusters of two to four individuals were observed on 19 separate occasions for *L. colubrina* and once for *L. laticaudata* (Table 1).

The most utilized terrestrial substratum of the sea kraits was found to be uprooted *Manilkara littoralis* while

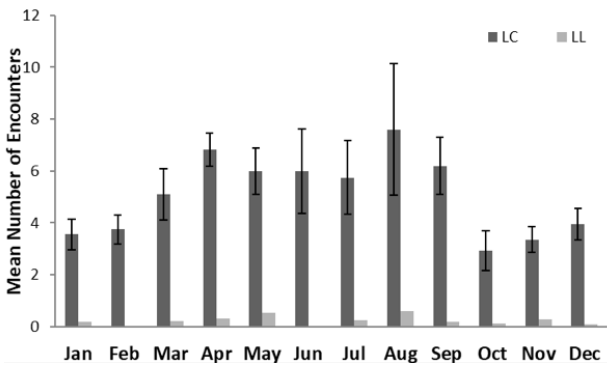

Figure 2. The average number of encounters of *Laticauda colubrina* and *L. laticaudata* on New Wandoor Beach, South Andaman Island, from 2012 to 2016; error bars indicate the standard error by month

Table 1. The encounter rate of sloughing snakes, gravid females, and cluster size for *Laticauda colubrina* (LC) and *L. laticaudata* (LL) on New Wandoor Beach, South Andaman Island

	Sloughing		Gravid female		Cluster size (≥2)	
	LC	LL	LC	LL	LC	LL
Jan	0	0	1	0	4	0
Feb	0	0	3	0	5	1
Mar	1	0	0	0	0	0
Apr	0	0	14	0	3	0
May	0	0	2	1	5	0
Jun	0	0	0	0	0	0
Jul	0	0	4	0	0	0
Aug	2	0	0	0	0	0
Sep	0	0	5	0	0	0
Oct	1	0	0	0	0	0
Nov	1	0	4	0	2	0
Dec	1	0	4	0	0	0

Table 2. Terrestrial substrate use and associated behaviour of *Laticauda colubrina* and *L. laticaudata* on New Wandoor Beach, South Andaman Island

Substratum	Activity	*L. colubrina*	*L. laticaudata*
Ipomea pes-caprae	Dead	1	0
Sand	Dead	3	1
	Mating	1	0
	Moving	132	8
	Resting	29	1
Manilkara littoralis	Mating	6	0
	Moving	272	14
	Resting	357	15

resting (Image 1), followed by sand (Table 2). Eighty per cent of the sea kraits encountered on sand were moving (Table 2). Five dead sea kraits were recorded during the study, out of which one was found on *Ipomea* sp., whereas the other four were found on sand (Table 2).

Natural history observations

Some of the sea kraits living in the crevices and hollows of the uprooted trees were seen to be sharing their space with hermit crabs, unperturbed by them. Sea kraits displayed signs of disturbance when tourists photographed them using a flash. The snakes, however, were not aggressive but only changed their direction of movement. During the sampling period, only two aggressive snakes were encountered even though the surveyors were at a distance of more than 5m away. Out of the two snakes, one was injured and struggling on the dry section of the sandy beach.

On 02 December 2015, a gravid *L. colubrina* was recorded to be resting in the hollow of an uprooted tree with an egg partially covered by the snake's coiled form (Image 2). The individual was photographed and no further disturbance was caused. The next day, the egg was observed to be fully exposed, outside the snake's coiled form (Image 3). The egg was creamy-beige speckled with small dark spots, oviducal, approximately 7cm long, and appeared soft-shelled. The following day, the hollow was empty with no signs of the sea krait or the egg. The hollow was located 9.6m from the water's edge at low tide at an elevation of 0.8m from the ground. Due to its low location, the hollow would have received an influx of water during high tide.

Image 1. *Laticauda colubrina* on an uprooted littoral tree at New Wandoor Beach, South Andaman Island.

On 04 December 2015, courtship behaviour was observed. A female *L. colubrina* was observed to be moving from the waterline towards the beach. Once

Image 2. Record of nesting by *Laticauda colubrina* at New Wandoor Beach, South Andaman Island, where an egg is partially covered by the gravid female's coiled form.

Image 3. Record of the exposed egg of *Laticauda colubrina* at New Wandoor Beach, South Andaman Island.

on the trunk and root of the uprooted tree, the sea krait disappeared into a crevice. A conspecific male was observed following the path the female had taken. The male was seen to be repeatedly tongue-flicking while following the path. Once near the crevice, it circled the area and entered another crevice, close to where the female had entered.

DISCUSSION

This study provides long-term data on the number of encounters, habitat use, and behaviour of sea kraits. The encounters of *L. colubrina* was found to be 20 times higher than that of *L. laticaudata*, similar to the findings on South Reef Island (Bhaskar 1996). This rarity in abundance likely contributes to the fragmented distribution of *L. laticaudata.* Both the rate of cutaneous evaporative water loss and the extent of terrestrial dependence are known to differ among the sea krait species with *L. colubrina* having relatively higher dehydration rates in seawater (Brischoux et al. 2012), lower rate of cutaneous evaporative water loss, and higher dependence on the terrestrial habitat, and with *L. laticaudata* showing intermediate levels of water loss and terrestrial dependence (Liu et al. 2012). *Laticauda laticaudata* are known to utilize shelters almost exclusively under mobile beach rocks, which are both easily accessible from the sea and regularly submerged at high tide (Bonnet et al. 2009). In contrast, *L. colubrina* frequently travel long distances overland, with males moving significantly further from the beach than females (Bonnet et al. 2005; Shine & Shetty 2001). The availability of both shelter and fresh water are important to the habitat selection of sea kraits; while *L. laticaudata* requires a source of fresh water, *L. colubrina* is characterized by a greater preference for the terrestrial habitat and possibly greater opportunities for access to a freshwater source (Liu et al. 2012). The difference in the number of encounters between the two sea kraits is likely due to the varying degree of dependence on terrestrial habitats or site selection (Bonnet et al. 2005) and naturally low densities of *L. laticaudata* (Bhaskar 1996). Avoidance of *L. colubrina* by *L. laticaudata* and vulnerability of *L. laticaudata* to anthropogenic disturbance, however, cannot be ruled out. Relatively high numbers of sea kraits were encountered between April and September. Although the mean abundance of sea kraits has been observed to be three-fold higher in the wet season compared to the dry season due to the dependence on availability of fresh water (Bonnet et al. 2009; Lillywhite & Tu 2012), the results from this study could be skewed due to the low sampling size during these monsoon months.

Ambient abiotic factors such as atmospheric temperature & humidity and sand temperature & humidity were found to significantly correlate with the number of encounters of *L. colubrina*; however, these relationships were not biologically meaningful given the poor model fit values. Neither lunar nor tidal phases were found to influence the number of encounters. Moreover, these results do not match the findings of studies that show nocturnal high tides to influence encounters with sea kraits (Girons 1964; Heatwole & Guinea 1993). Sea kraits of different age and sex classes, however, use terrestrial habitats differently and thus vary in their temporal and spatial distribution (Shetty & Shine 2002a).

The results from this study could be attributed to the influence of moon phase and tide on all the individuals of the species collectively. As the microclimatic conditions of the sea krait sites were not recorded in order to avoid disturbing them, comments on the sea kraits' microclimatic distribution cannot be made.

The use of substrates by sea kraits was studied where a majority of the individuals were encountered on wood where they were predominantly resting, followed by sand where they were moving (Table 2). Sea kraits are known to use natural refuges on beaches, which are both easily accessible from the sea and regularly submerged at high tide (Bonnet et al. 2009). Moreover, the spatial arrangement of terrestrial coastline microhabitats, especially refugia, plays a key role in the distribution of different sea krait species (Bonnet et al. 2009). In the current study area, sea kraits utilized the gradual slopes of the sandy beach to move from the sea to refugia in the form of uprooted trees dispersed along the intertidal zone. The protection of such refugia can lead to the conservation of these species (Webb et al. 2000; Berryman et al. 2006; Bonnet et al. 2009). Clustering of sea snakes was observed to increase from January to May; unconfirmed reports of mass aggregations (ca. 200 individuals) on Rutland Island were recorded and are pending validation. The sea kraits' resting behaviour on wood and clustering could possibly be explained by 1) thermoregulation (Shetty & Shine 2002a) and kleptothermy (Brischoux et al. 2009b), 2) sharing of resources to increase body temperature, or 3) mating behaviour (Parrish & Edelstein-Keshet 1999; Gregory 2004).

Previous observations on the mating behaviour of sea kraits describe the male locating the female through vomerolfaction (Bhaskar 1996; Shine 2003). This corresponds with the description stated in this paper of an instance where a male followed a female by regularly flicking its tongue at short intervals (we determined the sex of the sea kraits by body sizes). A sophisticated vomeronasal system not only allows male snakes to locate receptive females by following scent trails but also facilitates pheromonally mediated mate choice (Shine 2003). The presence of gravid *L. colubrina* peaked concurrently in April with the first nesting observation in the Andaman Islands, India, recorded in this paper. The breeding cycle for *L. colubrina* varies geographically with some populations showing aseasonal breeding whereas others showing seasonal breeding patterns (Gorman et al. 1981; Guinea 1986; Brischoux & Bonnet 2009). In oviparous reptiles, incubation requires well-buffered thermal and hydric conditions (Packard & Packard 1988; Ackerman 1991; Shine et al. 1997; Delmas et al. 2008). Coastal sites catch greater volumes of rain and, coupled with ambient temperature, are more stable compared to remote islets (Bonnet et al. 2014).

Thus, the New Wandoor beach with the crevices that uprooted trees provide may provide thermally buffered and relatively humid microhabitats that are suitable for incubation. Sea kraits are known to lay their eggs in below-ground caves or in narrow crevices to exclude human entry (Guinea 1986). With only two recorded incidents of egg laying from the wild, however, the nesting behaviour of *L. colubrina* is unknown. Further studies are required to investigate the breeding and nesting behaviour of sea kraits to determine the factors influencing reproductive failure such as stressors leading to observed egg-laying or abandonment of the egg. In 2016, a crocodile exclusion net was introduced by the government to provide a safe swimming area for tourists. The net cordons off 200m of the New Wandoor beach coinciding with the sites where sea kraits were most commonly sighted. In addition, the authorities removed the uprooted trees after the end of our study to clear the beach for tourism purposes. These actions, collectively, could have negative repercussions for the sea kraits that utilized the natural refuge that these uprooted trees on the beach at New Wandoor once provided. Overall, our findings emphasize the need to promote the conservation of crucial terrestrial habitats of sea kraits and justify their inclusion in marine protected areas, which in turn will benefit a wide array of other organisms also dependent on beach substrates.

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COMMUNICATION

Fishing Cat *Prionailurus viverrinus* Bennett, 1833 (Carnivora: Felidae) distribution and habitat characteristics in Chitwan National Park, Nepal

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OPEN ACCESS

Abstract: The Fishing Cat is a highly specialized and threatened felid, and its status is poorly known in the Terai region of Nepal. Systematic camera-trap surveys, comprising 868 camera-trap days in four survey blocks of 40km^2 in Rapti, Reu and Narayani river floodplains of Chitwan National Park, were used to determine the distribution and habitat characteristics of this species. A total of 19 photographs of five individual cats were recorded at three locations in six independent events. Eleven camera-trap records obtained during surveys in 2010, 2012 and 2013 were used to map the species distribution inside Chitwan National Park and its buffer zone. Habitat characteristics were described at six locations where cats were photographed. The majority of records were obtained in tall grassland surrounding oxbow lakes and riverbanks. Wetland shrinkage, prey (fish) depletion in natural wetlands and persecution threaten species persistence. Wetland restoration, reducing human pressure and increasing fish densities in the wetlands, provision of compensation for loss from Fishing Cats and awareness programs should be conducted to ensure their survival. We also recommend studying genetic diversity of sub-populations, as well as habitat use by radio-tagging.

Keywords: Camera trapping, Chitwan National Park, Fishing Cat, distribution, habitat characteristics, status.

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Author Contribution: RM & BRL designed and conducted the survey; RM, BRL & RA analyzed the data and RM, BRL, KB and RA wrote the paper.

For **Nepali abstract** see end of this article.

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INTRODUCTION

The Fishing Cat *Prionailurus viverrinus* (Bennet, 1833), is a medium-sized cat endemic to South and Southeast Asia. The species is classified as Vulnerable by the IUCN Red List of Threatened Species (Mukherjee et al. 2016) and is threatened by habitat loss and persecution throughout its range. Fishing Cats are strongly associated with water bodies, marshlands and swamps (Pocock 1939; Nowell & Jackson 1996; Mukherjee et al. 2016; Macdonald et al. 2010). Fish are their primary prey, although they also consume mollusks, arthropods, amphibians, reptiles, birds, small mammals (Haque & Vijayan 1993; Sunquist & Sunquist 2002; Macdonald et al. 2010) and deer fawns (James L. David Smith pers. comm. 2013). Cats are largely nocturnal (Mukherjee 1989; Sunquist & Sunquist 2002; Lynam et al. 2013) and shelter mostly in densely vegetated areas near water, rivers and streams during daytime (Prater 1980; Duckworth et al. 2010).

Fishing Cats have been recorded in five protected areas of the Nepal Terai: Shuklaphanta National Park, Bardia National Park, Chitwan National Park, Parsa National Park, and Koshi Tappu Wildlife Reserve (Jnawali et al. 2011; Karki 2011; Mishra 2016; Tylor et al. 2016; Yadav et al. 2018; DNPWC unpublished data). They have also been recently recorded outside protected areas in Gagdishpur reservoir, a Ramsar site in southwestern Nepal (Dahal 2016); however, few studies have been carried out to understand the ecology, distribution and conservation status of this species in Nepal (Karki 2011; Dahal & Dahal 2012; Taylor et al. 2016). A radio-collared study of four Fishing Cats (three females and a male) in Chitwan showed that they spent most of their time in thick vegetation of short or tall grasslands, sometimes well away from water (Sunquist & Sunquist 2002). A better understanding of habitat characteristics and use patterns is essential for the conservation of this highly specialized species (Krausman 1999). Although Fishing Cat is known to occur in Chitwan National Park, its actual distribution and habitat characteristic remain unexplained. This paper presents the findings of our camera trap surveys conducted specifically for the species in 2012, and also from data obtained during systematic camera trap surveys carried out for Bengal Tiger *Panthera tigris* in 2010 and 2013.

Study Area

The study was carried out in alluvial floodplain of the Rapti, Reu and Narayani rivers of Chitwan National Park (CNP) and Buffer Zone (BZ) located at 27.230–27.630 ^{0}N and 83.810–84.710 ^{0}E (Fig. 1). CNP was established in 1973 as the first national park of Nepal and it was designated a world heritage site in 1984. A

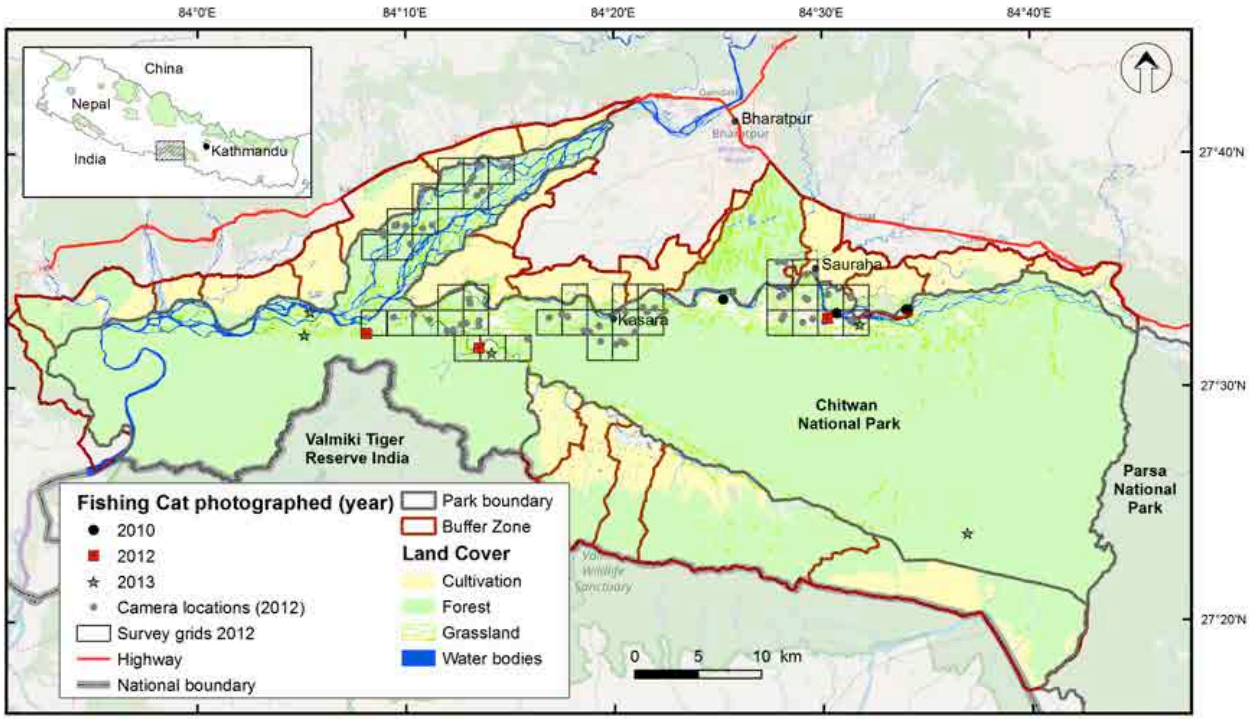

Figure 1. Fishing Cat distribution in Chitwan National Park, Nepal based on camera trapped locations. Survey in 2012 was done only in the areas within the grid cells.

larger portion (73%) of the 953 km^2 park is covered by Sal *Shorea robusta* dominated forest followed by grasslands (12%), riverine forest (7%), wetlands (3%), and exposed surfaces (5%) (Thapa 2011). An additional 750km^2 (29km^2 of which was included into CNP in 2016) of the area around the park was designated a BZ in 1996. CNP has three ecological zones—Churia hills (350–735 m altitude, 566km^2), Bhawar (200–350 m altitude, 233km^2), and alluvial floodplain (120–200 m altitude, 154km^2) (Smith 1984). CNP includes three large river systems (Narayani, Rapti and Reu rivers) and more than 50 oxbow lakes (Khadka et al. 2015). The Park has sub-tropical climate with three distinct seasons i.e. monsoon (mid-June to mid-September), cool dry (mid-September to mid-March) and hot dry (mid-March to mid-June) (Subedi et al. 2013). Average annual rainfall is ~2,250mm (2000–2010), 80% of which occurs during the monsoon season. Average monthly maximum and minimum temperature ranges range 24–38 ^{0}C and 11–26 ^{0}C respectively (Sudedi et al. 2013).

CNP provides shelter to 70 mammal and >600 bird species. Bengal Tiger and Leopard *Panthera pardus* are large carnivores of the park (Karki et al. 2015). Along with Fishing Cat, a range of small-to-medium sized carnivores including Clouded Leopard *Neofelis nebulosa*, Dhole *Cuon alpinus*, Striped Hyena *Hyaena hyaena*, Golden Jackal *Canis aureus*, Jungle Cat *Felis chaus*, Leopard Cat *Prionailurus bengalensis*, Bengal Fox *Vulpes bengalensis*, Honey Badger *Mellivora capensis*, and Indian Crested Porcupine *Hystrix indica* are found in CNP. In addition to the terrestrial carnivores, more than 100 endangered Gharial *Gavialis gangeticus* are found in Rapti and Narayani rivers along with ca. 350 Marsh Mugger crocodiles in the rivers and lakes of CNP (Khadka et al. 2015). A total of 126 fish species are found in CNP (CNP 2017), including Sahar *Tor putitora*, Katle *Neolissocheilus hexagonolepis*, Catfish *Wallago attu*, *Mystus seenghala,* and *Mystus aor* (Dhital & Jha 2002).

MATERIALS AND METHODS

Field survey

During February 2012, a preliminary pugmark sign survey was conducted and informal interviews were carried out with local fishermen, nature guides, wildlife technicians and park personnel to identify sites of Fishing Cat occurrence. Based on these surveys and interviews, four blocks (Sauraha, Kasara, Tiger Tops, and Island) of ca. 40km^2 each were chosen in the alluvial floodplains of CNP and BZ for a camera trap survey (Mishra 2016). The survey was subsequently carried out between 25 March and 11 June 2012. Each 40km^2 block was divided into 2x2 km^2 cells and ten cells were identified in each block and within each cell, two camera trap stations were selected based on likely Fishing Cat presence. A pair of camera traps was placed 4–7 m apart facing each other at 30–45 cm above the ground at each station. Reconyx RM 45 Rapidfire and Moultrie Game Camera were used. Cameras operated throughout 24hr for 10–15 days and were programmed to take three photographs per trigger with no delay between triggers. Camera's detection range was 25+ m. Moultrie game cameras used a white flash to obtain color images whereas Roconyx RM 45 cameras had infrared flash giving black and white pictures.

All pictures of cats obtained from camera traps were stored in a folder and individual identification was done based on body spot patterns (Cutter 2009). A sequence of photographs of Fishing Cat occurring after an interval of >60 minutes from the previous photograph was considered as an independent event.

Fishing Cat distribution

In addition to the data from our targeted survey, we used Fishing Cat records from the 2010 and 2013 camera trap surveys targeted for Bengal Tigers, which covered CNP and BZ forests with a total of 310 and 362 CT stations respectively. Detailed methodology of these surveys can be found in Karki et al. (2015) and in Dhakal et al. (2014).

We recorded habitat characteristics, i.e., habitat type (grassland, sal forest, riverbank, riverine forest, lake/marsh, wooded grassland), tree canopy cover, distance to wetland, wetland type and wetland state (area, depth and disturbance) of each camera trap station during camera deployment. We visually quantified the tree canopy cover within a circular area 50m radius from the centre of the camera into 0, 1–10 %, 11–50 %, >50% tree canopy cover. A buffer of 7.065km^2 (1.5km radius) was created around the camera trap stations of fishing cat capture. The buffer was based on the assumption that a female Fishing Cat home range is 4–8 km^2 (Sunquist & Sunquist 2002). Animals do not use the habitat uniformly and their home ranges are not exactly circular but we used circular buffer around the camera trap station as the best possible way to represent home range. Habitat type within the buffer area was quantified as forest, grassland, water bodies and sand/gravel using land cover layers of topographic map of 1:25000 scale produced by Survey Department of Nepal Government (https://ngiip.gov.np/index.php) in 1998. Spatial analysis

was undertaken in ArcGIS 10.0 (ESRI 2010).

RESULTS

Survey effort and cat detections

A total of 868 camera trap-days in 78 camera trap stations in CNP and BZ resulted in 640 photographs of 13 carnivore species including Fishing Cat (Table 1). Survey effort varied among the habitats with highest effort in grasslands (30.2%). About half (46%) of the camera traps stations were placed in vicinity of the wetlands (lakes, marshes or river bank). Only 11 camera trap stations (14%) were in riverine and Sal forests (Table 1). A total of 19 photographs (11 right and eight left flank) of Fishing Cat were recorded at three camera trap stations, one in grassland surrounding a lake and the other two at the edge of an oxbow lake. Three individuals were captured at one station i.e., grid no C05 (Tiger Tops tented camp area) (Image 1). One individual was captured in A03 (Patna Lake) and C11 grids (Devi Lake) (Fig. 2). Individual identification was based on pelage patterns. None of the camera stations in the BZ (n = 4) detected Fishing Cat.

Image 1. Camera trap photograph of a Fishing Cat in Chitwan National Park, April 2012.

Fishing Cat distribution

Overall, Fishing Cat was recorded at 11 camera-trap stations in CNP (Table 2, Fig. 1) from the three different camera trap survey years: 2010 (three), 2012 (three) and 2013 (five). The elevation range of camera stations was 97–628 m and Fishing Cats were captured between 117 and 307 m. Most of the stations (n=8) recorded single individuals once only. Two and three individuals were photographed in two and one locations, respectively. Majority of the stations with Fishing Cat detections (n=7) were in alluvial floodplain grassland or grassland-wetland edge habitat (Fig. 2, Table 2).

Habitat characteristics

Fishing Cats were detected near lakes and swamps surrounded by dense tall grass (average height of 1–2 m) dominated by *Phragmitis karka* and *Saccharum* sp. The animals were detected on animal trails at the edge (within 10m) of lakes and swamps (Table 3).

Table 1. Survey effort and detection of Fishing Cat and other carnivore species during March–June 2012 in different habitats of Chitwan National Park, Nepal.

Habitat type	No. of stations	No. of trap nights	Carnivore species recorded in camera traps	No. of Fishing Cat detections (No. of photographs)	No. of Fishing Cat individuals
Grassland	23	262	Tiger, Fishing Cat, Golden Jackal, Himalayan Crestless Porcupine *Hystrix brachyura*, Common Palm Civet *Paradoxurus hermaphroditus*, Large Indian Civet *Viverra zibetha*, Small Indian Civet *Viverricula indica*, Sloth Bear *Melursus ursinus*	1 (3)	1
Sal forest	5	54	Himalayan Crestless Porcupine, Asian Palm Civet, Tiger, Small Indian Civet, Sloth Bear	-	-
River bank	17	190	Golden Jackal, Jungle Cat, Indian Grey Mongoose *Herpestes edwardsii*, Himalayan Crestless Porcupine, Common Palm Civet, Tiger, Large Indian Civet, Small Indian Civet, Sloth Bear	-	-
Riverine forest	6	80	Golden Jackal, Leopard Cat, Indian Grey Mongoose, Himalayan Crestless Porcupine, Asian Palm Civet, Large Indian Civet, Small Indian Civet, Sloth Bear	-	-
Lake/Marsh	19	198	Fishing Cat, Jungle Cat, Indian Grey Mongoose, Tiger, Large Indian Civet, Sloth Bear	5 (16)	4
Wooded grassland	8	84	Jungle Cat, Small Asian Mongoose, Indian Grey Mongoose, Himalayan Crestless Porcupine, Common Leopard, Large Indian Civet, Small Indian Civet, Sloth Bear	-	
Total	**78**	**868**		**6 (19)**	**5**

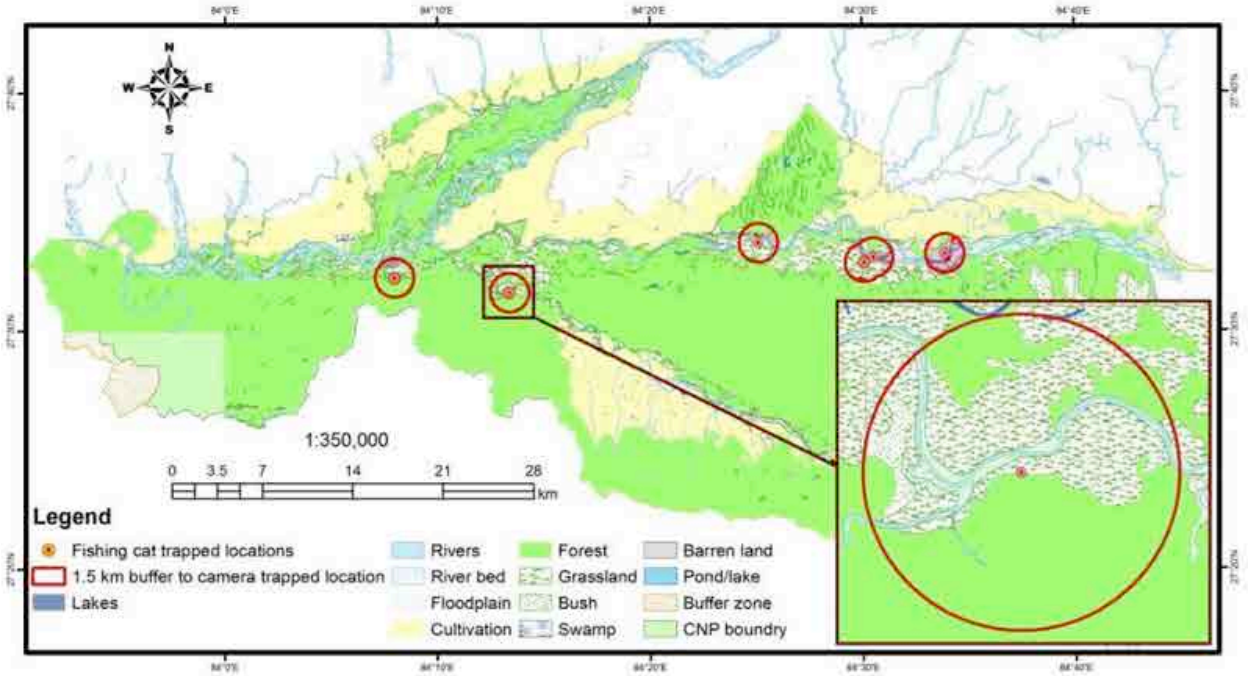

Figure 2. Fishing Cat habitat within 1.5km of camera trap locations in Chitwan National Park, Nepal

Table 2. Fishing Cat camera trapped locations in Chitwan National Park, Nepal in different camera trap sessions (2010, 2012, and 2013).

	Location	Coordinates	Date	Time	Elevation (m)	Habitat type
1	Ghatgain	27.56239°N & 84.41631°E	16.ii.2010	00:02	156	Riverine forest
2	Amrite	27.55470°N & 84.56258°E	04.iii.2010	20:12	174	Grassland
			20.iii.2010	03:42		
3	Icharny	27.55208°N & 84.50666°E	16.iii.2010	02:42	171	Grassland
4	Patnatal	27.54815°N & 84.49961°E	28.iii.2012	22:34	187	Grassland
5	Tiger tops tented camp	27.52784°N & 84.22099°E	23.iv.2012	19:25	177	Wetland
			27.iv.2012	22:39		
			28.iv.2012	00:06		
			02.v.2012	03:41		
6	Devital	27.53825°N & 84.13084°E	24.iv.2012	16:28	145	Wetland
7	Temple tiger	27.55386°N & 84.08595°E	21.ii.2013	02:28	119	Grassland
8	Temple tiger	27.5373°N & 84.08124°E	22.ii.2013	02:19	117	Wetland
			24.ii.2013	20:12		
			26.ii.2013	19:21		
9	Tented camp east	27.52457°N & 84.23104°E	21.iii.2013	01:37	145	Grassland / Riverine forest
10	Amrite	27.54395°N & 84.52535°E	12.iv.2013	22:44	171	Grassland
11	Thori	27.39494°N & 84.6107°E	04.v.2013	01:18	307	Mixed forest

The major habitat within 1.5km radius buffer area around the camera trap stations where Fishing Cat were detected (Fig. 2) was grassland (45%) followed by forest (27.8%), sand and gravel (16.6%) and water-bodies (10.6%) (Table 4). All six camera trapped locations were in grassland but they were close to forests (within 1km) in the core area of CNP.

DISCUSSION

A survey effort of 868 trap nights in 78 camera trap locations in CNP in 2012 resulted in capture of five individuals in six events from three locations, for a capture rate of 0.73/100 trap nights. Survey effort was highest (46.2%) in wetlands (lake, marsh and riverbanks) followed by grasslands (39.7%) and forests (12.8%). Fishing cats were recorded only in wetlands (5 of six events) and grassland (one event) with highest probability of capture (1.3 events/100 trap nights) in wetlands followed by grasslands (0.3 events/100 trap nights). Fishing Cats were only recorded in close proximity to water edge. During 2012 survey we did not record Fishing Cat from forests, but during 2010 and 2013 Fishing Cats were photographed from locations in riverine forest and mixed forest respectively. In 2013, an additional location of Fishing Cat camera trap was at the edge of grassland and forest (Table 1).

Fishing Cat distribution in CNP is strongly associated with rivers, oxbow lakes and floodplain grasslands. Cats were recorded within 125km^2 of Reu, Rapti and Narayani floodplains in CNP (Fig. 1). During our study we photographed Fishing Cat in the location where Dahal & Dahal (2012) and Karki (2011) had also found Fishing Cat during their survey between 2010 and 2011. Recently (in 2016 December), a wildlife photographer photographed a Fishing Cat walking on a forest road in Sal forest 200m from a lake (GPS 27.535^{0}N & 84.337^{0}E) close (1.5km) to the park headquarters where we failed to record the species during our survey (Kasara block). In Nepal, Fishing Cat is distributed from east (Koshi Tappu Wildlife Reserve) to west (Shuklaphanta National Park); however, they have patchy distribution within the range and we lack information whether the Fishing Cat sub-populations found (both in and outside of the protected areas) are connected to each-other.

Sunquist & Sunquist (2002) reported the radio-tagging of Fishing Cats in CNP during 1980s. With the help of wildlife technicians (Mr. Bishhnu Bahadur Lama and Mr. Harkaman Lama; National Trust for Nature Conservation) who were involved in the radio-tagging,

Table 3. Fishing Cat habitat characteristics of camera trapped locations during field survey in March–April 2012 in Chitwan National Park, Nepal.

	Location	Coordinates	Type of wetland	Distance to water edge	Distance to forest edge	Surrounding Hab. type	Dominant grass	Ht. of grass	Other carnivores
1	Patna	27.54815°N &84.49961°E	Lake	10m	1.1km	Tall grass	*Phragmitis karka and Imperata cylindrica*	>2m	None
2	Tented Camp	27.52763°N & 84.22112°E	Swamp	2m	0.1km	Tall grass	Simghans, *Phragmitis karka*	> 2m	Sloth Bear, jungle Cat & large Indian Civet
3	Devi Tal	27.53804°N & 84.13097°E	Lake	5m	0.1km	Tall grass	*Saccharum Bangalensis* and *S. spontaneum*	1-2m	None

Table 4. Habitat within 1.5km radius of Fishing Cat camera trap locations in Chitwan National Park, Nepal.

Year	Location	Coordinates	Habitat area in hectares within 1.5km radius of CT location (% coverage)			
			Forest	Grassland	Sand/gravel	Wetland
2012	Tented camp	27.52763°N & 84.22112°E	369.76 (52.3)	286.31 (40.5)	24.89 (3.5)	25.83 (3.7)
2012	Devi Tal	27.53804°N & 84.13097°E	439.31 (62.2)	165.39 (23.4)	36.36 (5.1)	65.75 (9.3)
2012	Patna Tal	27.54815°N & 84.49961°E	27.84 (3.9)	540.94 (76.5)	64.29 (9.1)	73.73 (10.4)
2010	Ghatgain	27.55208°N & 84.50666°E	177.44 (25.1)	389.96 (55.2)	66.27 (9.4)	73.13 (10.3)
2010	Amrite	27.55470°N & 84.56258°E	71.73 (10.1)	135.35 (19.1)	407.63 (57.7)	92.08 (13)
2010	Icherny	27.55208°N & 84.50666°E	93.78 (13.3)	391.72 (55.4)	102.76 (14.5)	118.53 (16.8)
	Total		**1179.85 (27.8%)**	**1909.67 (45%)**	**702.2 (16.6%)**	**449.05 (10.6%)**

we placed camera traps at the locations of the live captures (Jayamangala ghol, 27.561^{0}N & 84.480^{0}E). We failed to photograph Fishing Cat at the location but obtained a camera trap photograph of a Fishing Cat about two kilometers south-east of this location (i.e., Patna Tal, Table 2). Smith (James L.D. Smith pers. comm. 2013) described the Jayamangala ghol as a wetland during 1980s which is now converted to grassland (Khadka et al. 2015). This is an example of the rapid change in habitat of Fishing Cat in just 30 years. Such habitation alteration and drying of wetland areas can severely affect the distribution and abundance of the species. In addition to the shrinkage, reduced fish abundance and high human pressure (both in terms of pollution and fishing) in the remaining wetlands makes Fishing Cats more vulnerable.

Grasslands, river banks (sand/gravel) and wetlands altogether make about three fourth of the 7.065km^2 (1.5km radius) of Fishing Cat captured location. It indicates the preference of Fishing Cats for the areas with mosaics of habitats abundant with water as found by Nair (2012) in Western Terai Arc Landscape in India. In contrast to our record of Fishing Cat in the core area of CNP, Taylor et al. (2016) reported Fishing Cat from private fish ponds along the eastern border of Koshi Tappu Wildlife Reserve in Eastern Nepal. Similar report of Fishing Cats intensively using aquaculture and rice fields was reported by Cutter (2015) in Thailand. But they also face a threat of persecution by the aquaculture farmers in such areas (Taylor et al. 2016).

We recommend to focus fishing cat conservation actions on wetland restoration, reduce human pressure in identified pocket areas of Fishing Cat, increase fish density in the wetlands, provision of compensation for loss from Fishing Cat and awareness programs for the local communities living close to Fishing Cats. We also recommend examining the genetic diversity and relatedness among Fishing Cat sub-populations in Nepal through non-invasive genetic study. A detailed understanding of habitat use by Fishing Cat can also be obtained through radio-tagging of few Fishing Cat individuals (Nair 2012; Cutter 2015), both in natural conditions like CNP and in close proximity of settlements (like Koshi Tappu eastern buffer zone).

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सारांश

मलाहा बिरालो वासस्थान विषेशमा मात्र पाईने संकटापन्न बिरालो प्रजाति हो। नेपालको तराई क्षेत्रमा यसको अवस्थाबारे थोरैमात्र थाहा छ। चितवन राष्ट्रिय निकुञ्जको राप्ती, रिउ र नारायणी नदीको नदी तटीय क्षेत्रमा क्रमबद्ध रुपमा करीब ४० वर्ग कि.मी.का चारवटा सर्भे ब्लकमा ६८६ क्यामेरा ट्रयाप दिनको प्रयत्नबाट यस प्रजातिको वितरण क्षेत्र र वासस्थानको प्रकार/विषेशता अध्ययन गरियो। तीनवटा स्थानमा छ पटकमा गरी पाँचवटा मलाहा बिरालोको १९ वटा फोटोहरु प्राप्त भयो। तीन वर्ष (२०१०, २०१२ र २०१३) को क्यामेरा-ट्रयाप सर्भेमा मलाहा बिरालोको फोटो खिचिएका ११ वटा स्थानहरु प्रयोग गरी मलाहा बिरालोको वितरण क्षेत्र नक्शांकन गरियो। मलाहा बिरालो क्यामेरा ट्रयापले फोटो खिचेको ६ वटा स्थानको वरिपरि रहेको वासस्थानको प्रकार/विशेषता व्याख्या गरियो। मलाहा बिरालो भेटिएको धेरैजसो स्थान अग्लो घाँसे मैदानले घेरिएको सिमसार (ताल) र नदीकिनारा छन्। खुम्चँदै गएको सिमसार क्षेत्र, प्राकृतिक सिमसारमा आहारा (माछा) घटिरहेको तथा मान्छेले पतिशोधले मार्ने आदि यीनिहरुको दिगो संरक्षणमा खतराको रुपमा रहेका छन्। यीनिहरुलाई बचाईराख सिमसार क्षेत्रको पुनर्स्थापना, प्रकृतिक सिमसारमा मानवीय चाप कम गरी माछाको घनत्व बढाउने, मलाहा बिरालोबाट हुने क्षतिको राहतको व्यवस्था तथा जनचेतनाका कार्यक्रमहरु सँचालन गरिनुपर्छ। नेपालका विभिन्न क्षेत्रका मलाहा बिरालाहरुको वंशाणुगत विविधता साथै रेडियो ट्रयागको सहयोगबाट वासस्थान प्रयोगको बारेमा विस्तृत अध्ययन गर्ने हामी सिफारिस गर्दछौं।

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COMMUNICATION

Status distribution and feeding habit of Wild Boar *Sus scrofa* (Mammalia: Artiodactyla: Suidae) in Pench Tiger Reserve, Madhya Pradesh, India

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OPEN ACCESS

Abstract: The Wild Boar *Sus scrofa* is omnivorous, serves as the prey base for large carnivores, performs the role of a natural scavenger, and is often involved in crop raiding. The species is included in Schedule V of the Indian Wildlife (Protection) Act, 1972, meaning hunting of the species may be allowed by the Chief Wildlife Warden in instances where individuals of the species are considered dangerous to human life or property. Faecal samples of Wild Boar in Pench Tiger Reserve, Madhya Pradesh, India, were collected from January to June 2013 to assess the distribution of Wild Boar in Karmajhiri range. The density of Wild Boar in Sapath and Tikadi beat was 25.5±0.29 and 23.9±0.33 per hectare, respectively, and was the lowest in Teliya at 1.6±0.05 per hectare. Sixteen different beats were sampled and surveyed to understand the diet of Wild Boar during the winter season. Ingested items included stones, roots, grass, fruits and seeds, hairs, earthworms, flowers, and green plant material. Out of these, the most frequent item was grass, followed by roots and stones.

Keywords: Density, distribution, feeding habit, India, Karmajhiri range, Madhya Pradesh, Pench Tiger Reserve, scavenger, *Sus scrofa*, Wild Boar.

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Author Contribution: OI and SK conceived the ideas and designed methodology; SK collected the data and analysed the data; SK and OI led the writing of the manuscript. Both the authors contributed critically to the drafts and gave final approval for publication.

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INTRODUCTION

Wild Boar *Sus scrofa* is one of the eight species of ungulates present in Pench Tiger Reserve (PTR) in Madhya Pradesh in central India. It is an omnivore, is included in Schedule V of Wildlife (Protection) Act, 1972 (WPA), and belongs to the family Suidae. The Wild Boar is widely distributed all across the world, extending from western Europe to southeastern Asia (Bratton 1975; Massei & Genov 1981). In recent years, their numbers have increased globally (Baubet et. al. 2004). Wild Boar is very active and feeds upon almost all kinds of plant material and animal matter. It plays the role of a scavenger in the forest and forms a good prey base for large cats like tiger and leopard, thus balancing the ecosystem (Barwal 2013). The boars habitually group together and mostly feed at night (Stegemen 1938). They are known to impact a variety of ecosystems throughout the world by dispersing seeds, disturbing the soil, feeding upon invertebrates and small vertebrates, contending with large vertebrates and often causing damages due to crop-raiding (Bratton 1975; Genov 1981; Alexiou 1983; Welander 1995). These damages cause retaliation and Wild Boar population come under threats from human beings. Wild Boar is one of the most studied species throughout the world but somehow not many studies have been carried out in India (Srivastava & Khan 2009; Barwal 2013).

Study on the feeding habit of Wild Boar is important in perspectives of conservation (Sih 1993) for determining the necessities of the species and for improving its management (Kruuk & Parish 1981). The estimations of the population sizes, densities, and home ranges for any species are important aspects that help in guiding better management and conservation of the species (Burnham et al. 1980). Wild Boar populations have high growth rate due to high fecundity and early onset of sexual maturation (Coblentz & Baber 1987) and therefore need to be evaluated from time to time for better management of the species and the habitats.

Several studies have been conducted on the diversity of flora and fauna of PTR (Dwivedi & Shukla 1988; Shukla 1990; Karanth & Nichols 1998; Sankar et al. 2000). Most of the faunal studies are concentrated on tigers (Karanth & Nichols 1998; Biswas & Sankar 2002) and on Sambar and Chital (Sankar et al. 2000; Pasha et al. 2002). The present study was carried out to supplement the existing knowledge on Wild Boar of PTR.

STUDY AREA

The PTR spans the Seoni and Chhindwara districts of Madhya Pradesh in central India and consists of three forest ranges, namely, Karmajhiri, Gumtara, and Kurai. The reserve gets its name from the river Pench that flows 74km through it from north to south. The river bisects PTR into nearly equal parts: the 147.61km² of the western block in the Gumtara range of the Chhindwara Forest division and the 145.24km² of the eastern block in the Karmajhiri range of the Seoni Forest division. The total area of PTR is 757.89km².

The central Indian highlands have a tropical continental climate, with a distinct monsoon (July–September), winter (November–February), and summer (April–June). The mean annual rainfall is around 1,400mm, with the southwest monsoon accounting for most of the rainfall in the region. For the dry season, (November–May), the mean rainfall is 59.5mm. The temperature in PTR varies from a minimum of 0°C in winter to a maximum of 45°C in summer (Sankar et al. 2000).

PTR belongs to the Indo-Malayan phytogeographical region. Teak *Tectona grandis* and its associated species such *as Madhuca indica*, *Diospyros melanoxylon*, *Terminalia tomentosa*, *Buchanania lanzan*, *Lagerstroemia parviflora*, *Ougeinia dalbergoides*, *Miliusa velutina*, and *Lannea coromandalica* occur on the flat terrain. The undulating terrain and hill slopes have patches of mixed forest dominated by *Boswellia serrata* and *Anogeissus latifolia*. Species like *Sterculia urens* and *Gardenia latifolia* are found scattered on rocky slopes. Bamboo forests occur in the hill slopes and along streams. Some of the open patches of PTR are covered with tall grass interspersed with *Butea monosperma* and *Zizyphus mauritiana*. Evergreen tree species like *Terminalia arjuna*, *Syzygium cumini*, and *Ixora parviflora* are found in riparian vegetation along streams and river banks. Dominant patches of *Cleistanthus collinus* are also found in some parts of PTR.

METHODS

The study area in PTR was divided into 16 different management beats and in each beat two line transects of 2km length were laid. On each transect, a circular plot was laid at every 200m and a total of 320 plots were sampled. The radius of each circular plot measured 10m. The preliminary status and population assessment were done by assessing the faecal matter present in each plot.

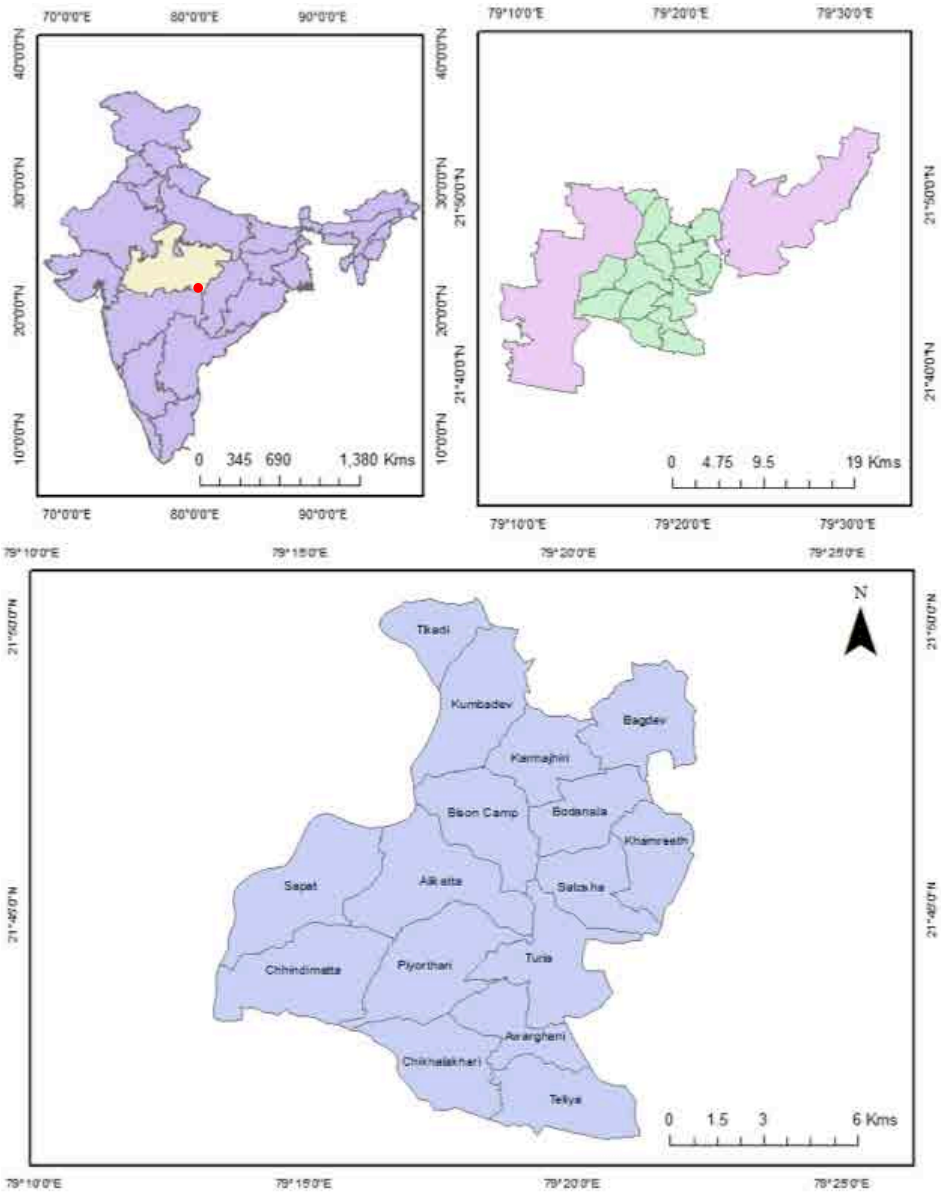

Figure 1. Map of the study area. Top left - the map of India with Madhya Pradesh State and study area (spot) bordering, top right. top right - the map of Karmajhiri range of Pench Tiger Reserve in Madhya Pradesh, bottom - sampled beats of Karmajhiri Range

Faecal matter from the plots was collected from January to June 2013 for feeding analysis.

A total of 83 faecal matter samples, collected from 320 circular plots, were deposited in air-tight bags. The samples were then randomized by dividing these into four equal parts. Out of the four, two diagonal halves were selected for further study (Baubet et al. 2004). After completing the process, a total of 33 faecal samples were taken for feeding analysis. The air-dried faecal matter was washed in flowing water through a fine nylon sieve (Fournier-Chambrillon 1995). Samples were first oven-dried for about 24hr and then placed on filter paper. Five small portions were randomly selected and placed on another piece of paper. Again, five semi-digested materials were randomly picked up from each portion. Plant and animal fragments found in the samples were separated and identified to the lowest possible taxa using reference collections established prior to the study and were evaluated for the percentage of occurrence.

RESULTS

The overall faecal matter density (FMD) of Wild Boar was found to be 8.2FMD/ha. FMD was assessed in different management beats of Karmajhiri range. The highest FMD of Wild Boar was found in Sapath

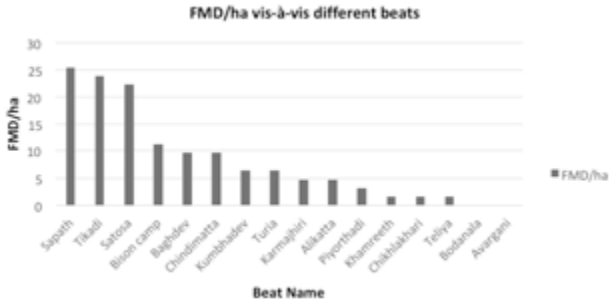

Figure 2. Overall faecal matter density (FMD) of Wild Boar species in different beats of Karmajhiri range of Pench Tiger Reserve, Madhya Pradesh

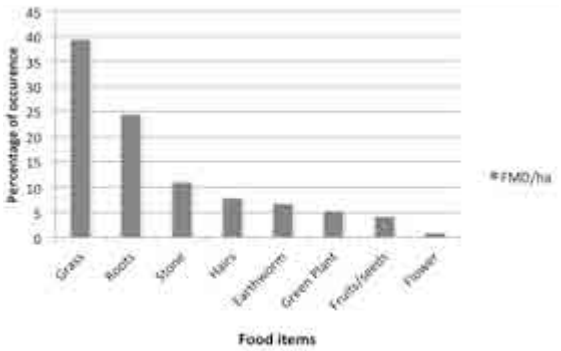

Figure 3. Percent of occurrence of various ingested items as per evidence in scats of Wild Boar in Karmajhari range of Pench Tiger Reserve, Madhya Pradesh

beat with 25.5±0.29/ha, followed by beats Tikadi with 23.9±0.33/ha, Satosa with 22.3±0.7/ha, and Bison camp with 11.1±0.18/ha. In Bodanala and Avarghani beats no faecal matter of Wild Boar were found during the study period. The lowest FMD was recorded in Khamreeth, Chikhlakhari, and Teliya beats with 1.6±0.05/ha. The FMD of Baghdev beat was recorded at 9.6±0.16/ha, followed by that of beats Chindimatta at 9.6±0.16/ha, Kumbhadev at 6.4 ±0.15/ha, Turia at 3.2±0.06/ha, Alikatta at 4.8±0.10/ha, Karmajhiri 4.8±0.10/ha, and Piyorthadi at 3.2 ±0.06)/ha (Fig. 2). Kruskal Wallis One Way ANOVA and post hoc Scheffe's performed for comparing the nature of different sample sizes showed that the results were not significant ($F_{15\ 314}$ = 1.357, P > 0.05), indicating that the samples were not universal or that there is a wide variation in Wild Boar density.

This study provides a general idea of the average dietary spectrum of Wild Boar in PTR. It indicates that 75% of the diet of the species consisted of plant matter and the remaining 25% of animal matter, stones, and earthworm setae. The most commonly detected item was grass, which represented up to 39.37% of the diet (Fig. 3). The second most frequent item was subterranean parts of plants, mainly roots and bulbs, which represented up to 24.5% of the samples (Fig. 3). This was followed by stones (11%), animal hairs (7.8%), and earthworm setae (6.8%). Green plant materials accounted for 5.25%, while fruits & seeds and flowers accounted for 4.25% and 0.8%, respectively.

DISCUSSION

Wild Boar are omnivorous and their depredation on certain forest tree seedlings, saplings, and agricultural crops is known to result in rampant human-animal negative interactions that cause grave concern to foresters and farmers (Wood & Barrett 1979).

The faecal matter of Wild Boar in PTR comprised mainly on plant matter and significant amount of animal matter such as earthworm setae. Among plant matter, the presence of monocots, i.e., grass (39.3%) was the highest, followed by roots and tubers (24.5%). The consumption of earthworm accounted for 6.87% of the total ingested material.

Studies carried out in different geographical regions show that earthworms are the most preferred animal matter for Wild Boar because of its high protein content (Howe et al. 1981; Fournier-Chambrillon et. al. 1995; Massei et al. 1996; Baubet et al. 2004). The consumption of earthworm, however, appears to be very low in this study, which may be due to reduced availability of earthworms during low temperatures of the study period. Earthworms remain inactive when the temperature is very low and probably remain buried deep in the ground (Baubet et. al. 2003).

The present study showed that the FMD of Wild Boar in PTR was 8.2/ha, and the densities were high in beats that are situated adjacent to human habitation and are potential sites for human-animal negative interactions. The maximum density was in Sapath beat followed by beats Tikadi and minimum in Turia beat.

The Wild Boar is a Protected species in India under WPA, 1972, however, hunting of the species may be allowed by the Chief Wildlife Warden in instances where individuals of the species are considered dangerous to human life or property. In spite of such a provision in the Act, it is necessary to prevent the persecution of Wild Boar through education and awareness among agriculturists for adopting crop protection measures and avoiding retaliation against depredation by the Wild Boar.

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The composition and status of waterbirds of Perur Lake in Tamil Nadu, India

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Abstract: The composition and status of waterbirds in Perur-Sundakamuthur Lake, a wetland in Coimbatore, Tamil Nadu, was studied from May 2014 to April 2016. This wetland is home to resident and local migrant birds throughout the year and is also used by winter migrant birds during a part of the year (September to March). From the data collected so far, the highest number of birds and species diversity was recorded from February to April. It is, therefore, imperative to maintain adequate water levels in these wetlands during these crucial months for the benefit of the northward migrating waterbirds. During the study period, it was also found that activities like road building could have had a deleterious effect on the number of birds that used this wetland. We recommend that similar studies be carried out in some of the adjoining wetlands of the area in a synchronous manner to further understand the subtlety of local avian movements within the greater Coimbatore area.

Keywords: Birds, Coimbatore, diversity, Perur-Sundakamuthur Lake, waterbirds, water level, wetland.

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INTRODUCTION

Birds occupy a range of habitats and are responsive and sensitive to environmental changes. Wetlands are one of the most productive ecosystems and waterbirds play a vital role in its effective functioning. Urban habitats that include wetlands are continuously disturbed by development activities, which affect bird populations (Raju 2015). Although most urban wetlands in India are considered to be extremely polluted, they still attract a large number of winged visitors (Reginald et al. 2007). Our conclusions are based on the compilation and interpretation of data gathered during monthly bird counts in Perur-Sundakamuthur Lake from May 2014 to April 2016.

STUDY AREA

This study was carried out in Perur-Sundakamuthur Lake (Perur Lake henceforth) (10.968 N & 76.928 E), a wetland complex located in the urban fringe of metropolitan Coimbatore, Tamil Nadu. According to Pragatheesh & Jain (2013), the wetland complex in Coimbatore consisting of around 30 lakes was constructed during the Kongu-Chola regimes in 8th and 9th Century AD in the vicinity of the Noyyal River basin. Considering the nature of the river to flood downstream near Noyyal villages and to exploit the scanty rainfall typical of this region, the Kongu-Chola kings channelized the fury of the monsoon by creating a system of lakes and anicuts to aid the recharging of groundwater. Over a period of time, these wetlands came to house a lot of species of birds, fish, and other forms of life. Thus, the wetlands in this dry region not only provide the much-needed water for agriculture but also perform functions such as flood control, groundwater recharge, water purification, nutrient retention, and biodiversity conservation.

The Perur Lake, which has a catchment area of 5.768km^2, is fed by Kuniyamuthur anicut channel from Noyyal River as an overflow of excess water from Ganganarayanasamudhram Lake, located further upstream. The length of the road that adjoins the Perur Lake on the eastern side is approximately 2km (formerly a mere bund), which is shaped like a crescent and filled with partial vegetation on one side and residential areas on the other. Given the lack of industrial activity in the area and non-flow of sewer into this lake, it is relatively unpolluted and contains a rich diversity of molluscs and fish that provide food for waterbirds. According to Wetland (Conservation and Management) Rules, 2010, the violations in this lake are encroachment and road construction as presented in Table 3 (Pragatheesh & Jain 2013).

Size of the wetland

Catchment area: 5.768km^2
Water spread area: 1.072km^2
Capacity: 1,470,777m^3 (51.94 m.cft)
Full tank level: 4.51m
Maximum water level: 5.12m
Top bund level: 6.49m
Depth: 4.511m
Length of the bund: 1,350.00m
Length of shoreline: unknown
Anicut: 3.5Sq.km

Inlets and outlets

It receives excess water from the Ganganarayanasamudharam Lake.
Number of inlets: 1 (channel)
Number of outlets: 7 (one weir & six sluices)
Length of surplus escape: 35.67m

MATERIALS AND METHODS

The field observations of birds were carried out from May 2014 to April 2016. The periodicity of the survey was once a month, which usually fell on the second Saturdays. A systematic count of birds that were seen and heard was recorded in a checklist by walking along the 2km road in the mornings. The equipment that was used included binoculars (Nikon 10x42.5, Zeiss 10x42 & Eagle optics 10x42) and a spotting scope (Bausch & Lomb 20–80x magnification). In addition, cameras were also used when necessary during the count. The number of people who participated in the count on any given day varied from three to eight.

The identification of birds was carried out with the help of field guides (Grimmet et al. 2011; Paulson 2005; Rasmussen & Anderton 2012). The checklist was prepared using standardized common and scientific names after Grimmet et al. (2011). The status of birds was categorized as resident, local migrant, winter migrant, and vagrant and are defined as follows. It should be added that some species like Lesser Whistling-duck *Dendrocygna javanica* and Little Ringed Plover *Charadrius dubius* have dual status due to their migrant and resident populations.

Resident (R) – A species that stays and breeds in the area throughout the year or most of the year (e.g.: Spot-billed Duck *Anas poecilorhyncha*).

Local migrant (LM) – A species that stays in an area throughout the year or most of the year whose adult population moves outside the area to breed (e.g.: Painted Stork *Mycteria leucocephala*).

Winter migrant (WM) – A species that spends its non-breeding winter months (mostly from September to April) in the area (e.g.: Wood Sandpiper *Tringa glareola*).

Vagrant (V) – A species that occasionally visits an area and whose pattern cannot be discerned (e.g.: Woolly-necked Stork *Ciconia episcopus*).

RESULTS

The bird species recorded in Perur Lake during this period were 112, belonging to 44 families and 18 orders. Since this study focuses exclusively on waterbirds, which are 49 in number belonging to 14 families and seven orders, only their status is discussed in detail and listed in Table 1.

Anseriformes: Anatidae

1. Lesser Whistling-duck *Dendrocygna javanica* is a species that has the potential to breed in this area when conditions are favourable and to not do so when they are not. Therefore, it has the dual status of a possible resident or a local migrant, based on local factors like water levels in the wetland (Ali 2002). This species was recorded throughout the year except during the dry months from April to June (the only exception being that in May 2015 when five birds were recorded due to favourable water conditions). The highest numbers of this species were seen during the winter months of January 2015 and February and March 2016 when 97, 159, and 74 species were recorded, respectively. Based on these observations, this possible breeder in the area during the southwestern monsoon months (Rasmussen & Anderton 2012) is primarily a local migrant during winters in Perur Lake (Fig. 1).

2. Cotton Pygmy-goose *Nettapus coromandelianus* is a local migrant duck in the area that was recorded only during winter months in an erratic manner. They were sighted from November 2014 to January 2015; a single individual was sighted in December 2015 (Fig. 2).

3. Indian Spot-billed Duck *Anas poecilorhyncha* is a resident species that was recorded every month since the count began in March 2014. Its highest counts were recorded during the migratory months of September and October during autumn and also in February, March, and April during spring. In September and October 2014, however, its numbers were depressed due to very high water levels, which were devoid of shoreline exposure. This dabbling duck favours shallow freshwater lakes with extensive emergent vegetation (Madge & Burn 1988) and shoreline exposure. This characteristic helps to explain its low numbers in September and October of 2014, which were 14 and 22. During similar periods in 2015, however, the numbers of this species were 227 and 114, respectively, due to favourable conditions (Fig. 3). In January 2015, a pair was observed in courtship behaviour, which terminated in copulation. In the October 2015 bird count, when 114 individuals of this species was recorded, an adult bird with a crèche of five chicks was also observed, confirming the breeding status of this bird in this lake.

4. Northern Shoveler *Anas clypeata* is a winter migrant species (Fig. 4a) that was recorded during the winter months between December 2014 and March 2015. The numbers were 113, 140, 131, and 99 in each month of this period. Due to some inexplicable reason, three and nine individuals of this species were recorded only in October 2015 and February 2016, respectively, of the second season.

5. Northern Pintail *Anas acuta* is also a winter migrant duck (Fig. 5a) that was recorded from December 2014 to March 2015, whose numbers were 71, 218, 436, and 30, respectively. Similar to Northern Shoveler, the Pintails were also reduced in numbers during the subsequent year; only two and 14 individuals were recorded in January and February 2016, respectively.

6. Garganey *Anas querquedula***,** according to our records for Perur Lake, is the most numerous winter migrant duck (Figs. 6a,b). It was recorded every month from December 2014 to April 2015, with peak sightings in February and March 2015, which were 532 and 436, respectively. Its sightings, however, dwindled during the winter months of 2015–2016 as only 21 and 152 individuals were recorded in February and March 2016, respectively. Note: Species 4, 5 & 6 that are winter migrant ducks were recorded in lesser numbers in 2015–2016 when compared with similar months in 2014–2015. Only continued monitoring can possibly reveal the reasons behind these annual variations.

7. Common Teal *Anas crecca* is a winter migrant species with erratic presence in the lake. The species was recorded in January and February 2015 and a pair was observed in October 2015 (Figs. 7a,b).

Podicipediformes: Podicipedidae

8. Little Grebe *Tachybaptus ruficollis* is a resident species recorded throughout the year, except in the months of May and June. This bird is extremely water

Table 1. Waterbirds of Perur Lake, Coimbatore, Tamil Nadu

	Common name	Scientific name	Status	Observed months
	Anseriformes: Anatidae			
1	Lesser Whistling-duck	*Dendrocygna javanica*	R/ LM	YR except for Apr & Jun
2	Cotton Pygmy-goose	*Nettapus coromandelianus*	LM	Nov–Jan
3	Indian Spot-billed Duck	*Anas poecilorhyncha*	R	YR
4	Northern Shoveler	*A. clypeata*	WM	Oct–Mar
5	Northern Pintail	*A. acuta*	WM	Dec– Mar
6	Garganey	*A. querquedula*	WM	Aug–Apr
7	Common Teal	*A. crecca*	WM	Oct, Jan, Feb
	Podicipediformes: Podicipedidae			
8	Little Grebe	*Tachybaptus ruficollis*	R	YR except for May, Jun
	Ciconiiformes: Ciconiidae			
9	Asian Openbill	*Anastomus oscitans*	LM	YR
10	Woolly-necked Stork	*Ciconia episcopus*	V	Mar, Apr
11	Painted Stork	*Mycteria leucocephala*	LM	Feb–May, Jul, Sep–Dec
	Suliformes: Phalacrocoracidae			
12	Indian Cormorant	*Phalacrocorax fuscicollis*	R	YR except for May, Jun
13	Great Cormorant	*P. carbo*	LM	Dec, Jan
14	Little Cormorant	*P. niger*	R	YR
	Suliformes: Anhingidae			
15	Oriental Darter	*Anhinga melanogaster*	R	YR
	Pelecaniformes: Pelecanidae			
16	Spot-billed Pelican	*Pelecanus philippensis*	LM	Jul, Sep, Oct
	Pelecaniformes: Ardeidae			
17	Yellow Bittern	*Ixobrychus sinensis*	LM	Feb–Apr
18	Cinnamon Bittern	*I. cinnamomeus*	LM	Feb, Apr
19	Grey Heron	*Ardea cinerea*	R	YR
20	Purple Heron	*A. purpurea*	R	YR
21	Great Egret	*Casmerodius albus*	LM	YR
22	Intermediate Egret	*Mesophoyx intermedia*	LM	YR
23	Little Egret	*Egretta garzetta*	LM	YR
24	Western Reef-Heron	*E. gularis*	V	O (Mar)
25	Cattle Egret	*Bubulcus ibis*	R	YR
26	Indian Pond-Heron	*Ardeola grayii*	R	YR
27	Striated Heron	*Butorides striata*	R	Mar, Apr, Jun–Aug
28	Black-crowned Night-Heron	*Nycticorax nycticorax*	R	Feb–Apr, Jul–Sep, Nov
	Pelecaniformes: Threskiornithidae			
29	Glossy Ibis	*Plegadis falcinellus*	WM	Sep–Mar
30	Black-headed Ibis	*Threskiornis melanocephalus*	LM	Mar–May, Aug, Sep
31	Eurasian Spoonbill	*Platalea leucorodia*	LM	O (Oct)
	Gruiformes: Rallidae			
32	White-breasted Waterhen	*Amaurornis phoenicurus*	R	YR except for Jun
33	Grey-headed Swamphen	*Porphyrio porphyrio*	R	YR
34	Common Moorhen	*Gallinula chloropus*	R	YR except for Jun, Jul
35	Eurasian Coot	*Fulica atra*	R	YR
	Charadriiformes: Recurvirostridae			
36	Black-winged Stilt	*Himantopus himantopus*	WM	Feb–May, Nov
	Charadriiformes: Charadriidae			
37	Red-wattled Lapwing	*Vanellus indicus*	R	YR
38	Little Ringed Plover	*Charadrius dubius*	WM/ R	Feb–Jun, Sep, Oct
	Charadriiformes: Jacanidae			
39	Pheasant-tailed Jacana	*Hydrophasianus chirurgus*	LM	Sep, Oct, Dec, Jan
40	Bronze-winged Jacana	*Metopidius indicus*	LM	Aug, Jan
	Charadriiformes: Scolopacidae			
41	Common Sandpiper	*Actitis hypoleucos*	WM	Aug–Apr
42	Green Sandpiper	*Tringa ochropus*	WM	Nov, Jan–Apr
43	Common Greenshank	*T. nebularia*	WM	Oct, Feb–Apr
44	Marsh Sandpiper	*T. stagnatilis*	WM	Feb–Apr
45	Wood Sandpiper	*T. glareola*	WM	Sep–Nov, Feb–Apr
46	Temminck's Stint	*Calidris temminckii*	WM	Feb, Mar
47	Little Stint	*C. minuta*	WM	Oct, Feb–Apr
	Charadriiformes: Laridae			
48	Whiskered Tern	*Chlidonias hybrid*	WM	Sep, Jan–Mar
49	River Tern	*Sterna aurantia*	WM	Nov, Jan

R - resident, LM - local migrant, WM - winter migrant, V - vagrant,
YR - year-round (recorded throughout the year), O - recorded only once

Table 2. Description of water level

Water level	Description
Dry	The absence of water in the lake or the presence of a negligible amount of wetness
Low	The presence of a small amount of water in a few isolated puddles
Medium	The presence of water in the whole lake with shoreline exposure in the periphery
Full	Lake completely filled with water without any shoreline exposure

Table 3. Types of encroachments in Perur Lake (Pragatheesh & Jain 2013)

Type of encroachment	Authority	Violation of wetland rules	
Hutments	Private	Section 4(1)(vi)	Hutments located in the land-filled areas.
Agriculture	Private	Section 4(2)(x)	
Dumping of waste		Section 4(1)(iv)	Dumping debris and domestic solid waste along the bund.
Roads		Section 4(1)(vi)	Kovai-Puthur bypass road on the eastern side on the lake & a metal road connecting SH-164 with Kovai-Puthur bypass road on the northern bund.

dependent and rarely leaves the water (Rasmussen & Anderton 2012). Accordingly, its highest counts were recorded during the months when the water level was high, such as 33 in September 2014, 50 and 29 in January and February 2015, respectively (Fig. 8). The breeding season of this species ranges principally between April and October (Ali 2002). This species could probably breed in this lake when water levels are medium to full, which occurs usually after the arrival of the southwestern monsoon. Its breeding status was confirmed in the lake when a flock with three chicks was observed in September 2014. This is evidence of post-breeding dispersal when they were recorded in low numbers from September onwards; however, only future observations can verify this behaviour.

Ciconiiformes: Ciconiidae

9. Asian Openbill *Anastomus oscitans* is a local migrant stork that breeds in southern India mostly from November to March (Ali 2002). This bird was consistently recorded in Perur Lake from May to July 2014 and again from January to June 2015, with a brief presence in September and October 2015 and then being sighted in sufficient numbers from March 2016 onwards. This pattern indicates that the breeding adults migrate out of the area during its breeding season, which could vary from September to March. High water levels with unexposed shoreline are a deterrent to its presence, as indicated

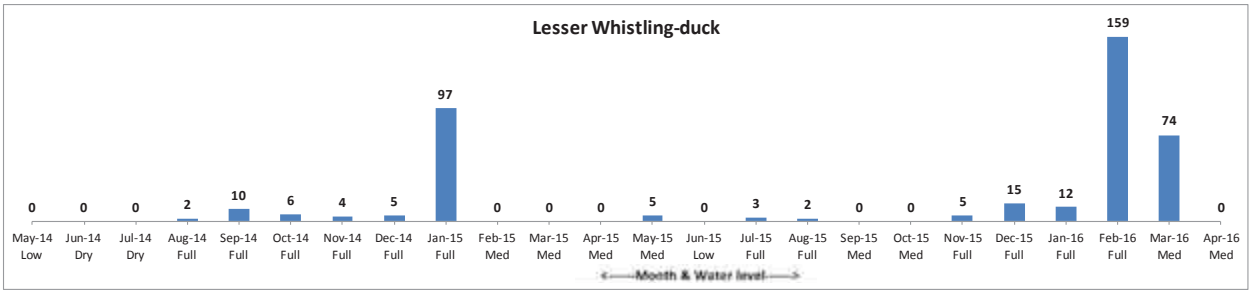

Figure 1. Bar graph showing the occurrence trend (in numbers) of Lesser Whistling-duck

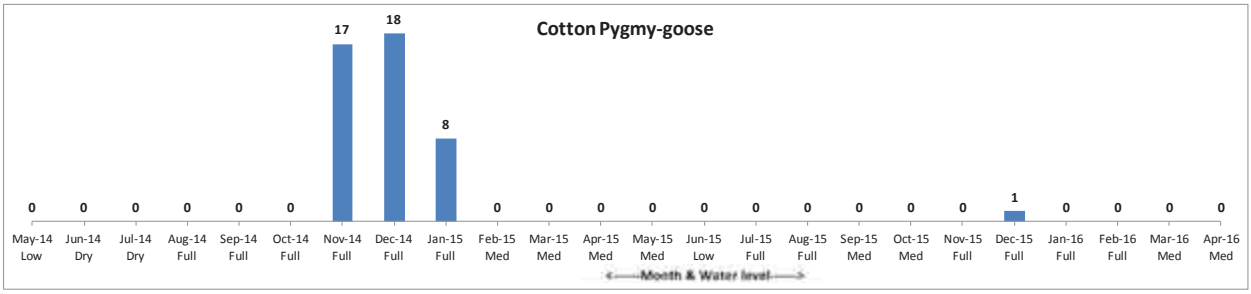

Figure 2. Bar graph showing the occurrence trend (in numbers) of Cotton Pygmy-goose

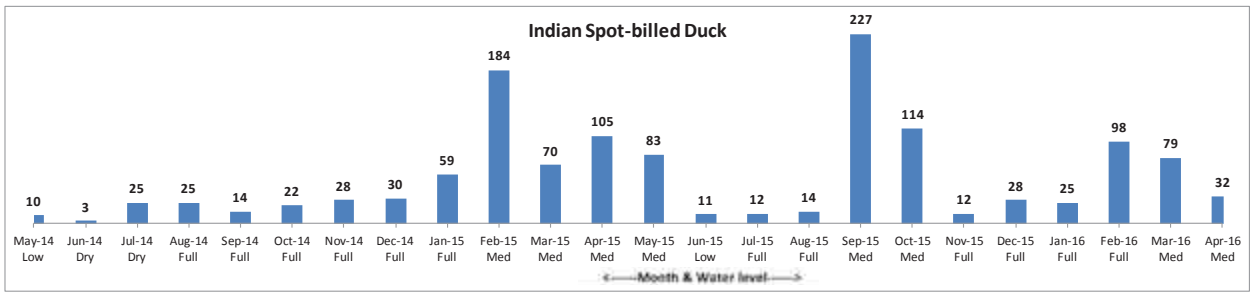

Figure 3. Bar graph showing the occurrence trend (in numbers) of Indian Spot-billed Duck

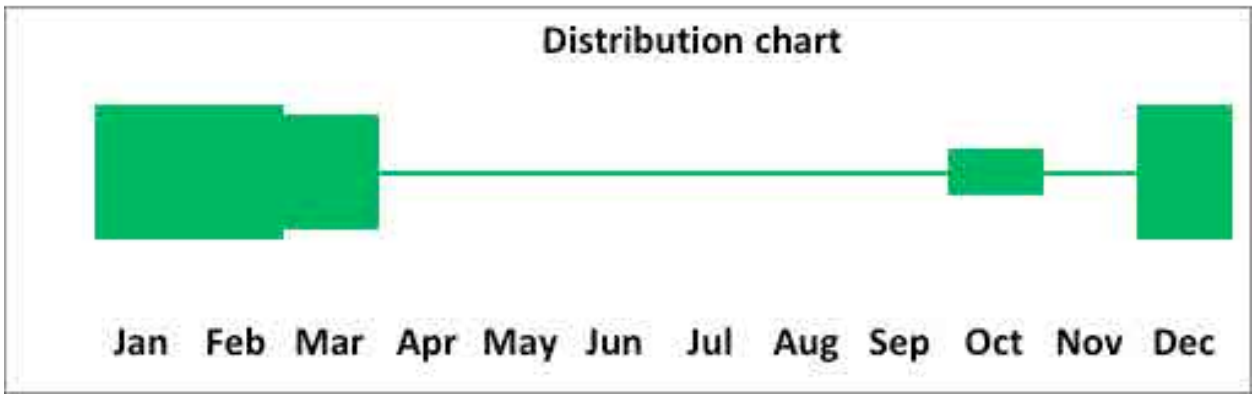

Figure 4a. Distribution chart of Northern Shoveler

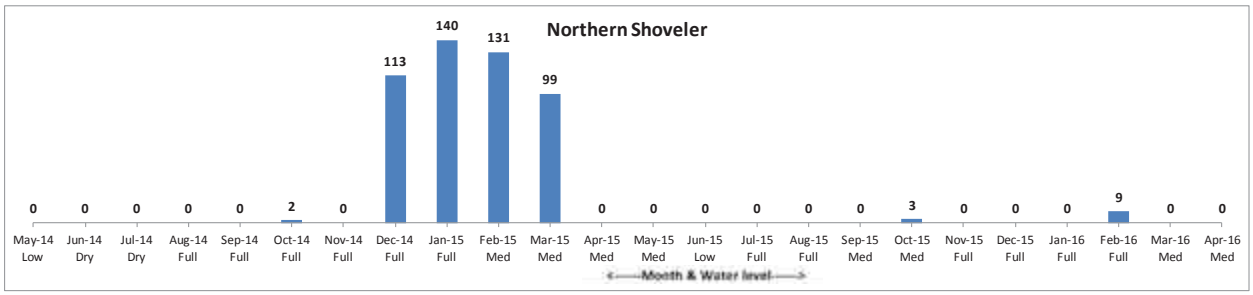

Figure 4b. Bar graph showing the occurrence trend (in numbers) of Northern Shoveler

by the full water levels from August to December 2014 when very few individuals of the species were recorded. In contrast, in September and October 2015, when water levels were less than full with some shoreline exposure, 24 and 17 individuals of this species were recorded, respectively (Fig. 9). Exposed shoreline makes prey-finding possible for this species. Subsequently, when water levels became higher from November 2015 onwards, very few numbers of this species were sighted. This species, however, started to return during the winter months after the full water level receded to expose the shoreline and gradually increased in numbers as the lake dried out.

10. Woolly-necked Stork *Ciconia episcopus* is a vagrant in Perur Lake and was sighted twice in our count period when three and one individuals were recorded in March 2015 and April 2016, respectively. In addition, Sharang (2016) also reported a flock of 62 birds of this stork species on 29 March 2016 from this lake (Fig. 10). These observations, even though scanty in nature, probably indicate that this species might be using Perur Lake as a transit point during spring migration only. A small population of Woolly-necked Stork breeds in the neighbouring districts of Kerala (Sashikumar et al. 2011).

11. Painted Stork *Mycteria leucocephala* is another local migrant species that breeds in southern India between August and January, varying with local conditions (Ali 2002; Rasmussen & Anderton 2012). This species was observed in the lake only when the water was present in levels that were conducive to prey-finding. Its

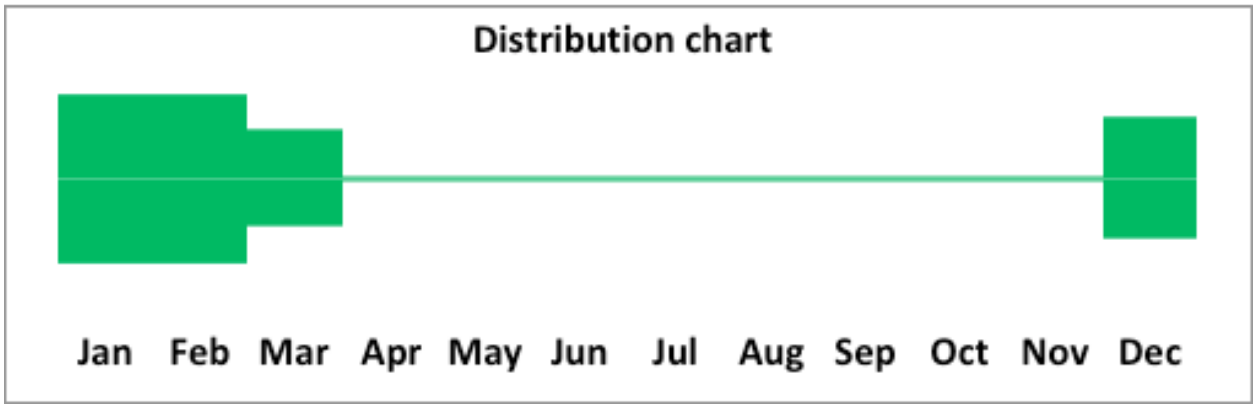

Figure 5a. Distribution chart of Northern Pintail

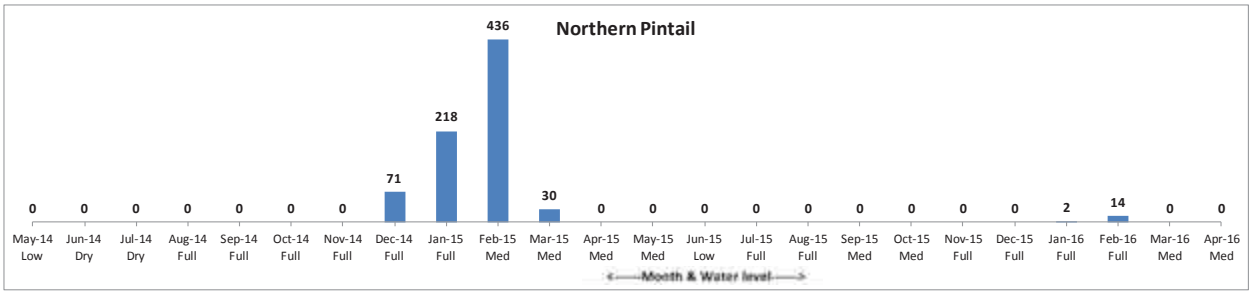

Figure 5b. Bar graph showing the occurrence trend (in number) of Northern Pintail

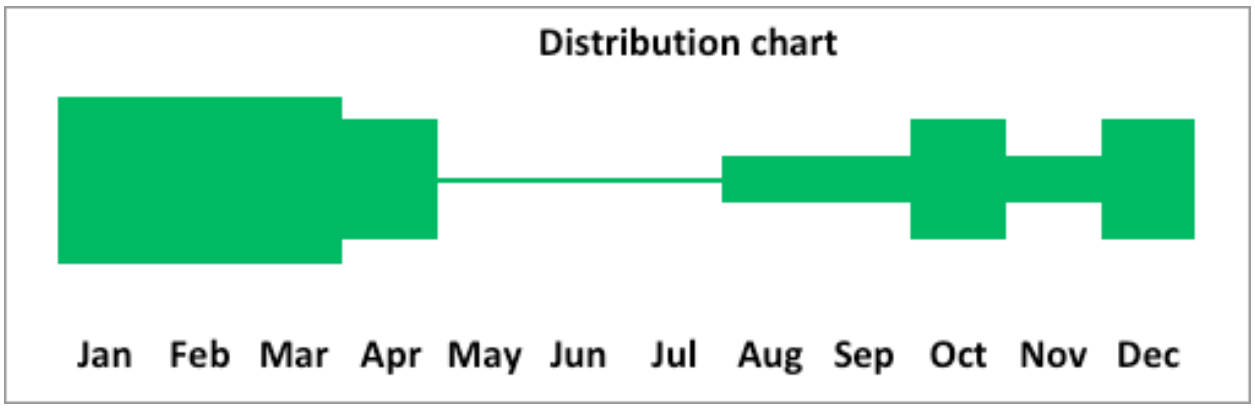

Figure 6a. Distribution chart of Garganey

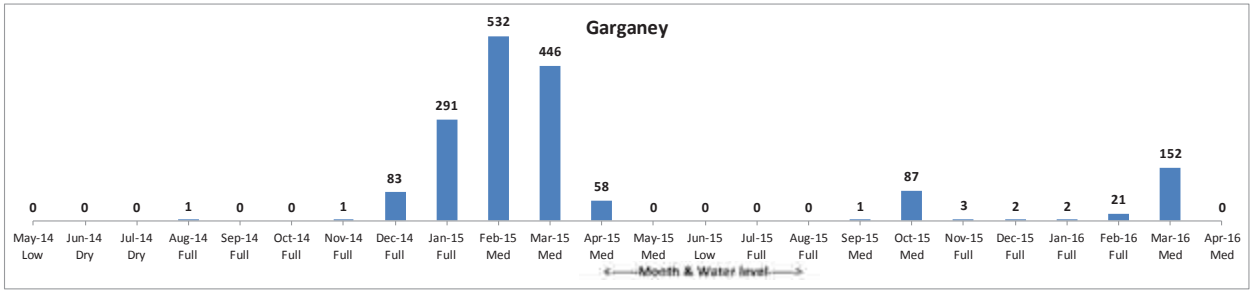

Figure 6b. Bar graph showing the occurrence trend (in numbers) of Garganey

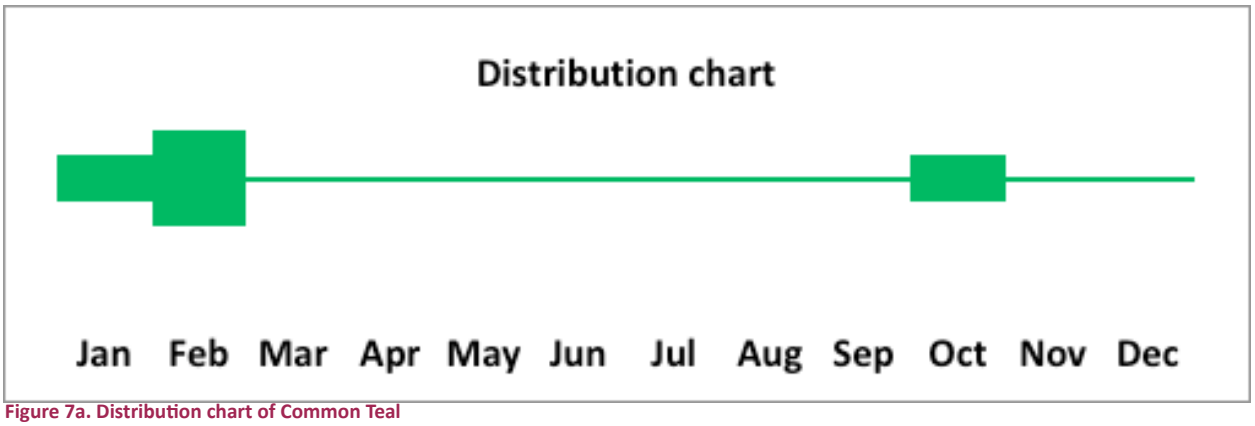

Figure 7a. Distribution chart of Common Teal

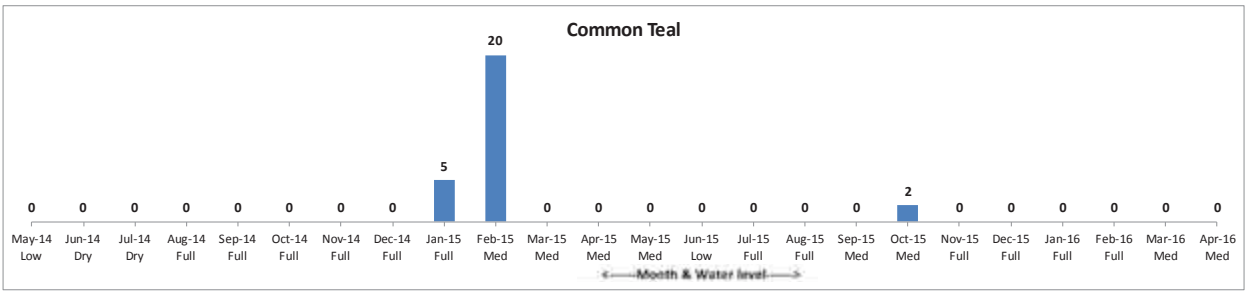

Figure 7b. Bar graph showing the occurrence trend (in numbers) of Common Teal

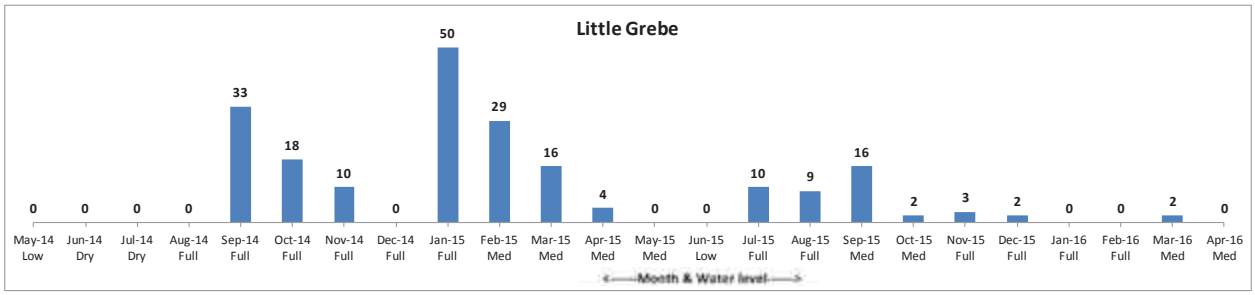

Figure 8. Bar graph showing the occurrence trend (in numbers) of Little Grebe

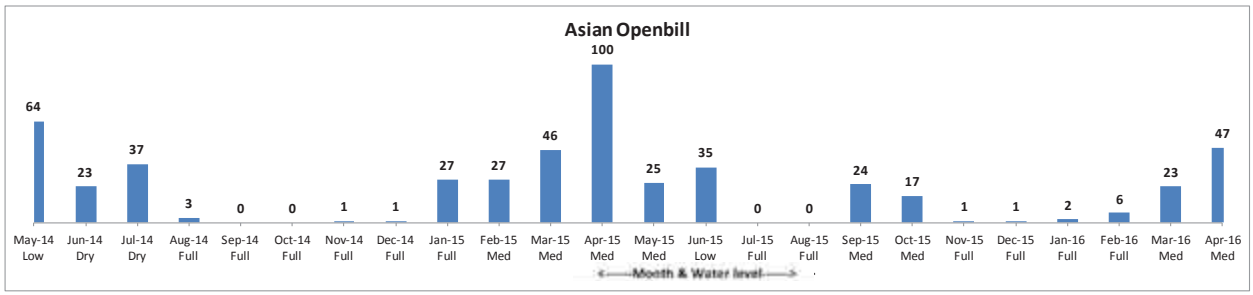

Figure 9. Bar graph showing the occurrence trend (in numbers) of Asian Openbill

highest counts were recorded in September and October 2015 and in April 2016 when 30, 34, and 35 individuals were sighted, respectively (Fig. 11), when the water level was between shallow and medium, which made prey-finding possible. In the study area, it was present mostly from September to May. This species is listed as Near Threatened due to its moderate population reduction owing to hunting, drainage, and pollution (Rahmani 2012).

Suliformes: Phalacrocoracidae

12. Indian Cormorant *Phalacrocorax fuscicollis* is a resident cormorant species and its presence is sparse in Perur Lake. This species was observed in all months of the year except during the summer months of May, June, and July 2014 and from March to June 2015. The highest number was recorded in February 2016 when 11 individuals of this species were sighted. Its absence in October 2014 even when the water level was full shows the erratic presence of this species in Perur Lake. This species probably breeds in the area in other water bodies.

13. Great Cormorant *Phalacrocorax carbo* is a local migrant cormorant species that was sighted twice during our count period, in December 2015 and January 2016. In both the occurrences, only a single bird was recorded (Fig. 13).

14. Little Cormorant *Phalacrocorax niger* is a resident cormorant species that was recorded every month since the count began in March 2014. Its highest counts were recorded in the winter months of January and February 2015 when 252 and 203 individuals were sighted, respectively (Fig. 14). The population of this species drastically reduced when the water levels were low, especially during the summer months from April to July. This species could be a possible breeder in this lake when conditions are favourable. The breeding season of this bird in southern India chiefly lies between November and February (Ali 2002).

Suliformes: Anhingidae

15. Oriental Darter *Anhinga melanogaster* is a resident species that was recorded year-round except in May & September 2014 and March & April 2016. Its highest counts were recorded in November and December 2014 and in September 2015 when 22, 24, and 23 individuals of this species were sighted, respectively. This species is listed as Near Threatened because of its moderate population reduction due to pollution, drainage, hunting, and collection of eggs and nestlings (Rahmani 2012).

Pelecaniformes: Pelecanidae

16. Spot-billed Pelican *Pelecanus philippensis* is a local migrant species and its sighting in Perur Lake is sparse. This species was recorded in September and October of 2014 and 2015; a single member was recorded in July 2015. Its highest count was recorded in September 2015 when 25 numbers of this species were sighted. Notably, the presence of this species was observed in the lake when water levels were above medium. In 2001, Bird Life International listed this species as Vulnerable. Increased protection, however, enabled a recovery in numbers of this species and it was downlisted from Vulnerable to Near Threatened in 2007 (Rahmani 2012)

Pelecaniformes: Ardeidae

Bitterns, as a group, are uncommon in Perur Lake and their secretive nature resulted in infrequent sightings.

17. Yellow Bittern *Ixobrychus sinensis* &

18. Cinnamon Bittern *Ixobrychus cinnamomeus* are the two species of local migrant (LM) bitterns recorded in Perur Lake. Yellow Bittern was recorded in February, March & April 2015 and March 2016 and their numbers were three, two, two, and one, respectively (Fig. 17). Cinnamon Bittern was recorded in February 2015 and April 2016; in both occurrences, a single bird was sighted (Fig. 18). These are possibly local migrants that are sparsely recorded in the lake during winter months.

19. Grey Heron *Ardea cinerea* is a resident species that was recorded year-round in Perur Lake. Its highest counts were recorded in September and October 2015 when 46 and 21 individuals were sighted, respectively, when the water conditions were probably favourable. Their habitat preferences are brackish water, wetlands, reedbeds, and paddy fields (Rasmussen & Anderton 2012). Its breeding season in southern India ranges from November to March (Ali 2002). It is probable that in September and October this species might be using this lake as a transit point (Fig. 19).

20. Purple Heron *Ardea purpurea* is a resident species that was recorded year-round except in May 2014 and July 2015. Its highest counts were recorded in April 2015 and February 2016 when nine and 11 individuals of this species were sighted, respectively. Its breeding season in India ranges from June to March depending on locality (Ali 2002), and in neighbouring Kerala, it reportedly breeds in July and August (Sashikumar et al. 2011).

21. Great Egret *Casmerodius albus* is a local migrant species in the lake. It was recorded year-round in Perur Lake except from August to October 2014, July 2015, and December 2015. They were usually sighted in

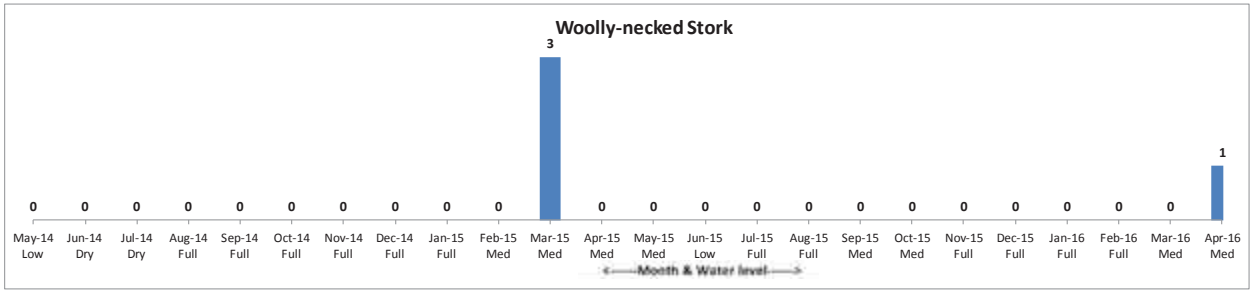

Figure 10. Bar graph showing the occurrence trend (in numbers) of Woolly-necked Stork

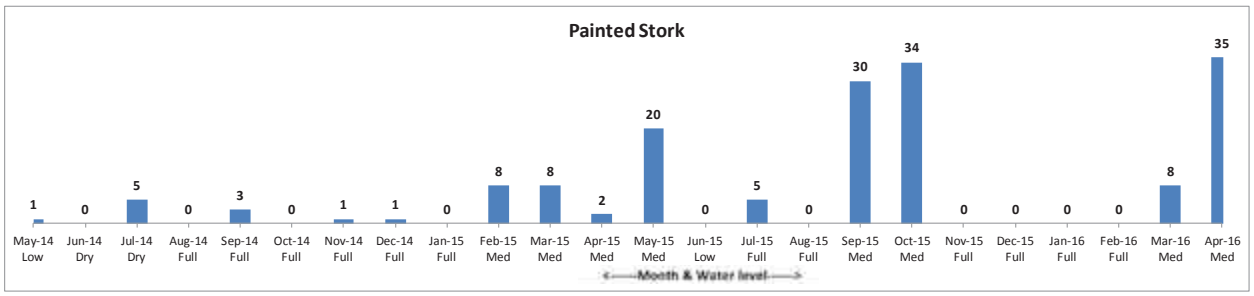

Figure 11. Bar graph showing the occurrence trend (in numbers) of Painted Stork

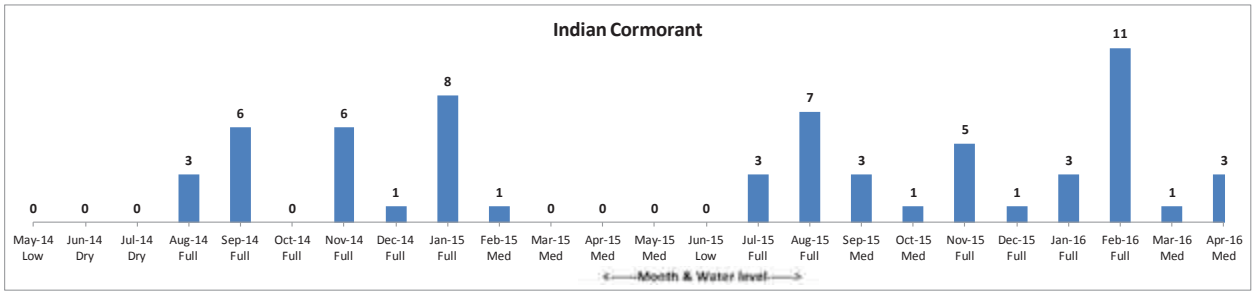

Figure 12. Bar graph showing the occurrence trend (in numbers) of Indian Cormorant

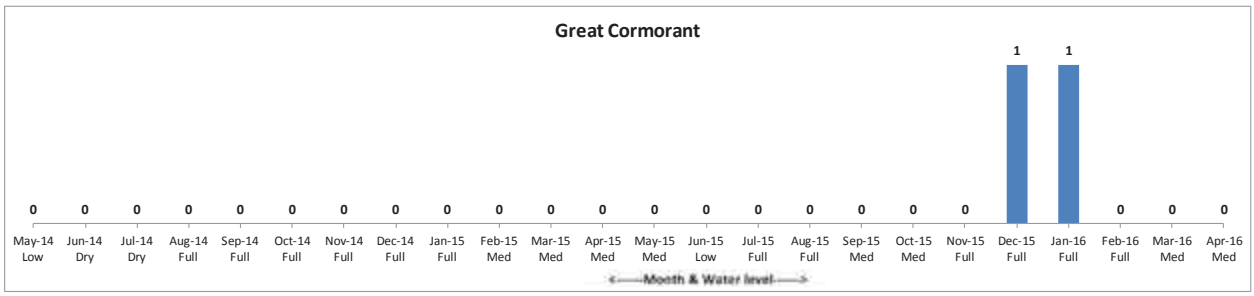

Figure 13. Bar graph showing the occurrence trend (in numbers) of Great Cormorant

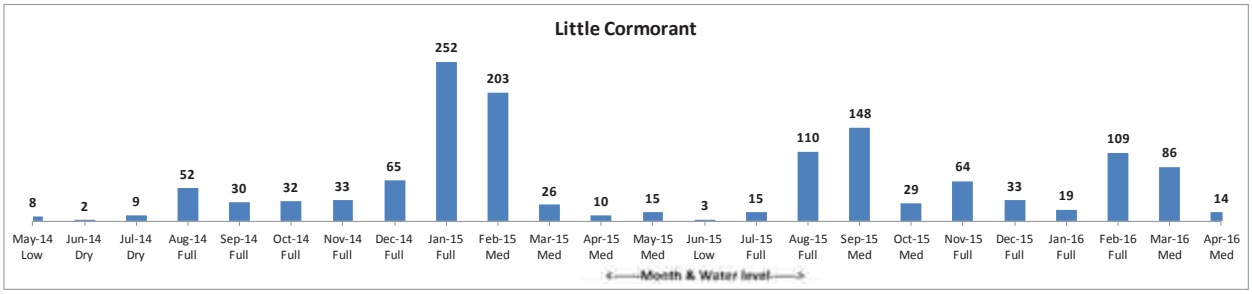

Figure 14. Bar graph showing the occurrence trend (in numbers) of Little Cormorant

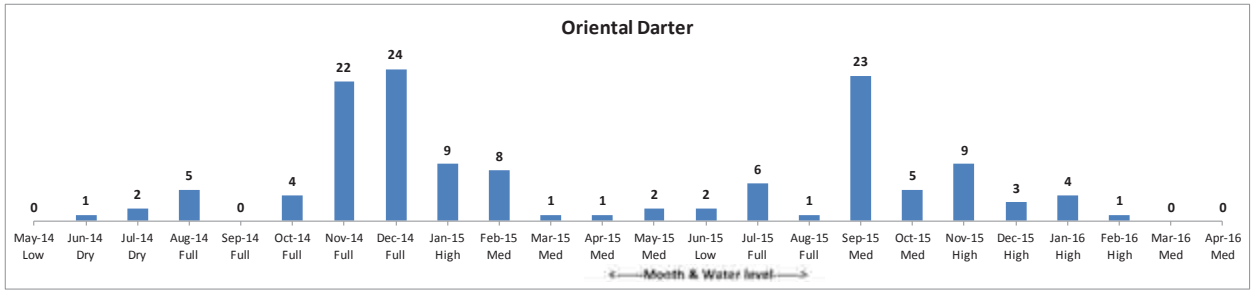

Figure 15. Bar graph showing the occurrence trend (in numbers) of Oriental Darter

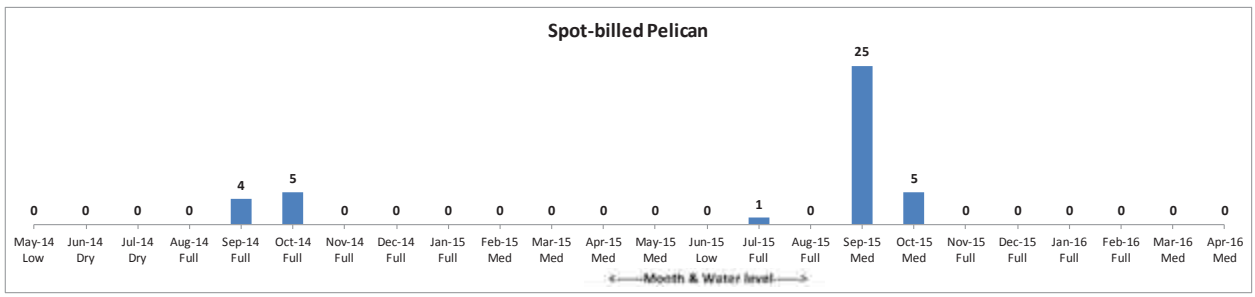

Figure 16. Bar graph showing the occurrence trend (in numbers) of Spot-billed Pelican

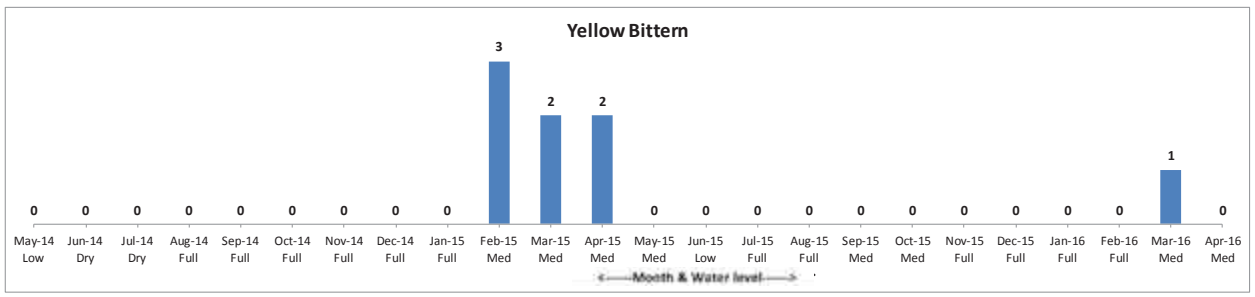

Figure 17. Bar graph showing the occurrence trend (in numbers) of Yellow Bittern

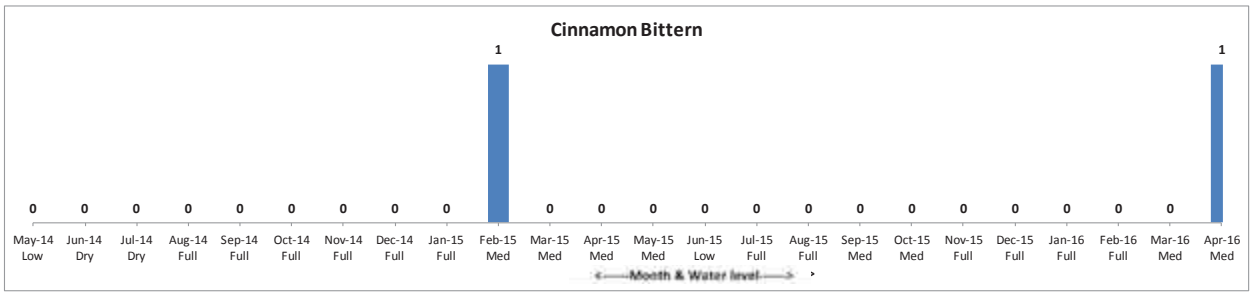

Figure 18. Bar graph showing the occurrence trend (in numbers) of Cinnamon Bittern

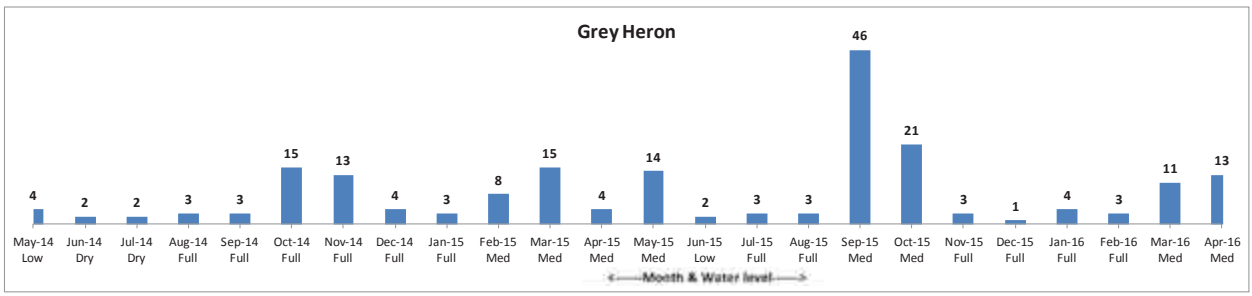

Figure 19. Bar graph showing the occurrence trend (in numbers) of Grey Heron

numbers ranging from one to eight in this lake; however, the highest count was recorded in April 2016 when 31 individuals of this species were sighted (Fig. 21). This observation shows that this species might be using Perur Lake as a transit point during spring migration.

22. Intermediate Egret *Mesophoyx intermedia* is a local migrant species in the lake. It was recorded year-round in the lake, except for the dry months of May and June 2014 and the months from September to November 2014 when the water level was full. Its highest count was recorded in April 2016 and December 2015 when 24 and 17 individuals of the species were sighted, respectively.

23. Little Egret *Egretta garzetta* is another local migrant species in the lake that was recorded year-round. The highest counts of this species were recorded in the spring migration period of March and April 2015 and April 2016 when 60, 116, and 215 individuals were sighted, respectively (Fig. 23).

Note: In analysing the numbers of the three white egret species, namely Great, Intermediate, and Little, it can be deduced that these species probably use Perur Lake as a transit point mostly during the months of March and April. This can be clearly seen in the respective figures (Figs. 21, 22 & 23) when their numbers are at the highest levels.

24. Western Reef-Heron *Egretta gularis* is a vagrant species in the area. This bird was recorded once in Perur Lake when a sole bird was sighted in March 2015 (Fig. 24).

25. Cattle Egret *Bubulcus ibis* is a resident species that was recorded year-round in the lake. The highest counts of this species were recorded in November 2014 and April 2015 when 37 and 40 individuals of this species were sighted, respectively (Fig. 25). Birds with breeding plumage were observed during its breeding months of November to March; however, no nests were recorded in the vicinity of the lake. It builds untidy stick nests in mixed colonies with Cormorants and Pond Herons, often in the vicinity of little villages (Ali 2002).

26. Indian Pond Heron *Ardeola grayii* is a resident that was recorded year-round in the lake. Its highest counts were recorded in January 2015 and April 2016 when 65 and 64 of this species were sighted, respectively (Fig. 26). According to Ali (2002), its breeding season in southern India is from November to January and its nesting behaviour is similar to that of Cattle Egret. We, however, sighted some birds of this species displaying its breeding plumage in April and May 2015 though no nests were recorded in the vicinity of the lake. Its presence is higher in winter and also during spring migration, indicating that some of them might be using this lake as a transit point.

27. Striated Heron *Butorides striata* is a resident species in our area that was recorded in the months of August 2014, March 2015, June to August 2015, and April 2016. The highest count of this species was recorded in April 2016, when four birds were sighted. Even though a resident breeder, it was unrecorded for many months during our count (Fig. 27), due to its secretive and crepuscular behaviour. Occasionally, however, it may be also active during the daytime, particularly in cloudy overcast weather. Its breeding season is from March to August with local variations (Ali 2002). In April 2016, a single bird in breeding plumage was observed in this lake.

28. Black-crowned Night-Heron *Nycticorax nycticorax* is a resident species and its presence is sparse in Perur Lake. Its highest count was recorded in February 2016 when 18 individuals of this species were sighted flying overhead (Fig. 28). Most of them were immature or juvenile birds, indicating its possible breeding in the area. This species, however, is largely unrecorded during our counting sessions due to its nocturnal and crepuscular nature similar to that of the Striated Heron. According to (Ali 2002), this species breeds from December to February in southern India.

Pelecaniformes: Threskiornithidae

29. Glossy Ibis *Plegadis falcinellus* is a winter migrant species that was recorded in the lake during the winter months from September to March. The highest counts were recorded in September and October of 2015 when 53 and 68 of this species were sighted, respectively. During September and October of 2014, however, this species was not recorded in the lake. A plausible explanation can be arrived at by analysing its sight recordings in conjunction with the water level variations. When water levels were shallow with shoreline exposure that facilitated prey-finding, this species was recorded in large numbers as was the case in September and October 2015. When water levels were full in September and October of 2014, however, they were absent. This fact can be clearly seen in Fig. 29b where the water level was medium and its numbers were higher.

30. Black-headed Ibis *Threskiornis melanocephalus* is a local migrant species that was recorded erratically in the lake. The highest count was recorded in April 2016 when six of this species were sighted. According to (Ali 2002), its nesting season is largely "ill-defined" and it may nest in southern India from November to December. This species was unrecorded in the lake during those months. According to Rahmani (2012), this species is nomadic and migratory in nature depending upon the availability

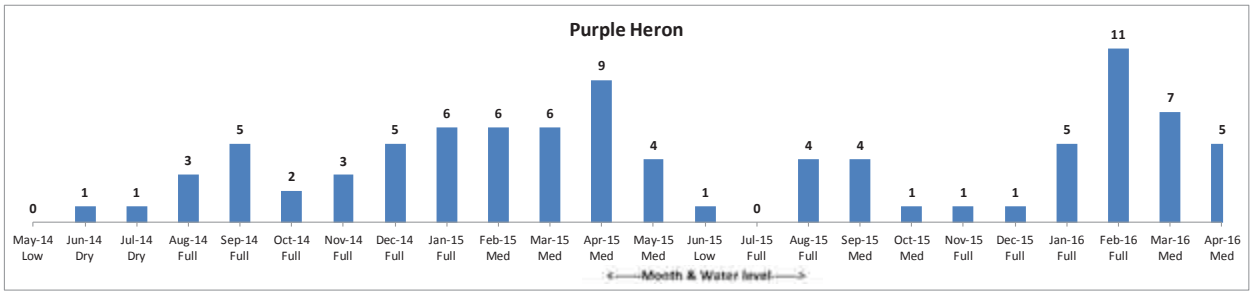

Figure 20. Bar graph showing the occurrence trend (in numbers) of Purple Heron

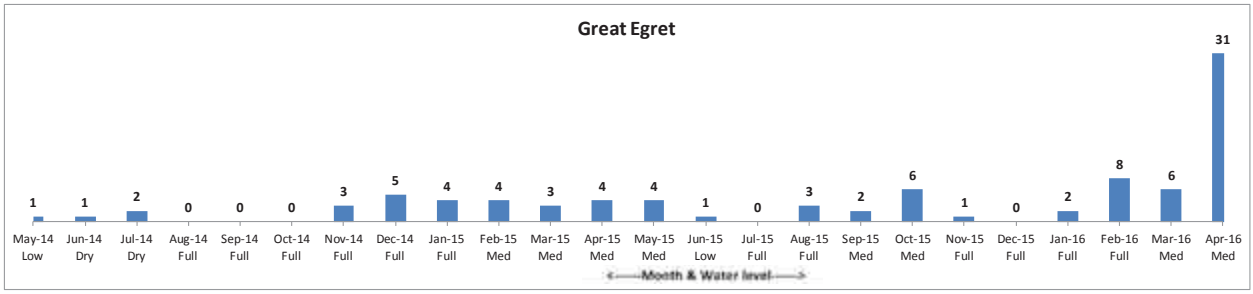

Figure 21. Bar graph showing the occurrence trend (in numbers) of Great Egret

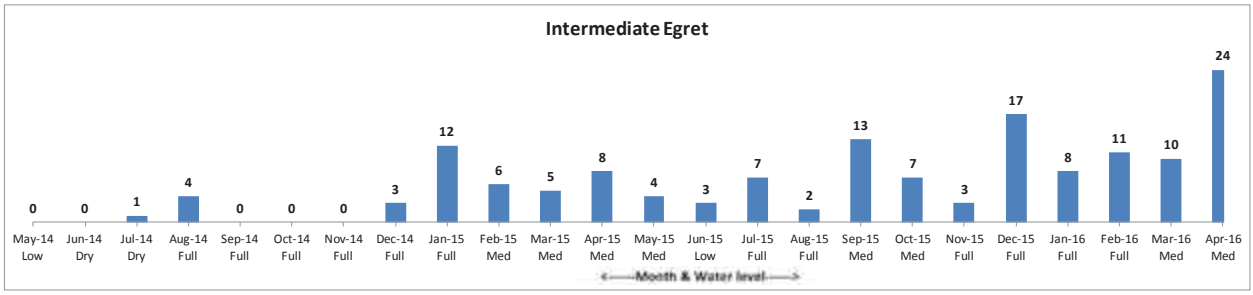

Figure 22. Bar graph showing the occurrence trend (in numbers) of Intermediate Egret

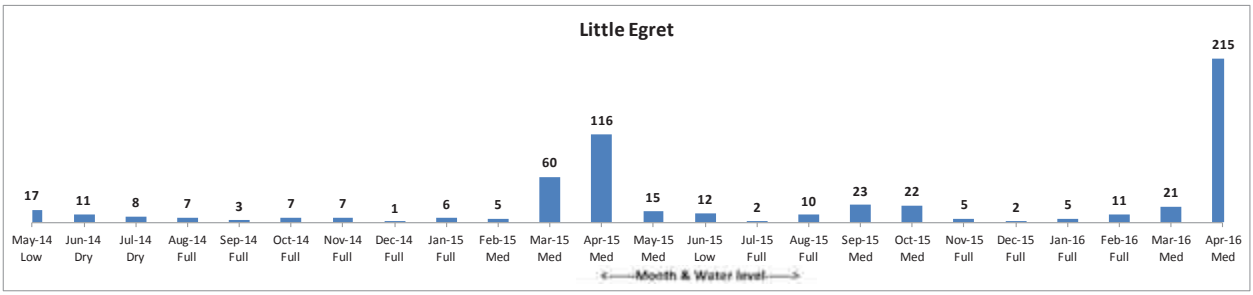

Figure 23. Bar graph showing the occurrence trend (in numbers) of Little Egret

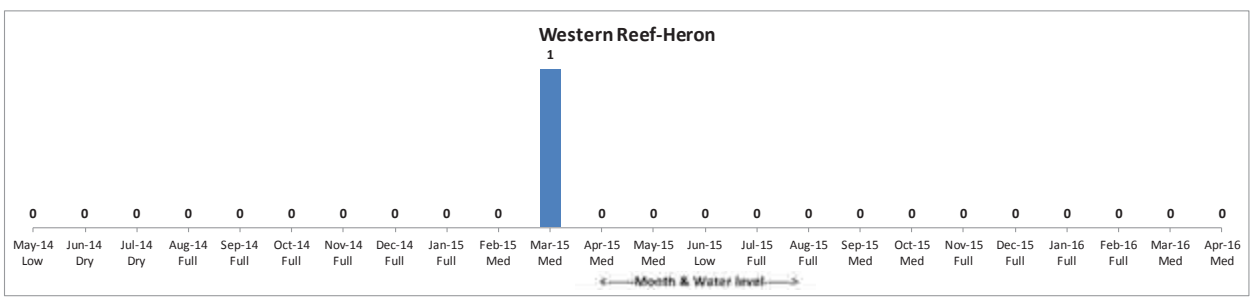

Figure 24. Bar graph showing the occurrence trend (in numbers) of Western Reef-Heron

of water. Since its population reduction in Asia due to an entire gamut of threats from hunting, disturbances at the breeding colonies to drainage, and conversion of foraging habitats to agriculture lands, it is listed as Near Threatened.

31. Eurasian Spoonbill *Platalea leucorodia* is a local migrant species that was recorded only once in October 2015 when 11 individuals of the species were sighted. It is not possible to conduct an analysis based on this single observation.

Gruiformes: Rallidae

32. White-breasted Waterhen *Amaurornis phoenicurus* is a resident species that was recorded year-round except during the drier months in the lake from May to July. Its highest count was recorded in February 2015 when six individuals of this species were sighted (Fig. 32). Its breeding season is from June to October or during southwestern monsoon (Ali 2002).

33. Grey-headed Swamphen *Porphyrio porphyrio* is a resident species that was recorded year-round in Perur Lake. The highest counts of this species were recorded in February and March of 2015 and 2016 when 48, 25, 44, and 74 individuals were sighted, respectively. In addition, in April 2016, 27 birds were sighted, possibly indicating its larger counts during spring migration. In the lake, this species is mostly recorded when water is present and its highest counts are recorded when the water levels vary between low and medium. Its breeding season is during the monsoon months of June to September (Ali 2002). During the March 2016 count, however, when the highest number of this species was recorded, three chicks were sighted accompanying an adult indicating its possible breeding status.

34. Common Moorhen *Gallinula chloropus* is a resident species that was recorded year-round, except in June and July in the lake. Its breeding season is from June to September or during the southwestern monsoon (Ali 2002). The highest counts were recorded in January and April of 2015 when 25 and 30 individuals of this species were sighted, respectively.

35. Eurasian Coot *Fulica atra* is a resident species that was recorded year-round in the lake except for the months of July 2014, June 2015, and April 2016. From August 2014 to February 2015, the range of variation of this species sighted was from 68 to 584, when the highest counts occurred between September and October 2014 and also during the winter months of January and February 2015. The plausible reasons behind such an occurrence could be the fact that the combination of local migrant birds, as well as locally breeding birds, could have been sighted simultaneously, especially in September and October 2014 when the counts were 575 and 584, respectively. It is worth noting that during this period, the water levels were favourable for breeding, which ranged from medium to full. During a similar period in 2015-2016, however, its numbers were significantly reduced due to unfavourable water levels. Even though Ali (2002) states that Eurasian Coots breed during the monsoonal months of July and August, according to Rasmussen & Anderton (2012), this species could possibly breed in southern India up to November. A juvenile bird and a nest of grassy vegetation were recorded during our November 2014 count. Additionally, a single chick was observed in March 2016. These observations confirm its breeding status in the lake when conditions are favourable.

Charadriiformes: Recurvirostridae

36. Black-winged Stilt *Himantopus himantopus* is a winter migrant species that was recorded in the lake in a sporadic manner when water levels were less than full with adequate shallow water and shoreline exposure. The highest counts were recorded in March 2015 and 2016 when 26 and 56 of this species were sighted, respectively. During these months, water levels were medium and facilitated prey–finding. Its long stilt-like legs, when compared with other waders, enable it to find prey by walking further in the water (Ali 2002).

Charadriiformes: Charadriidae

37. Red-wattled Lapwing *Vanellus indicus* is a resident species that was recorded year-round, except in May and June 2014 when the water level was very low and January of 2015 and 2016 when the water level was high. Its highest count was recorded in September and October of 2015 when 15 and 16 individuals were sighted, respectively. Its breeding season is chiefly from March to August (Ali 2002). A juvenile of this species was observed in July 2015

38. Little Ringed Plover *Charadrius dubius* has two subspecies that are called *C.d.curonicus*, which is entirely a winter migrant in India, and *C.d.jerdoni*, a possible breeder and resident (Hayman et al. 1986). This species was recorded in February and March of 2015 and 2016 and in May, June, September and October 2015. Its highest counts were recorded in March 2015 and 2016 when 84 and 39 individuals of this species were sighted, respectively, during the spring migration season when water levels were favourable and there was adequate shoreline exposure. An overwhelming majority of the birds sighted during these months are the migratory form *C.d. curonicus*. When conditions are favourable,

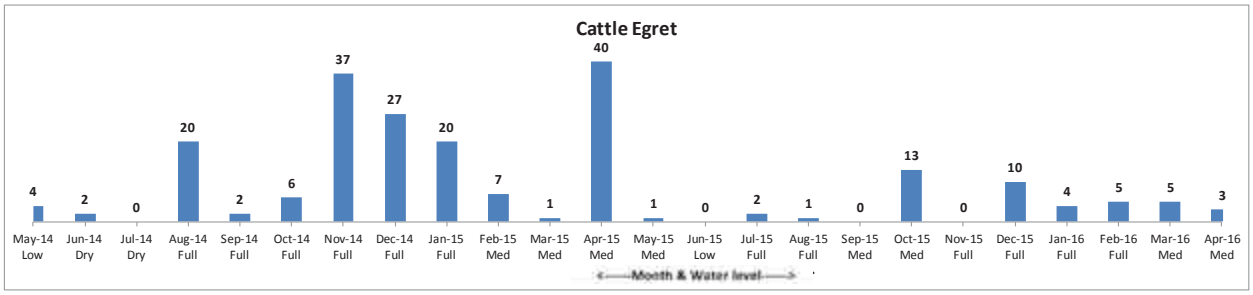

Figure 25. Bar graph showing the occurrence trend (in numbers) of Cattle Egret

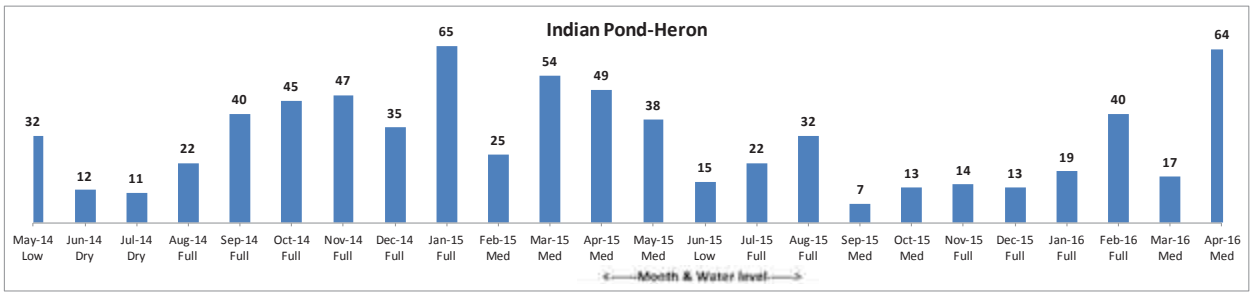

Figure 26. Bar graph showing the occurrence trend (in numbers) of Indian Pond-Heron

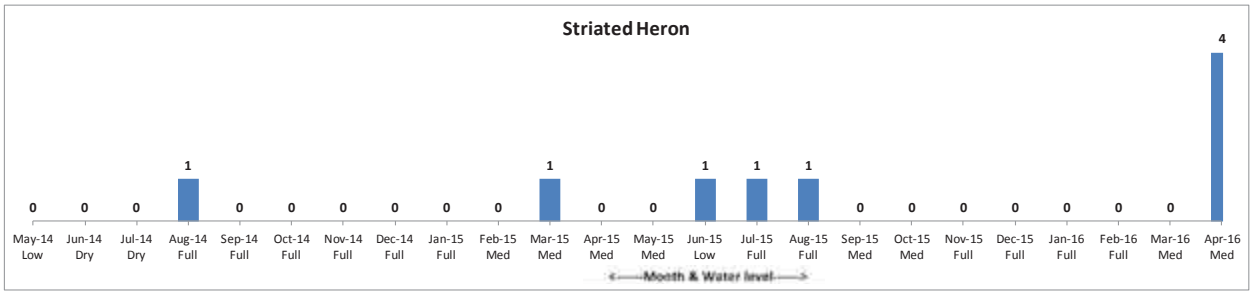

Figure 27. Bar graph showing the occurrence trend (in numbers) of Striated Heron

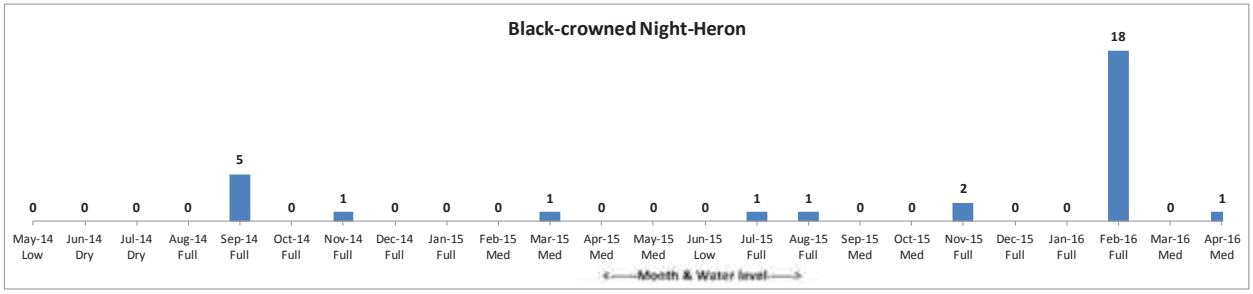

Figure 28. Bar graph showing the occurrence trend (in numbers) of Black-crowned Night-Heron

the resident subspecies *C.d. jerdoni* could be a possible breeder in this lake. In May and June 2015, three and one individuals of this subspecies were recorded, respectively. Due to changing water levels, however, its nesting could not be confirmed.

Charadriiformes: Jacanidae

39. Pheasant-tailed Jacana *Hydrophasianus chirurgus* is a local migrant species that was infrequently recorded in the lake. Its numbers when sighted were very few such as one, one, and two in September, October, and December 2014, respectively; however, 17 individuals of the species were sighted in January 2015, which is an

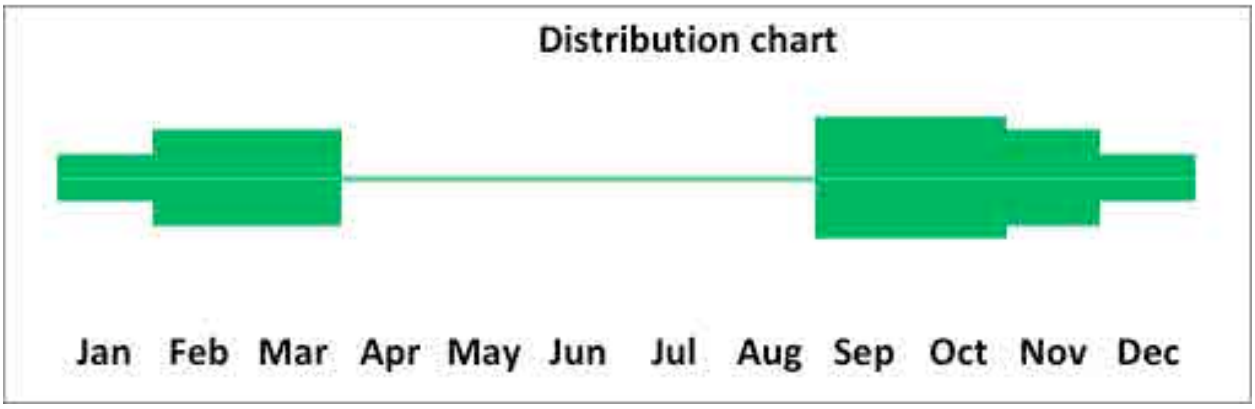

Figure 29a. Distribution chart of Glossy Ibis

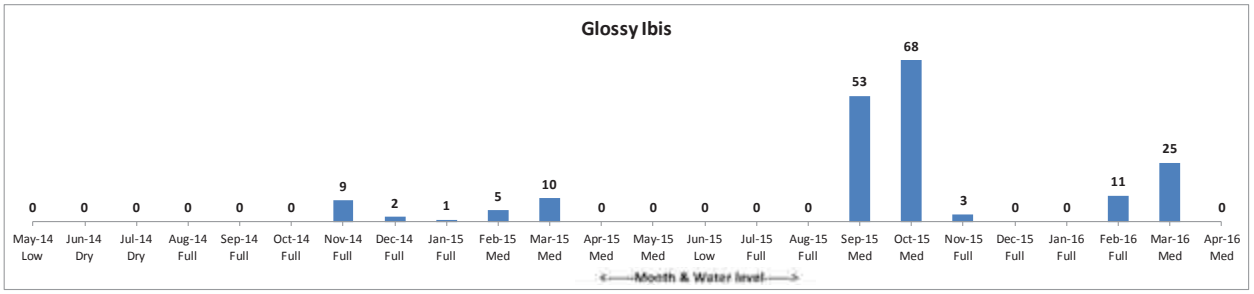

Figure 29b. Bar graph showing the occurrence trend (in numbers) of Glossy Ibis

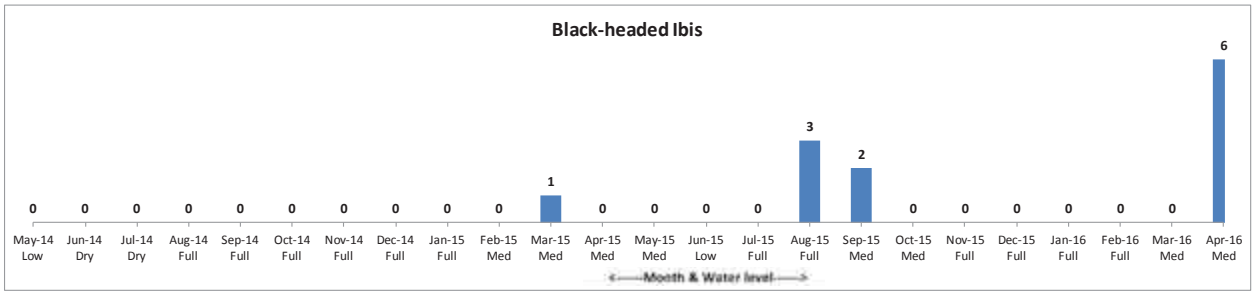

Figure 30. Bar graph showing the occurrence trend (in numbers) of Black-headed Ibis

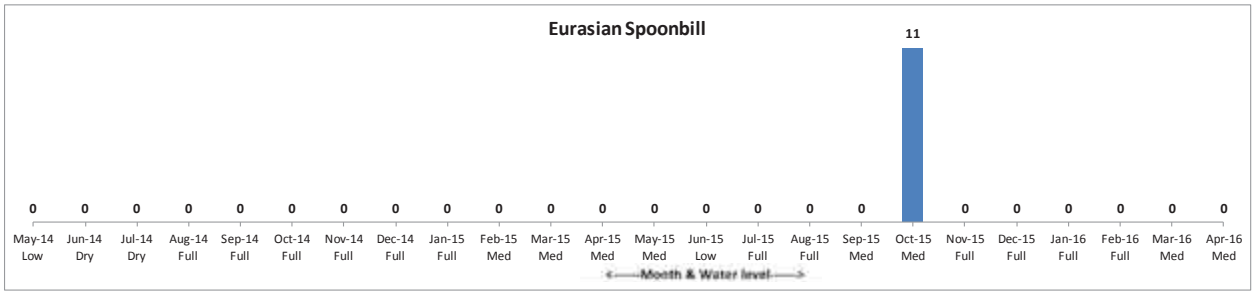

Figure 31. Bar graph showing the occurrence trend (in numbers) of Eurasian Spoonbill

inexplicable anomaly. It is not been recorded in the lake since then.

40. Bronze-winged Jacana *Metopidius indicus* is a local migrant species that is infrequently recorded in the lake, similar to Pheasant-tailed Jacana. A single individual of this species was sighted in January and August 2015.

Charadriiformes: Scolopacidae

41. Common Sandpiper *Actitis hypoleucos* is a winter migrant species that was recorded from August to

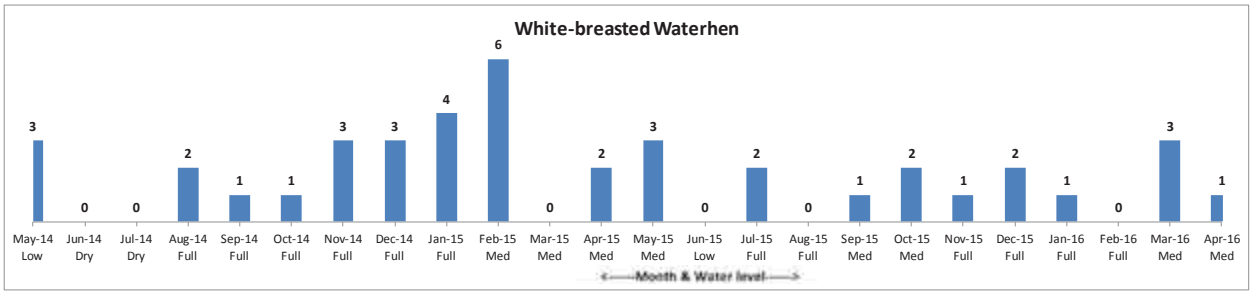

Figure 32. Bar graph showing the occurrence trend (in numbers) of White-breasted Waterhen

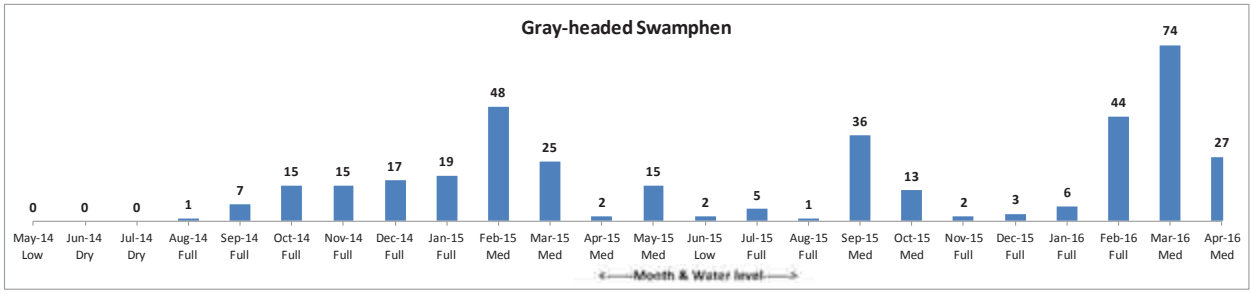

Figure 33. Bar graph showing the occurrence trend (in numbers) of Gray-headed Swamphen

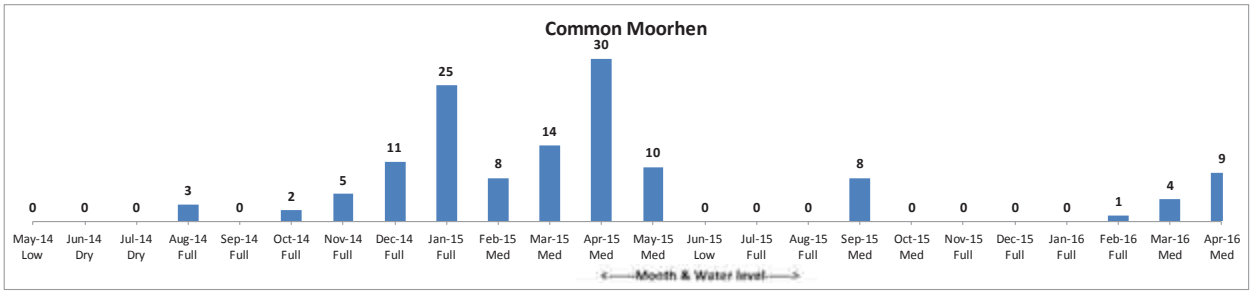

Figure 34. Bar graph showing the occurrence trend (in numbers) of Common Moorhen

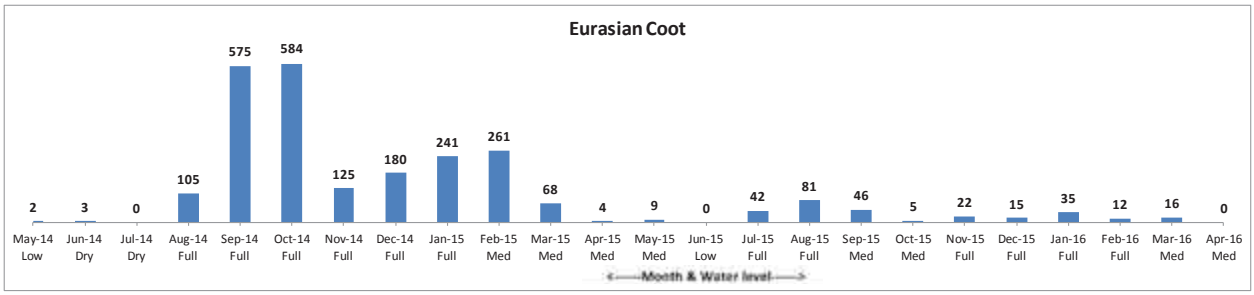

Figure 35. Bar graph showing the occurrence trend (in number) of Eurasian Coot

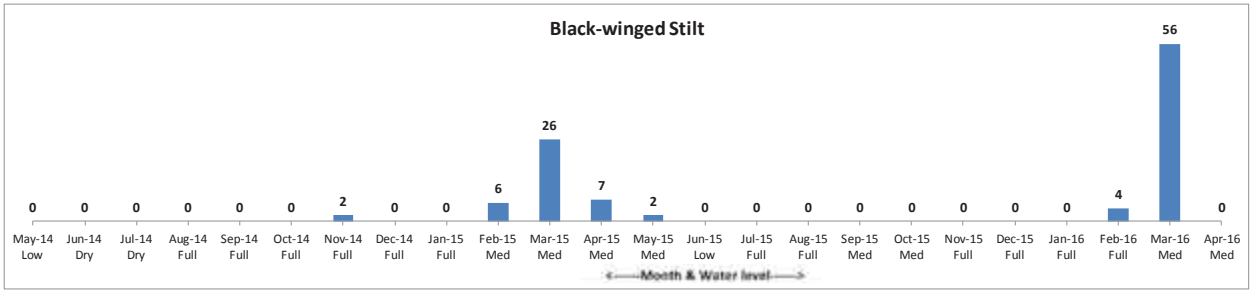

Figure 36. Bar graph showing the occurrence trend (in numbers) of Black-winged Stilt

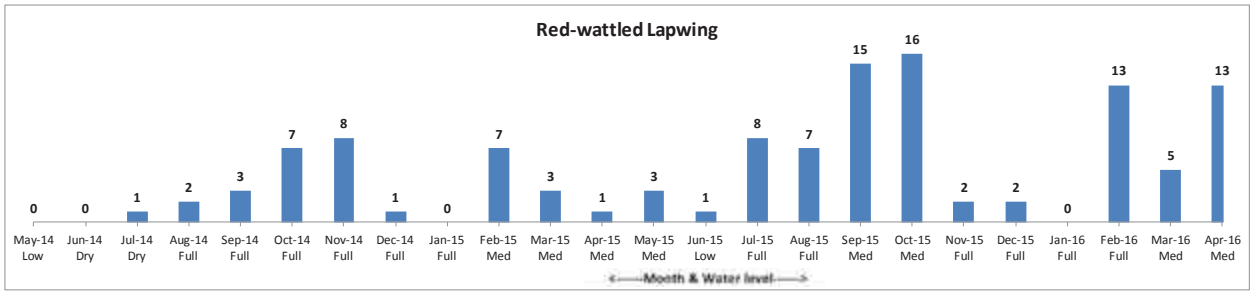

Figure 37. Bar graph showing the occurrence trend (in numbers) of Red-wattled Lapwing

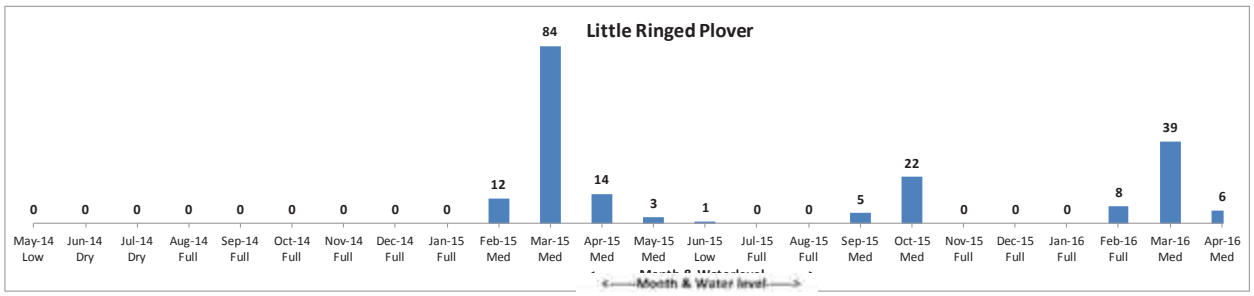

Figure 38. Bar graph showing the occurrence trend (in numbers) of Little Ringed Plover

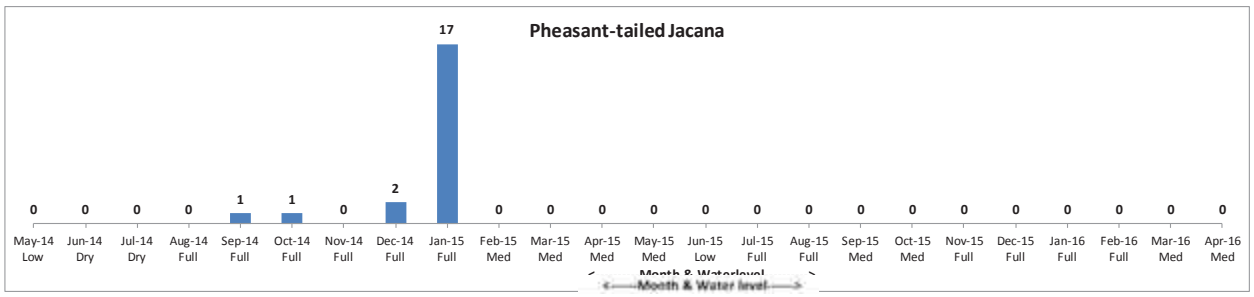

Figure 39. Bar graph showing the occurrence trend (in numbers) of Pheasant-tailed Jacana

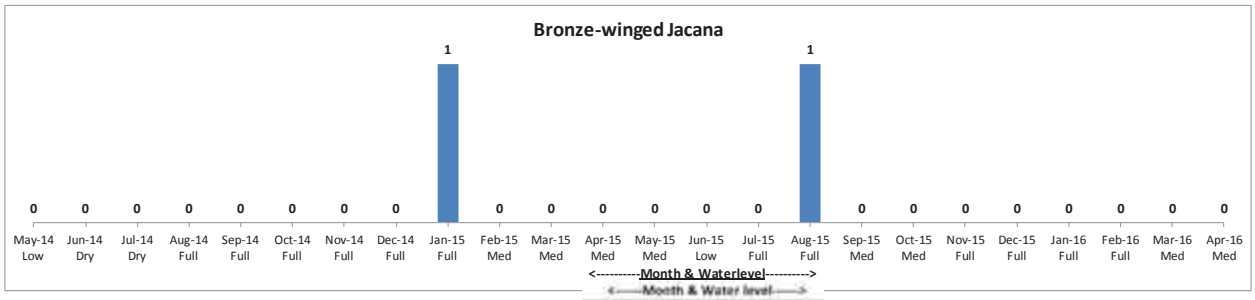

Figure 40. Bar graph showing the occurrence trend (in numbers) of Bronze-winged Jacana

April. Its highest count was recorded in March 2015 when 21 individuals of this species were sighted. According to Ali (2002), it is one of the earliest wader migrants to arrive (August) and also one of the last to leave (May). The sightings of this species in this lake match this statement to a large extent.

42. Green Sandpiper *Tringa ochropus* is a winter migrant species that was recorded during the period of January to March of 2015 and 2016 and additionally in November 2014 and April 2016. The highest counts were five and six recorded in February 2015 and March 2016, respectively, during the spring migration season.

43. Common Greenshank *Tringa nebularia* is a winter migrant species that was recorded in February–April 2015, October 2015, and March & April 2016 in the lake when the water levels were favourable with adequate

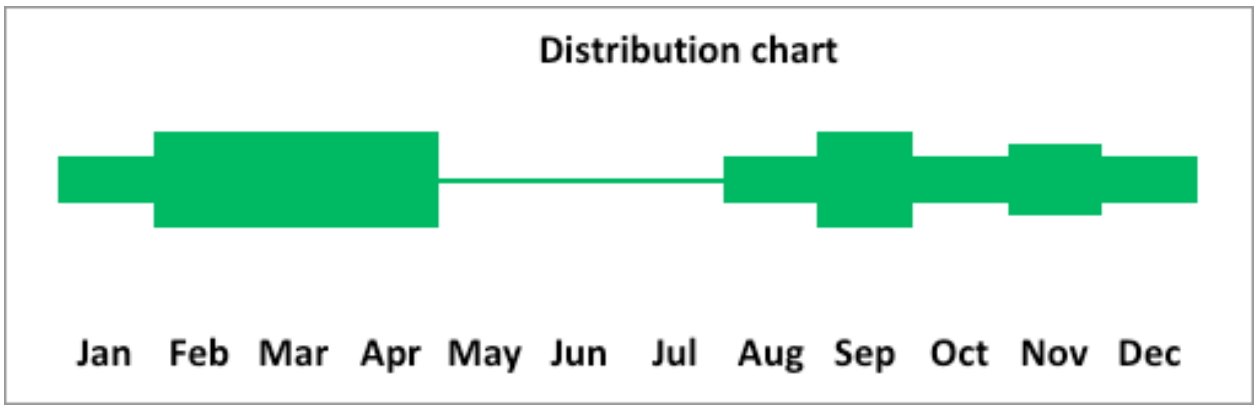

Figure 41a. Distribution chart of Common Sandpiper

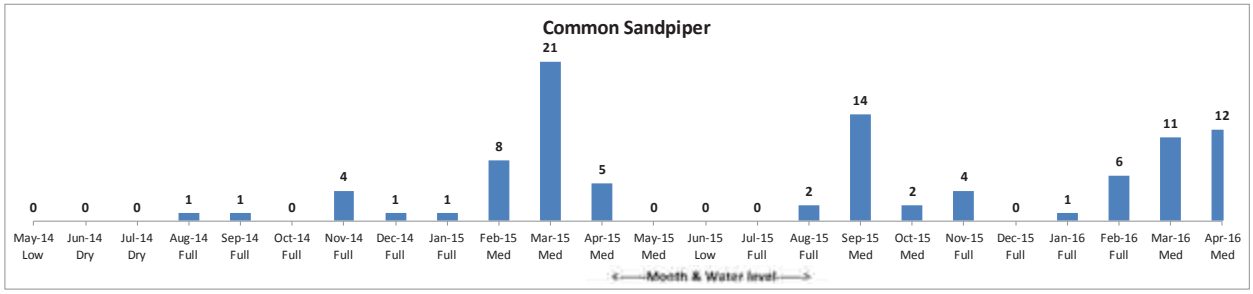

Figure 41b. Bar graph showing the occurrence trend (in numbers) of Common Sandpiper

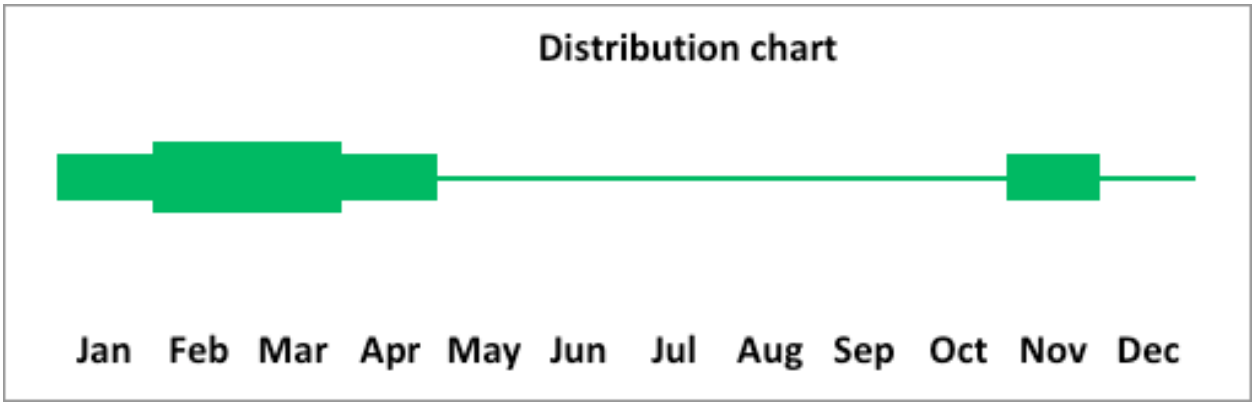

Figure 42a. Distribution chart of Green Sandpiper

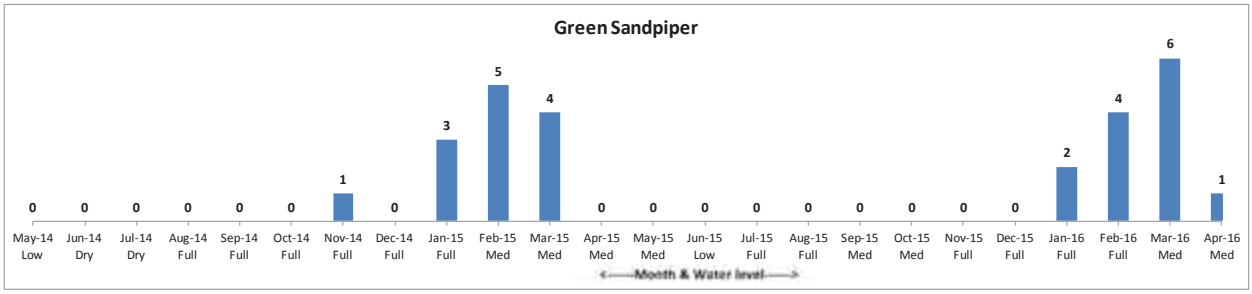

Figure 42b. Bar graph showing the occurrence trend (in numbers) of Green Sandpiper

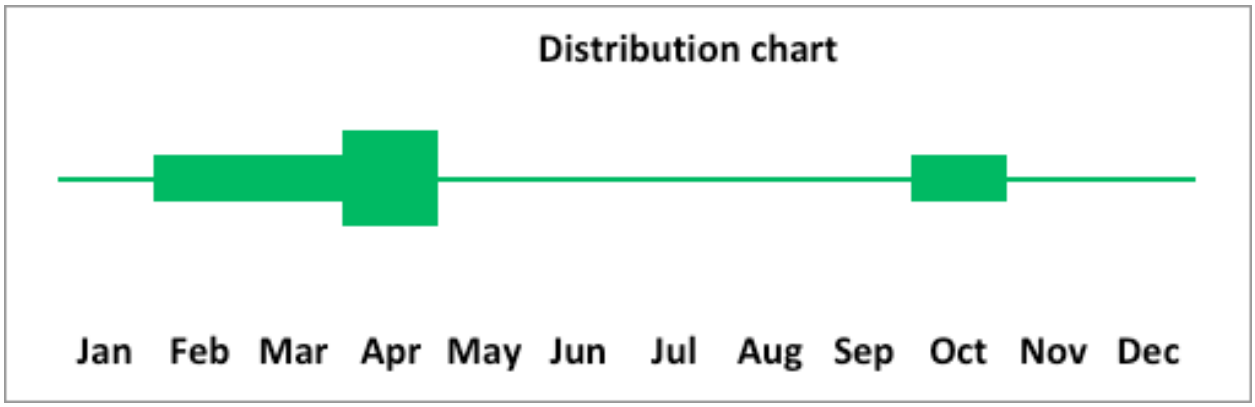

Figure 43a. Distribution chart of Common Greenshank

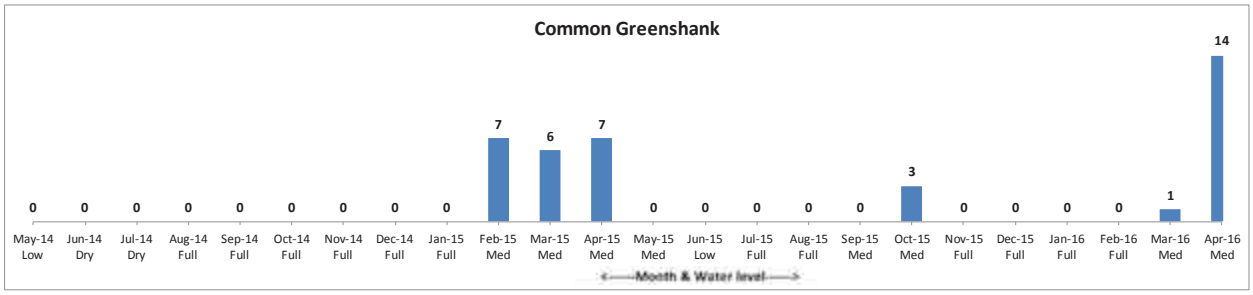

Figure 43b. Bar graph showing the occurrence trend (in numbers) of Common Greenshank

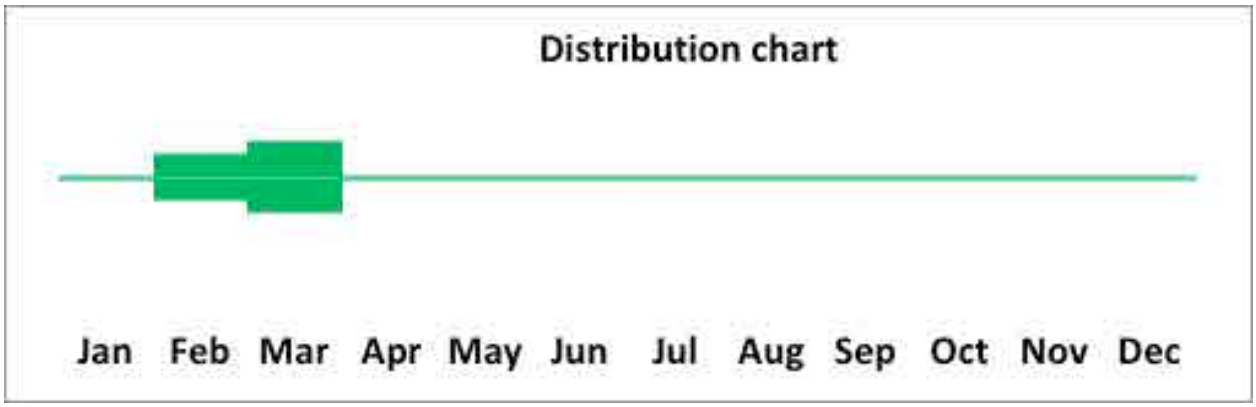

Figure 44a. Distribution chart of Marsh Sandpiper

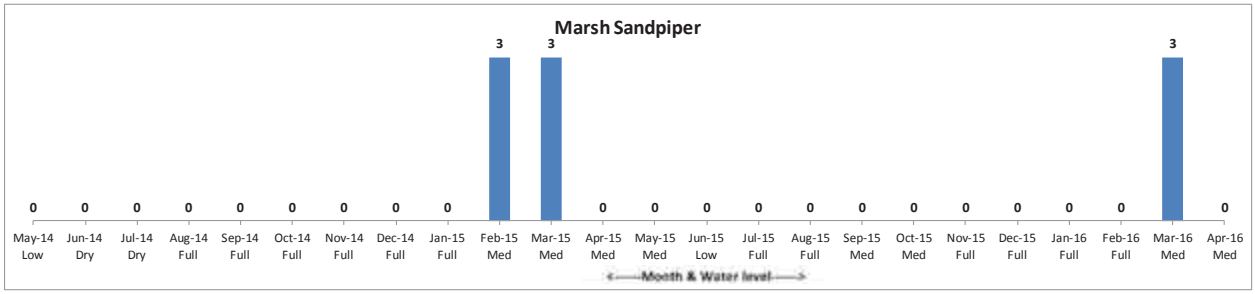

Figure 44b. Bar graph showing the occurrence trend (in numbers) of Marsh Sandpiper

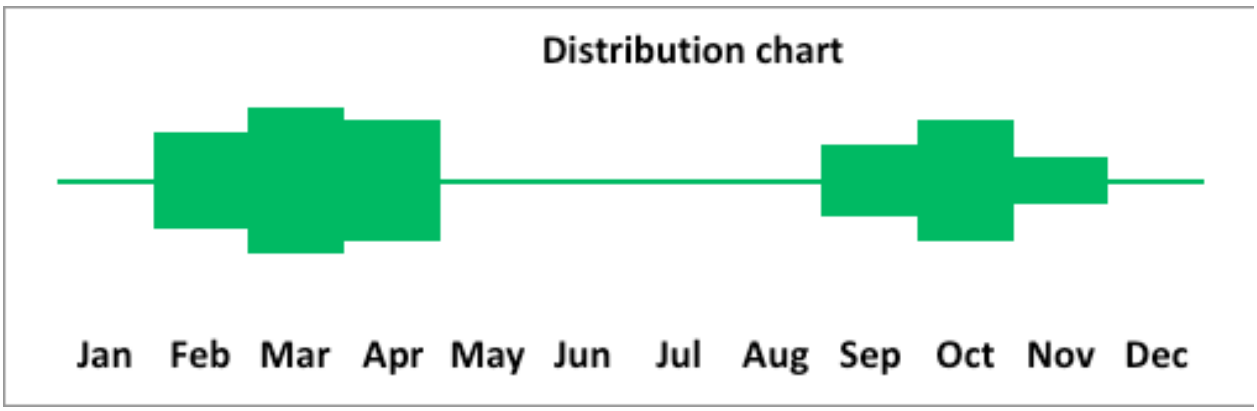

Figure 45a. Distribution chart of Wood Sandpiper

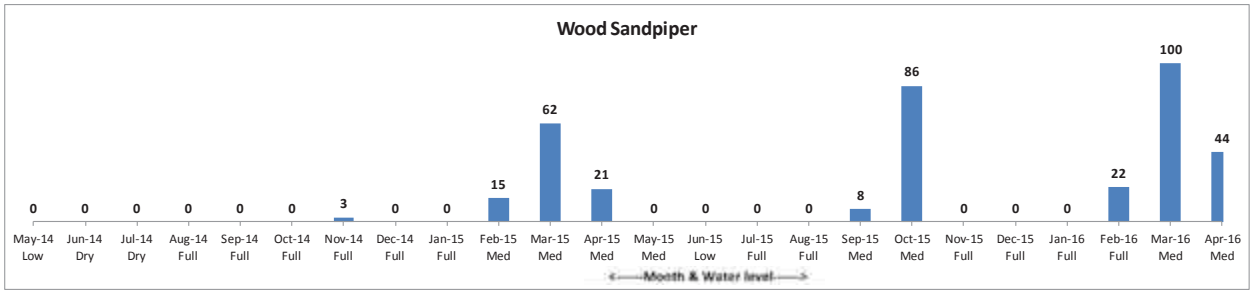

Figure 45b. Bar graph showing the occurrence trend (in numbers) of Wood Sandpiper

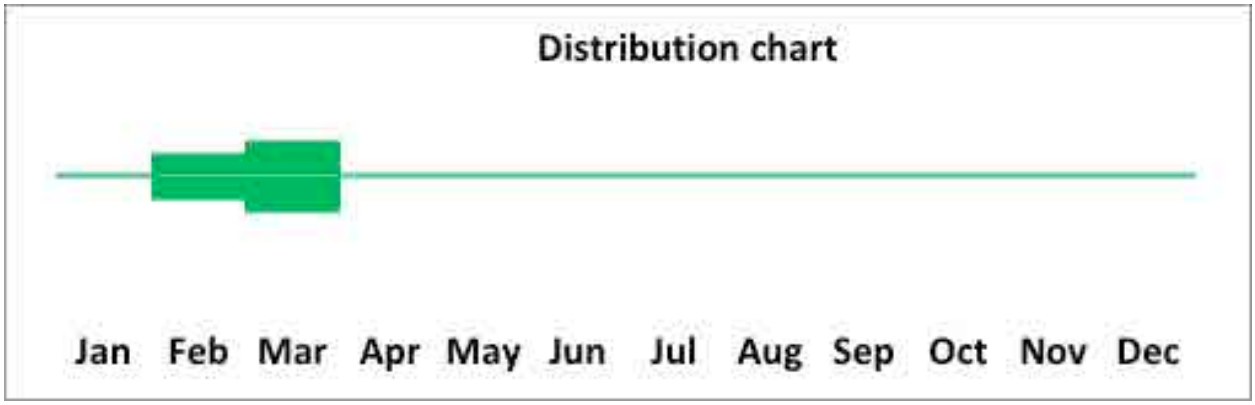

Figure 46a. Distribution chart of Temminck's Stint

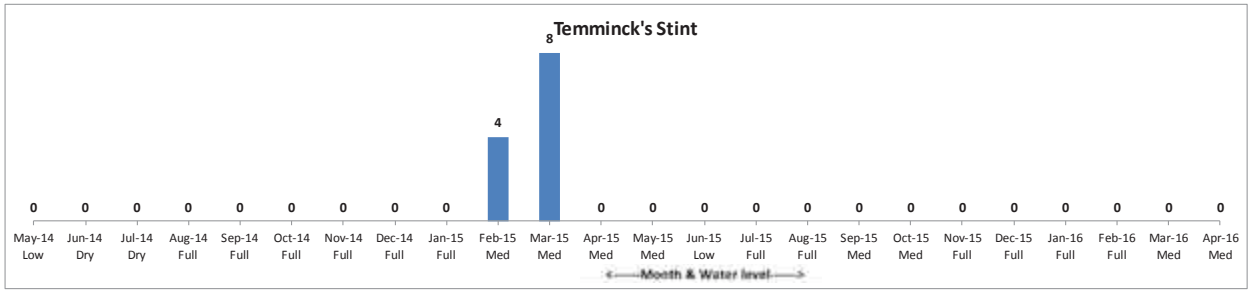

Figure 46b. Bar graph showing the occurrence trend (in numbers) of Temminck's Stint

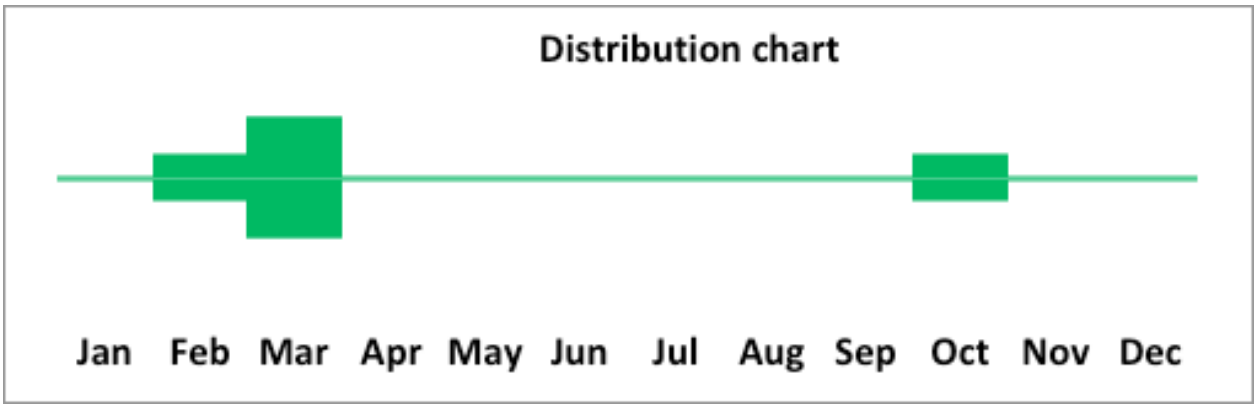

Figure 47a. Distribution chart of Little Stint

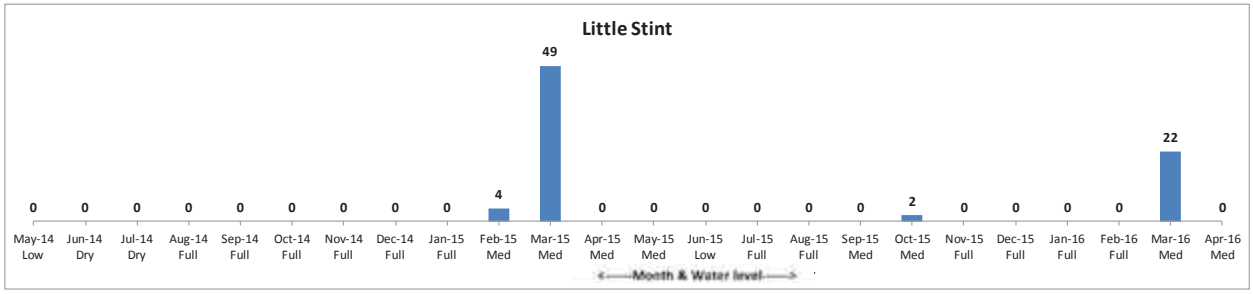

Figure 47b. Bar graph showing the occurrence trend (in numbers) of Little Stint

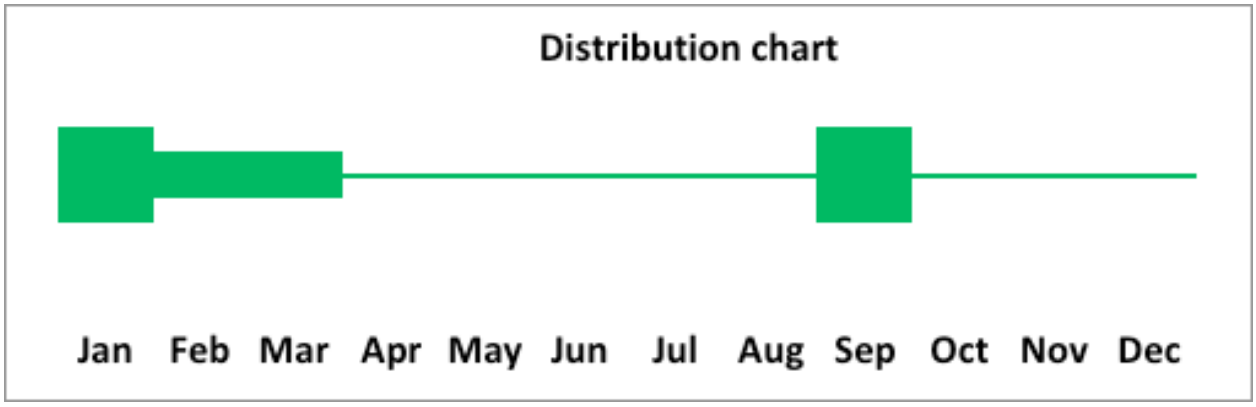

Figure 48a. Distribution chart of Whiskered Tern

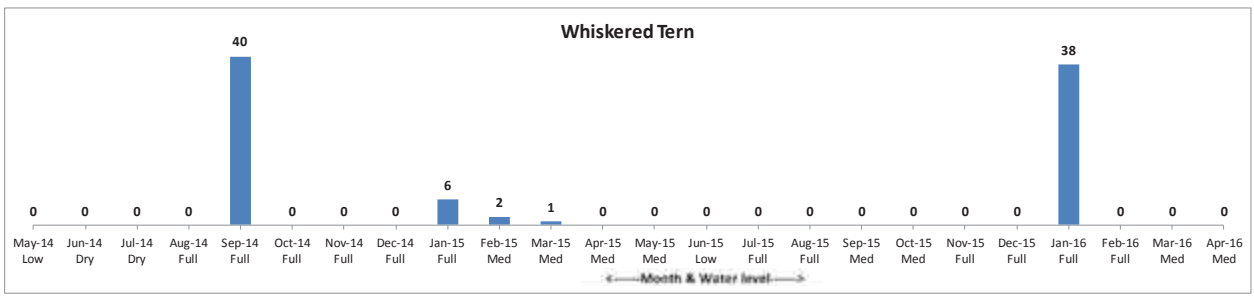

Figure 48b. Bar graph showing the occurrence trend (in numbers) of Whiskered Tern

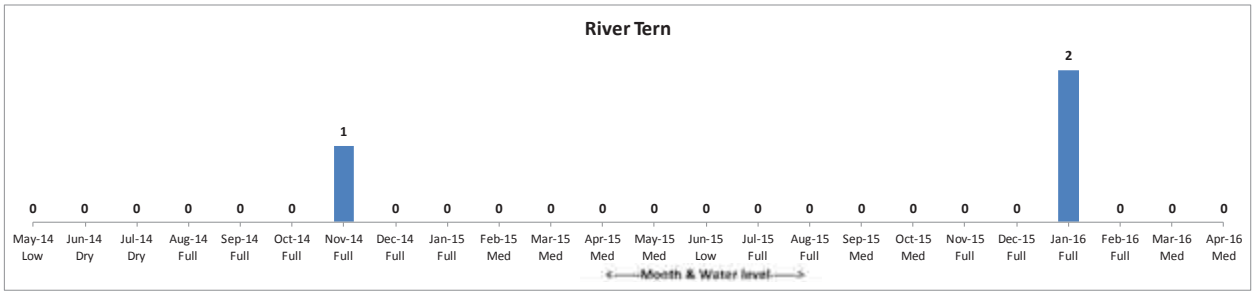

Figure 49. Bar graph showing the occurrence trend (in numbers) of River Tern

shoreline exposure. This pattern usually happens during the spring migration months from February to April. Its highest counts were recorded in February to April 2015 and April 2016, when seven, six, and 14 of this species were sighted, respectively.

44. Marsh Sandpiper *Tringa stagnatilis* is a winter migrant species that was sighted sparsely in the lake. Most of the sightings were during the spring migration months of February and March 2015 and March 2016 when three individuals were sighted on each occasion.

45. Wood Sandpiper *Tringa glareola* is the most numerous winter migrant sandpiper species in the lake. Even though it was recorded from September to April, it is primarily a species that is sighted during the spring migration months from February to April. Its highest counts during this season were in March 2015 and 2016 when 62 and 100 individuals were sighted, respectively. When water level conditions are favourable with shoreline exposure, as was the case in October 2015, 86 individuals of this species were recorded.

46. Temminck's Stint *Calidris temminckii* is a winter migrant species that was recorded only twice in the lake during the count period of February and March 2015 when four and eight of this species were sighted, respectively; this correlates with the spring migration season.

47. Little Stint *Calidris minuta* is a winter migrant species that was recorded primarily during the spring migration months of February & March 2015 and March 2016. Its highest counts were recorded in March 2015 and 2016 when 49 and 22 of this species were sighted, respectively.

Charadriiformes: Laridae

48. Whiskered Tern *Chlidonias hybrid* is a winter migrant species that was recorded sporadically in September 2014, January–March 2015, and January 2016. Its highest counts of 40 and 38 were recorded in September 2014 and January 2016, respectively, when the water level was high.

49. River Tern *Sterna aurantia* is a winter migrant species that was recorded only twice in the lake when a single bird in November 2014 and a couple in January 2016 were sighted. The water levels of the lake during both the sightings were full.

Types of Encroachments

Waterbirds usually avoid areas with extensive disturbance, choose roosting or foraging sites with fewer disturbances, and generally prefer wetlands with features that maximise the abundance and accessibility of their food (Khan et al. 2016). The types of habitat encroachments in Perur Lake that impair its functionality are road construction and its use for motor vehicles, illegal and unauthorised dumping of waste material, conversion to an artificial reservoir for agricultural use, and establishment of hutments.

For instance, road construction was carried out on the eastern bund of the Perur Lake covering the entire eastern border of 2km for use by motor vehicles. The probable effect of road construction on bird population and species diversity can be interpreted from the graphs given below. The road building activity appears to have reduced the sightings of the number and diversity of birds during the construction period, which lasted from March to August 2014.

DISCUSSION

From the analysis of the data collected from May 2014 to April 2016, it is clear that it is the resident/ local migrant birds that utilise this wetland throughout the year (Figs. 50–53). In addition, this wetland complex is also home to at least 17 species of winter migrant birds. Relations between habitat characteristics and waterbird abundances are often difficult to interpret as different factors act simultaneously, confounding the effects of individual ones, as birds frequent wetlands not only for food but also for rest and shelter. Migratory waterbirds

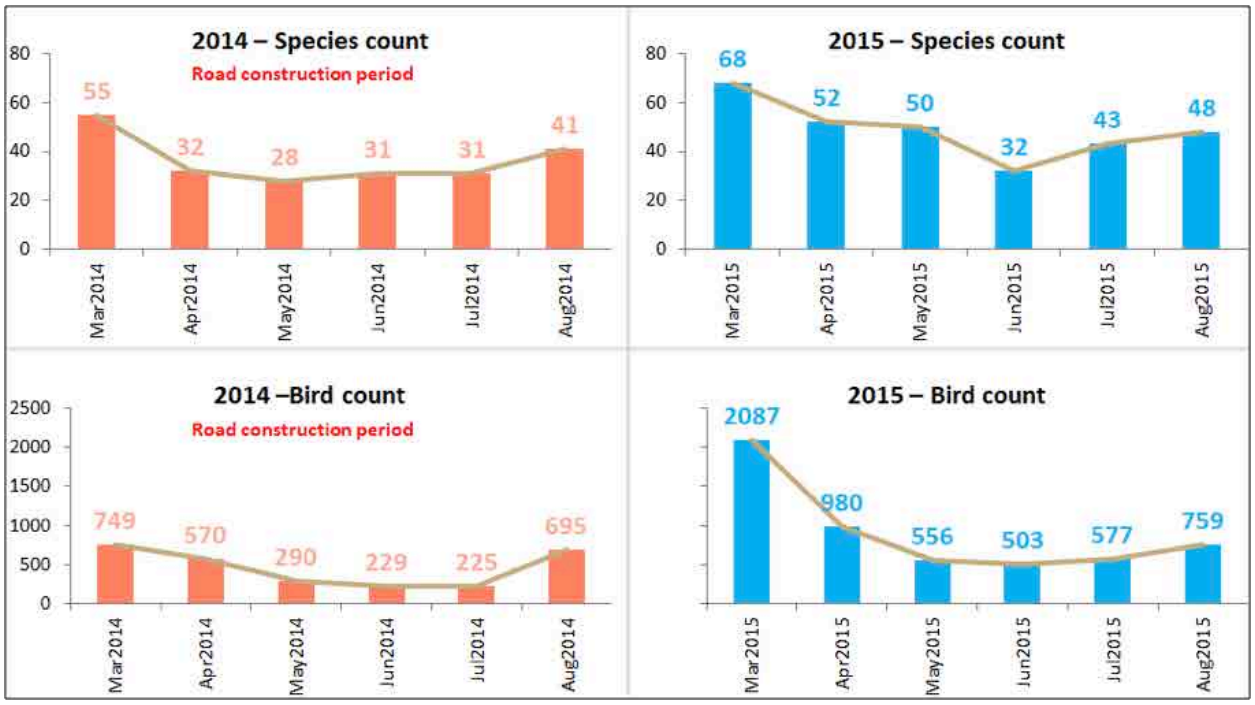

Figure 50. Bar graphs showing the comparison of bird species and population trends (in number) during and after the road construction period

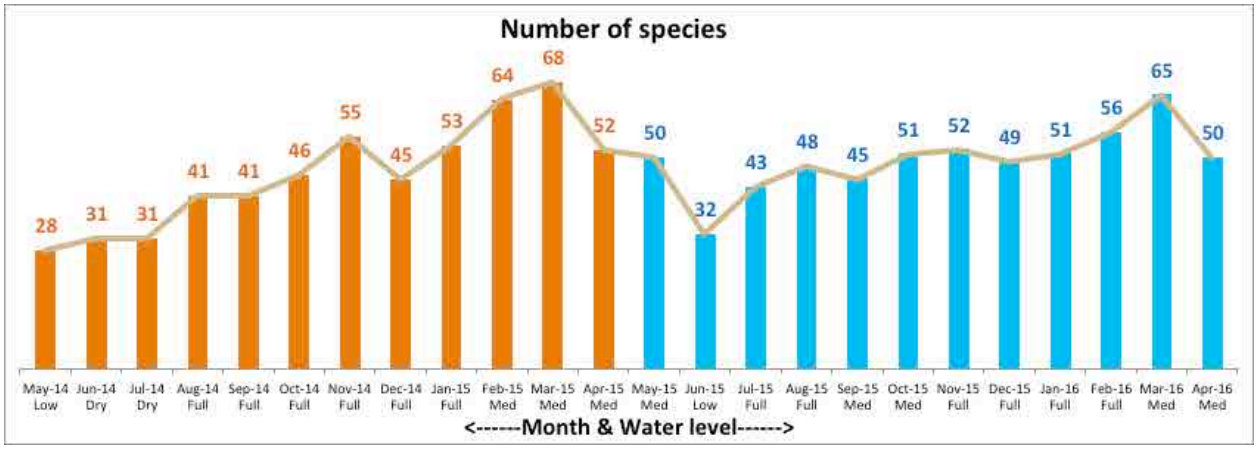

Figure 51. Bar graph showing the occurrence trend (in numbers) of bird species in Perur Lake during the count period

are, however, opportunistic and adapt to utilise various habitat types during migration and colonisation (Khan et al. 2016).

Our conclusions from the observations can be stated as follows:

- As far as Perur Lake is concerned, the presence or absence of water and its levels is a key determining factor of the avian species composition, the details of which are discussed in the individual species accounts.
- It appears from the data collected so far that the bird species diversity and actual numbers are at their highest (Figs. 51, 52 & 53) during the months of February, March, and April, thus possibly pointing towards the highest avian diversity and numbers during their northward migration in spring.

A mere two years' set of data, however, is simply insufficient to substantiate this possible pattern. Nevertheless, it behoves us to maintain adequate water levels in these wetlands for all birds, especially for migrant birds, during the critical months of March, April, and May. Local communities too might derive benefits

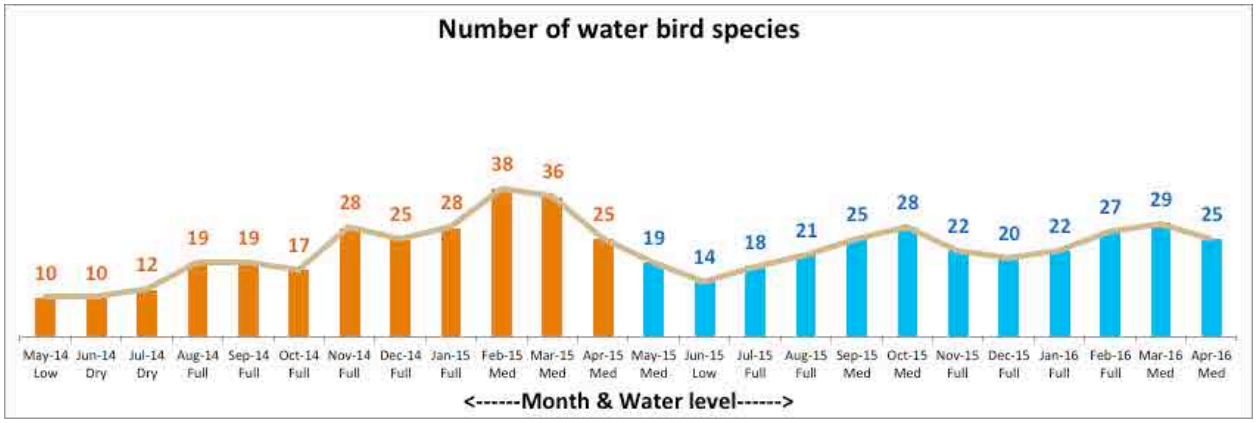

Figure 52. Bar graph showing the occurrence trend (in numbers) of waterbird species in Perur Lake during the count period

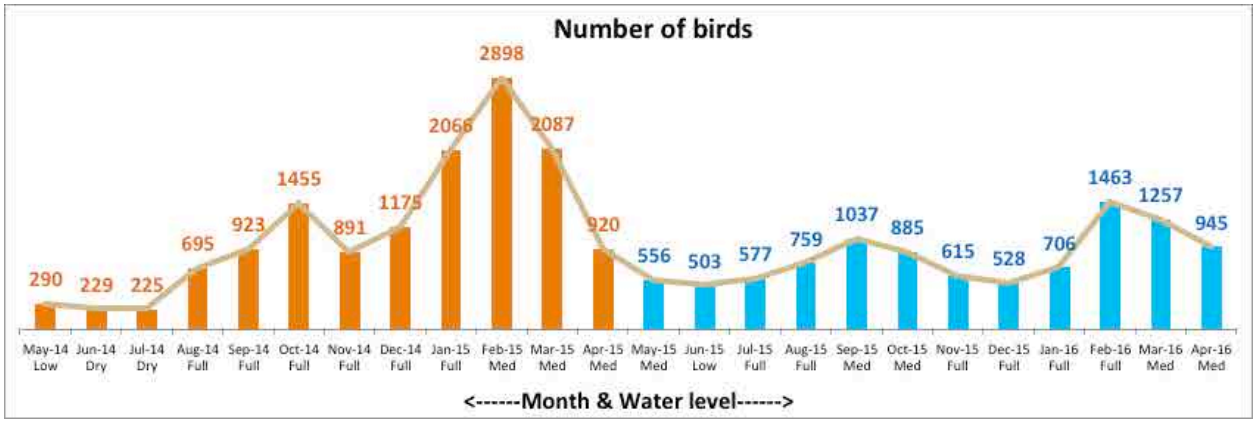

Figure 53. Bar graph showing the bird population trend (in numbers) in Perur Lake during the count period

from this practice as it allows more time and opportunity for groundwater recharge.

Finally, looking at the larger picture, it is extremely important that similar studies be conducted in some of the adjoining wetlands of the area in a synchronous manner. Only an analysis of such a comprehensive collection of data can provide a better understanding of the subtlety of avian movements and their population in the area.

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COMMUNICATION

The herpetofauna of Jigme Singye Wangchuck National Park in central Bhutan: status, distribution and new records

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Abstract: A checklist of herpetofauna in Jigme Singye Wangchuck National Park in central Bhutan based on field surveys and photographic records is presented. Twelve families, 30 genera, and 42 species of herpetofauna were recorded; 33 species from 24 genera and eight families were reptiles and nine species belonging to six genera and four families were amphibians. Two ophidians, *Bungarus caerulus* and *B. lividus*, and one anuran, *Amolops formosus*, are new records for Bhutan. The compiled record also includes three threatened species. We recommend enhanced monitoring and herpetofauna-oriented conservation and research for Jigme Singye Wangchuck National Park.

Keywords: Amphibians, Bhutan, herpetofauna, lizards, protected area, reptiles, snakes, turtles.

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Author Details: Sangay Tshewang serves as Park Ranger of Adha Deputy Park Park Range Office under Jigme Singye Wangchuck National Park and is also the park focal for SMART patrolling. He is an active field biologists with deep taxonomical knowledge in flora and fauna. Limited experts in the herpetological field in Bhutan made Tshewang put special interests in herpetofauna. Letro Letro serves as a Forestry Officer at Jigme Singye Wangchuck National Park and coordinates various conservation research works in the park. Currently he is a graduate student at the University of Greifswald, studying Landscape Ecology and Nature Conservation. His research focuses on landscape approach conservation of wildlife.

Author Contribution: ST organized the field survey works, collected the data, identified the species, and drafted the paper. LL conceptualized the research work, analysed the data, and wrote the paper.

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INTRODUCTION

Humans frequently depend on diverse sources for essentials such as food, refuge, medicine, combustibles, and industrial products (Dirzo & Raven 2003). Amphibians and reptiles are an essential component of the earth's biodiversity (Urbina-Cardona 2008) and play a key role in most ecosystems, both terrestrial and aquatic, as prey and predators (Schneider et al. 2001). Herpetofauna are excellent ecological indicators owing to their high sensitivity to environmental change (Roy 2002), and are also among the most threatened taxa (Böhm et al. 2013) with more than 30% of amphibians and 19% of reptile species listed under threatened categories in the IUCN Red List (Stuart 2004; Böhm et al. 2013). While many taxa are still data deficient, known amphibian and reptile species are reported to be declining on a global scale due to factors such as deforestation, draining of wetlands, and pollution from agricultural runoff (Alford & Richards 1999; Gibbon et al. 2000; Kiesecker et al. 2001; Becker et al. 2007).

Bhutan's biodiversity database is strong for vertebrates like mammals and birds, but herpetofauna is less well studied (Wangyal 2013). A recent review by Wangyal (2014) recorded 183 species of reptiles and amphibians; 84 species of snakes, 23 species of lizards, 20 species of tortoises and turtles, and 56 species of frogs. Currently, none of these are listed under Schedule I of the Forests and Nature Conservation Act (FNCA) 1995 (RGoB 1995), and without any specific conservation plan, these diverse species are likely to face considerable threats from habitat destruction and degradation (Wangyal 2014). Most existing records are based on opportunistic encounters by enthusiasts (Wangyal 2012), and for protected areas the limited reports describe the herpetofauna of Royal Manas National Park (RMNP) (Das et al. 2016), the diversity and distribution of snakes in Jigme Dorji National Park (JDNP) (Koirala et al. 2016), and snakes and lizards from Bumdeling Wildlife Sanctuary (BWS) (Wangyal & Tenzin 2009). Two decades after its gazettement in 1995 (JSWNP 2014), Jigme Singye Wangchuck National Park (JSWNP) still does not have a checklist of its herpetofauna. In this paper, we provide the first checklist of reptiles and amphibians from the biologically diverse JSWNP, thereby filling the information gap and establishing baseline information for future conservation measures.

MATERIAL & METHODS

Study Area

The study was conducted in JSWNP, located in the central part of Bhutan (27.022–27.488 ^{0}N & 90.069–90.693 ^{0}E; Figs. 1 & 2). With an area of 1,730km^2, JSWNP is the third largest protected area in Bhutan, spread across 10 'gewogs' (sub-district administrative blocks) in five districts (JSWNP 2014). For effective conservation and sustainable management of resources, the park is divided into four park ranges: Langthel park range, Nabji park range, Taksha park range, and Tingtibi park range. JSWNP connects with JDNP and Wangchuck Centennial National Park (WCNP) in the north and with RMNP and Phibsoo Wildlife Sanctuary (PWS) in the south through biological corridors. Thus, JSWNP forms a vital link between the northern and southern protected areas network of Bhutan. JSWNP has a diverse habitat representation from sub-tropical forests at 464m to alpine scrubs with the centrally located Black Moutain (Jowo Durshing) going up as high as 4925m. This wide altitudinal variation has bestowed the park with six major forest types: (i) subtropical forests, (ii) chirpine forests, (iii) warm temperate broadleaf forest, (iv) cool temperate broadleaf forests, (v) subalpine conifer forests, and (vi) alpine meadows (JSWNP 2014). The national park has a good biodiversity database (Letro 2015) with a recording of 39 mammal species including the endangered tiger and Red Panda, 218 birds including the critically endangered White-bellied Heron, and 139 butterflies. These diverse ecological habitats, together with well-drained catchments and wetlands, prominent geophysical features, and agricultural farmlands, provide varied habitats for diverse herpetofauna.

Methods

The survey was conducted in all park range jurisdictions from May 2016 to June 2017. Searches were intensified in spring and summer months when reptiles and amphibians are most active. Data for reptiles were collected by randomly walking along opportunistic footpaths and trails between 9:00am and 3.30pm employing visual encounter surveys (Campbell & Christman 1982). For amphibians, the potential wetland habitats like marshes, ponds, streams, and riversides (Becker et al. 2007) were scanned by employing visual encounter searches between 7:00pm and 8:00pm. These areas were searched for all morphological stages of herpetofauna. Additional survey techniques to optimize detection success included night spot-light search, aural identification of species calls, recording road kills, and species killed by villagers. No voucher samples were collected during the survey, but all

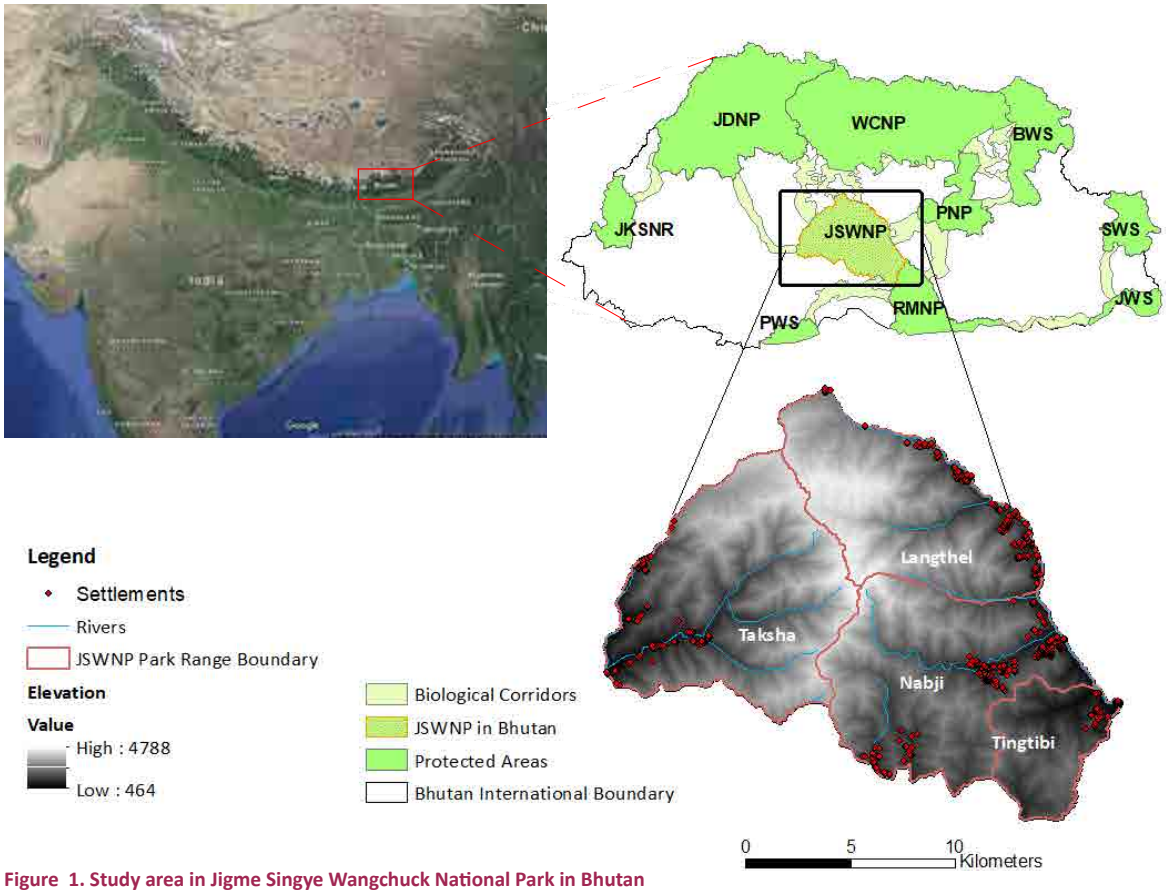

Figure 1. Study area in Jigme Singye Wangchuck National Park in Bhutan

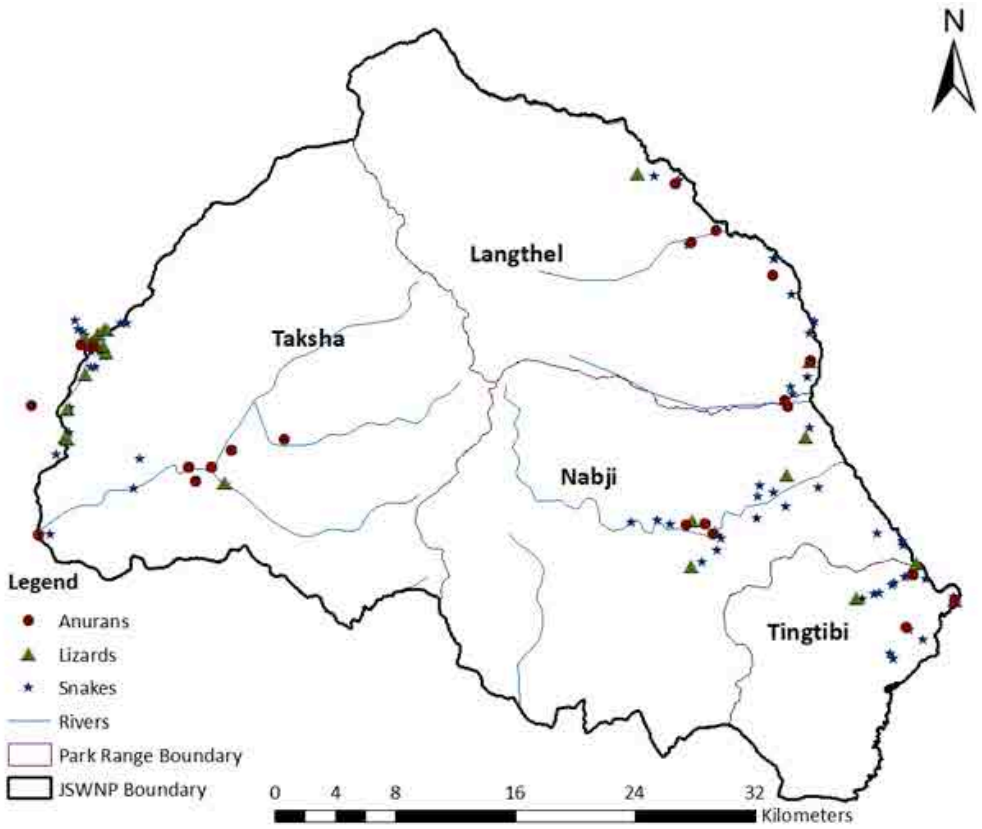

Figure 2. Sampled localities in JSWNP

the species encountered were identified either in the field or were photographed for identification and released back to their natural habitat. For every individual encountered, details such as species name, number of individuals, sex, and habitat inhabited were recorded along with the GPS coordinates. Garmin eTrex 30 was used to record geographic coordinates of the sites. The field guides on reptiles and amphibians by authors Purkayastha (2013) , Ahmed et al. (2009), and Daniel (2002) were referred for species identification in the field.

RESULTS

A total of 42 species were recorded from the national park, belonging to 30 genera and 12 families. Of these, 32 species belonging to 24 genera and eight families were reptiles and nine species from six genera and four families were amphibians.

Snakes

We observed 24 species of snakes from 18 genera belonging to four families (Table 1; Images 1–23). The family Colubridae was the most diverse with 16 species belonging to 12 genera, whereas Pythonidae appeared to be the least diverse with only one species. In terms of relative abundance based on individuals sighted, Colubridae was the most abundant, accounting for 75% (n=56) of all snakes, followed by Elapidae with 18%. Individual counts were least for Pythonidae and Viperidae, at 3% each (Fig. 3). Among species, the Green Rat Snake *Ptyas nigromarginata* has the highest observation record with 10 sightings. Two ophidians, *Bungarus caerulus* and *Bungarus lividus*, are new records for Bhutan, and *Python bivittatus* was recorded at an elevation of 1350m, a new highest elevation record for the species.

Lizards

We recorded eight species of lizards belonging to three families (Table 2; Images 24–31). The family Scincidae was the most diverse with three species and two genera. In the families Gekkonidae and Agamidae, we recorded two species each. Based on the individual numbers, the family Scincidae was the most abundant accounting for

Table 1. Checklist of snake species found in Jigme Singye Wangchuck National Park

	Family	Species	Locality	IUCN status
1	Colubridae	*Ahaetulla prasina* (Boie, 1827)	Tingtibi	LC
2		*Herpetoreas platyceps* (Blyth, 1854)	Taksha, Tingtibi	DD
3		*Boiga multifaciata* (Blyth, 1861)	Langthel, Taksha	DD
4		*Boiga ochracea* (Günther, 1868)	Langthel, Taksha	LC
5		*Coelognathus radiatus* (Boie, 1827)	Langthel, Taksha	LC
6		*Dendrelaphis cyanochloris* (Wall, 1921)	Nabji	LC
7		*Lycodon aulicus* (Linnaeus, 1758)	Langthel, Taksha	LC
8		*Lycodon septentrionalis* (Günther, 1875)	Langthel	NE
9		*Oligodon taeniolatus* (Jerdon, 1853)	Langthel, Taksha	LC
10		*Orthriophis cantoris* (Cantor, 1839)	Nabji, Taksha	NE
11		*Orthriophis taeniurus* (Anderson, 1879)	Nabji, Tingtibi	NE
12		*Pseudoxenodon macrops* (Blyth, 1855)	Nabji	LC
13		*Ptyas korros* (Schlegel, 1837)	Taksha	NE
14		*Ptyas nigromarginata* (Blyth, 1854)	Langthel, Nabji, Taksha, Tingtibi	NE
15		*Rhabdophis himalayanus* (Günther, 1864)	Nabji, Tingtibi	NE
16		*Sibynophis collaris* (Gray, 1853)	Langthel, Taksha	LC
17	Elapidae	*Naja kaouthia* (Lesson, 1831)	Langthel, Nabji, Taksha, Tingtibi	LC
18		*Bungarus caeruleus* (Schneider, 1801)	Tingtibi	NE
19		*Bungarus lividus* (Cantor, 1839)	Langthel	NE
20		*Ophiophagus hannah* (Cantor, 1836)	Tingtibi	**VU**
21		*Sinomicrurus macclellandi* (Reinhardt, 1844)	Tingtibi	NE
22	Pythonidae	*Python bivittatus* (Kuhl, 1820)	Taksha	**VU**
23	Viperidae	*Ovophis monticola* (Günther, 1864)	Tingtibi	LC
24		*Protobothrops himalayanus* Pan et al. 2013	Langthel	NE

NA: Not Available, NE: Not Evaluated, DD: Data Deficit, LC: Least Concern, VU: Vulnerable, EN: Endangered

Table 2. Checklist of lizards and tortoises found in Jigme Singye Wangchuck National Park

	Family	Species	Locality	IUCN status
1	Agamidae	*Calotes versicolor* (Daudin, 1802)	Langthel, Taksha, Tingtibi	NE
2		*Calotes jerdoni* (Guenther, 1870)	Langthel	NE
3		*Japalura variegata* (Gray, 1853)	Langthel, Nabji, Taksha	NA
4	Gekkonidae	*Hemidactylus brookii* (Gray, 1845)	Langthel, Taksha	NE
5		*Hemidactylus platyurus* (Schneider, 1792)	Langthel, Taksha, Tingtibi	NE
6	Scincidae	*Asymblepharus sikimmensis* (Blyth, 1854)	Langthel	NE
7		*Sphenomorphus indicus* (Gray, 1853)	Langthel, Nabji, Taksha, Tingtibi	NE
8		*Sphenomorphus maculatus* (Blyth, 1853)	Langthel, Taksha,	NE
9	Geoemydidae	*Cuora mouhotii* (Gray, 1862)	Tingtibi	EN
NA - Not Available, NE - Not Evaluated, DD - Data Deficient, LC - Least Concern, VU - Vulnerable, EN - Endangered				

Table 3. The diversity of anurans in Jigme Singye Wangchuck National Park

	Family	Species	Locality	IUCN status
1	Ranidae	*Amolops marmoratus* (Blyth, 1855)	Langthel, Nabji, Taksha, Tingtibi	LC
2		*Amolops formosus* (Günther, 1876)	Langthel	LC
3	Bufonidae	*Duttaphrynus himalayanus* (Günther, 1864)	Taksha	LC
4		*Duttaphrynus melanostictus* (Schneider, 1799)	Taksha	LC
5	Dicroglossidae	*Euphlyctis cyanophlyctis* (Schneider, 1799)	Nabji, Taksha	LC
6		*Nanorana liebigii* (Günther, 1860)	Taksha	NA
7	Rhacophoridae	*Polypedates himalayanus* (Annandale, 1912)	Nabji, Taksha	NE
8		*Polypedates teraiensis* (Dubois, 1987)	Langthel, Nabji	LC
9		*Rhacophorus maximus* (Günther, 1858)	Taksha, Tingtibi	LC
NA - Not Available, NE - Not Evaluated, DD - Data Deficient, LC - Least Concern, VU - Vulnerable, EN - Endangered				

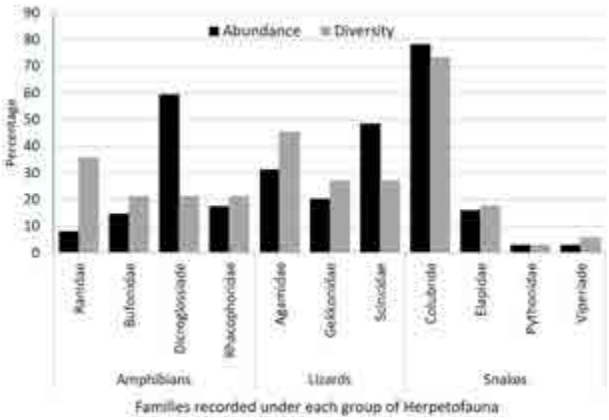

Figure 3. The diversity and abundance of herpetofauna in JSWNP

52% (n=59) of the total individual lizards sighted, followed by Agamidae with 32% and Gekkonidae with 15% (Fig. 2). Himalayan Litter Skink *Sphenomorphus indicus* and Common Garden Lizard *Calotes versicolor* were the most sighted species with 23 and 15 sightings, respectively. We also recorded a lone turtle species, *Cuora mouhotii* belonging to Geometridae family (Image 32), which is listed as endangered in IUCN Red List of Threatened Species.

Anurans

We recorded a total of nine frog species belonging to six genera and four families (Table 3; Images 33–40). Of these, Rhacophoridae was the most diverse with three species, followed by Bufonidae, Dicroglossidae, and Ranidae with two species each. Maximum count of individuals was recorded for the family Dicroglosidae accounting for 60% (n=336), followed by Rhacophoridae with 18%, Bufonidae with 14%, and least for family Ranidae with only 7% (Fig. 3). One species of anuran, *Amolops formosus*, is a new record for Bhutan.

DISCUSSION

Our results show JSWNP as a rich repository of reptiles and amphibians. With 42 species recorded, this diversity in JSWNP accounts for 23% (n=183) of the total species recorded from Bhutan. This can be attributed to the great elevation gradient and various habitat types of the park. The species were observed in diverse habitats such

as along footpaths and agricultural fields, by streams and rivers, near villages, and in various forests types, indicating that holistic habitat management is vital for the conservation of herpetofauna.

Of the 42 species of herpetofauna recorded in JSWNP, at least three species are new records for Bhutan, namely *Bungarus caeruleus*, *Bungarus lividus*, and the anuran *Amolops formosus*. *Bungarus caeruleus*, which was earlier listed as an expected species in the country (Wangyal 2014), is now in the confirmed list with our first record from Tingtibi Park Range. *Bungarus lividus* was recorded during our survey at Adha under Taksha Range in May 2016, and later also observed in Langthel Range in 2017. *Bungarus lividus* differs from all other kraits like *Bungarus niger* and *Bungarus caeruleus* in having normal-sized or only slightly enlarged mid-dorsal scales (arrows mark scales of the mid-dorsal row) (Kuch et al. 2011). *Amolops formosus* was also listed by Wangyal (2014) as an expected species, which we have recorded for the first time from Peka Chhu at an elevation of 1,350m, in the Taksha Park Range.

Two species of snakes and the lone turtle species are also found to be in the threatened category of the IUCN Red List of Threatened Species. The Burmese Python *Python bivittatus*, categorized as Vulnerable was reported from the tropical regions of India, Bangladesh, Nepal, China, and southeast China (Stuart et al. 2012). In Bhutan, it was first reported by Ahmed, Das & Dutta (2009) from an unspecified location but later its presence was reconfirmed when it was observed at Gortey and Kanamakura (245m) in Royal Manas National Park (Wangyal 2012), which has tropical climatic conditions. Unexpectedly, we recorded this threatened giant reptile at an altitude of 1,350m at Adha under Taksha Range during the recent survey, thus setting a new elevation record. The highest elevation at which the species was recorded was 1200m by Orlov, Murphy & Papenfuss (2000) in a bamboo forest of the Tam-Dao Mountain Range of Vietnam. Other higher records were without proper validation (Cota 2010). The King Cobra *Ophiophagus hannah* is another threatened snake species recorded in JSWNP. Listed as Vulnerable in the IUCN Red List, it is widely distributed in southern Asia (Stuart et al. 2012) with few sightings from Bhutan. Its presence was reported from Royal Manas National Park, Sarpang Dzongkhag, and Tashi Yangtse Dzongkhag (Wangyal & Tenzin 2009). In JSWNP, we observed one individual (SVL 120cm, TL 20cm) by the side of Berti Chhu in the Tingtibi Park Range, adding a new distribution record for the species in Bhutan. The Keeled Box Turtle *Cuora mouhotii* is the lone turtle species that we recorded in JSWNP and it too falls under the threatened category of the IUCN Red List. Found in freshwater and terrestrial habitats, the Keeled Box Turtle is native to China, India, Lao People's Democratic Republic, Myanmar, and Vietnam, and is listed as Endangered in the IUCN Red List of Threatened Species (Asian Turtle Trade Working Group 2000). In Bhutan, its presence was first reported by Wangyal et al. (2012) at an elevation of 370m in Zhemgang District.

Some species could not be identified while some were identified at the genus level, and these will be added to the checklist after proper identification. While the national park has many intact habitats, the coming up of numerous developmental activities like hydropower construction, road construction, installation of high tension electric lines, and the use of fertilizers and pesticides by the park residents are likely to threaten the habitats of herpetofauna. Cross-sectoral consultation is necessary to safeguard prime habitats of herpetofauna and further studies with sample collection are vital to confirm the species that could not be identified from the photographs and field notes. The areas that were not covered during the present study should be explored as well. Besides that, it is also vital to educate the communities within the park regarding the implications of herpetofauna conservation, so that members of herpetofauna do not fall victim to killing by humans out of fear.

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Image 1. *Ahaetulla prasina*

Image 2. *Boiga multifasciata*

Image 3. *Boiga ochracea*

Image 4. *Bungarus caeruleus*

Image 5. *Bungarus lividus*

Image 6. *Coelognathus radiatus*

Image 7. *Dendrelaphis cynochloris*

Image 8. *Herpetoreas platyceps*

Image 9. *Lycodon aulicus*

Image 10. *Lycodon septentrionalis*

Image 11 a & b. *Naja kaouthia*

Image 12. *Oligodon taeniolatus*

Image 13. *Ophiophagus hannah*

Image 14. *Orthriophis cantoris*

Image 15. *Orthriophis taeniurus*

Image 16. *Ovophis monticola*

Image 17. *Protobothrops himalayanus*

Image 18. *Pseudoxenodon macrops*

Image 19. *Ptyas korros*

Image 20. *Ptyas nigromarginata*

Image 21. *Python bivittatus*

Image 22. *Rhabdophis himalayanus*

Image 23. *Sinomicrurus macclellandi*

Image 24. *Asymblepharus sikimmensis*

Image 25. *Sphenomorphus indicus*

Image 26. *Sphenomorphus maculatus*

Image 27. *Japalura variegata*

Image 28. *Calotes jerdoni*

Image 29. *Calotes versicolor*

Image 30. *Hemidactylus brookii*

Image 31. *Hemidactylus platyurus*

Image 32. *Cuora mouhotii*

Image 33. *Amolops formosus*

Image 34 a & b. *Amolops marmoratus*

Image 35. *Duttaphrynus melanostictus*

Image 36. *Euphlyctis cyanophlyctis*

Image 37. *Nanorana liebeiii*

Image 38. *Polypedates himalayensis*

Image 39. *Polypedates teraiensis*

Image 40. *Rhacophorus maximus*

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COMMUNICATION

The Odonata (Insecta) of Dhofar, southern Oman

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Abstract: The Dhofar governorate of Oman ('Dhofar') is largely desert with a mainly arid climate. It contains an Afrotropical escarpment region influenced by monsoon precipitation. We summarise published records of odonates for Dhofar, organised by four natural regions, present our unpublished photographic records for 23 sites according to these regions and produce a Dhofar apparent-status statement for most odonate species. Records for the regionally Endangered *Urothemis thomasi* and regionally Endangered *Acisoma variegatum* and regionally Least Concern *Paragomphus sinaiticus* are discussed.

Keywords: *Acisoma variegatum*, Arabian peninsula, dragonflies, *Paragomphus sinaiticus,* species inventory, *Urothemis thomasi.*

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INTRODUCTION

Dhofar governorate (hereafter Dhofar) in southern Oman is climatically somewhat distinct from northern and central Oman (Fisher et al. 1999) and is often considered to contain some biota of Afrotropical origin (e.g., Larsen 1984). The monsoon-influenced escarpment of Dhofar (region 2 in Fig. 1) is especially distinctive (Reade et al. 1980; Miller & Morris 1988; Pickering & Patzelt 2008; Jennings 2010). The western slopes of the Sarawat mountains in western Yemen and southwestern Saudi Arabia, south of the tropic of Cancer, are somewhat analogous (e.g., Le Houerou 2003). In Dhofar, the vegetation of the Jebel Qara escarpment (just north of Salalah City), of the Jebel Qamar escarpment (west of Jebel Qara) and the western portion of the Jebel Samhan escarpment (east of Jebel Qara) are greatly influenced by the 'Khareef' (Arabic: southwest monsoon). During the Khareef season, between June and September, fog wetting and drizzle are especially frequent on southwesterly facing slopes. Annual rain-gauge rainfall rises to more than 300mm on these mountains and altitude lessens temperature (El-Baz 2002). During the Khareef, vegetation on the seaward-facing scarps becomes lush and 'ains' (Arabic: springs) and related pools and streams are full. The back, i.e., dip slope and inland mountains lie in the rain shadow of the monsoon but inland-flowing wadis bring water seasonally to this area and beyond. Ground wells are a major water source in the interior of Dhofar for agriculture and settlements. These, plus sewage works, related reedbeds, 'aflaj' (Arabic plural of 'falaj': irrigation channels) and outflows from palmeries, i.e., palm groves can feed occasional and more permanent pools.

Forty-four species of odonates (dragonflies and damselflies) have been recorded for Oman as a whole (Schneider & Ikemeyer 2016; Cowan & Cowan 2017). Previously, we (Cowan & Cowan 2017) summarised the published records for Odonata in northern and central Oman and presented our own unpublished, photographic, records (December 2008–June 2016) for 50 sites there, organised by eight geographical regions. Odonate records for one site in northern Oman, visited by us on more than 78 occasions to 10 June 2015, in the foothills of the 'Jebel' (Arabic: mountain) Akhdar range, have also been presented (Cowan & Cowan 2013, 2015). The present paper summarises the published records and presents our photographic records at 23 sites, of odonates in Dhofar, southern Oman.

METHODS

The odonate records presented for Dhofar in the present paper have been organised into four geographic regions (Fig. 1):

- Coastal Plains (region 1), from the Yemeni border eastwards to the border with Oman's Wusta governorate (at Ra's Qarwaw) and including the Hallaniyat Islands, has a desert climate.
- Monsoon Slopes (region 2), the scarp slopes and monsoon-influenced wadi sides from the Yemeni border (inland of Ras Darbat Ali) to behind Mirbat, includes various base-of-scarp ains and related water bodies.
- Dry Slopes (region 3), the inland facing dip slopes of the coastal mountains and the mountains and high plains further north (plus the central and eastern Jebel Samhan escarpment), has a desert climate.
- The Northern Desert Plains (region 4) include the Dhofari section of the Rub al Khali sand sea, bordering Saudi Arabia and the Wusta governorate of Oman.

Our records in the systematic list and records of odonates for Dhofar first published in Waterston (1980), Waterston & Pittaway (1991), Schneider & Dumont (1997), van der Weide & Kalkman (2008), Reimer (2009), Ball (2014), Schneider & Ikemeyer (2016), and Lambret et al. (2017) are organised by species in the four geographic regions (Fig. 1) and given in the Results section below. The historical specimen records of Bertram Thomas from the Qara mountains, reported on by Longfield in 1931/32, included the first specimen of *Urothemis thomasi,* and have been discussed to some extent by Waterston (1980). Lambret et al. (2017) stated that their "Records are based on adult sighting, more rarely only on exuvia collecting." It is not clear which of their records are based solely on exuviae. We have treated van der Weide & Kalkman's (2008) two locations in 'Wadi' (Arabic: valley) Ash Shuwaymiyyah as a single site (in our Dry Slopes), their three locations at Ain Hamran (Monsoon Slopes) as a single site and their Wadi Hanna (Monsoon Slopes) as a single site. Ball's (2014; Ball et al. 2015) 11 collection sites along Wadi Sayq in southwestern Dhofar have been treated as two sites: his sites A–H (Monsoon Slopes) and I–K (Coastal Plains). We have treated Schneider & Ikemeyer's (2016) sites in Wadi Darbat as a single site (Monsoon Slopes) and Lambret et al.'s (2017) 'Locations' 52, 58 and 69 (each divided into two 'sites' by them) as single sites (52 in our Northern Desert and 58 and 69 in Coastal Plains). We have considered Lambret et al.'s (2017) location 55, sites 1 and 2 as a single site (in Dry Slopes), their location 55, site 3 as a single site (Coastal Plains), their location

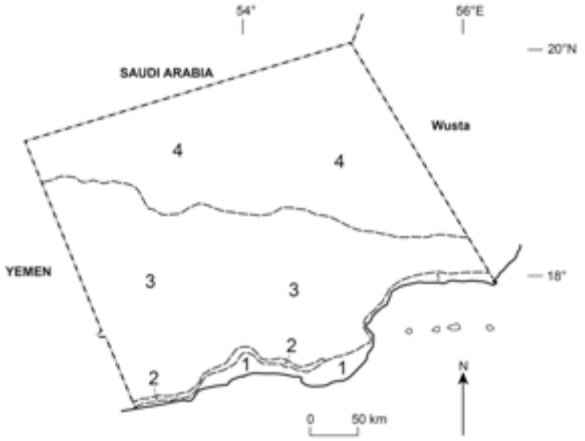

Figure 1. Map of Dhofar, Oman, showing the geographic regions used in the present paper. Geographic regions: 1 - Coastal Plains, 2 - Monsoon Slopes, 3 - Dry Slopes, 4 - Northern Desert. Wusta is the adjoining Omani governorate to Dhofar. The four islands off the southeast coast represent the Hallaniyat islands archipelago (Kuria Muria islands), which we have treated as part of our Coastal Plains region.

85, sites 1–3 as a single site (Monsoon Slopes) and their location 85, site 4 as a separate site (in Coastal Plains).

Photographic records of odonates were made by us at 23 sites in Dhofar September 2009–March 2017. Our sites were selected through reference to the previous odonate and ornithological literature (e.g., Sargeant et al. 2008), local contacts and serendipity. Table 2 lists the location and a brief description for each of our sites. We have not visited the Hallaniyat (Kuria Muria) islands (Coastal Plains). Every one of our records for each site is supported by a photographic voucher held in EMC's personal collection. All photos were taken by EMC using a handheld Sony Cybershot compact/bridge camera. Images 1–17 and 19–25 of the present paper were taken by EMC and Image 18 by Jens & Hanne Eriksen. In most cases these are of species not illustrated in Cowan & Cowan (2013, 2015, 2017).

EMC's photographs allowed for later deliberation and confirmation of identification (ID). Identification was again facilitated by reference to a wide range of field guides and other publications (including Giles 1998; Dijkstra & Lewington 2006; Feulner et al. 2007; Samways 2008; Reimer et al. 2009; Subramanian 2009; Djikstra & Clausnitzer 2014; Smallshire & Swash 2014; Boudot & Kalkman 2015; Tarboton & Tarboton 2015). Spellings of transliterated place names in Oman vary widely in the literature and within Oman.

Photographic records by other observers in Dhofar have also been included where the location was clearly stated and we were satisfied with the claimed identification. These are photos on the expert-moderated 'All Odonata website (2018)', on 'Jens & Hanne Eriksen's website (Eriksen & Eriksen 2018—26 records from 9 sites in Dhofar)' and in the trip reports by Wiprächtiger (2010) and Räz & Wiprächtiger (2012).

Each species account in the systematic list of the Results section below (species sequence as Schneider & Dumont 1997) gives the scientific name and authority citation (IUCN 2017, Schorr & Paulson 2018) and regional (Arabian peninsula) Red List status (García et al. 2015; Schneider & Samraoui 2015) where DD = Data Deficient, NE = Not Evaluated, LC = Least Concern, NT = Near Threatened, VU = vulnerable, EN = Endangered and CR = Critically Endangered, followed by a summary of published records for each of our geographic regions where (WP 1991) = Waterston & Pittaway 1991; (SD 1997) = Schneider & Dumont 1997; (WK 2008) = van der Weide & Kalkman 2008; (SI 2016) = Schneider & Ikemeyer 2016; (L et al. 2017) = Lambret et al. 2017. We felt the best way to summarise previously published records was to present the number of sites where authors recorded a species. Clearly some records, between publications, are likely to involve the same locations. These literature records are followed by 'C & C:' (Cowan & Cowan), our photographic records. In our records, * indicates reproductive behaviour (mating wheels, ovipositing, flying in tandem). None of our records are based on exuviae. Records by other observers 'OO:' are also summarised by number of sites. Those from the All Odonata web gallery are indicated by 'Allodonata/ photographer's name' and those by Jens and Hanne Eriksen by 'E & E'.

Other abbreviations used are A. = Ain, W. = Wadi, K. = 'Khor' (Arabic: coastal creek, usually a sand-blocked lagoon). In the systematic list below, our opinion of 'Apparent status' is given when the status of a species seems reasonably clear (common, can be expected to be seen at a site; uncommon, might be seen at a site; Rare, unlikely to be seen at a site; local, can be found at a few sites in the area concerned).

The specimen collection sites in Dhofar of Waterston & Pittaway (1991); Schneider & Dumont (1997); van de Weide & Kalkman (2008); Schneider & Ikemeyer (2016) and Lambret et al. (2017) have been grouped into our four geographic regions in Table 1. Table 2 lists species located by the authors (and the number of visits) at each of the 23 sites visited, with brief site descriptions.

Table 1. Sites of records in Dhofar of Waterston & Pittaway (1991), Schneider & Dumont (1997), van de Weide & Kalkman (2008), Schneider & Ikemeyer (2016) and Lambret et al. (2017) organised by the four geographic regions of the present paper.
A. = Ain (spring), K. = Khor (coastal lagoon), W. = Wadi (valley). Spellings of names and site numbers are as in their papers. Lambret et al. (2017) presented a district name in front of their site name. We have put their district name in brackets.

COASTAL PLAINS
(WP 1991): Darbat-Mirbat road; Raysut; Salalah; Taqah. **(SD 1997):** 19. K. Dahariz (K. Dahareez); 20a. K. Rawri (K. Rori); 20b. K. Taqah/36. Taqah; 21. K. Sahaur (K. Seehor); 22. K. Sawli; 30. Salalah; 31. as-Sawda Island, Kuria Muria Islands; 55. W. Nahiz (W. Nihaz). **(WK 2008):** 10. beach, ash Shuwaymiyyah; 11. nature reserve Salalah; 13. K. Dahariz; 14. Sahnawt farm, Salalah; 15. beach houses Salalah; 18. K. Taqah; 22. Jarziz farm, Salalah. **(SI 2016):** 9. lagoon and coastal lake west of Taqah; 10. coastal lake west of Salalah; 11. mouth of W. Ashawq; 13. northern fringe of East Khawr. **(L et al. 2017):** 54. K. Sharbithat (Sharbithat); 55. Ras Shuwaymiya, site 3 (Ash Shuwaymiya); 56. W. Sana'ak (Hasik); 58. Bandar Bay (Sadh); 59. K. Hadbeen (Sadh); 60. K. Mahall (Sadh); 61. W. Baqlat (Mirbat); 62. W. Anshayr (Mirbat); 63. A. Shabun (Mirbat); 67. khor and beach 12.5 km east of Taqah (Taqah); 69. K. Rawri (Taqah); 70. K. Taqah (Taqah); 72. K. Sawli (Taqah); 77. K. Ad Dahariz (Salalah); 78. K. Al Baleed (Salalah); 79. Jarziz farm (Salalah); 84. W. Madom at K. Madom (Salalah, Al Mughsayl); 85. W. Ashawq, site 4 (Salalah, Al Mughsayl); 86. K. Rass Sajir (Salalah, Shaat).
MONSOON SLOPES
(WP 1991): A., Jabal Qara; A. Arzat (al rizat); W.Arzat; Jarsis (A.); Khuyuut (Khiyunt); Milwah al Aud; Naqa; Sahalnaut; Darbat pools; W. Saiq; W. Sha'ath. **(SD 1997):** 1. A. Hamran (A. Umran); 2. A. Jarsis; 3. A. ar-Rizat (A. Arzat); 4. A. Tobruk; 10. Dhalqut; 44. W. Darbat, above waterfall; 49. W. Hinnah. **(WK 2008):** 12, 16 & 17. A. Hamran; 19 & 20. W. Hanna; 21. W. Darbat. **(SI 2016):** 8. W. Darbat northeast of Taqah; 12. W. Sayq. **(L et al. 2017):** 64. A. Hashir (Mirbat); 66. Tawi Atayr (Taqah); 68. Wadi Darbat lake and supply stream above the waterfall (Taqah); 71. A. Athum (Taqah); 73. A. Tabraq (Taqah); 74. A. Hamran (Taqah); 75. A. Razat (Taqah); 76. A. Sahalnaut (Salalah); 80. A. Jarziz (Salalah); 82. A. Ishat (Salalah); 83. Aftalqut (Salalah); 85. Wadi Ashawq, sites 1–3 (Salalah, Al Mughsayl); 87. Sinkhole Shaat (Salalah).
DRY SLOPES
(WP 1991): Ayun pools; Thumrait (Thamarit). **(SD 1997):** 6. Ayun; 24. Marmul. **(WK 2008):** 8 & 9. W. ash Shuwaymiyyah. **(SI 2016):** None. **(L et al. 2017):** 55. Ras Shuwaymiya, sites 1 & 2 (Ash Shuwaymiya); 57. Natif waterfall (Hasik); 65. A. Hut (Tayq); 81. 'Ayun pools' (Salalah).
NORTHERN DESERT
(WP 1991): None. **(SD 1997):** 8. Dawkah. **(WK 2008):** 23. oasis Qatbit, central desert; 24. oasis Montasar, central desert. **(SI 2016):** None. **(L et al. 2017):** 51. Muntasar oasis (Muqshin); 52. Qatbit (Muqshin); 53. Dawkah Farm (Thumrait).

RESULTS

Zygoptera (Damselflies)

Coenagrionidae

***Agriocnemis pygmaea* (Rambur, 1842) CR**

Coastal plains: *A.* cf. *pygmaea* 1 site (Reimer 2009). 1 site (SI 2016). 2 sites (L et al. 2017). C & C: K. Taqah 26 Mar 2017. Monsoon Slopes: 1 site (Ball 2014). 1 site (L et al. 2017).

Apparent status: Rare.

***Azuragrion nigridorsum* (Selys, 1876) EN**

Coastal plains OO: 1 site (Allodonata/Ton Elzerman). Monsoon Slopes: 1 site (WP 1991). 1 site (SD 1997). 1 site (WK 2008). 1 site (Ball 2014). 1 site (SI 2016). 5 sites (L et al. 2017). C & C: W. Ghadit 15, 17 Jan 2017, 25 Mar 2017; W. Darbat 17 Oct 2013 (Image 1), 15 Jan 2014, 8* Oct 2014, 21 Sep 2015 (Image 2), 16 Jan 2017; A. Tobruq 22* (Image 3), 24* Sep 2015, 29* Aug 2016, 18* Jan 2017; A. Sahnawt 15 Oct 2013; W. Ashawq 24 Sep 2015. OO: 1 site (Allodonata/Paul Schrijvershof), 1 site (Allodonata/Ton Elzerman), 1 site (E & E).

Apparent status: Common Monsoon Slopes.

***Azuragrion somalicum* (Longfield, 1931) VU**

Coastal plains: 1 site (L et al. 2017). Monsoon Slopes: 1 site (WP 1991). 2 sites (SD 1997). 1 site (SI 2016). Dry Slopes: 1 site (Waterston 1980). 1 site (WK 2008). 2 sites (L et al. 2017). C & C: Hanging Gardens 18* Jan 2014, 9* Oct 2014, 25* Sep 2015, 19* Jan 2017 (Images 4, 5). OO: 1 site (Allodonata/Paul Schrijvershof).

Apparent status: Local Dry Slopes. Rare elsewhere.

***Ischnura evansi* Morton, 1919 LC**

Coastal plains: 3 sites (L et al. 2017). OO: 1 site (Allodonata/Ton Elzerman). Monsoon Slopes: 2 sites (WP 1991). 1 site (SD 1997). 1 site (WK 2008). 2 sites (SI 2016). 3 sites (L et al. 2017). Dry Slopes: 2 sites (L et al. 2017). C & C: Mudhay 28 Aug 2016. Northern Desert: 1 site (L et al. 2017).

Apparent status: Rare.

***Ischnura senegalensis* (Rambur, 1842) LC**

Coastal plains: 2 sites (Waterston 1980). 1 site (WP 1991). 4 sites (SD 1997). 3 sites (WK 2008). 1 site (Ball

Image 1. Male *Azuragrion nigridorsum*, Wadi Darbat 17 October 2013. Blue eyes and face. Blue postocular line surrounded by black. Black along upper abdomen and distinctive blue bands on S8–10.

Image 2. Male *Azuragrion nigridorsum* (lower) Wadi Darbat 21 September 2015. Blue with distinctly black markings on thorax and black abdomen. Compare with paler blue and longer *Pseudagrion decorum* (upper).

Image 3. *Azuragrion nigridorsum* Ain Tobruq 22 September 2015. Mating pair. Male blue with clear black markings. Female pale greenish-brown.

2014). 2 sites (SI 2016). 14 sites (L et al. 2017). C & C: K. Ash Shuwaymiyyah 9 Oct 2014; K. Taqah 17 Oct 2013, 14, 16, 17 Jan 2014, 6 Oct 2014, 22 Sep 2015, 27, 30 Aug 2016, 26, 28* Mar 2017; K. Rawri 17 Jan 2014, 23* Sep 2015, 29* Aug 2016; Al Baleed 18* Jan, 28 March 2017; K. Muhit 27 Aug 2016; K. Mudam 7 Oct 2014. OO: 1 site (Allodonata/Ton Elzerman), 1 site (E & E). Monsoon Slopes: 1 site (Waterston 1980). 1 site (SD 1997). 1 site (Ball 2014). 4 sites (L et al. 2017). C & C: W. Darbat 15 Jan 2014, 16 Jan 2017; A. Sahnawt 15 Oct 2013, 16 Jan 2014; W. Ashawq 7 Oct 2014, 24 Sep 2015. OO: I site (Allodonata/Paul Schrijvershof). Dry Slopes: 1 site (L et al. 2017). C & C: Hanging Gardens 18 Jan 2014, 9 Oct 2014, 25 Sep 2015; Mudhay 28 Aug 2016, 27 Mar 2017; Mazyunah waste water 27 Mar 2017; Mazyunah farm 27 Mar 2017. Northern Desert: 1 site (L et al. 2017).

Apparent status: Common at coastal or near-coastal sites. Uncommon elsewhere.

***Ceriagrion glabrum* (Burmeister, 1839) LC**

Coastal plains: 1 site (Waterston 1980). 2 sites (WP 1991). 2 sites (SD 1997). 1 site (SI 2016). 3 sites (L et al. 2017). C & C: K. Taqah 14 Jan 2014 (Image 6), 27 Aug 2016. OO: 1 site (Räz & Wiprächtiger 2012). Monsoon Slopes: 1 site (Waterston 1980). 2 sites (WP 1991). 4 sites (SD 1997). 1 site (WK 2008). 1 site (Ball 2014). 1 site (SI 2016). 6 sites (L et al. 2017). C & C: W. Ghadit 15, 17* Jan 2017 (Image 7); A. Tobruq 22 Sep 2015. Dry Slopes: 1 site (Waterston 1980). 2 sites (L et al. 2017).

Apparent status: Uncommon.

***Pseudagrion decorum* (Rambur, 1842) NT**

Coastal plains: 1 site (WK 2008). 1 site (SI 2016). 3 sites (L et al. 2017). C & C: K. Taqah 22 Sep 2015, 26*, 28 Mar 2017; K. Rawri 17 Jan 2014, 23 Sep 2015; K. Mudam 7 Oct 2014. Monsoon Slopes: 1 site (SD 1997). 1 site (WK 2008). 1 site (Ball 2014). 1 site (SI 2016). 4 sites (L et al. 2017). C & C: W. Ghadit 15, 17 Jan 2017; W. Darbat 17 Oct 2013, 15 Jan 2014, 8 Oct 2014, 21* Sep 2015 (Image 2), 29* Aug 2016, 16 Jan 2017; A. Hamran 8 Oct 2014; A. Sahnawt 15 Oct 2013; W. Ashawq 24 Sep 2015. OO: 1 site (Wiprächtiger 2010).

Apparent status: Common coastal plains and monsoon slopes.

***Pseudagrion sublacteum* (Karsch, 1893) LC**

Monsoon Slopes: 2 sites (WP 1991). 1 site (SD 1997). 2 sites (WK 2008). 1 site (Reimer 2009). 1 site (SI 2016). 4 sites (L et al. 2017). C & C: W. Darbat 17* Oct 2013 (Image 8), 15 Jan 2014; A. Tobruq 18 Jan 2017; A. Hamran 16* Oct 2013, 23* Sep 2015 (Image 9); A. Sahnawt 15

Image 4. *Azuragrion somalicum* Hanging Gardens, Wadi Ash Shuwaymiyyah, 25 September 2015. Ovipositing in tandem. Female paler with thicker black lance shapes dorsally along abdomen.

Image 5. Male *Azuragrion somalicum* Hanging Gardens, Wadi Ash Shuwaymiyyah, 19 January 2017. Blue overall, in life usually appears a darker, azure, blue. Fine dorsal stripes on thorax. Black segment bands and lance shapes dorsally along abdomen

Image 6. *Ceriagrion glabrum* Khor Taqah 14 January 2014. Dark orange-red mature male. Green eyes.

Image 7. *Ceriagrion glabrum* pair in tandem, Wadi Ghadit 17 January 2017. Female: green eyes, pale thorax, brown abdomen.

Image 8. Male *Pseudagrion sublacteum* Wadi Darbat 17 October 2013. Cherry red eyes. Blue sides of thorax. Two complete bright blue bands on abdomen (S8–9).

Image 9. *Pseudagrion sublacteum* Ain Hamran 23 September 2015. Pair in tandem, ovipositing.

Oct 2013; OO: 1 site (Räz & Wiprächtiger 2012), 1 site (Allodonata / Paul Schrijvershof), 2 sites (E & E).

Apparent status: Uncommon Monsoon Slopes.

Platycnemididae

***Arabicnemis caerulea* Waterston, 1984 LC**

Monsoon Slopes: 1 site (L et al. 2017).

***Arabineura khalidi* (Schneider, 1988) EN**

Dry Slopes: 1 site (L et al. 2017).

Anisoptera (Dragonflies)

Aeshnidae

***Anax imperator* Leach, 1815 LC**

Coastal plains: 1 site (WP 1991). 1 site (SD 1997). 10 sites (L et al. 2017). C & C: K. Taqah 26*, 28* Mar 2017. OO: 1 site (E & E). Monsoon Slopes: 1 site (WP 1991). 2 sites (SD 1997). 3 sites (WK 2008). 1 site (Ball 2014). 1 site (SI 2016). 8 sites (L et al. 2017). C & C: W. Ghadit 15 Jan, 25* Mar 2017; W. Darbat 15* Jan 2014, 8* Oct 2014; A. Sahnawt 15* Oct 2013, 16* Jan 2014; A. Razat 16 Jan 2014; A. Tobruq 22 Sep 2015, 18 Jan 2017; W. Ashawq 7 Oct 2014. Dry Slopes: 1 site (WK 2008). 3 sites (L et al. 2017). C & C: Hanging Gardens 18 Jan, 9 Oct 2014, 25 Sep 2015. Northern Desert: 1 site (L et al. 2017).

Apparent status: Uncommon.

***Anax parthenope* (Selys, 1839) LC**

Coastal plains: 2 sites (L et al. 2017). Monsoon Slopes: 1 site (WK 2008). 3 sites (L et al. 2017). Dry Slopes: 1 site (WP 1991). 2 sites (L et al. 2017). C & C: Mudhay 27 Mar 2017; Mazyunah farm 27 Mar 2017. OO: 1 site (E & E). Northern Desert: 1 site (WK 2008). 1 site (L et al. 2017).

Apparent status: Rare.

***Anax ephippiger* (Burmeister, 1839) LC**

Coastal plains: 2 sites (SD 1997). 8 sites (L et al. 2017). Monsoon slopes: 1 site (Ball 2014). 5 sites (L et al. 2017). C & C: W. Ghadit 15 Jan 2017. Dry Slopes: 1 site (WP 1991). 1 site (SD 1997). 2 sites (L et al. 2017). OO: 1 site (E & E). Northern Desert: 1 site (WK 2008). 3 sites (L et al. 2017). CC: Muntasar 14 Jan 2017.

Apparent status: Rare.

Gomphidae

***Lindenia tetraphylla* (Vander Linden, 1825) LC**

Monsoon Slopes: 1 site (SD 1997). 1 site (Reimer 2009). 1 site (SI 2016). 1 site (L et al. 2017). C & C: W. Ghadit 17 Jan 2017, 25 Mar 2017; W. Darbat 8 Oct 2014, 21 Sep 2015, 16 Jan 2017. OO: 1 site (Allodonata/Richard Hornby, Wiprächtiger 2010), 1 site (E & E). Dry Slopes: 1 site (L et al. 2017).

Apparent status: Local Monsoon Slopes.

***Paragomphus sinaiticus* (Morton, 1929) LC**

Monsoon Slopes: 1 site (Reimer 2009). 7 sites (L et al. 2017). C & C: W. Darbat 21 Sep 2015; A. Sahnawt 15 Oct 2013; A. Hamran 20 Sep 2009, 23 Sep 2015, 29 Mar 2017. Dry Slopes: 1 site (L et al. 2017).

Apparent status: Uncommon Monsoon Slopes.

Libellulidae

***Nesciothemis farinosa* (Förster, 1898) LC**

Coastal Plains OO: 1 site (Allodonata/Ton Elzerman). Monsoon Slopes: 2 sites (WP 1991). 2 sites (SD 1997). 1 site (WK 2008). 1 site (Ball 2014). 2 sites (SI 2016). 4 sites (L et al. 2017). C & C: W. Ghadit 17 Jan 2017; W. Darbat 8 Oct 2014; A. Hamran 16 Oct 2013; A. Tobruq 22 Sep 2015, 18 Jan 2017; A. Razat 29 Aug 2016 (Image 10). OO: 1 site (Allodonata/Ton Elzerman), 1 site (Allodonata/Geert De Knijf), 1 site (Allodonata/Paul Schrijvershof), 1 site (E & E). Dry Slopes: 1 site (WP 1991). 1 site (L et al. 2017).

Apparent status: Locally common Monsoon Slopes.

***Orthetrum chrysostigma* (Burmeister, 1839) LC**

Coastal plains: 1 site (Ball 2014). 6 sites (L et al. 2017). OO: 1 site (Allodonata/Ton Elzerman). Monsoon Slopes: 3 sites (Waterston 1980). 2 sites (WP 1991). 6 sites (SD 1997). 3 sites (WK 2008). 1 site (Ball 2014). 1 site (SI 2016). 10 sites (L et al. 2017). C & C: W. Ghadit 15, 17* Jan, 25 Mar 2017; W. Darbat 17 Oct 2013, 15* Jan, 8 Oct 2014, 21 Sep 2015, 29* Aug 2016; A. Sahnawt 15* Oct 2013, 16 Jan 2014; A. Tobruq 22 Sep 2015, 18 Jan 2017; A. Hamran 20 Sep 2009, 16* Oct 2013, 8* Oct 2014, 23 Sep 2015, 30* Aug 2016, 18 Jan, 29 Mar 2017; A. Razat 29* Aug 2016, 18 Jan 2017. OO: 1 site (Wiprächtiger 2010), 1 site (Allodonata/Paul Schrijvershof), 3 sites (E & E). Dry Slopes: 1 site (WP 1991). 2 sites (L et al. 2017). C & C: Mudhay 27 Mar 2017. OO: 1 site (Allodonata/Paul Schrijvershof).

Apparent status: Common Monsoon Slopes.

***Orthetrum ransonnetii* (Brauer, 1865) LC**

Coastal plains: 1 site (L et al. 2017). Monsoon Slopes: 1 site (Ball 2014). 1 site (L et al. 2017). Dry Slopes: 1 site (WP 1991). 1 site (L et al. 2017).

Apparent status: Rare.

***Orthetrum sabina* (Drury, 1773) LC**

Coastal plains: 1 site (Waterston 1980). 1 site (WP 1991). 3 sites (SD 1997). 2 sites (WK 2008). 1 site (Ball 2014). 1 site (SI 2016). 12 sites (L et al. 2017). C & C: W. Ataran 31 Aug 2016; K. Rawri 17 Jan 2014, 29 Aug 2016; K. Taqah 14, 17 Jan 2014, 6 Oct 2014, 22 Sep 2015, 27,

30 Aug 2016, 28 Mar 2017; K. Dahariez 27 Aug 2016; K. Muhit 27 Aug 2016; K. Mudam 7 Oct 2014. OO: 2 sites (Allodonata/Ton Elzerman). Monsoon Slopes: 1 site (WP 1991). 1 site (SD 1997). 2 sites (WK 2008). 1 site (Ball 2014). 1 site (SI 2016). 7 sites (L et al. 2017). C & C: W. Ghadit 15, 17 Jan 2017; W. Darbat 15 Jan 2014, 21 Sep 2015; A. Tobruq 22* Sep 2015, 18* Jan 2017, 25 Mar 2017; A. Hamran 20 Sep 2009, 16 Oct 2013, 23 Sep 2015, 30 Aug 2016; A. Razat 29 Aug 2016, 18 Jan 2017; A. Sahnawt 15 Oct 2013; W. Ashawq 24 Sep 2015. OO: 1 site (E & E). Dry Slopes: 1 site (WP 1991). 2 sites (L et al. 2017). C & C: Hanging Gardens 9 Oct 2014; Mudhay 28* Aug 2016, 27 Mar 2017; Mazyunah waste water 27 Mar 2017; Mazyunah farm 27 Mar 2017. OO: 1 site (E & E). Northern Desert: 1 site (SD 1997). 1 site (WK 2008). 2 sites (L et al. 2017). C & C: Muntasar 5 Oct 2014, 20 Sep 2015, 14 Jan 2017; Qitbit 26 Aug 2016. OO: 1 site (E & E).

Apparent status: Common.

***Crocothemis erythraea* (Brullé, 1832) LC**

Coastal plains: 1 site (Waterston 1980). 2 sites (WP 1991). 2 sites (SD 1997). 2 sites (WK 2008). 1 site (Ball 2014). 2 sites (SI 2016). 14 sites (L et al. 2017). C & C: K. Samhal 25 Sep 2015; K. Taqah 16, 17 Oct 2013, 14, 16 Jan 2014, 6 Oct 2014, 22 Sep 2015, 27*, 30 Aug 2016, 16 Jan, 26 Mar 2017; K. Rawri 17 Jan 2014; K. Mudam 7 Oct 2014. OO: 2 sites (Allodonata/Ton Elzerman), 1 site (E & E). Monsoon Slopes: 1 site (WP 1991). 6 sites (SD 1997). 2 sites (WK 2008). 1 site (Ball 2014). 1 site (SI 2016). 10 sites (L et al. 2017). C & C: W. Ghadit 15, 17 Jan, 25* Mar 2017; W. Darbat 17 Sep 2009, 17 Oct 2013, 15 Jan, 8 Oct 2014, 21 Sep 2015, 16 Jan 2017; A. Sahnawt 15 Oct 2013, 16 Jan 2014; A. Tobruq 22* Sep 2015, 18* Jan 2017; A. Hamran 20 Sep 2009, 16 Oct 2013, 8* Oct 2014, 23 Sep 2015, 30 Aug 2016; A. Razat 29 Aug 2016; W. Ashawq 7 Oct 2014, 24 Sep 2015. OO: 1 site (E & E). Dry Slopes: 1 site (WP 1991). 1 site (WK 2008). 2 sites (L et al. 2017). C & C: Hanging Gardens 9 Oct 2014, 25 Sep 2015, 26 Feb 2016, 19 Jan 2017; Mudhay 28 Aug 2016; Mazyunah farm 27 Mar 2017. OO: 1 site (Allodonata/Paul Schrijvershof). Northern Desert: 3 sites (L et al. 2017). C & C: Muntasar 20 Sep 2015, 14 Jan 2017. OO: 1 site (Allodonata/Ton Elzerman), 1 site (Allodonata/Vink), 1 site (E & E).

Apparent status: Common.

***Crocothemis sanguinolenta* (Burmeister, 1839) LC**

Coastal plains: 6 sites (L et al. 2017). Monsoon Slopes: 2 sites (SD 1997). 1 site (WK 2008). 2 sites (SI 2016). 5 sites (L et al. 2017). Dry Slopes: 1 site (L et al. 2017). OO: 1 site (Allodonata/Paul Schrijvershof).

Image 10. *Nesciothemis farinosa* Ain Razat 29 August 2016. Blue thorax and black eyes, dark abdomen (S6–10), dark legs and wing veins.

Image 11. *Rhyothemis semihyalina* Khor Taqah 6 October 2014. Shows clear (here appear beige) triangles within the hind wing patches.

Image 12. *Rhyothemis semihyalina* Khor Taqah 22 September 2015. Large purple/blue iridescent hind-wing patches.

Apparent status: Rare.

***Diplacodes lefebvrii* (Rambur, 1842) LC**

Coastal plains: 1 site (Waterston 1980). 2 sites (WP 1991). 6 sites (SD 1997). I site (WK 2008). 1 site (Ball 2014). 13 sites (L et al. 2017). C & C: W. Ataran 31 Aug 2016; K. Samhal 25 Sep 2015; K. Taqah 16, 17 Oct 2013, 14, 16, 17 Jan 2014, 6 Oct 2014, 22 Sep 2015, 27, 30 Aug 2016, 28 Mar 2017. OO: 1 site (E & E). Monsoon Slopes: I site (WP 1991). 1 site (SD 1997). I site (Ball 2014). 1 site (SI 2016). 6 sites (L et al. 2017). C & C: W. Ghadit 15, 17* Jan, 25 Mar 2017; W. Darbat 8 Oct 2014; A. Sahnawt 15 Oct 2013; A. Razat 29 Aug 2016; W. Ashawq 7* Oct 2014, 24* Sep 2015. OO: 1 site (Wiprächtiger 2010), 1 site (E & E). Dry Slopes: 1 site (WP 1991). 2 sites (L et al. 2017). OO: 1 site (Allodonata/Paul Schrijvershof). Northern Desert: 2 sites (L et al. 2017). C & C: Muntasar 5 Oct 2014, 20 Sep 2015. OO: 3 sites (Allodonata/Ton Elzerman).

Apparent status: Common, sometimes in large numbers.

***Sympetrum fonscolombii* (Selys, 1840) LC**

Monsoon Slopes: 1 site (SI 2016). Northern Desert: 1 site (L et al. 2017).

***Trithemis annulata* (Palisot de Beauvois, 1807) LC**

Coastal plains: 1 site (SD 1997). 3 sites (WK 2008). 1 site (Ball 2014). 5 sites (L et al. 2017). C & C: K. Taqah 16 Jan, 26, 28 Mar 2017. OO: 1 site (Allodonata/Ton Elzerman), 1 site (Allodonata/Paul Schrijvershof). Monsoon Slopes: 2 sites (Waterston 1980). 5 sites (WP 1991). 2 sites (SD 1997). 2 sites (WK 2008). 1 site (Ball 2014). 1 site (SI 2016). 9 sites (L et al. 2017). C & C: Wadi Ghadit 15, 17 Jan, 25 Mar 2017; W. Darbat 19 Sep 2009, 17 Oct 2013, 15 Jan 2014, 8* Oct 2014, 21 Sep 2015, 29 Aug 2016, 16 Jan 2017; A. Sahnawt 15 Oct 2013, 16 Jan 2014; A. Hamran 16 Oct 2013, 8 Oct 2014, 23 Sep 2015, 30 Aug 2016, 18 Jan, 29 Mar 2017; A. Tobruq 22, 24 Sep 2015, 29 Aug 2016, 18 Jan 2017; A. Razat 29 Aug 2016, 18 Jan 2017. OO: 1 site (E & E). Dry Slopes: 1 site (WP 1991). 1 site (L et al. 2017).

Apparent status: Common Monsoon Slopes, uncommon Coastal Plains.

***Trithemis arteriosa* (Burmeister, 1839) LC**

Coastal plains: 1 site (Ball 2014). 4 sites (L et al. 2017). OO: 1 site (Allodonata/Ton Elzerman). Monsoon Slopes: 4 sites (WP 1991). 3 sites (SD 1997). 2 sites (WK 2008). 1 site (Ball 2014). 1 site (SI 2016). 9 sites (L et al. 2017). C & C: W. Ghadit 17 Jan 2017; A. Razat 16 Jan 2014, 18 Jan 2017; A. Tobruq 22 Sep 2015, 18 Jan 2017; A. Hamran 20 Sep 2009, 16 Oct 2013, 8 Oct 2014, 23 Sep 2015, 30 Aug 2016, 18 Jan, 29 Mar 2017; A. Sahnawt 15 Oct 2013, 16 Jan 2014. OO: 1 site (Allodonata/Paul Schrijvershof). Dry Slopes: 2 sites (WP 1991). 1 site (SD 1997). 1 site (WK 2008). 3 sites (L et al. 2017). C & C: Hanging Gardens 19 Jan 2017, Mudhay 28 Aug 2016, 27 Mar 2017.

Apparent status: Common Monsoon Slopes, uncommon elsewhere.

***Trithemis kirbyi* Selys, 1891 LC**

Coastal plains: 1 site (L et al. 2017). Monsoon Slopes: 4 sites (L et al. 2017).

***Rhyothemis semihyalina* (Desjardins, 1835) EN**

Coastal plains: 2 sites (Waterston 1980). 3 sites (WP 1991). 3 sites (SD 1997). 1 site (WK 2008). 1 site (Reimer 2009). 2 sites (SI 2016). 11 sites (L et al. 2017). C & C: W. Ataran 31 Aug 2016; K. Taqah 16, 17 Oct 2013, 14 Jan, 6 Oct 2014 (Image 11), 22 Sep 2015 (Image 12), 27*, 31 Aug 2016, 26, 28 Mar 2017; Al Baleed 28 Mar 2017. OO: 1 site (E & E). Monsoon Slopes: 2 sites (WP 1991). 1 site (SD 1997). 1 site (Ball 2014). 1 site (SI 2016). 6 sites (L et al. 2017). C & C: W. Ghadit 25 Mar 2017; W. Darbat 21 Sep 2015; W. Ashawq 7 Oct 2014, 24* Sep 2015.

Apparent status: Common Coastal Plains and Monsoon Slopes.

***Pantala flavescens* (Fabricius, 1798) LC**

Coastal plains: 4 sites (WP 1991). 3 sites (SD 1997). 6 sites (WK 2008). 1 site (Ball 2014). 1 site (SI 2016). 5 sites (L et al. 2017). C & C: K. Taqah 27, 30 Aug 2016; K. Muhit 27 Aug 2016. Monsoon Slopes: 1 site (SD 1997). 3 sites (WK 2008). 1 site (Ball 2014). 1 site (SI 2016). 5 sites (L et al. 2017). C & C: W. Ghadit 15, 17* Jan 2017; W. Darbat 17 Oct 2013, 8 Oct 2014, 21* Sep 2015, 29 Aug 2016; A. Tobruq 22 Sep 2015; A. Hamran 23 Sep 2015, 30 Aug 2016; A. Razat 29 Aug 2016. Dry Slopes: 1 site (WP 1991). 1 site (WK 2008). 1 site (L et al. 2017). Northern Desert: 2 sites (WK 2008). 3 sites (L et al. 2017). C & C: Muntasar 5 Oct 2014, 14 Jan 2017. OO: 1 site (E & E).

Apparent status: Common.

***Tholymis tillarga* (Fabricius, 1798) DD**

Coastal plains: 1 site (L et al. 2017). Monsoon Slopes: 1 site (Ball 2014).

Apparent status: Rare.

***Tramea basilaris* (Palisot de Beauvois, 1817) NE**

Coastal plains: 3 sites (L et al. 2017). Monsoon Slopes: 3 sites (L et al. 2017). Northern Desert: 1 site (L

Image 13. Male *Tramea limbata* Wadi Ghadit 15 January 2017. Wing bases dark red either side of thorax. Dark dorsal abdominal terminal segments 8–10 and long anal appendages. Typical pennant pose.

Image 14. Male *Tramea limbata* Wadi Ghadit, 17 January 2017. Wing bases dark red either side of thorax. Dark terminal abdominal segments 8–10 and long dark anal appendages. Pennant pose.

Image 15. Mating wheel *Tramea limbata* Ain Tobruq 18 January 2017. Wing patches visible on both. Male red abdomen with black on S8–9 and female with darker abdomen.

et al 2017).

Apparent status: Rare.

***Tramea limbata* (Desjardins, 1835) NT**

Coastal plains: 3 sites (SI 2016). 1 site (L et al. 2017). Monsoon Slopes: 2 sites (WP 1991). 1 site (SD 1997). 1 site (Reimer 2009). 1 site (SI 2016). 6 sites (L et al. 2017). C & C: W. Ghadit 15 (Image 13), 17* Jan (Image 14), 25 Mar 2017; W. Darbat 16 Sep 2009, 15 Jan 2014, 8 Oct 2014, 21* Sep 2015, 16 Jan 2017; A. Tobruq 18* Jan 2017 (Image 15). OO: 1 site (Allodonata/Geert De Knijf).

Apparent status: Common Monsoon Slopes.

***Acisoma variegatum* Kirby, 1898**

sensu Mens et al. (2016)

Coastal plains: "widespread… in wet and dry wadis during August 1981" (WP 1991). 1 site (SD 1997). Monsoon Slopes: 2 sites (WP 1991). 1 site (SD 1997). 1 site (SI 2016). C & C: W. Ghadit 17 Jan, 25* Mar 2017 (Image 16, 17). OO: 1 site (E & E, Image 18).

Apparent status: Local and rare Monsoon Slopes.

***Macrodiplax cora* (Kaup in Brauer, 1867) NT**

Coastal plains: 1 site (Schneider & Krupp 1993, "… seems to be quite common around Salalah town."). 2 sites (SD 1997). 2 sites (WK 2008). 1 site (Reimer 2009). 1 site (Ball 2014). 2 sites (SI 2016). 14 sites (L et al. 2017). C & C: K. Ash Shuwaymiyyah 9 Oct 2014, 25 Sep 2015; K. Sanaq 31 Aug 2016; W. Ataran 31 Aug 2016; K. Samhal 25* Sep 2015; K. Rawri 17 Jan 2014, 23 Sep 2015, 29 Aug 2016; K. Taqah 17 Oct 2013, 14, 16 Jan 2014, 6 Oct 2014, 22 Sep 2015, 26, 28 Mar 2017; K. Dahariez 27 Aug 2016; K. Muhit 27 Aug 2016; K. Mudam 7 Oct 2014. OO: 1 site (Wiprächtiger 2010), 1 site (Allodonata/Paul Schrijvershof), 1 site (E & E). Monsoon Slopes: 1 site (Ball 2014). 4 sites (L et al. 2017). C & C: W. Darbat 15 Jan 2014, 21 Sep 2015; W. Ashawq 7 Oct 2014, 24 Sep 2015. OO: 1 site (Allodonata/Paul Schrijvershof). Dry Slopes: 1 site (L et al. 2017). C & C: Hanging Gardens 9 Oct 2014. Northern Desert: 2 sites (L et al. 2017).

Apparent status: Common Coastal Plains, uncommon or rare elsewhere.

***Selysiothemis nigra* (Vander Linden, 1825) LC**

Coastal plains: 1 site (L et al. 2017). Monsoon Slopes: 1 site (L et al. 2017).

***Urothemis edwardsii* (Selys in Lucas, 1849) EN**

Coastal plains: 2 sites (WP 1991). 1 site (SD 1997). 2 sites (SI 2016). 5 sites (L et al. 2017). C & C: K. Taqah 16, 17 Oct 2013, 14 Jan 2014, 6 Oct 2014 (Image 19), 22 Sep

Image 16. Male *Acisoma variegatum* Wadi Ghadit 25 March 2017. Blue eyes, blue abdomen with black dorsal line, white anal appendages, long pale pterostigmas on wings.

Image 17. Male *Acisoma variegatum* Wadi Ghadit 25 March 2017. Abdomen swollen at base to S4. No ventral 'step' between S5 and long S6, slender to tip. Distinctive abdominal pattern.

Image 18. Female *Acisoma variegatum* Wadi Ghadit 1 October 2016. Slight orange markings on wings at thorax.

Image 19. Immature *Urothemis edwardsii* Khor Taqah 6 October 2014.

Image 20. Male *Urothemis edwardsii* Wadi Ashawq 7 October 2014. Dark wing patches and blue abdomen.

Image 21. Mating pair tandem *Urothemis edwardsii* Wadi Ashawq 7 October 2014

Table 2. Sites in Dhofar, organised by geographic region, at which the authors recorded odonates, 2009–2017. A. = Ain (spring), K. = Khor (coastal lagoon), W. = Wadi (valley).

Site name, GPS coordinates, brief description, elevation (m A.S.L)	Species seen at site by us (number visits)
Coastal Plains	
K. Ash Shuwaymiyyah 17.8827° N, 55.6028° E. Brackish pools, beach side of main road at southern entry to town (10).	*Ischnura senegalensis, Macrodiplax cora* (2 visits).
K. Sanaq 17.4334° N, 55.2501° E. Large khor, 22 km north of Hasik at foot of cliffs, reeds, sedges and extensive palmerie (20).	*Macrodiplax cora* (1 visit).
W. Ataran 17.4550° N, 55.2531° E. Wadi with reeds at seaward side of new coast road 2 km north of Hasik petrol station (15).	*Orthetrum sabina*, *Diplacodes lefebvrii, Rhyothemis semihyalina, Macrodiplax cora* (1 visit).
K. Samhal 17.3502° N, 55.2835° E. 12 km south of Hasik, seaward side of new coast road, wadi outflow from Jebel Qamar, brackish with sedges and grasses (15).	*Crocothemis erythraea, Diplacodes lefebvrii, Macrodiplax cora* (1 visit).
K. Taqah 17.0334° N, 54.3668° E. Inlet, reedbeds, pools, open grass (14).	*Agriocnemis pygmaea, Ischnura senegalensis, Pseudagrion decorum, Ceriagrion glabrum*, *Anax imperator, Orthetrum sabina*, *Crocothemis erythraea, Diplacodes lefebvrii, Trithemis annulata, Rhyothemis semihyalina, Pantala flavescens, Macrodiplax cora, Urothemis edwardsii* (11 visits).
K. Rawri 17.0335° N, 54.4169° E. Extensive lagoon with open sandy areas and reeds (7).	*Ischnura senegalensis, Pseudagrion decorum, Orthetrum sabina*, *Crocothemis erythraea, Macrodiplax cora* (3 visits).
K. Dahariez 17.0002° N, 54.1668° E. Eastern outskirts of Salalah, extensive lagoon, mangroves and reeds (15).	*Orthetrum sabina*, *Macrodiplax cora* (1 visit).
Al Baleed park 17.0084° N, 54.1389° E. Archaeological site, gardens, khor with reeds and hotel (6).	*Ischnura senegalensis, Rhyothemis semihyalina* (2 visits).
K. Muhit 16.9669° N, 54.0002° E. Small pool, scrubby vegetation west of Hilton Hotel grounds (17).	*Ischnura senegalensis, Orthetrum sabina*, *Pantala flavescens, Macrodiplax cora* (1 visit).
K. Mudam 16.8835° N, 53.8168° E. Extensive khor inland from sea east of Mugsayl, low vegetation with grass in water (20).	*Ischnura senegalensis, Pseudagrion decorum, Orthetrum sabina*, *Crocothemis erythraea, Macrodiplax cora* (1 visit).
Monsoon Slopes	
W. Ghadit 17.1423° N, 54.4695° E. Tributary wadi to W. Darbat with spring fed pool (320).	*Azuragrion nigridorsum, Ceriagrion glabrum*, *Pseudagrion decorum, Anax imperator, A. ephippiger, Lindenia tetraphylla, Nesciothemis farinosa, Orthetrum chrysostigma, O. sabina, Crocothemis erythraea, Diplacodes lefebvrii, Trithemis annulata, T. arteriosa, Rhyothemis semihyalina, Pantala flavescens, Tramea limbata, Acisoma variegatum* (2 visits).
W. Darbat 17.1047° N, 54.4526° E. Wide wadi, seasonal river and pools, acacias (205).	*Azuragrion nigridorsum, Ischnura senegalensis, Pseudagrion decorum, P. sublacteum, Anax imperator, Lindenia tetraphylla, Paragomphus sinaiticus, Nesciothemis farinosa, Orthetrum chrysostigma, O. sabina, Crocothemis erythraea, Diplacodes lefebvrii, Trithemis annulata, Rhyothemis semihyalina, Pantala flavescens, Tramea limbata, Macrodiplax cora, Urothemis edwardsii* (4 visits).
A. Tobruq 17.1000° N, 54.3168° E. Concrete falaj and pool from spring, outflow into muddy ford, pools with grasses, shrubs and trees (110).	*Azuragrion nigridorsum, Ceriagrion glabrum, Pseudagrion sublacteum, Anax imperator, Nesciothemis farinosa, Orthetrum chrysostigma, O. sabina, Crocothemis erythraea, Trithemis annulata, T. arteriosa, Pantala flavescens, Tramea limbata, Zygonyx torridus* (3 visits).
A. Hamran 17.0836° N, 54.2669° E. Spring, falaj, pools, palms (85).	*Pseudagrion decorum, P. sublacteum, Paragomphus sinaiticus, Nesciothemis farinosa, Orthetrum chrysostigma, O. sabina, Crocothemis erythraea, Trithemis annulata, T. arteriosa, Pantala flavescens, Urothemis edwardsii, Zygonyx torridus* (6 visits).
A. Razat 17.1169° N, 54.2334° E. Gardens, falaj, stream with small rapids, large car park with trees and scrub (90).	*Anax imperator, Nesciothemis farinosa, Orthetrum chrysostigma, O. sabina, Crocothemis erythraea, Diplacodes lefebvrii, Trithemis annulata, T. arteriosa, Pantala flavescens, Zygonyx torridus* (2 visits).
A. Sahnawt 17.1335° N, 54.1669° E. Spring, pools and rapids, falaj (130).	*Azuragrion nigridorsum, Ischnura senegalensis, Pseudagrion decorum, P. sublacteum, Anax imperator, Paragomphus sinaiticus, Orthetrum chrysostigma, O. sabina, Crocothemis erythraea, Diplacodes lefebvrii, Trithemis annulata, T. arteriosa, Zygonyx torridus* (2 visits).
W. Ashawq 16.8834° N, 53.7668° E. Spring-fed wadi pool near cliff, 1–2 km 'upstream' from Mugsayl beach, waterside vegetation with reeds, sedges and grass, extensive algal mats (41).	*Azuragrion nigridorsum, Ischnura senegalensis, Pseudagrion decorum, Anax imperator, Orthetrum sabina, Crocothemis erythraea, Diplacodes lefebvrii, Rhyothemis semihyalina, Macrodiplax cora, Urothemis edwardsii* (2 visits).
Dry Slopes	
Hanging Gardens 17.9336° N, 55.5266° E. Pools above main floor of W. Ash Shuwaymiyyah *c*10 km from Ash Shuwaymiyyah town and coast (70).	*Azuragrion somalicum, Ischnura senegalensis, Anax imperator, Orthetrum sabina, Crocothemis erythraea, Trithemis arteriosa, Macrodiplax cora, Urothemis thomasi* (4 visits).
Mudhay 17.3668° N, 53.3500° E. Pool/large tank near picnic area at head of palmerie at south end of village (540).	*Ischnura evansi, I. senegalensis, Anax parthenope, Orthetrum chrysostigma, O. sabina, Crocothemis erythraea, Trithemis arteriosa* (2 visits).

Mazyunah waste water 17.8501° N, 52.6336° E. Waste water site (520).	*Ischnura senegalensis, Orthetrum sabina* (1 visit).
Mazyunah farm 17.8835° N, 52.6335° E. Farmland (502).	*Ischnura senegalensis, Anax parthenope, Orthetrum sabina, Crocothemis erythraea* (1 visit).
Northern Desert	
Muntasar 19.4500° N, 54.6167° E. Palmerie, runoff overflow pools from well (136).	*Anax ephippiger, Orthetrum sabina, Crocothemis erythraea, Diplacodes lefebvrii, Pantala flavescens* (4 visits).
Qitbit oasis 19.1501° N, 54.5001° E. Small spring adjacent to trees near the larger oasis and pool c. 2 km east from resthouse (165).	*Orthetrum sabina* (1 visit).

2015, 27 Aug 2016, 28 Mar 2017. OO: 1 site (Allodonata/Paul Schrijvershof), 1 site (E & E). Monsoon Slopes: 1 site (Waterston 1980). 1 site (WP 1991). 1 site (SD 1997). 1 site (SI 2016). 2 sites (L et al. 2017). C & C: W. Darbat 8 Oct 2014, 21 Sep 2015; A. Hamran 16 Oct 2013; W. Ashawq 7* Oct 2014 (Image 20, 21), 24 Sep 2015. Dry Slopes: 1 site (L et al. 2017).

Apparent status: Local and uncommon Coastal Plains and Monsoon Slopes.

***Urothemis thomasi* Longfield, 1932 EN**

Coastal plains: 1 site (SD 1997). Monsoon Slopes: 1 site (WP 1991). 2 sites (SI 2016). 4 sites (L et al. 2017). Dry Slopes: 1 site (WP 1991). C & C: Hanging Gardens 9 Oct 2014 (Image 22), 25 Sep 2015 (Images 23, 24).

Apparent status: Local, uncommon.

***Zygonyx torridus* (Kirby, 1889) LC**

Monsoon Slopes: 1 site (Waterston 1980). 1 site (WP 1991). 2 sites (SD 1997). 2 sites (WK 2008). 1 site (SI 2016). 6 sites (L et al. 2017). C & C: A. Sahnawt 15 Oct 2013, 16 Jan 2014; A. Hamran 20* Sep 2009, 16 Oct 2013, 23 Sep 2015 (Image 25), 30* Aug 2016, 18 Jan, 29* Mar 2017; A. Tobruq 22 Sep 2015; A. Razat 29 Aug 2016, 18 Jan 2017. OO: 1 site (Räz & Wiprächtiger 2012), 1 site (Allodonata/Ton Elzerman).

Apparent status: Common Monsoon Slopes where flowing water.

DISCUSSION

Of the 44 species recorded from Oman, 37 have been noted as occurring in Dhofar. We recorded and photographed eight zygopteran and 20 anisopteran species in this area. Of the 37 species recorded, *Arabineura khalidi* and *Arabicnemis caerulea* have both been recorded on one occasion only (Lambret et al. 2017), *Sympetrum fonscolombii* twice (Schneider & Ikemeyer 2016; Lambret et al. 2017) and *Trithemis kirbyi* five times (Lambret et al. 2017). *Selysiothemis nigra* has been recorded on two dates including a record of 10 individuals (Lambret et al. 2017). *Arabineura khalidi* and *Arabicnemis caerulea* both occur in the Hajar mountains of northern Oman (and according to Schneider & Nasher (2013), the latter is also known from the Hadhramout in Yemen). *Trithemis kirbyi* is very common in northern Oman (Cowan & Cowan 2017) and has also been recorded in the Hadhramout (Schneider & Nasher 2013). Species of odonate recorded for Dhofar are mainly regionally Least Concern though *Arabineura khalidi*, *Azuragrion nigridorsum, Rhyothemis semihyalina, A. variegatum* (under its regionally incorrect name *Acisoma panorpoides ascalaphoides*), *Urothemis edwardsii* and *U. thomasi* are regionally Endangered. *Agriocnemis pygmaea* is considered to be Critically Endangered and *Pseudagrion decorum, Tramea limbata* and *Macrodiplax cora* are regionally Near Threatened (García et al. 2015). *Azuragrion somalicum* is classed regionally as Vulnerable.

Odonate species listed for Oman that have only been recorded in Dhofar are *Azuragrion nigridorsum, A. somalicum, Pseudagrion sublacteum, Nesciothemis farinosa, Rhyothemis semihyalina, Tholymis tillarga, Acisoma variegatum* and *Urothemis edwardsii.* All also occur in Afrotropical Africa (Dijkstra & Clausnitzer 2014, Dijkstra 2016). We have recorded each of them except *T. tillarga. Tholymis tillarga* was added to the Dhofar and Oman lists by Ball (2014), with a record of a male and an ovipositing female in Wadi Sayq, which is close to the Yemeni border, though no ID evidence was presented. Lambret et al. (2017) recorded *T. tillarga*, a record of two individuals on 11 November 2010, at a different site from Ball's (2014), but presented no evidence except "observed at close distance". *T. tillarga* is apparently a migrant (Lambret et al. 2017), occurs in India and Africa, and is crepuscular (Subramanian 2009, Djikstra & Clausnitzer 2014) and may well have been overlooked in Dhofar by other observers. *Tramea basilaris* has been recorded on several occasions in Dhofar by Lambret et al. 2017. It is probably a rare migrant to Oman (cf. Reimer 2011).

Image 22. Old female *Urothemis thomasi* Hanging Gardens, Wadi Ash Shuwaymiyyah, 9 October 2014. Pale/very faded thorax and abdomen. Faded orange wing patches. Dark rear pointed markings dorsally on abdomen (as male, see Images 23 and 24).

Image 23. Male *Urothemis thomasi* Hanging Gardens, Wadi Ash Shuwaymiyyah, 25 September 2015. Bicoloured orange patches on hind wings.

Image 24. Male *Urothemis thomasi* Hanging Gardens, Wadi Ash Shuwaymiyyah, 25 September 2015. Thoracic stripes, pale pink frons, bicoloured orange patches on hind wings and black pointed markings dorsally on red abdomen.

Image 25. Male *Zygonyx torridus* Ain Hamran 23 September 2015. 'Hanging' early morning.

Included are our records of *Acisoma variegatum* from Wadi Ghadit (Images 16–18). Until Schneider & Ikemeyer's (2016) records, this species (recorded as *A. panorpoides ascalaphoides*) had not been recorded in Dhofar (and Oman) for many years. It now seems to be locally resident in Wadi Darbat and its upper tributary Wadi Ghadit. We recorded mating pairs ovipositing in some of the pools of Wadi Ghadit.

Ball (2014) indicated that the most species rich areas within Wadi Sayq, studied intensively in February 2012 and February/March 2013, were two areas of freshwater pools (his sites E and F, both in our Monsoon Slopes) inland from more saline, coastal sites. Our observations indicate that the freshwater sites (ains, streams/aflaj, pools and wadis) in Monsoon Slopes have the greatest number of species: Wadi Darbat (we recorded 18 species), Wadi Ghadit (17), Ain Sahnawt (13), Ain Hamran (12), Wadi Ashawq (10). Khor Taqah was our most prolific coastal site (we recorded 13 species).

Azuragrion somalicum was recorded on each of our visits, including mating, to the Hanging Gardens site in Wadi Ashuwayymiyah, c. 10km from the sea. This site has been subject to recreational 'improvements' that have removed the edge of reeds surrounding the pool; however, *A. somalicum* was spotted most recently by us

in the adjacent stream in spite of visible pollution.

Before 2013, when it was discovered in the United Arab Emirates (Feulner & Judas 2013), *Urothemis thomasi* had been mostly recorded in Oman (Schneider 1988; Waterston & Pittaway 1991; Schneider & Dumont 1997). It does seem to be present occasionally at rocky sites, usually inland, such as Wadi Sayq (Ball 2014; Schneider & Ikemeyer 2016) and the Hanging Gardens of Wadi Ash Shuwaymiyyah. Males are easy to overlook because of their initial similarity to other red dragonflies e.g. *Trithemis kirbyi*. Image 22 of the present paper shows an old female (a male was also present on the same visit). *Urothemis thomasi* has been recorded several times in northern Oman (Schneider 1988; Schneider & Dumont 1997; Cowan & Cowan 2017; Lambret et al. 2017). *Paragomphus sinaiticus* occurs at some ains in Dhofar (Hamran, Sawnaut) and also in Wadi Darbat, seeming to prefer rockier areas. It occurs commonly in the Hajar mountains of northern Oman (Cowan & Cowan 2017). *Lindenia tetraphylla* and *Tramea limbata* seem to be resident at both Wadi Darbat and Wadi Ghadit, with 10 records or more regularly available since 1993 and 1981, respectively. The latter species has also been seen by us at Ain Razat with mating at Ain Tobruq and Wadi Ghadit.

In Dhofar *Rhyothemis semihyalina* and *Urothemis edwardsii* usually occur at sites quite close to the sea, e.g., at Khor Taqah in large numbers, and more occasionally (not seen there by ourselves), at nearby Khor Rawri. The furthest north occurrence for *R. semihyalina* was at the Coastal Plains (one of our regions) site Wadi Ataran (just north of Hasik). There were occasional more southerly sightings slightly more inland e.g. at Wadi Ashawq and Wadi Darbat. In his intensive study of Wadi Sayq, Ball (2014) surprisingly had only one *R. semihyalina* and did not record *U. edwardsii* but these are regulars further east in similar geographic locations. *Paragomphus genei* (locally common in the Hajar mountains of northern Oman), *Orthetrum julia* and *O. caffrum* do not seem to occur in Dhofar but have been recorded to the west in Yemen (Schneider & Krupp 1993; Schneider & Nasher 2013).

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New kissing bug (Hemiptera: Reduviidae: Triatominae) records from Napo and Morona-Santiago provinces with distribution updates in Ecuador

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Abstract: Four species of Triatominae (Hemiptera: Reduviidae) are reported in four localities in Ecuadorian Amazonia. *Eratyrus mucronatus* Stål, 1859, *Rhodnius pictipes* Stål, 1872 & *Panstrongylus geniculatus* (Latreille, 1811) in Napo Province, and *Rhodnius robustus* Larrousse, 1927 in Morona-Santiago Province. Two specimens of *R. pictipes* were found in an urban area of Tena City (capital province). These findings can indicate a risk of Chagas disease transmission in urban and peri-urban areas of the Amazonia.

Keywords: Chagas disease, new records, Rhodniini, Triatomini.

Spanish Abstract: Se reportan cuatro especies de Triatominae (Hemiptera: Reduviidae) en cuatro localidades en la Amazonía ecuatoriana. *Eratyrus mucronatus* Stål, 1859, *Rhodnius pictipes* Stål, 1872 y *Panstrongylus geniculatus* (Latreille, 1811) en la provincia de Napo, y *Rhodnius robustus* Larrousse, 1927 en la Provincia de Morona-Santiago. Dos especímenes de *R. pictipes* se encontraron en el área urbana de la ciudad de Tena (provincia capital). Estos hallazgos pueden indicar un riesgo de transmisión de la enfermedad de Chagas en áreas urbanas y periurbanas de la Amazonía.

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INTRODUCTION

The triatomine bugs are characterized by the hematophagous habit and morphological adaptations associated with the blood feeding. These insects are the main vectors of Chagas Disease or American Trypanosomiasis (Lent & Wygodzinski 1979; World Bank 1993). The Triatominae subfamily comprises five tribes, 17 genera, and 150 species, where *Triatoma* Laporte, 1832 and *Rhodnius* Stål 1859, are the most important vectors. Ecuador currently contains about 17 species such as the following: *Triatoma dimidiata* (Latreille, 1811), *Triatoma carrioni* Larrousse, 1926, *Triatoma venosa* (Stål, 1872), *Triatoma dispar* Lent, 1950, *Eratyrus mucronatus* Stål, 1859, *Eratyrus cuspidatus* Stål, 1859, *Cavernicola pilosa* Barber, 1937, *Panstrongylus geniculatus* (Latreille, 1811), *Panstrongylus rufotuberculatus* (Champion, 1899), *Panstrongylus howardi* (Neiva, 1911), *Panstrongylus chinai* (Del Ponte, 1929), *Panstrongylus lignarius* (Walker, 1873), *Pastrongylus herreri* (Wygodzinsky, 1948), *Rhodnius ecuadoriensis* Lent & León, 1958, *Rhodnius pictipes* Stål, 1872, *Rhodnius robustus* Larrousse, 1927, and was recently described *Rhodnius barretti* Abad-Franch et al. 2013 (Abad-Franch et al. 2001; Galvão et al. 2003; Abad-Franch et al. 2013; Vaca-Moncayo et al. 2017).

Triatoma dimidiata is the main vector in Ecuador associated with the Chagas disease transmission in Guayas and Manabí provinces; this species is distributed in Los Ríos, El Oro, Pichincha and Bolivar provinces. On the other hand, *R. ecuadoriensis* is associated with the transmission in Loja and El Oro provinces and is reported in Manabí, Guayas and Los Ríos too. Finally, *T. carrioni* is reported in Azuay, Cañar, Loja, El Oro, Zamora Chinchipe, and recently in Pichincha (Grijalva et al. 2003). Other species with less importance are *P. rufotuberculatus*, *P. chinai, P. geniculatus*, *P. lignarius*, *P. howardi*, *T. venosa*, *T. dispar*, *E. mucronatus*, *E. cuspidatus* and *C. pilosa*; however in the Amazonia *R. pictipes* and *R. robustus* are sylvatic vectors (Aguilar et al. 1999; Abad-Franch et al. 2001; Galvão et al. 2003; Vaca-Moncayo et al. 2017). Due to this, we reported new triatomine records in two Ecuadorian Amazonia Provinces with update distribution in Ecuador.

MATERIAL AND METHODS

This study is based on, one male specimen of *E. mucronatus*, three males specimens of *R. pictipes* and one female specimen of *P. geniculatus,* found dead in the main entrance of the Universidad Regional Amazónica Ikiam (0.954^{0}S & 77.862^{0}W); more recently, two dead female specimens of *R. robustus* were found in the Universidad Regional Amazónica Ikiam (same coordinates). Later, two additional dead female specimens of *R. pictipes* were found in two houses of the urban area of Tena City (0.989^{0}S & 77.827^{0}W and 0.987^{0}S & 77.812^{0}W). The first specimen was found inside the house in the living room close to the kitchen, and the second specimen was found outside the house on the third floor in the department entrance. Houses are surrounded by secondary forest patches at 20–125 m and 200–278 m to the Tena River. All the insects were pinned, mounted and the identification was determined using taxonomic keys of Lent & Wygodzinsky (1979), Carcavallo et al. (1998a) and Soto-Vivas (2009). In *R. pictipes,* the male genitalia were dissected following the morphological description of Bérenger & Pluot-Sigwalt (2002). The triatomine specimens were deposited at the entomological collection of Instituto de Investigación en Salud Pública y Zoonosis in the Universidad Central del Ecuador: "Colección Nacional de Referencia de Artrópodos de Importancia en Zoonosis (CONRAZ)". Finally, the four specimens of *R. robustus* collected in Yuwientza (2.067^{0}S & 77.883^{0}W), a Shuar community located in Morona Santiago Province was verified by CONRAZ.

RESULTS AND DISCUSION

The list of species with diagnostic characters, distribution and medical importance are given below:

Family Reduviidae
Subfamily Triatominae
Tribe Triatomini

***Eratyrus mucronatus* Stål, 1859 (Image 1)**

Diagnostic characters: Rostrum with first and second segments larger (subequal in length), third segment short; anterior process of scutellum form a sharply pointed spine (the spine as long as the entire scutellum); fore lobe of pronotum with 1+1 strong discal spines; humeral angles distinctly spinose; subapical reddish spot of corium comparatively small, anteriorly not attaining level of m-cu cross-vein; free portion of vesica flattened apically in side view; abdomen dorsally with five prominent tubercles along each uroterguites (Lent & Wygodzinsky 1979; Soto-Vivas 2009).

Material examined: EC-N-M-T25, 01.ix.2016, 1 male, Campus Universidad Regional Amazónica Ikiam (7km to Muyuna), Napo, 0.954^{0}S & 77.862^{0}W, 600m, coll. Conraz.

Distribution (Carcavallo et al. 1999; Galvão et al. 2003; Chávez 2006; Guhl et al. 2007; Bérenger et al. 2009; Morocoima et al. 2010; Meneguetti et al. 2011; Obara et al. 2013; Hiwat 2014; Galvão 2014; Ceccarelli et al. 2018): Bolivia (Beni, La Paz, Chuquisaca, Oruro, Potosí); Brazil (Acre, Amazonas, Goiás, Maranhão, Mato Grosso, Pará, Rondonia, Tocantins); Colombia (Antioquia, Boyacá, Casanare, Cundinamarca, Meta, Norte Santander, Vaupés); Ecuador (Esmeraldas, Loja, Napo, Orellana, Sucumbíos), Guatemala, Guiana, French Guiana (Cayenne, Grand Santi, Montsinéry-Tonnegrande, Mana, Régina, Roura, Saul, Kourou, Sinnamary); Panama, Perú (Junín, Madre de Dios, Loreto, Ucayali, San Martín), Suriname (Brokopondo, Paramaribo, Para, Sipaliwini); Trinidad (Tunapuna-Piarco, San Juan-Laventille); Venezuela (Anzoátegui, Aragua, Amazonas, Barinas, Carabobo, Cojedes, Guárico, Falcón, Lara, Mérida, Monagas, Portuguesa, Sucre, Táchira, Trujillo, Yaracuy, Zulia).

Medical importance: *Eratyrus mucronatus* has been found naturally infected with *Trypanosoma cruzi* (Chagas 1909); It was reported in small domestic colonies attracted to light in Andean areas of Bolivia. Also, it was recorded in domiciliation process, invading urban and rural areas near fragmented forests (Soto-Vivas et al. 2001; Abad-Franch et al. 2009).

***Panstrongylus geniculatus* (Latreille, 1811) (Image 2)**

Diagnostic characters: Length more than 20mm; head comparatively short and stout, in lateral view; posterior process of scutellum elongate subcylindrical, narrowly tapering apically; pronotum with extensive, conspicuous black markings; all connexival segments with light and dark marking; abdomen light colored ventrally, with longitudinal series of black spots (Lent & Wygodzinsky 1979; Soto-Vivas 2009).

Material examined: EC-N-M-T34, 22.viii.2018, 1 female, Campus Universidad Regional Amazónica Ikiam (7km to Muyuna), Napo, 0.954^{0}S & 77.862^{0}W, 600m, coll. Conraz.

Distribution (Carcavallo et al., 1999; Galvão et al. 2003; Chávez 2006; Guhl et al. 2007; Leite et al. 2007; Bérenger et al. 2009; Morocoima et al. 2010; Meneguetti et al. 2011; Obara et al. 2013; Hiwat 2014; Galvão 2014; Ceccarelli et al. 2018): Argentina (Chaco, Corrientes, Entre Ríos, Formosa, Misiones, Santa Fe, Santiago Del Estero); Bolivia (Beni, Cochabamba, Santa Cruz, Tarija); Brazil (Acre, Amapá, Amazonas, Bahia, Ceará, Distrito Federal, Espírito Santo, Goiás, Maranhão, Mato Grosso, Mato Grosso do Sul, Minas Gerais, Pará, Paraná, Piauí, Rio de Janeiro, Rondônia, Roraima, São Paulo, Tocantins); Colombia (Antioquia, Amazonas, Bolívar, Boyacá, Cauca, Casanare, Cesar, Cundinamarca, Magdalena, Huila, Meta, Norte de Santander, Putumayo, Santander, Sucre, Tolima, Valle del Cauca); Costa Rica (Alajuela, Cartago, Guanacaste, Heredia, Limón, Puntarenas, San José); Ecuador (Esmeraldas, Imbabura, Manabí, Napo, Orellana, Pastaza, Pichincha, Sucumbíos); French Guiana (Cayenne, Saint-Laurent-du-Maroni); Guatemala, Guyana (Cuyuni-Mazaruni); Mexico (Chiapas, Veracruz, Yucatán); Nicaragua (Atlántico Norte, Atlántico Sur, Managua, Río San Juan); Panama (Bocas del Toro, Colón, Los Santos, Panamá); Paraguay (Alto Paraná, Boquerón, Caaguazú, Concepción, Paraguarí); Peru (Amazonas, Ayacucho, Cajamarca, Cusco, Huánuco, Junín, Madre de Dios, Loreto, Pasco, San Martín, Ucayali); Suriname (Brokopondo, Commewijne, Para, Paramaribo, Saramacca, Sipaliwini, Wanica); Trinidad & Tobago (Diego Martín, San Juan-Laventille, Sangre Grande, Siparia, Tunapuna-Piarco); Uruguay; Venezuela (Anzoátegui, Amazonas, Aragua, Barinas, Bolívar, Carabobo, Delta Amacuro, Distrito Capital, Falcón, Guárico, Lara, Mérida, Miranda, Monagas,

Image 1. Dorsal view of *Eratyrus mucronatus* (male) collected at Campus Universidad Regional Amazónica Ikiam, Napo.

Trujillo, Táchira, Yaracuy, Vargas, Zulia).

Medical importance: *Panstrongylus geniculatus* is a widely distributed species occupying natural habitats like burrows; this species shows association with *Dasypus novemcinctus* Linnaeus, 1758 and *Didelphis marsupialis* Linnaeus, 1758 (Abad-Franch et al. 2001) and rodents. It is believed that it is responsible for maintaining the enzootic cycle of *T. cruzi*.

Tribe Rhodniini

***Rhodnius pictipes* Stål, 1872 (Image 3)**

Diagnostic characters: Head laterally behind the eyes with callosities setiferous tubercles; antenna inserted proximal to head; anteocular region of the head at least 2.7 times as long as postocular; pronotum very granulose, rugose; femora yellowish, mottled with dark brown; tibiae of all pairs of legs with dark submedian annulus; corium brownish, irregularly spotted with black; rectangular dark spots of dorsal connexival segments with conspicuous pointed projection posteriorly, at least on segments 3 to 5; process of pygophore bispinous with short base (Lent & Wygodzinsky 1979; Bérenger & Pluot-Sigwalt 2002; Soto-Vivas 2009).

Material examined: EC-N-M-T26, EC-N-M-T27, EC-N-M-T28, 03.iii.2016, 3 males, Campus Universidad Regional Amazónica Ikiam (7km to Muyuna), Napo, 0.954^{0}S & 77.862^{0}W, 600m, coll. CONRAZ. EC-N-T-T29, 23.iii.2018, 1 female, Barrio El Dorado (Tena City), Napo, 0.987^{0}S & 77.812^{0}W, 500m, CONRAZ. EC-N-T-T30, 20.v.2018, 1 female Barrio San Antonio (Tena City), Napo, 0.989^{0}S & 77.827^{0}W, 517m, coll. CONRAZ.

Distribution (Carcavallo et al. 1999; Abad-Franch et al. 2001; Galvão et al. 2003; Chávez 2006; Cortez et al. 2007; Guhl et al. 2007; Hiwat 2014; Galvão 2014; Ceccarelli et al. 2018): Bolivia (Cochabamba, Santa Cruz, Beni, Pando); Belize, Brazil (Amapá, Amazonas, Goiás, Maranhão, Mato Grosso, Pará, Piauí, Roraima, Tocantins); Colombia (Amazonas, Boyacá, Caquetá, Cundinamarca, Guaviare, Meta, Norte Santander, Putumayo, Vaupés); Ecuador (Azuay, Morona Santiago, Napo, Orellana, Sucumbíos); Guiana, French Guiana (Cayenne, Saint-Laurent du Maroni); Peru (Ayacucho, Cusco, Huánuco, Madre de Dios, Loreto, Ucayali, San Martín, Junín); Suriname (Brokopondo, Commewijne, Coronie, Marowijne, Paramaribo, Para, Saramacca, Sipaliwini, Wanica); Trinidad (Diego Martín, Rio Claro-Mayaro, Siparia, Tanapuma-Piarco); Venezuela (Anzoátegui, Amazonas, Apure, Aragua, Bolívar, Carabobo, Cojedes, Delta Amacuro, Falcón, Mérida, Miranda, Monagas, Portuguesa, Táchira, Trujillo, Sucre, Yaracuy, Zulia).

Medical importance: Occasionally attracted to light in human dwellings. It has been found naturally infected with *T. cruzi*. (Carcavallo et al. 1999; Feliciangeli et al. 2004a; Abad-Franch et al. 2009).

***Rhodnius robustus* Larrousse, 1927 (Image 4)**

Diagnostic characters: Head laterally behind the eyes with callosities setiferous tubercles; antenna inserted proximal to the head apex; anteocular region about four times as long as postocular; distance between eyes dorsally smaller than, or equal to, width of eye; head distinctly longer than pronotum (1:0.65–0.80); median process of pygophore narrow, pointed apically and with narrow triangular base; larger species, length of males

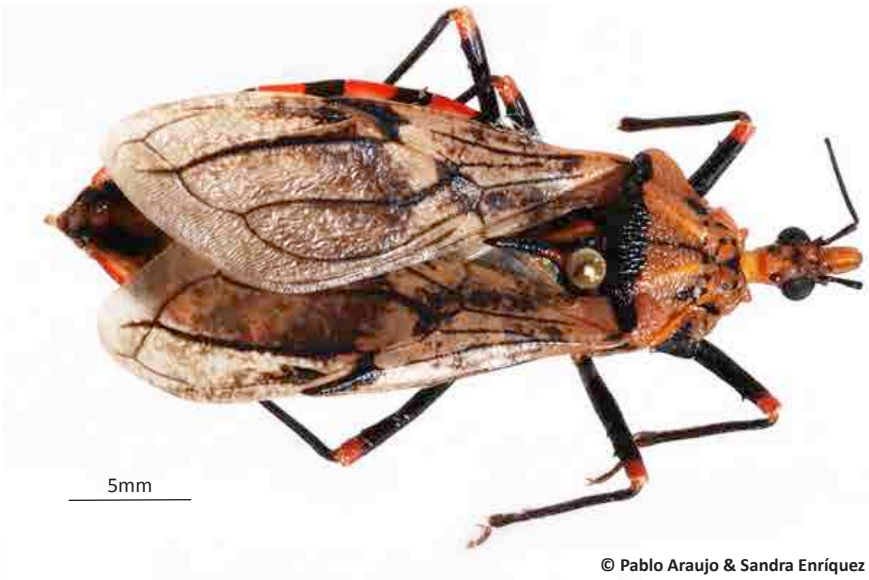

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Image 2. Dorsal view of *Panstrongylus geniculatus* (female) collected at Campus Universidad Regional Amazónica Ikiam, Napo.

20–23.5 mm, of females 23–26 mm (Lent & Wygodzinsky 1979; Soto-Vivas 2009).

Material examined: EC-MS-Y-T17, EC-MS-Y-T18, EC-MS-Y-T19, EC-MS-Y-T20, 14.xi.2009, 3 males and 1 female, Yuwientza "Shuar community", Morona Santiago, 2.067^{0}S & 77.883^{0}W, 1,126m, coll. Conraz; EC-N-M-T32, 12.vii.2018, 1 female, Campus Universidad Regional Amazónica Ikiam (7km to Muyuna), Napo, 0.954^{0}S & 77.862^{0}W, 600m, coll. Conraz; EC-N-M-T33, 23.viii.2018, 1 female, Campus Universidad Regional Amazónica Ikiam (7km to Muyuna), Napo, 0.954^{0}S & 77.862^{0}W, 600m, coll. Conraz.

Distribution: (Carcavallo et al. 1999; Abad-Franch et al. 2001; Galvão et al. 2003; Chávez 2006; Cortez et al. 2007; Guhl et al. 2007; Bérenger et al. 2009; Hiwat, 2014; Galvão 2014; Ceccarelli et al. 2018): Bolivia (Cochabamba, Beni, La Paz, Santa Cruz, Pando); Brazil (Acre, Amapá, Amazonas, Goiás, Maranhão, Mato Grosso, Pará, Rondonia, Roraima, Tocantins); Colombia (Amazonas, Arauca, Bolívar, Cundinamarca, Norte Santander, Santander, Tolima); Ecuador (Napo, Morona Santiago, Sucumbíos, Orellana); French Guiana (Cayenne, Macouria, Matoury, Grand-Santi, Regina), Perú (Amazonas, Cajamarca, Junín, Madre de Dios, Loreto, San Martín, Ucayali); Suriname (Brokopondo, Marowijne, Para, Saramacca, Sipaliwini); Venezuela (Apure, Barinas, Bolívar, Cojedes, Falcón, Mérida, Monagas, Sucre, Táchira, Trujillo, Yaracuy).

Medical importance: This species is closely related to *R. prolixus*, and has been associated to sylvatic habits and infected with *T. cruzi*. In northern South America, they were found migrating from palms to the houses, occurring where *R. prolixus* was eliminated by Chagas disease control programs (Monteiro et al. 2003; Guhl et al. 2007; Longa & Scorza 2007).

Epidemiological significance

The Amazonian Chagas disease transmission has increased in recent years; the first reports were in Brazil by Coura et al. (1994, 1995, 2002) and Albajar et al. (2003); recently Santalla et al. (2011), stated a case from Bolivian Amazonia. In Ecuador, the first records were registered by Aguilar & Yépez (1995) in three Amazonian Provinces: Sucumbíos, Napo, and Pastaza. More recently, Amunárriz et al. (2010), reported a population infected by *T. cruzi* located between the margins of Napo and Aguarico rivers. These authors mentioned three triatomine species involved: *P. geniculatus*, *R. pictipes* and *R. robustus*. Abad-Franch & Monteiro (2007) stated that all Amazonian triatomine species comprises four tribes: Rhodniini, Bolbolderini, Cavernicolini, and Triatomini (with *Eratyrus*).

Eratyrus mucronatus is a sylvatic species responsible for the enzootic Chagas transmission (Morocoima et al. 2010) and reported occasionally in the peridomicile with a synanthropic trend (Noireau et al. 1995; Carcavallo et

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Image 3. Dorsal view of *Rhodnius pictipes* (male) collected at Campus Universidad Regional Amazónica Ikiam, Napo.

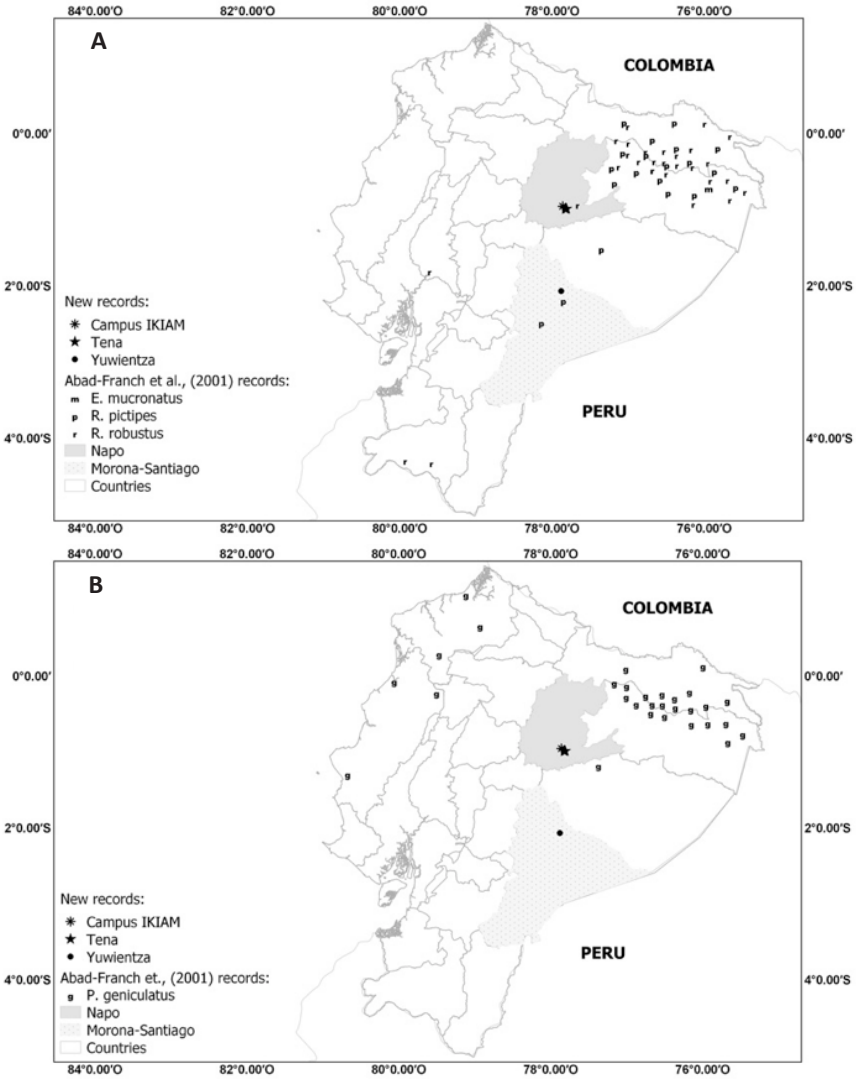

Figure 1. New records from Napo and Morona Santiago Provinces and distribution in Ecuador based on Abad-Franch et al. (2001): A - *E. mucronatus* (m), *R. pictipes* (p) and *R. robustus* (r), and B - *P. geniculatus* (g).

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Image 4. Dorsal view of *Rhodnius robustus* (male) collected at Yuwientza "Shuar community", Morona Santiago.

al. 1998b; Soto-Vivas et al. 2001).

Panstrongylus geniculatus is a sylvatic species associated with animal burrows and trees that provide microclimate conditions for their survival (Herrera & Urdaneta-Morales 1992; 1997). In the last decade, this species has been associated with domiciliated environments, frequently found in chicken coops and invading homes attracted by light or in search of food (Feliciangeli et al. 2004b). Also, it has been found colonizing *Rattus rattus* Linnaeus, 1758 burrows in precarious dwellings (Reyes-Lugo 2009). Although it is true that in urban environments this species prefers to feed on chickens, dogs, cats, and synanthropic rodents, it is important to keep the entomological vigilance and its possible implication in the transmission of *T. cruzi*. (Herrera et al. 2003).

Sylvatic *Rhodnius* species distribution is related to the Arecaceae (Palms), and their feeding habits are associated with birds; this triatomine species are specialized to explore the Palm microhabitats (Lent & Wygodzinsky 1979; Abad-Franch et al. 2009). Also, several authors stated the association between *Rhodnius* and birds nest of *Phacellodomus rufifrons* (Wied-Neuwied, 1821) and other Furnariidae species (Lent & Jurberg 1975; Abad-Franch & Monteiro 2007).

Abad-Franch et al. (2001) studied the biogeography of Ecuadorian triatomine based on distribution maps for each species. We georeferenced all Orellana/Napo records for *E. mucronatus*, *R. pictipes* and *P. geniculatus*, and the entire records correspond only to Orellana based on the Provinces boundaries (Fig. 1 A,B); also, we checked all triatomine records found in the Zoology Museum (QCAZ) on-line data base at the Pontificia Universidad Católica del Ecuador (QCAZ 2018). Due to this it was recorded for the first time that three species in Napo, and also the *R. robustus* distribution has spread out to Morona Santiago Province.

Finally, the land use changes, the wild source feed availability and triatomine species competence, can be a risk of disease transmission in urban and peri-urban areas of the Ecuadorian Amazonia. Due to this it is relevant to implement programs for entomological vigilance for the Chagas disease.

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COMMUNICATION

Orchid diversity in two community forests of Makawanpur District, central Nepal

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Abstract: Orchidaceae is one of the largest and most diverse families of flowering plants, comprising more than 450 species that span 107 genera in Nepal. Since orchids are facing an extinction risk from various anthropogenic factors at the regional and global level, we attempted to explore the diversity of orchid in two community managed forests – Karunabhumi Community Forest at Daman & Chandragiri Community Forest at Chitlang of Makawanpur District in central Nepal. We compiled a list of 58 species of orchids belonging to 23 genera, including 47 epiphytic and 11 terrestrial species, of which 29 species have medicinal value. Our result also revealed that epiphytic orchids are associated with particular host communities.

Keywords: Community forests, epiphyte, host association, medicinal value, Orchidaceae, threats.

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INTRODUCTION

Orchidaceae is one of the largest and most diverse families of flowering plants, comprising of 736 genera worldwide with around 27,000 species (Chase et al. 2015; Govaerts et al. 2018). In Nepal, 450 orchid species are reported from 107 genera, among which 18 species have been known to be endemic (Rajbhandari 2014). Further systematic studies may reveal additional species of the family in Nepal, as new findings are still being reported every year (Raskoti & Ale 2011, 2013, 2014; Raskoti & Kurzweil 2015; Raskoti 2012, 2013, 2015; Gajurel et al. 2013; Raskoti et al. 2013; Rai et al. 2013, 2014; Rajbhandari 2015).

In the history of orchid exploration in Nepal, many plant collectors and naturalists collected and documented orchids. During 1820–1821, N. Wallich collected many orchid species around Kathmandu valley and other parts of Nepal. In 1825, D. Don published the description of 50 species of orchids collected from Nepal (Rajbhandari 1976). A comprehensive documentation of the Nepalese orchids given by Hara et al. (1978) enumerated 90 genera & 315 species. Later on, Banerjee & Thapa (1978) reported 55 genera & 196 species of orchids from the eastern part of Nepal. Banerjee & Pradhan (1984) described and illustrated 247 species in the book 'The Orchids of Nepal Himalaya'. Press et al. (2000) reported 89 genera & 323 species of orchids in an annotated checklist of flowering plants of Nepal. Rajbhandari & Bhattarai (2001) published desciptions and images of 101 species of orchids of Nepal. Rajbhandari & Dahal (2004) enumerated 100 genera & 377 species in a checklist of orchids in Nepal. Raskoti (2009) enumerated 302 species of orchid along with their detailed descriptions. Similarly, Rokaya et al. (2013) published an annotated checklist of orchid species in Nepal with a list of 104 genera & 437 species. A recent study showed 450 species from 107 genera of orchids in Nepal (Rajbhandari 2014). Amongst the orchids of Nepal, however, only 98 species have been reported with medicinal value (Pant & Raskoti 2013; Chand et al. 2016; Paudel et al. 2017, 2018). As the floristic explorations and vegetation studies in Nepal has been the priority of botanical works, the number of orchid species and their new records are increasing with subsequent studies (Rajbhandari 2014; Rokaya et al. 2013). Numerous orchids, however, are becoming victims of population decline and threats due to various causes such as anthropogenic factors and some natural limitations on the propagation of orchids themselves (Pant 2013; Subedi et al. 2013).

Orchidaceae is considered to have the highest rate of speciation, but also the highest rate of extinction (Gravendeel et al. 2004; Swarts & Dixon 2009). The rapid speciation and high species diversity within Orchidaceae are linked to the family's specialized pollination syndromes, symbiotic associations with mycorrhizal fungi, and colonization of epiphytic habitats (Gravendeel et al. 2004; Pant et al. 2017). Because of their mycorrhizal specificity, pollinator specialization, and germination limitation, however, many species are only distributed in specific habitats (Gravendeel et al. 2004; Swarts & Dixon 2009; Liu et al. 2015). Moreover, due to their great economic importance in the floral and pharmaceutical industries, many species are over-collected, traded illegally, and becoming endangered (Swarts & Dixon 2009; Liu et al. 2015; Hinsley et al. 2017).

The abundance and diversity of orchids are decreasing throughout the world, beginning with genetic erosion and ending with local and global species loss. The main driving forces of orchid loss in community forests of Nepal are overgrazing, exploitation for ornamental and medicinal uses, construction projects in the forest, and massive collection and export to neighbouring countries (Subedi et al. 2013). The sustainable and speedy propagation of orchids by tissue culture technique and their reintroduction, however, can meet both biodiversity conservation and commercial propagation of valuable species (Pant 2013; Pradhan et al. 2014). Therefore, orchids need urgent conservation in their natural habitats. Conventionally, habitat and species protection are the two important strategies that can prevent a species from extinction. There should be a priority for exploring the diversity of orchid and their threats to apply these two strategies.

Since at the global level, only a few species are listed in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), all known orchid species are listed in Appendix II and categorized into different threat categories by the International Union for the Conservation of Nature (IUCN 2001). The prime objective of our study is to explore the diversity of orchid in two community forests of Makawanpur District, central Nepal, and to identify their major threats.

METHODS

Study area

Karunabhumi Community Forest (KCF) in Daman (KCF) & Chandragiri Community Forest (CCF) in Chitlang in Makawanpur District, central Nepal, in (KCF) were

selected for the study.

KCF (27.59–27.63 ^{0}N & 85.08–85.16 ^{0}E) occupies an area of 868ha. It is a hilly area rising from 1,800m to 2,550m. The adjoining forests of KCF that are habitats for orchids are Hrishweshwar Community Forest in the west & Jhirghari-Setoguransh Community Forest in the south. The climatic conditions of this site are in a transitional zone between sub-tropical and temperate. KCF has *Pinus wallichiana*, *Quercus semecarpifolia*, *Rhododendron arboreum*, *Castanopsis* sp. and *Pieris formosa* as dominant tree species while the understory of the forest is covered by bushes including *Daphne bholua*.

CCF (27.66–27.68 ^{0}N & 85.18–85.21 ^{0}E), with an area of 431.47ha, varies in altitude between 1,800m and 2,525m. The forest area is rich in biodiversity due to low human intervention. The adjoining areas of CCF are Falkhel in the east, Mahadevthan & Thankot in the north, and Gurjudhara Village in the west, and & Siran-Pauwa in the south. The climatic conditions of these forests range from sub-tropical to temperate. Plants such as *Rhododendron arboreum*, *Castanopsis* sp. and *Quercus* sp. thrive as dominant trees. *Berberis aristata*, *Mahonia nepalensis*, *Prunus persica*, *Rubus ellipticus*, and *Viburnum* sp. grow as bushes covering the understory of the forest.

Field survey

Field survey for the exploration and diversity assessment of orchids was conducted by a simple random sampling method in the years 2014 and 2015. We recorded all the orchid species found during the field survey and identified the host tree species for the epiphytic species. The study area was visited in the months of March, May, July, September, November and January of each successive year with the forest guard of each forest or with members of the community forest user group in order to carry out the research with the participation of local people. Orchid genera and species were identified with their morphological and floristic characters in the field with standard references and literature and confirmed with the images taken from special references of the herbarium specimens available in National Herbarium (KATH) in Godavari and Tribhuvan University Central Herbarium (TUCH) in Kirtipur. The specimens were not collected for herbarium preparation as we were concerned about their in situ conservation.

RESULT AND DISCUSSION

The present research explored different species of epiphytic and terrestrial orchids in the study area (Image 1). A total of 58 species were recorded from the two community forests; 49 species from 19 genera were recorded in KCF and 29 species from 15 genera in CCF (Table 1). *Dendrobium* was a genus frequently spotted among the study sites, followed by *Bulbophyllum*, *Otochilus*, *Pholidota*, *Gastrochilus*, *Pinalia*, *Coelogyne*, *Cymbidium*, *Goodyera* and *Calanthe*. *Bulbophyllum raskotii* is reported from its type locality in KCF (Raskoti & Ale 2011). Out of the 58 species recorded from the two community forests, 29 species have been recognized with medicinal values (Table 1) based on previous literature (Pant & Raskoti 2013) and information obtained from local people. Amongst the species recorded from the study sites, most of them are epiphytic (43 species in KCF & 22 species in CCF) and a few are terrestrial (6 species in KCF & seven species in CCF) (Fig. 1). This result also revealed that epiphytic orchid diversity is simply associated with host communities (Table 1), supporting the previous result analysed by Timsina et al. (2016).

Among the identified orchid species, *Gastrochilus calceolaris* is already known to be Critically Endangered (CR), and *Bulbophyllum leopardinum* & *Spiranthes sinensis* have been assessed as Least Concern (LC) (IUCN 2001). Although most of the orchids encountered in the selected forests have not been evaluated for their conservation status, they are equally threatened at least at the local and national level in Nepal by various anthropogenic factors such as deforestation, habitat destruction, and overexploitation of natural habitats. Since White & Sharma (2000) reported 175 species of orchids from these sites along Tribhuvan Rajpath, from Hetauda of Makawanpur to Naubise of Dhading and its adjoining areas, there is no available documentation on orchids from these study sites. Thus, this study gives the current insight that these areas still harbour good orchid

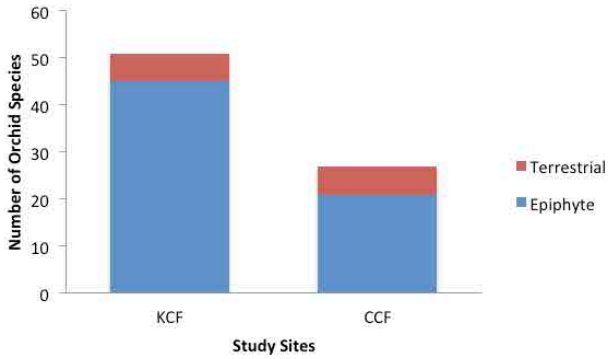

Figure 1. The total number of orchid species at the study sites Karunabhumi Community Forest (KCF) & Chandragiri Community Forest (CCF) based on habitats

Image 1. Exploration of diversity and habitats of orchid. A, B, C - exploration of orchid species; epiphytic species D - *Otochilus lancilabius*, E - *Bulbophyllum reptans* & F - *Dendrobium fimbriatum*; terrestrial species G - *Satyrium nepalense*, H - *Goodyera schlechtendaliana*, I - *Dienia cylindrostachya*

Table 1. The diversity of orchid species in Karunabhumi Community Forest (KCF) & Chandragiri Community Forest (CCF) of Makawanpur District, central Nepal

Species	Habitat/ Host/ Special Habitat	KCF	CCF	Medicinal use
Agrostophyllum callosum Rchb.f.	Epiphyte/*Pinus wallichiana*	+	-	-
Bulbophyllum careyanum (Hook.) Spreng	Epiphyte/*Quercus glauca*, *Rhododendron arboreum*	+	+	A paste made of pseudobulbs & leaves is used to treat burns.
Bulbophyllum griffithii (Lindl.) Rchb.f	Epiphyte/*Quercus glauca*, *Schima wallichii*, *Rhododendron arboreum*	+	+	-
Bulbophyllum leopardinum (Wall.) Lindl.	Epiphyte/ *Quercus glauca*, *Schima wallichii*	+	-	A paste made from pseudobulbs is used to treat burns.
Bulbophyllum muscicola Rchb.f.	Epiphyte/ *Rhododendron arboreum*, *Quercus glauca*	+	-	-
*Bulbophyllum raskoti*i J.J. Verm., Schuit. & de Vogel	Epiphyte/ *Schima wallichii*, *Quercus* sp.	+	-	-
Bulbophyllum reptans (Lindl.) Lindl. ex Wall.	Epiphyte/ *Rhododendron arboreum*, *Castanopsis indica*	+	-	-
Bulbophyllum retusiusculum Rchb.f.	Epiphyte/ *Quercus glauca*, *Schima wallichii*, *Rhododendron arboreum*	-	+	-
Calanthe plantaginea Lindl.	Terrestrial/ full shade	-	+	Dry powdered rhizomes are mixed with milk and taken as a tonic & an aphrodisiac.
Calanthe puberula Lindl.	Terrestrial/ light sun	-	+	Rhizomes are used as an antipyretic.
Calanthe tricarinata Lindl.	Terrestrial/ full shade	+	-	Leaves and pseudobulbs are thought to be aphrodisiacs and a paste of leaves is applied to treat sores & eczema.
Coelogyne cristata Lindl.	Epiphyte/ *Quercus glauca*, *Rhododendron arboreum*	+	+	Infusions of pseudobulbs are used as aphrodisiac and to treat constipation; their juice is applied to wounds & boils.
Coelogyne nitida (Wall. ex D. Don) Lindl.	Epiphyte/ *Castanopsis indica, Quercus glauca* & *Rhododendron arboreum*	+	+	The juice of pseudobulbs is used to treat stomachaches & other gastric ailments.
Coelogyne stricta (D. Don) Schltr.	Epiphyte/ *Quercus glauca*	+	-	A paste made from pseudobulbs is used to relieve headaches & fever.
Cymbidium cyperifolium Wall. ex Lindl.	Terrestrial/ light sun	+	+	-
Cymbidium erythraeum Lindl.	Epiphyte/*Quercus glauca, Rhododendron arboreum*	+	-	-
Cymbidium iridioides D. Don	Epiphyte/ *Quercus glauca*, *Schima wallichii*, *Rhododendron arboreum*	+	-	Juice of fresh leaf is applied to deep wounds to stop bleeding.
Dendrobium amoenum Wall. ex Lindl	Epiphyte/ *Pinus wallichiana*	+	+	Stems are used as a tonic.
Dendrobium bicameratum Lindl.	Epiphyte/*Schima wallichii*	+	-	-
Dendrobium chrysanthum Wall. ex Lindl.	Epiphyte/ *Schima wallichii*, *Quercus glauca*	+	-	-
Dendrobium eriiflorum Griff.	Epiphyte/ *Quercus glauca*, *Schima wallichii*, *Rhododendron arboreum*, *Pinus wallichiana*	+	-	The whole plant is taken as a tonic.
Dendrobium fimbriatum Hook.	Epiphyte/ *Quercus glauca*, *Schima wallichii, Rhododendron arboreum*	+	-	The whole plant is taken to treat liver ailments & nervous debility.
Dendrobium heterocarpum Wall. ex Lindl.	Epiphyte/ *Pinus roxburghii*	+	-	A paste of stems is applied to fractured & dislocated bones.
Dendrobium longicornu Lindl.	Epiphyte/ *Pinus roxburghii*, *Castanopsis indica*, *Quercus glauca*	+	+	Plant juice is used to relieve fever; boiled roots are fed to livestock suffering from coughs.
Dendrobium moniliforme (L.) Sw.	Epiphyte/ *Castanopsis indica*	+	-	Stems are used as a tonic.
Dendrobium monticola P.F.Hunt & Summerh.	Epiphyte/ *Quercus glauca*, *Rhododendron arboreum*	+	-	The pulp of stems is used to treat boils, pimples & other skin eruptions.
Dienia cylindrostachya Lindl.	Terrestrial/ Full shade	-	+	-
Gastrochilus acutifolius (Lindl.) Kuntze	Epiphyte/ *Quercus glauca*	+	+	-
Gastrochilus calceolaris (Buch.-Ham. ex Sm.) D. Don	Epiphyte/*Quercus* sp.	+	+	-
Gastrochilus distichus (Lindl.) Kuntze	Epiphyte/ *Quercus glauca*, *Rhododendron arboreum*	+	-	-
Gastrochilus pseudodisticus (King & Pantl.) Schltr	Epiphyte/ *Quercus glauca, Rhododendron arboreum*	+	-	-
Goodyera biflora (Lindl.) Hook. f.	Terrestrial/ full shade, moist forest floor	+	+	-
Goodyera foliosa (Lindl.) Benth. ex C.B. Clarke	Terrestrial/ full shade, moist forest floor	+	-	-
Goodyera schlechtendaliana Rchb.f.	Terrestrial/ full shade, moist forest floors	+	-	-
Luisia brachystachys (Lindl.) Blume	Epiphyte/ *Quercus glauca*, *Schima wallichii*	+	-	-

Species	Habitat/ Host/ Special Habitat	KCF	CCF	Medicinal use
Oberonia caulescens Lindl.	Epiphyte/ *Quercus galuca*, *Pieris* sp.	+	+	Tubers are used to treat liver ailments.
Otochilus albus Lindl.	Epiphyte/ *Quercus glauca, Schima wallichii*	+	+	Pseudobulbs are applied to bone fractures.
Otochilus fuscus Lindl.	Epiphyte/ *Schima wallichii*	+	-	Pseudobulbs are applied to bone fractures.
Otochilus lancilabius Seidenf.	Epiphyte/ *Castanopsis indica*	+	+	-
Otochilus porrectus Lindl.	Epiphyte/ *Castanopsis* sp., *Quercus glauca*, *Schima wallichii*, *Rhododendron arboreum*.	+	+	Pseudobulb is used in treating sinusitis & rheumatism and taken as a tonic.
Papilionanthe uniflora (Lindl.) Garay	Epiphyte/ *Prunus* sp.	-	+	-
Phalaeonopsis taenialis (Lindl.) Christenson & Pradhan	Epiphyte/ *Prunus* sp.	-	+	-
Pholidata articulata Lindl.	Epiphyte/ *Schima wallichii*	+	-	The whole plant is used as a tonic, root powder is used to treat cancer, and the plant's juice is applied to skin disorders.
Pholidota pallida Lindl.	Epiphyte/ *Schima wallichii*, *Pinus roxburghii*	-	+	Pseudobulbs are applied to relieve naval, abdominal & rheumatic pains. Powder made from pseudobulbs is used to induce sleep.
Pholidota protracta Hook.f.	Epiphyte/ *Schima wallichii*	+	+	-
Pholidota recurva Lindl.	Epiphyte/ *Schima wallichii*	+	+	-
Pinalia bipunctata (Lindl.) Kuntze	Epiphyte/ *Castanopsis* sp., *Quercus semecarpifolia*, *Rhododendron arboreum*.	+	+	-
Pinalia excavata (Lindl.) Kuntze	Epiphyte/ *Quercus glauca*	+	+	-
Pinalia graminifolia (Lindl.) Kuntze	Epiphyte/ *Quercus glauca*	+	+	-
Pinalia spicata (D. Don) S.C. Chen & J.J. Wood	Epiphyte/ *Schima wallichii*, *Castanopsis indica*	+	+	A paste of the stem is used to alleviate stomachaches & headaches.
Pleione humilis (Sm.) D. Don	Epiphyte/ *Quercus semecarpifolia*	+	-	A paste made from pseudobulbs is used to treat cuts & wounds.
Pleione praecox (Sm.) D. Don	Epiphyte/ *Quercus semecarpifolia*	+		-
Rhynchostylis retusa (L.) Blume	Epiphyte/ *Prunus* sp.	+	-	Leaves are used to treat rheumatism and the juice of roots is applied to cuts & wounds.
Satyrium nepalense D. Don	Terrestrial/ full sun, cool open grasslands.	+	-	Tubers are used as a tonic and to treat diarrhoea & malaria.
Spiranthes sinensis (Pers.) Ames	Terrestrial/ full sun, open wet meadows.	-	+	A decoction of plants is used to treat intermittent fever; tubers are used as a tonic.
Spiranthes spiralis (L.) Chevall	Terrestrial/ full sun, open wet meadows.	-	+	-
Vanda cristata Wall. ex.Lindl.	Epiphyte/ *Pinus roxburghii*, *Schima wallichii*	+	-	A paste of roots is applied to cuts, wounds, boils & dislocated bones.
Vandopsis undulata (Lindl.) J.J. Sm.	Epiphyte/ *Schima wallichii*, *Castanopsis indica*	+	-	-

Here, "+" = presence, "-" = absence

diversity despite various disturbing factors.

CONCLUSION

The present study documented 58 species of orchids including 29 medicinal, one Critically Endangered, and two Least Concern species within two community forests in central Nepal. Our study throws further light on studies of orchid flora in these areas persecuted by anthropogenic factors. More pressure occurs on the population of orchid species due to overexploitation and export in both community forests. Further, cutting down of host trees for use as fodder, firewood, and timber leads to a decrease in the population of orchids. Conservation of such economically and environmentally important group of plants, which are also important components of biodiversity, has been the matter of concern for the last several decades. With the introduction of community forests in Nepal, some progress has been made in raising awareness for conserving these habitats among the locals, which has minimized unsystematic and illegal collection and cutting down of trees. Furthermore, as the local people were involved in the exploration and documentation process in our study, the stakeholders realized the necessity of conservation of orchids in their area. Finally, our study will provide more attention to the conservation of orchids among community leaders, members of community forests, and local people in general to national-level stakeholders.

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Image 2. Blossom of orchid species in the study area. A - *Bulbophyllum leopardinum*, B - *Cymbidium cyperifolium*, C - *Dendrobium heterocarpum*, D - *Gastrochilus calceolaris*, E - *Pinalia spicata* & F - *Spiranthes sinensis*

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COMMUNICATION

Habitat distribution modeling for reintroduction and conservation of *Aristolochia indica* L. - a threatened medicinal plant in Assam, India

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Abstract: A detailed study on the regeneration ecology of *Aristolochia indica* L. was carried out to prevent this threatened medicinal plant from its future extirpation in Assam, India. The population stock of the species has been depleting fast in its natural habitats as a consequence of certain factors such as habitat fragmentation, over-exploitation due to its high medicinal properties, and other anthropogenic activities. For improving the conservation status of the species, potential area and habitat for its reintroduction were predicted using Maximum Entropy distribution modelling algorithm. The model was developed using environmental parameters and locality data in the natural range of Karbi Anglong District of Assam, India. The model predicted that the suitable habitats for the reintroduction of *A. indica* L. were restricted to parts of Assam, Nagaland, Meghalaya, and Arunachal Pradesh which have been identified to offer suitable environmental conditions for persistence of the species. Population status was positively correlated with higher model thresholds in the undisturbed habitats confirming the usefulness of the habitat model in population monitoring, particularly in predicting the successful establishment of the species.

Keywords: *Aristolochia indica*, Assam, conservation, habitat distribution modelling, India, MaxEnt, NDVI, reintroduction, threatened.

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Author Contribution: BS carried out the survey and execution of experiments. PSB prepared the manuscript. BT conceived and designed the experiment and critically analyzed the data. All authors read and approved the final manuscript.

INTRODUCTION

Rapidly changing climate, habitat fragmentation & loss, invasion of alien species & pathogens, over-exploitation, and rapid urbanization are the most important factors responsible for ecosystem degradation worldwide that alter the structural and functional integrity of ecosystems (Barnosky et al. 2011; Baruah et al. 2016). In addition to these, rising temperatures and rapid economic development, and can potentially affect ecosystems, rapidly disassemble communities, and negatively impact native biodiversity (Sanders et al. 2003; Lin et al. 2007; Thuiller et al. 2007; Kelly & Goulden 2008; Walther 2009). Such alterations have brought approximately one-fifth of plant species to the brink of extinction (Brummitt & Bachman 2010). Species (re)introduction is one of the successful ecological engineering techniques for the restoration of depleted species populations and degraded habitats &ecosystems (Leaper et al. 1999; Martinez-Meyer et al. 2006; Kuzovkina & Volk 2009; Ren et al. 2009; Rodríguez-Salinas et al. 2010; Polak & Saltz 2011). In order to reintroduce and rehabilitate the threatened species in terrestrial ecosystems, a detailed knowledge on the distribution of their potential habitats is essential. Habitat distribution modeling, therefore, helps to identify the areas for species reserves & reintroduction, and in developing effective species conservation measures. Habitat distribution modeling is a computer-based tool which uses algorithms to relate known occurrences of a species across landscapes to digital raster geographic information system (GIS) coverage summarizing environmental variation across the landscapes to develop a quantitative picture of the ecological distribution of the species. New insights into the factors governing the distribution of species have been developed using habitat distribution modeling or ecological niche modeling (ENM) (Guisan & Zimmermann 2000; Elith et al. 2006; Kozak et al. 2008). The technique of ENM uses computer algorithms that predict species distribution in a geographic space based on the mathematical representation of the ecological niche of the species. ENM considers environmental factors such as temperature, precipitation, soil, vegetation & land cover as ecological conditions and uses the dataset from GIS databases such as www.worldclim.org &www.diva-gis.org. Availability of high-resolution satellite imageries, downscaling tools for environmental variables, and interpolated spatial datasets on climate and vegetation has enhanced the accuracy of prediction of the models manifold. ENM facilitates interpolation as well as extrapolation of species distributions in geographic space across different time periods. This has made it possible to prepare species distribution maps with a high level of statistical confidence and to identify areas suitable for reintroduction of threatened species (Irfan-Ullah et al. 2006; Martinez-Meyer et al. 2006; Kumar & Stohlgren 2009; Ray et al. 2011; Sarma et al. 2015; Sarma & Tanti 2017).

Identification of suitable habitats for the reintroduction of species is the next logical step in species conservation effort. Therefore, the present work was undertaken to model the potential habitat distribution of *Aristolochia indica* L., a threatened medicinal plant species in northeastern India, in its native range.

MATERIALS AND METHODS

Plant materials

Aristolochia indica L. is a climber which belongs to the family Aristolochiaceae. The plant is a shrubby or herbaceous vine with a woody rootstock (Kanjilal et al. 2009). The leaves are glabrous, variable, usually obovate-oblong to sub-pendurate entire with undulate at the margins, cordate acuminate at the base. Flowers few, in axillary racemes with a perianth upto 4 cm long having a glabrum pale green inflated (Das et al. 2010). It is mostly distributed along tropical, subtropical, and Mediterranean regions of the world(Sarma & Tanti 2015; Neinhuis et al.2005; Wanke et al. 2007).The plant is used to treat cholera, intermittent fever, bowel troubles, ulcers, leprosy, and poisonous bites (Krishnarajuet al.2005; Kanjilalet al.2009). It is also used for its emmenagogue, abortifacient, antineoplastic, antiseptic, anti-inflammatory, and antibacterial properties (Achari et al. 1981; Das et al. 2010).

Habitat distribution modeling

Sixteen primary distributional records of the species were collected through field surveys. The coordinates of all the occurrence points were recorded to an accuracy of 10–40 m using a Global Positioning System (GarminEdge-1000). The coordinates were then converted to decimal degrees for use in modeling the distribution of potential habitats of the species in its native range. Over the years, a variety of environmental datasets have accumulated in public domain websites, which can be used in distributional modeling of species. Use of different formulation of environmental datasets, however, yields different results for the same set of species (Peterson & Nakazawa 2008). Hence, selection of appropriate data type and pixel resolution

is a prerequisite prior to predictive modeling (Parra et al. 2004). In the present study, normalized difference vegetation index (NDVI) was used to summarize the habitat boundaries for the species in northeastern India. All the analyses were conducted at the spatial resolution of 250m.

Validation of model robustness

Following standard methods, the potential habitat of *A. indica* L. was defined as 'a habitat which bears a set of ecological conditions that allows the species to persist and regenerate.' For habitat modeling, the pixel dimension was a 250 × 250 m grid cell and the model was developed using maximum entropy modeling (MaxEntversion 3.3.3e, Phillips et al. 2006). MaxEnt estimates the maximum entropy probability distribution function to predict the geographic location of a species based on environmental variables and reconstructs the boundaries of the ecological niche by placing constraints on the probability distribution based on the environmental parameters of the grid-cell presence record (Phillips et al. 2006). It is one of the 'presence-only' group of species distribution modeling methods that has been widely used. The strong attributes of MaxEnt are:

(i) It holds a strict mathematical definition.

(ii) It gives a continuous probabilistic output.

(iii) It simultaneously handles both continuous and categorical environmental data.

(iv) It investigates variable importance through jackknife procedure.

(v) It has the capacity to handle low sample sizes.

(vi) Its simplicity for model interpretation (Elith et al. 2006; Phillips et al. 2006; Pearson et al. 2007).

It also facilitates replicated runs to allow cross-validation, bootstrapping, and repeated sub-sampling in order to test model robustness.

Of the 16 records, 75% were used for model training and 25% for testing. To validate the model robustness, we executed 20 replicated model runs for the species with a threshold rule of 10 percentile training presence. In the replicated runs, we employed a cross-validation technique where samples were divided into replicate folds and each fold was used for test data. Other parameters were set to default as the program is already calibrated on a wide range of species datasets (Phillips & Dudík 2008). From the replicated runs, average, maximum, minimum, median, and standard deviation were generated. Model quality was evaluated based on area under curve (AUC) value and the model was graded following Thuiller et al. (2005) as poor (AUC < 0.8), fair (0.8 < AUC < 0.9), good (0.9 < AUC < 0.95), and very good (0.95 < AUC < 1.0). Further, potential area of distribution and/or reintroduction were categorized into five classes based on logistic threshold of 10 percentile training presence, i.e., very-high (0.762–1), high (0.572–0.761), medium (0.381–0.571), low (0.325–0.570), and very low (0–0.324).

Population status vis-à-vis model thresholds

Extensive field surveys were carried out in order to explore the robustness and pertinence of the model in predicting the population status of the species in each occurrence locality as predicted under various model thresholds. The total population of the species was ascertained through a direct count of all the individuals of seedlings, saplings, and mature individuals in each 250×250 m grid of occurrence within the predicted localities. The population data of *A. indica* L. in each locality was then correlated with the corresponding threshold level of the distribution models to assess whether regions covered in the higher thresholds maintain higher populations thus approving better habitat conditions for species establishment and vice versa.

Assessment of habitat status and identification of areas for reintroduction

Assessment of the actual habitat type of the species in the localities of occurrence as well as in the entire predicted potential area was done through repeated field surveys. We also superimposed the predicted potential areas on Google Earth Ver. 6 (Deka et al., 2018) imageries for habitat quality assessment. The predicted suitability maps were exported in KMZ format using Diva GIS ver. 7.3 (Baruah et al. 2016). KMZs are zipped Keyhole Markup Language (KML) files that specify a set of features such as place marks, images, polygons, 3D models, or textual descriptions for display in Google Earth. The exported KMZ files were overlaid on satellite imageries in Google Earth to ascertain the actual habitat condition prevailing in the areas of occurrence (Adhikari et al. 2012; Deka et al. 2017).

RESULTS

Calibration of models

The model calibration test for *A. indica* L. yielded satisfactory results (AUCtest = 0.95 ± 0.002). The highest percent contribution was given by eu7_1_eur (July), i.e., 29.3%. eu7_1_eurhad the maximum influence on the habitat model. Jackknife analysis revealed that

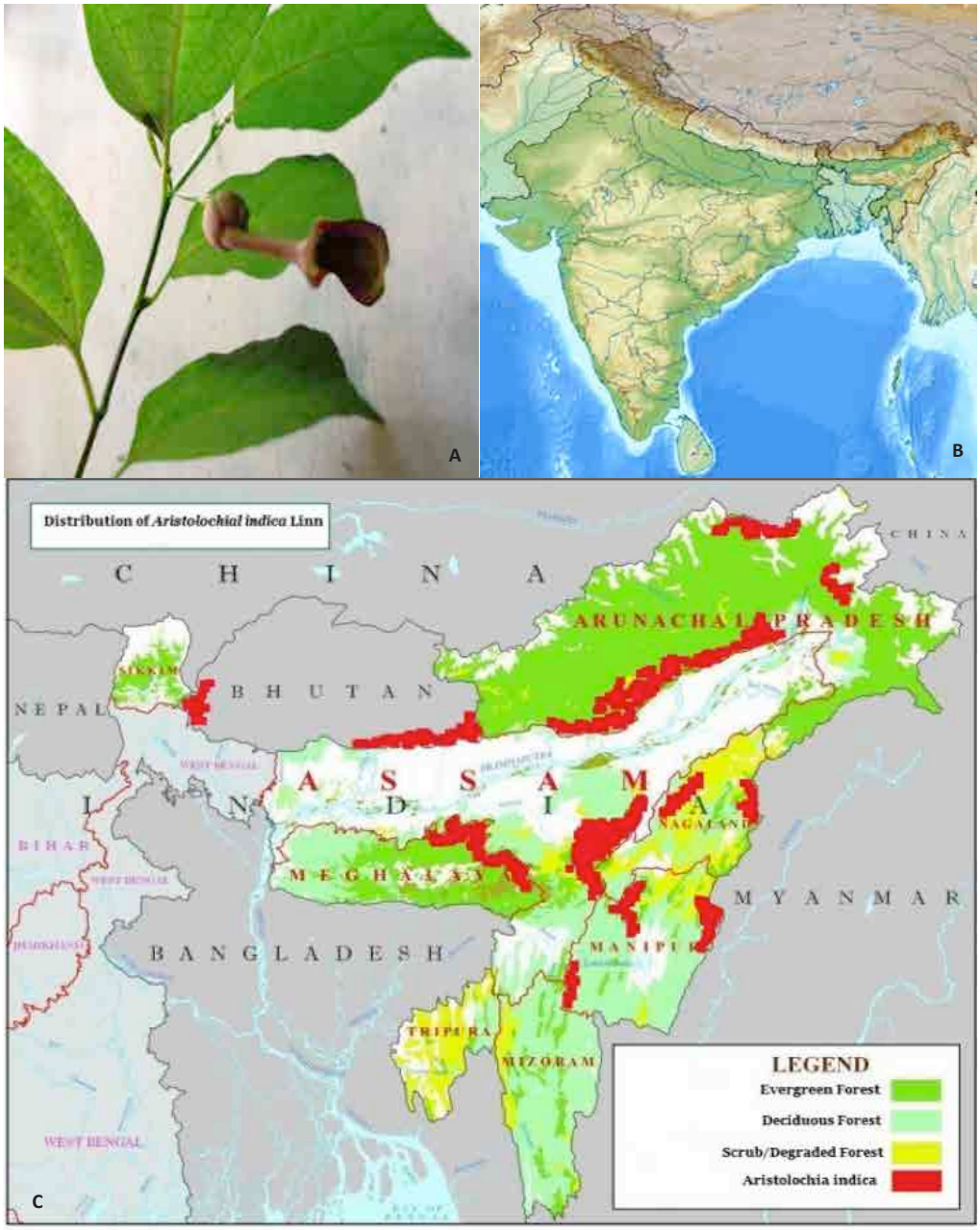

Image 1. A - *Aristolochia indica* L. plant in natural habitat; B - map of India; C - map showing potential habitat distribution of *A. indica* in northeastern India. The red patches in the map represent the occurrence localities of the species.

the environmental variable with the highest gain, when used in isolation, is eu7_1_eur, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is eu2_1_eur(February), which therefore appears to have the most information that is not present in other variables. Bioclimatic variables did not show any major contribution to the development of the model.

Potential habitat distribution area for reintroduction

In our field survey, we found the species only in some parts of Karbi Anglong District of Assam, India. When we superimposed the data with Google Earth, the suitable habitats where the species can be conserved and reintroduced were distributed in various parts of Assam, Nagaland, Meghalaya, and Arunachal Pradesh. Besides, some areas of Bhutan were also suitable for the reintroduction (Image 1).

Table 1. List of NDVI and variable contribution used in the model

Variable	Percent contribution	Permutation importance
eu8_1_eur	25.7	0
eu7_1_eur	29.3	64.2
eu2_1_eur	20	5.7
eu10_1_eur	12.5	17.3
eu3_1_eur	6.1	1.7
eu11_1_eur	4.5	9.2
eu5_1_eur	1.4	1.2
eu4_1_eur	0.3	0.3
eu6_1_eur	0.2	0.3
eu12_1_eur	0.1	0.1
eu1_1_eur	0	0
eu9_1_eur	0	0

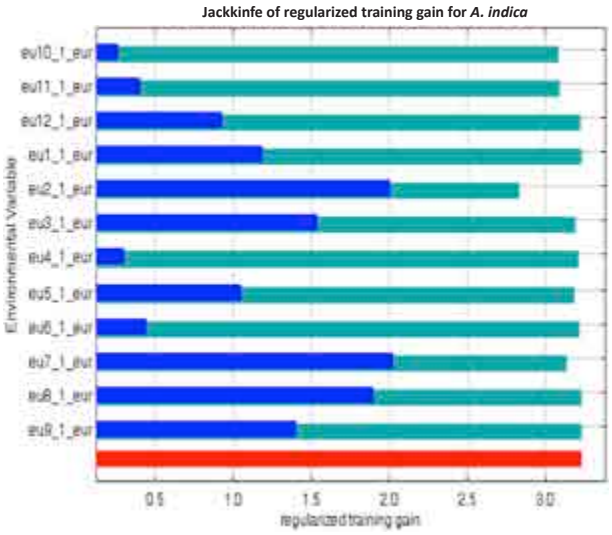

Figure 1. Jackknife test of variable importance for *A. indica* L.- individual variable contribution (blue bar), contribution when a given variable is excluded (green bar), whole set of variables (red bar)

Analysis of variable contributions

Table 1 gives estimates of relative contributions of environmental variables to the MaxEnt model. To determine the first estimate, in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of _ is negative. For the second estimate, for each environmental variable, in turn, the values of that variable on training presence and background data are randomly permuted. The model is re-evaluated on the permuted data and the resulting drop in training AUC is shown in the table, normalized to percentages. As with the variable jackknife, variable contributions should be interpreted with caution when the predictor variables are correlated. Values shown are averages over replicate runs (Table 1).

Figure 1 shows the results of the jackknife test of variable importance. The environmental variable with the highest gain, when used in isolation, is eu7_1_eur, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is eu2_1_eur, which therefore appears to have the most information that isn't present in the other variables. Values shown are averages over replicate runs (Baruah et al. 2018; Das et al. 2018).

DISCUSSION

Model output and field surveys revealed that suitable natural habitats of the species concurred with the distribution of humid subtropical forests. NDVI parameters offered a reasonable explanation on the underlying role of other environmental factors that determined the habitat suitability of the species. Various environmental factors such as geology, soil, and climate have a plausible influence on vegetation indices of a given place at a given time (Soleimani et al. 2008). The effects of such underlying environmental factors are reflected throughthe spatial and temporal variation in vegetation indices such as NDVI. Hence, NDVI also act as powerful and informative surrogate variables, representing the complex formulations of the underlying environmental factors that determine the boundaries of the potential habitat of species. Overall, the results of actual habitat assessment through Google Earth superimposition and field surveys were identical. Habitat status assessment through primary field surveys and secondary surveys using Google Earth satellite imageries revealed that the predicted potential areas of the species under all suitability threshold levels, i.e., low to very high suitability, encompass a mosaic of disturbed/ undisturbed forest patches, scrubs, grasslands, and human-generated land use elements such as rural/ urban settlements, settled cultivation areas, homestead gardens, and small groves, which essentially are components of the anthropobiome (Tanti et al. 2010). Species reintroduction plans should therefore carefully select appropriate areas under such a setting. In the present study, some areas consisting of continuous and intact patches of subtropical broadleaved and degraded

forest patches offer potential habitats at higher levels of probability. Hence, such forest areas could serve as habitats for in situ conservation and reintroduction. Predicted less suitable areas such as small groves and homestead gardens, however, could also be used for reintroduction of the species provided that adequate measures are taken for habitat protection. To achieve this, awareness and active participation of local people, non-government organizations (NGOs), and community based organizations are warranted. The present study demonstrates that habitat distribution modeling could be of great help in predicting the potential habitats of threatened species for reintroduction. Results of the study also suggest the strong relationship between the population size and model thresholds, thereby indicating the high potential value of ENM in population studies. The areas identified in the present study for the reintroduction of *A. indica* would not only help in ecorestoration of degraded forests and habitats where the species had existed before but also in rehabilitating the species population and improving its conservation status. Therefore, the results would be quite useful for natural resource managers in the management of this species and conservation of overall biological diversity in the region.

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POLLINATION ECOLOGY OF *SYNEDRELLA NODIFLORA* (L.) GAERTN. (ASTERACEAE)

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Abstract: *Synedrella nodiflora* (L.) Gaertn grows almost throughout the year if the soil is damp. It produces heterogamous capitula with female ray florets anthesing on the first day and bisexual disc florets anthesing on the next three consecutive days. Disc florets are dichogamous, herkogamous, self-compatible, self-pollinating (vector-mediated) and display secondary pollen presentation through an intermediate form of brush mechanism. Ray and disc florets exhibit facultative xenogamy. Butterflies are principal pollinators while bees, wasps and flies are supplementary pollinators. Thrips *Microcephalothrips abdominalis* uses the florets as breeding and feeding sites; the feeding activity effects pollination. The ray and disc florets produce cypselas; the cypselas produced by ray florets are heavier, elliptical, membranous with upwardly-pointing teeth along the margins and two short terminal awns while those produced by disc florets are lighter, cylindrical and tangentially compressed with 2 or 3 stiff terminal divaricate awns. Seed dispersal is polychorous and represented by anemochory, anthropochory, zoochory and ombrohydrochory. Cypselas of ray florets disperse to short distances and germinate under specific germination conditions either at parental sites or in similar habitats while those of disc florets disperse farther away from parental sites and germinate readily under a wide range of conditions. Therefore, bimorphic cypselas with different germination abilities enable the plant to grow as a widespread weed but not as an invasive weed.

Keywords: Bimorphiccypselas, entomophily, polychory, secondary pollen presentation, *Synedrella nodiflora*, thripsophily.

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INTRODUCTION

Synedrella is a monotypic genus with only a single species, *S. nodiflora*. The generic name is derived from the Greek word "*synedros"* meaning small flowers seated together while the species name indicates the presence of flower clusters around the nodes in the upper parts of the plant (Davidse et al. 2015). It is native to tropical America and from there it has become widespread throughout the warmer regions of the world (Holm et al. 1997). It is spread throughout the Southeast Asian region, found in the plains of India, in the Andamans and West Africa. It is also found in Bangladesh, Japan, Spain, China and England (Chauhan & Johnson 2009). The plant is used as feed for livestock and in traditional medicine to treat various health problems in Ghana, Nigeria, Malaysia and Indonesia (Burkill 1985; Idu & Onyibe 2007). This plant displays floral features which are characteristic of thripsophily (Ananthakrishnan 1993). Further, it is reported that this plant with small and less attractive heterogamous heads is inhabited only by one terebrantian thrip, *Microcephalotrhips abdominalis* which is able to move freely within the capitulum and also fly to other capitula of the same plant or other nearby plants. As a result, they effect both self and cross-pollination (Ananthakrishnan et al. 1981).

Kissmann & Groth (1992) reported that *Synedrella nodiflora* produces dimorphic cypselas. Rocha (1996) stated that the morphological differences between these cypselas influence dispersion strategies directly. Bradford (1990) stated that both the cypselas of *S. nodiflora* exhibit the same pattern of imbibition rates indicating no relationship to the germination rate or differences in the fruit coat permeability. Brandel (2004) reported that the germination responses between these cypsela types are not so marked because of a lack of deep innate dormancy. However, they show some differences in germination rates depending on their environment perception. The state of information available on pollination and seed ecology is insufficient to understand the pollination and propagation abilities of *S. nodiflora* as a widespread weed across tropical latitudes. In this context, the present study was contemplated to investigate the following objectives: flowering phenology, floral biology, pollination mechanism, pollinators, sexual system and seed dispersal ecology. This information presented in this paper enables us to understand the studied aspects of *S. nodiflora*.

MATERIALS AND METHODS

Populations of *Synedrella nodiflora* growing in Visakhapatnam region (17.686^{0}N & 83.218^{0}E) in Andhra Pradesh State, India were used for the study from 2015–2017. Observations regarding the organization of inflorescences, the spatial positioning of flowers, and their position on the plant were made since these features are regarded as important for effecting pollination by foragers. The life time of individuals of two floret types was recorded by marking twenty just open florets each and following them until fall off. Anthesis was initially recorded by observing ten marked mature capitula in the field. Later, the observations were repeated five times on different days; on each day we observed twenty marked mature capitula in order to provide an accurate anthesis schedule. Twenty mature disc florets were followed for recording the time of anther dehiscence. The presentation pattern of pollen was also investigated by recording how anthers dehisced and confirmed by observing the anthers under a 10x hand lens. The details of flower morphology such as flower sex, shape, size, colour, odour, sepals, petals, stamens and ovary were described.

Twenty mature but undehisced anthers from disc florets were collected from five randomly chosen plants and placed in a petri dish. The pollen output per anther/disc floret and pollen-ovule ratio was calculated using the protocol given by Cruden (1977). Individual volumes of nectar were recorded for 25 ray and 25 disc florets and then the average volume of nectar per each floret type was determined and expressed in µl. The capitula used for this purpose were bagged at the mature bud stage, opened after anthesis and squeezed the nectar from each floret into a micropipette to measure the volume of nectar. Based on nectar volume in individual ray and disc florets, the total volume of nectar secreted in a capitulum was calculated. Similarly, the nectar sugar concentration at the capitulum level was determined using a Hand Sugar Refractometer (Erma, Japan). Nectar analysis for sugar types was done as per the Paper Chromatography method described in Dafni et al. (2005). The sugar content/floret is expressed as the product of nectar volume and sugar concentration per unit volume, mg/µl. This was done by first noting the conversion value for the recorded sugar concentration on the refractometer scale and then by multiplying it with the volume of nectar/floret. Table 5.6 given in Dafni et al. (2005) was followed for recording the conversion value to mg of sugars present in one µl of nectar. Dinitrosalicylic acid method was followed for the first

two sugar types while Resorcinol method was followed for the last sugar type. The caloric reward of nectar/floret/day was measured as per the formula given in Heinrich (1975). He assumed that 1 mg of sugar yields 16.74 joules or 4 calories of energy and accordingly he used the formula for calculating the caloric reward of the nectar.

$$\frac{\text{Nectar volume (µl) X Concentration of nectar (\%)}}{100} \times 16.74$$

Paper chromatography method described in Dafni et al. (2005) was followed for identifying the amino acid types in the nectar of ray and disc florets; the amino acid types were the same in both ray and disc florets. The flower visitors were collected and identified with the representative specimens available with the Department of Environmental Sciences, Andhra University, Visakhapatnam. All butterflies were further confirmed by consulting the books of Kunte (2007) and Gunathilagaraj et al. (1998) while other insects, some to species level while a few others to genus level only. Thrips were identified using the key provided by Bhatti (1980) for Indian thrips. The insects were observed carefully for 10 hours a day for 15 days in different months each year during the profuse flowering period. The hourly foraging visits of each species were recorded on ten different days for which thirty capitula were selected. The data obtained was used to calculate the percentage of foraging visits made by each species per day and also to calculate the percentage of foraging visits of each category of insects per day. Simultaneously, the insects were observed for their foraging behavior such as mode of approach, landing, probing behaviour, the type of forage they collected, contact with essential organs to result in pollination, and inter-plant foraging activity. The insects were captured from the capitula during 10:00–12:00 hr on five different days for pollen analysis in the laboratory. For each insect species, 10 specimens were captured and the proboscides were separated for examination to record whether they carried pollen grains or not. They were washed first in ethyl alcohol and the contents stained with aniline-blue on a glass slide and then observed under a microscope to count the number of pollen grains present.

A sample of capitula was tagged and followed for fruit set rate of ray and disc florets in open-pollinations and the same sample was used for noting the duration of fruit maturation. Seed characteristics of ray and disc florets were carefully examined to note their special adaptations for dispersal modes. Field visits were made to record whether the seeds germinate immediately after they are dispersed or not. Field observations on seed germination and seedling formation were made to record the approximate number of generations produced during the rainy season.

RESULTS

Phenology

The plant is an erect, branched, ephemeral herb with long internodes and swollen nodes (Image 1a). The lower parts of the stems root at the nodes in damp soil conditions. The shallow tap root system is strongly branched. It grows in humid places, shaded and nutrient rich soils, crop fields, wastelands, roadsides, lawns and disturbed areas. The stems are ribbed, dichotomously branched, sub-angular, smooth to sparsely hairy. The leaves occur in opposite pairs, ovate to elliptic, finely hairy with short petioles and joined by a ridge across the stem. It propagates only by seed. Individual plants complete their life cycle within 4–5 months. The seeds germinate and produce new plants as soon as they are dispersed from the mother plants and in effect, the plants show vegetative, flowering (Image 1b) and fruiting phases simultaneously in different habitats. However, the plant shows prolific growth during the rainy season and displays peak flowering from October-November.

Flower morphology

A plant produces several capitula and their numbers vary depending upon the age, number of branches and nutrient condition of the soil. But, it produces an average of 22.6±4.6 capitula. The capitula are sessile and borne either singly or as groups of 2–8 to nodes in leaf axils; they are covered by two green herbaceous involucral bracts. Each capitulum consists of odorless outer ray florets and central disc florets and each floret type is enclosed by 3–5 mm long erect bracts. Ray florets vary from 5–8 (7.3±1.31) while disc florets vary from 11–15 (13.06±1.50); they are produced in the ratio of 1:2. The calyx is reduced to pappus of 2–3 barbed and strong bristles in both types of florets. The corolla is tubate, zygomorphic, yellow and tipped with one ligulate lobe in ray florets and five actinomorphic lobes in disc florets. The ray floret is 8.1±0.7 mm long and 2.0±0.3 mm wide while disc floret is 8.2±0.6 mm long and 1.2±0.3 mm wide. The ray florets lack stamens but have well developed pistil with ovary and style which is terminated into two smooth stylar arms (Image 1h,i). The disc florets have four stamens with yellow filaments and dark brown anthers. The stamens are epipetalous

Image 1. *Synedrella nodiflora*
a. Habit, b. Plant in flowering phase, c. Capitulum, d. Anthesing capitulum, e–g. Different stages of anthesis in capitulum, h. Ray floret, i. Ray floret with bifid stigma, j. Disc florets, k. Disc floret with unreceptive stigma, l. Disc floret with receptive stigma, m. Syngenecious anthers, n. Relative positions of stamens and stigma, o. Pollen grain. © A.J. Solomon Raju

and anthers are dithecous, fertile, united and cohered forming a hollow cylinder representing syngenesious condition (Image 1m). The anther has its connective prolonged into a hood and tend to separate when the flower withers. The pistil is well developed with ovary and long style which is terminated into two linear-lanceolate stylar arms covered abaxially at the base with sweeping hairs. A nectariferous disc is present at the base of the style inside the corolla tube. The style with its aligned arms extend beyond the height of anthers (Image 1j,k,n); the stylar arms diverge and curve inwards exposing the hidden stigmatic surfaces and finally over-arching the florets (Image 1l). In both floret types, the ovary is bicarpellary, syncarpous and unilocular with one anatropous ovule on basal placentation. The floral features indicate that ray florets are female and disc florets are bisexual.

Floral biology

The ray and disc florets open during early morning from 07:00-09:00 hr on clear sunny days(Image 1c–g) (Table 1). The florets open completely on sunny days while they are partially open on rainy days. In a capitulum, the ray florets open first and all of them open simultaneously; the disc florets open concentrically inwards from the next day for three successive days with 38% opening on day 1 and 31% each on day 2 and day 3 (Table 1). Individual ray and disc florets take about three hours to open from mature bud phase. The disc florets are protandrous with anther dehiscence taking place during mature bud stage by longitudinal slits. The narrow anthers are united to form a hollow space into which pollen is liberated. At the mature bud stage the style with its aligned stylar arms lies below the anthers, its forked arms are converged at this stage. During and immediately after anthesis, the style grows, elongates

Table 1. Anthesis of disc florets as a function of time in *Synedrella nodiflora*

Time (h)	No. of disc florets anthesed						
	Day 1	%	Day 2	%	Day 3	%	Total
06:00	-	-	-	-	-	-	-
07:00	2	15	1	8	1	8	31
08:00	2	15	2	15	2	15	45
09:00	1	8	1	8	1	8	24

First, all ray florets open at once on the first day of anthesis of capitulum. The next day onwards disc florets open for three consecutive days. Total No. of disc florets per capitulum 13

and passes through the anther tube brushing the pollen with its sweeping hairs. At this stage, the inner stigmatic surfaces are un-receptive and not exposed, the functional situation of which prevents the occurrence of autogamy. Such a form of pollen presentation is referred to as "secondary pollen presentation mechanism" which ensures the pollen availability to insects visiting the capitula on a daily basis. The style with its aligned branches gradually diverge in the early hours of the second day; then the inner stigmatic surfaces attain receptivity and remain so until the end of that day. The stylar arms curve downwards completely exposing the receptive stigmatic surfaces. Ray florets display stigma receptivity by diverging the stylar arms day-long on the day of anthesis only. The pollen grains are bright yellow, spheroidal, tricolporate, 35.96±0.04 µm in size and echinate. The pollen grains are 134.13±21.16 per anther, 536.53±84.66 per floret and 6,975 per capitulum (Image 1o). The pollen-ovule ratio is 955:1. The ray and disc florets are nectariferous. A ray or disc floret produces 1.3µl of nectar which rises up as it accumulates in the floret due to the narrow corolla tube. The beginning of nectar secretion coincided with anthesis in ray florets and with anther dehiscence in disc florets; its secretion ceased by the evening of day 1 in ray florets while it ceased by the evening of day 2 coinciding with cessation of stigma receptivity. A capitulum produces an average volume of 22.4µl of nectar during its lifespan; the nectar sugar concentration is 27±1.6 % with 0.4mg of sugar containing 1.6 calories of energy at floret level and 6.67mg sugar containing 26.68 calories of energy at capitulum level. The sugar types present in the nectar include sucrose, glucose and fructose; they are present in that order of dominance. The nectar contains five essential amino acids (arginine, histidine, lysine, tryptophan and threonine) and six non-essential amino acids (cysteine, glycine, serine, aspartic acid, glutamic acid, hydroxyproline, alanine, cystine and proline); they are present in that order of dominance. The ray and disc florets wither away on the 3rd day and fall off on the 4th day. The tubate corolla in ray florets and the tubate corolla and stamens in disc florets gradually fall off following fertilization and initiation of fruit formation.

Pollination mechanism

The ray florets devoid of stamens act as female and they expose the stigmatic region prominently by unfolding stylar arms immediately after anthesis against the ligulate petal to receive pollen from the foragers on par with disc florets. The disc florets present the stamens and stylar arms at different positions. The anthers dehisce inwardly and discharge pollen grains into the anther tube during mature bud stage. At this stage, the style lies below the basal part of the anthers. During and immediately after anthesis, the style with its aligned stylar arms elongates within the anther tube and brushes the pollen out of the anther tube by stylar hairs called "sweeping hairs" presenting the pollen only on the abaxial surface at the base of stylar arms (sterile portions). Such a pollen presentation pattern is indicative of secondary pollen presentation functional through an intermediate mechanism representative of brush mechanism. The stylar arms are in closed state on day 1 and the inside stigmatic surfaces are un-receptive, there is no possibility for the occurrence of autogamy. The staminate phase ends at 1700 h and the sterile portion of the stylar arms has residual pollen at that time. This is followed by the retraction of filaments and the consequent partial retraction of anthers into the corolla tube. The pistillate phase starts in the early hours of the second day, the stigmatic surfaces attain receptivity, gradually diverge and curve downwards within three hours totally exposing the inner stigmatic surfaces; the stigmatic surfaces remain receptive until the end of that day. The brush type pollen presentation mechanism, staminate phase on day 1 and pistillate phase on day 2 appear to have evolved to prevent autogamy and promote cross-pollination. However, the anthesis of disc florets for three consecutive days in the same and different capitula on the same plant facilitates the occurrence of vector-mediated self-pollination. Therefore, the secondary pollen presentation mechanism and the sexual system function do not insulate completely from the occurrence of self-pollination and hence the flowers set fruit and seed through self- as well as cross-pollination.

Thrips breeding, feeding and pollination

Thrips species, *Microcephalothrips abdominalis*

Image 2. *Synedrella nodiflora*
a. *Trigona iridipennis* collecting nectar, b. *Trigona iridipennis* collecting pollen, c. *Xylocopa latipes* collecting nectar, d. *Ceratina* sp. collecting nectar, e. *Ceratina smaragdula* collecting nectar, f. *Nomia* sp. collecting nectar, g. *Lasioglossum* sp. collecting nectar, h. *Rhynchium* sp. collecting nectar, i. *Ammophila* sp. collecting nectar, j. *Sarcophaga* sp. collecting nectar, k. *Eristalinus* sp. collecting nectar. © A.J. Solomon Raju.

Table 2. List of insect foragers on *Synedrella nodiflora*

Order	Family	Genus	Species	Common name	Forage sought
Hymenoptera	Apidae	*Trigona*	*iridipennis* Smith	Stingless Honey Bee	Pollen + Nectar
		Ceratina	sp.	Small Carpenter Bee	Pollen + Nectar
		Ceratina	*smaragdula* F.	Small Carpenter Bee	Pollen + Nectar
	Anthophoridae	*Xylocopa*	*latipes* L .	Large Carpenter Bee	Nectar
	Halictidae	*Nomia*	sp.	Alkali Bee	Pollen + Nectar
		Lasioglossum	sp.	Sweat Bee	Pollen + Nectar
	Vespidae	*Rhynchium*	sp.	Black Potter Wasp	Nectar
	Sphecidae	*Ammophila*	sp.	Digger Wasp	Nectar
Diptera	Sarcophagidae	*Sarcophaga*	sp.	Flesh Fly	Nectar
	Syrphidae	*Eristalinus*	sp.	Hover Fly	Nectar
Lepidoptera	Pieridae	*Eurema*	*hecabe* L.	Common Grass Yellow	Nectar
		Leptosia	*nina* F.	Psyche	Nectar
	Lycaenidae	*Zizula*	*hylax* F.	Tiny Grass Blue	Nectar
		Pseudozizeeria	*maha* Kollar	Pale Grass Blue	Nectar
		Zizeeria	*karsandra* Moore	Dark Grass Blue	Nectar
		Everes	*lacturnus* Godart	Indian Cupid	Nectar
	Hesperiidae	*Pelopidas*	*mathias* F.	Small Branded Swift	Nectar

(Thysanoptera: Thripidae) oviposited during early bud stage of florets of capitula. The larvae emerge from the eggs in synchrony with anthesis and nectar production in both ray and disc florets. The centripetal development of the capitulum was found to provide continuous availability of pollen and nectar for three days for their growth. The thrips were found feeding on pollen and nectar, especially from disc florets. They were dusted with pollen in their upward and downward movements within the corolla tube of disc florets. The echinate pollen surface facilitated the thrips to carry 180 to 345 pollen grains on their body setae, wings and legs. The thrips dispersed the pollen on the stigmatic region of the stylar arms of both ray and disc florets due to their active

movements, rubbing the abdomen on the stigmatic surface, cleansing of their body parts with their hind legs and also by their wing combing mechanism. Since the disc floret is staminate on day 1 and pistillate on day 2, the foraging activity of thrips within that floret does not contribute to self-pollination but may contribute to self-pollination between disc florets of the same or different capitula of the same plant. Further, self-pollination may also take place in ray florets due to deposition of pollen of disc florets of the same capitulum by thrips. As the plant occurs as small or large populations, thrips could fly to migrate to the capitula of other closely spaced plants and effect cross-pollination.

Insect foraging activity

The capitulum is the unit of attraction for insect foragers. Within the capitulum, the yellow ligulate petal of ray florets acts as chief attractant. The ray and disc florets were foraged by bees, wasps, flies and butterflies. The butterflies were the consistent and regular foragers while all others were inconsistent foragers and also they forage especially during the peak flowering season. The bees were *Trigona iridipennis* (Image 2a,b), *Ceratina* sp. (Image 2d), *Ceratina smaragdula* (Image 2e), *Xylocopa latipes* (Image 2c), *Nomia* sp. (Image 2f) and *Lasioglossum* sp. (Image 2g). The wasps were *Rhynchium* sp. (Image 2h) and *Ammophila* sp.(Image 2i). The flies were *Sarcophaga* sp. (Image 2j) and *Eristalinus* sp. (Image 2k). The butterflies included *Eurema hecabe* (Image 3a), *Leptosia nina* (Image 3b) (Pieridae), *Zizula hylax* (Image 3c), *Pseudozizeeria maha* (Image 3d), *Zizeeria karsandra, Everes lacturnus* (Image 3e) (Lycaenidae) and *Pelopidas mathias* (Image 3f) (Hesperiidae) (Table 2). Of these, all bees except *Xylocopa* sp. foraged for both pollen and nectar while *Xylocopa* sp. and all other foragers foraged for nectar only. All these insects approached the flowers in upright position, landed on the flat-topped capitulum and then probed ray and disc florets for nectar. They foraged several florets in a single visit and made multiple visits to several capitula on the same plant in quest of forage. They made frequent visits to capitula of different closely and distantly spaced plants to collect forage. Such a foraging behavior was considered to be promoting both self- and cross-pollination. The foraging activity pattern of insects showed a definite pattern with reference to foraging schedule. They foraged flowers during 08:00-16:00/17:00 hr with peak foraging during 10:00-12:00 hr (bees, wasps and flies) and during 10:00–11:00 hr (butterflies) coinciding well with the standing crop of nectar by that time (Figs. 1,2). Bees made 42%, wasps 13%, flies 11% and butterflies 34% of total foraging visits (Fig. 3). The body washings of insects collected from the flowers during peak foraging period revealed that all insects carry pollen but bees carry the highest number of pollen grains. Further, the mean number of pollen grains varied with each insect species (Table 3).

Fruiting ecology and seed dispersal

The fertilized disc florets produce single-seeded cypselas within two weeks. Natural cypsela set is 86% in ray florets and 98% in disc florets (Table 4). In ray florets, the cypsela is 3–5 mm long, 2.5–3.1 mm wide, pale brown, oval, tangentially flattened with upwardly-pointing teeth along the marginal wing and 2 short terminal awns (Image 3g). In disc florets, the cypsela is 4–5 mm long, 1.8–2.5 mm wide, cylindrical, thickened, 4-sided and tangentially compressed with 2 or rarely 3 terminal stiff divaricate awns (Image 3h). The cypselas of disc florets detach earlier than those produced from ray florets. The stiff echinate structures of cypselas of both types of florets enable them to stick readily to hair, fur, clothing and animal skin for dispersal; the cypselas of disc florets being light in weight disperse easily to long distances than those of ray florets which are comparably heavy. Wind dispersed the cypselas efficiently when ambient air is dry. Water also acted as an efficient dispersal agent for the dispersal of cypselas during the

Table 3. Pollen recorded in the body washings of insect foragers on *Synedrella nodiflora*

Insect species	Sample size (N)	Number of pollen grains		
		Range	Mean	S.D
Trigona iridipennis	10	56-134	106.7	21.08
Ceratina sp.	10	25-56	37.6	8.54
Ceratina smaragdula	10	21-63	48.5	11.78
Xylocopa latipes	10	17-50	29.8	9.47
Nomia sp.	10	20-53	35.7	10.13
Lasioglossum sp.	10	15-49	34.4	8.79
Rhynchium sp.	10	11-42	28.2	8.31
Ammophila sp.	10	8-25	15.9	5.27
Sarcophaga sp.	10	10-31	20.5	6.00
Eristalinus sp.	10	11-26	18.4	4.08
Eurema hecabe	10	21-54	37.9	8.64
Leptosia nina	10	8-27	20.2	5.61
Zizula hylax	10	5 -24	21.7	6.86
Pseudozizeeria maha	10	11-28	21.5	4.60
Zizeeria karsandra	10	9-36	26.4	7.47
Everes lacturnus	10	10-32	23.2	5.97
Pelopidas mathias	10	7-24	15.7	4.37

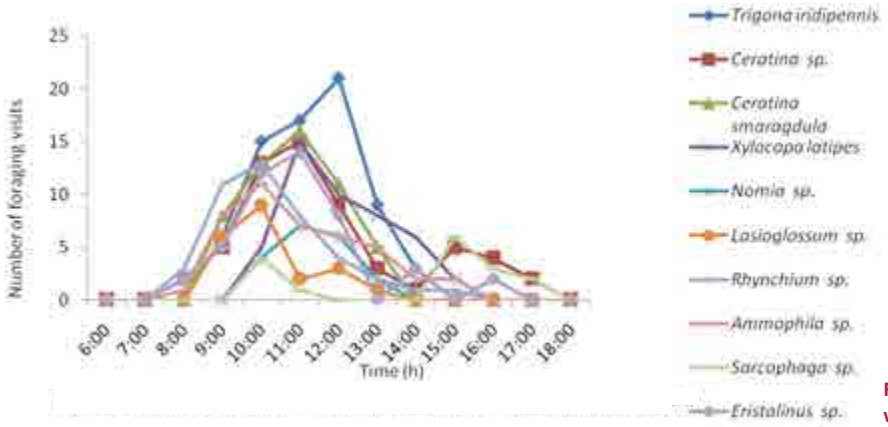

Figure 1. Hourly foraging activity of bees, wasps and flies on *Synedrella nodiflora*

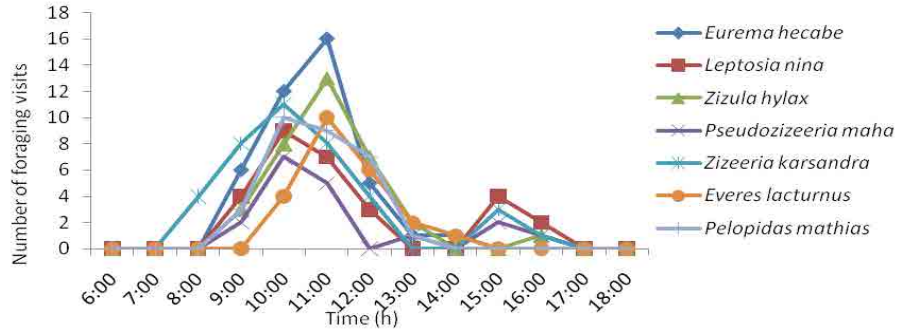

Figure 2. Hourly foraging activity of butterflies on *Synedrella nodiflora*

Table 4. Natural cypsela set in *Synedrella nodiflora*

Ray florets			Disc florets		
No. of florets sampled	No. of florets set cypsela	Cypsela set (%)	No. of florets sampled	No. of florets set cypsela	Cypsela set (%)
98*	84	86	258**	253	98
*Sample size: 14; **Sample size: 20					

rainy season. Therefore, zoochory, anthropochory, anemochory and ombrohydrochory are the functional forms of seed dispersal in this plant.

The cypselas of both ray and disc florets are viable and germinate within a week after their dispersal from the parental plants if the soil is damp and fertile (Image 3i). Cypselas of both floret types sowed in different pots filled with fertile soil produced seedlings within a week; germination rate is 60% in ray floret cypselas and 80% in disc floret cypselas. The seedlings have epigeal germination. The hypocotyl is 10–18 mm long, purplish and hairless. The cotyledons are elliptic, 5–9 mm long, purplish and shortly stalked. The paired juvenile leaves are similar to adult leaves but smaller. After two weeks, they were transplanted to natural soil and followed for their life cycle, which is nearly four months. The observations indicated that both types of cypselas produce identical individuals and produce both types of cypselas.

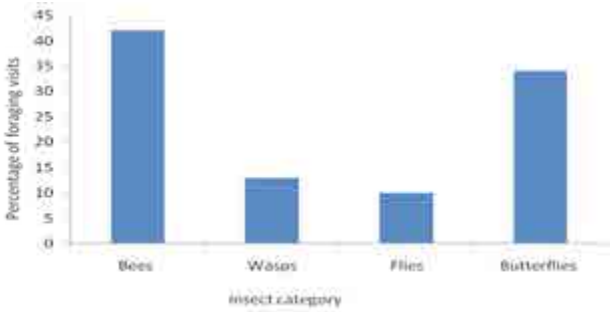

Figure 3. Percentage of foraging visits of different categories of insects on *Synedrella nodiflora*

Image 3. *Synedrella nodiflora*
a & b. Pierids - a. *Eurema hecabe*, b. *Leptosia nina*, c-e. Lycaenids ; c. *Zizula hylax*, d. *Pseudozizeeria maha*, e. *Everes lacturnus*, f. Hesperiid, *Pelopidas mathias*, g. Ray floret seeds, h. Disc floret seeds, i. Emergence of seedlings during rainy season. © A.J. Solomon Raju.

DISCUSSION

Synedrella nodiflora is a herbaceous weed and grows in soils with sufficient moisture for its rapid germination, growth, flowering and seed set. It grows in a very wide range of habitats and tolerates most forms of cultivation because of its short life cycle (Holm et al. 1997). As an exotic species, it is widely distributed in both natural habitats and cultivated fields in India (Ansari et al. 2016). It is one of the widespread weeds endangering the native flora (Singh et al. 2002) and causing a menace in cultivated fields due to its invasiveness (Singh et al. 2010). Despite this situation created by this weed, there are no studies on this species as to how it is able to grow and invade varied habitats. The present study shows that *S. nodiflora* is a therophyte and produces new sets of populations continuously in damp soils of forest and agricultural systems. As a result, it displays vegetative, flowering and fruiting phases simultaneously in different habitats throughout the year. But, the rainy season is the best period for its prolific growth in any habitat because the soil is damp and contains nutrients due to decomposition of organic matter at this time. Peak flowering occurs during October-November in different populations. Therefore, it can be said that soil moisture and nutrient content greatly influence the growth and population size of this weed in different habitats.

Jeffrey (2009) stated that Asteraceae members produce capitula consisting of peripherally located ray florets and centrally located disc florets. The ray florets are highly specialized in pollinator attraction while disc florets assume the reproductive function and hence improve the chances for reproductive success and facilitate a more flexible basis for breeding system

evolution than does a single flower. Further, this author stated that a particularly diverse trait in the capitulum is the perianth symmetry exhibited by peripheral ray and central disc florets; the ray florets display zygomorphic symmetry while disc florets display actinomorphic symmetry. The present study shows that *S. nodiflora* uses nectar-less ray florets for pollinator attraction and reproductive function, and nectariferous disc florets exclusively for reproductive function. The position of several florets in a capitulum as a unit enables the plant to maximize reproductive success. Torices et al. (2011) stated that the expression of floral sexuality is associated with changes in symmetry, which has important consequences for the evolution of reproductive biology in Asteraceae. This generalization is absolutely true in *S. nodiflora* because the peripheral zygomorphic ray florets are female while the actinomorphic disc florets are bisexual. Chapman & Abbott (2009) reported that the presence of peripheral ray florets shows a marked effect on attractiveness to pollinators, cross-pollination rate and fitness for the plant. In *S. nodiflora*, the highest fruit set recorded in both ray and disc florets indicate that ray florets attract pollinator fauna and enhance both self and cross-pollination rate in both types of florets enabling the plant to increase fitness as an invasive weed.

Allen et al. (2011) reported that dichogamous protandry and self-incompatibility are functional in Asteraceae; self-incompatibility occurs at the stigmatic surface either by failure of germination of self-pollen grains or by the arrest of pollen tube growth. Harder et al. (2000) noted that dichogamous protandry reduces rates of self-fertilization and enhances out-crossing. Nettancourt (2001) stated that self-incompatibility is another evolutionary strategy to avoid self-fertilization and inbreeding. The present study shows that *S. nodiflora* is dichogamous, protandrous, self-compatible and self-pollinating. But, disc florets have a mechanism to prevent spontaneous self-pollination but not vector-mediated self-pollination. In disc florets, the staminate phase on day 1 and pistillate phase on day 2 characterize temporal dioecy. These florets are also herkogamous as they have a physical barrier between the site of pollen deposition and stigmatic region; herkogamy favors xenogamy, and pollination occurs during pistillate phase. The occurrence of self-pollination, however, is possible due to the centripetal opening of florets in the capitulum on consecutive days. In this study, fruit set standing at 86% in ray florets and 98% in disc florets in open-pollinations indicate the function of self-compatibility and self-pollination in this plant. The pollen/ovule ratio recorded for *S. nodiflora* (955:1) in this study falls in the range of pollen/ovule ratio (244.7-2,588) for facultative xenogamy provided by Cruden (1977) and hence this plant has facultative xenogamous breeding system with low self-incompatibility. In this breeding system, xenogamy enables plants to increase genetic heterogeneity which favors their establishment in heterogeneous and variable environment (Hsu 2006) while geitonogamy facilitates to increase their population in the currently growing sites or other sites with similar environment. Therefore, the widespread and invasive character of *S. nodiflora* could be attributable to low self-incompatibility and facultative xenogamy.

Floret opening in the morning is a common feature among the Asteraceae (Proctor & Yeo 1978), and it usually occurs before 08:00hr (Mani & Saravanan 1999). In *S. nodiflora* also, anthesis of both ray and disc florets occurs in the morning from 07:00–0900 hr. Within a capitulum, ray florets open first exposing simultaneously the white ligulate petal and the receptive stigmatic region by unfolding the stylar arms to receive pollen from other capitula of the same or different plants. These florets cease stigma receptivity by the end of the same day and become non-functional to receive pollen from the next day onwards. The disc florets open concentrically on three consecutive days but each floret shows staminate and pistillate phases on two consecutive days to avoid spontaneous autogamy and minimize geitonogamy. In Asteraceae, secondary pollen presentation mechanism is an important characteristic associated with protandry (Howell et al. 1993) but it is an ancestral feature in this family (Jeffrey 2009). This pollen presentation mechanism has been considered to be a strategy to improve accuracy in pollen removal and deposition in order to enhance male and female fitness (Ladd 1994). In the present study, the disc florets of *S. nodiflora* display this form of pollen presentation. In these florets, the pollen shed from the anthers is brushed by the sterile sweeping hairs present at the base of the abaxial side of stylar arms when the style branches are joined and inner stigmatic surfaces are not receptive. This pollen presentation mechanism is an intermediate mechanism representative of brush mechanism *sensu* Leins & Erbar (2006). As the style grows out of the anther tube, the outer sweeping hairs of the style arms present pollen for pollination. The receptive papillate stigmatic surface is hidden between the two appressed style arms, preventing self pollination. During the functionally female phase of the floret which occurs on day 2, the style arms separate exposing the receptive papillae for the receipt of pollen. The style arms serve as secondary pollen presenters in the staminate phase and expose

receptive stigmatic surfaces for pollen during pistillate phase. This type of active pollen presentation is typical of disc florets of Asteraceae (Ladd 1994). The secondary pollen presentation system functional in *S. nodiflora* appears to have evolved to enhance the efficiency and accuracy of pollen exportation and/or pollen reception, thus increasing male and/or female fitness of the plant (Yeo 1993).

Varatharajan & Daniel (1984) reported that thrips have an intimate association with the capitula of Asteraceae. Laughlin (1977) reported that in Asteraceae, the duration of growth and development of thrips synchronizes well with the centripetal disc floral development whereby thrips, which are mostly pollen feeders, efficiently use the capitulum for their growth and survival. Kirk (1997) noted that thrips puncture the pollen coat and drain the grains; individual thrips consume more than 800 pollen grains per day. Abrol (2012) noted that thrips carry pollen ranging from 129–180 pollen grains but the pollen loads carried vary with the larvae and adults with the latter carrying an increased load due to greater surface area such as wing fringes, abdominal setae, as well as the antenna. Grimaldi & Engel (2005) stated that the higher the pollen production the greater the level of pollen carrying capacity. Ananthakrishnan (1982) reported that the pollen carrying capacity could also depend upon the pollen surface and architecture. Pollen grains attached to the body setae, wings and legs of thrips are dispersed on the stigma by way of their active movement, rubbing the abdomen on the stigmatic surface, cleansing of their body parts with their hind legs and also by their wing-combing mechanism. Kirk (1997) reported that thrips use the stigma for landing and take-off. During this process, thrips place the pollen directly on the stigma. The impressive petal colour and corolla tube of a small flower form is an ideal site to attract thrips for oviposition, enabling the emerging larvae to become dusted with pollen in their upward and downward movement eventually leading to pollination. Ananthakrishnan et al. (1981) reported that heterogamous capitula of Asteraceae facilitate free movement of both larvae and adults in between the individual florets, and adults carry a maximum pollen load on the body. In the present study, *Microcephalothrips abdominalis* is the only thrips species which uses *S. nodiflora* capitula for its breeding. The larvae emerge in synchrony with the timing of anthesis of capitulum which occurs for four consecutive days. The larvae and adults move freely up and down within and between ray and disc florets in search of pollen and nectar; the larvae carry less pollen while the adults carry more pollen because of variation in the surface area of the body. Further, they use stylar arms for take-off and landing during which the stigmatic area is dusted with pollen. The feeding activities of larvae and adult thrips within the capitulum contribute to self-pollination. As there is a continuous emergence of thrips in synchrony with sequential anthesis within the capitulum, the available forage becomes insufficient to meet their food requirement and in effect they migrate to other capitula on the same plant or nearby plants in search of forage due to which, chances of cross-pollination are enhanced. Ananthakrishnan et al. (1981) stated that the thrips living in the heterogamous capitula of Asteraceae with solitary inflorescences spend more energy for their visits to other flowers where the food is plenty. In *S. nodiflora*, the solitary as well as grouped capitula borne in leaf axils enable thrips to optimize energy expenditure to visit and acquire more energy from the forage they collect from different capitula within the plant. Such an interaction between *S. nodiflora* and *M. abdominalis* benefits both partners, the former in pollination and the latter in breeding and feeding.

In *S. nodiflora,* the peripheral nectar-less yellow ray florets attract foragers. In ray florets, the the stylar arms with exposed receptive stigmatic region standing above the tubular portion of the corolla is an adaptation for easy pollen deposition and pollination by the foragers which visit the disc florets for pollen and/or nectar. In the central yellow disc florets, the narrow tubular corolla containing nectar, pollen accessibility to foragers within and outside the corolla tube, and pollen characteristics such as spheroidal shape, tri-colporate apertures and echinate exine are adaptations for insect-pollination. Wodehouse (1935) stated that the echinate trait of the pollen grains is a special adaptation for adherence to insect vectors. Therefore, the characteristics of both ray and disc florets suggest that this plant is adapted for insect-pollination.

Faegri & Pijl (1979) described the floral characters of butterfly-pollination. They usually possess large, white, pink, red, yellow or blue, narrow, tubular flowers with deep nectaries and nectar guides. Baker & Baker (1982; 1983) categorized two categories of flowers with reference to flower-butterfly relationships. The first category is “true butterfly flowers” which are characterized by deep, narrow corolla tubes with relatively copious sucrose-rich nectar. The second category is “bee and butterfly flowers” which are characterized by short-tubed corolla with hexose-rich nectar. In *S. nodiflora*, the nectar of disc florets is sucrose-rich with moderate sugar concentration and sugar content, and has some essential and non-essential

amino acids. These characteristics of disc florets conform to "true butterfly pollination syndrome". The tubular corolla of ray florets lacking nectar and stamens and having functional pistil indicates that it is adapted for butterfly-pollination by deception.

In the present study, butterflies are the consistent and regular foragers throughout the year for *S. nodiflora*. The capitula attract butterflies belonging to pieridae, lycaenidae and hesperiidae but lycaenids are the principal pollinators. It is interesting to note that papilionid butterflies never visited the capitula. The small, narrow tubate ray and disc florets aggregated into capitula are appropriate for pollination by butterflies which efficiently handle several florets to collect nectar successfully in a single visit. In such an act, their proboscis gains contact with the dehisced anthers situated inside the corolla tube and also with the pollen adhered to sweeping hairs during staminate phase in disc florets. The proboscis is the carrier of pollen and the number of pollen grains carried by them vary with the length of proboscis and the time of nectar collection. In pistillate phase of disc florets, the butterflies with their proboscis contact the exposed stigmatic regions and in effect transfer and deposit pollen at this region effecting pollination. Further, the butterflies with pollen-laden proboscis pollinate the ray florets while probing their tubular corolla lacking nectar. In both disc and ray florets, self-pollination occurs due to simultaneous occurrence of staminate and pistillate phases in different disc florets, and only pistillate phase in ray florets at capitula and plant level. The standing crop of nectar at plant or population level is commensurate with the requirement of the butterflies as sufficient volume of nectar is available at capitulum level. The butterflies frequent the capitula of the same and/or different closely or distantly spaced individuals and promote cross-pollination. Their foraging schedule and the peak foraging activity period coincide well with the availability levels of standing crop of nectar. The consistent foraging activity of butterflies on this plant suggests that they use this plant as an important nectar source. Therefore, *S. nodiflora* is principally psychophilous.

In the present study, it is found that bees, wasps and flies also use the disc florets of *S. nodiflora* as pollen and/or nectar sources, especially during peak flowering season. The foraging behavior of the bees indicated that they are successful mostly as pollen collectors due to a slight mismatch between the length of their tongue and the length of the corolla tube to collect the deeply seated nectar. In case of wasps and flies, their proboscis length easily facilitates nectar collection from the disc florets. All these insects also probe the ray florets for nectar without any discrimination although there is no nectar; their visits to ray florets result in pollination. All these insects carry pollen on their body, transfer and effect self- and cross-pollination. Since they show foraging activity mainly during the peak flowering period, they serve as supplementary pollinators. Nectar feeding by the larvae and adults of *M. abdominalis* leads to reduced levels of nectar and make all nectar feeding insect species to increase foraging activity across populations to meet their nectar requirement and in effect, both self- and cross-pollination rates are enhanced.

Different authors reported that *Synedrella nodiflora* produces two types of fruits (Banerji & Pal 1959; Kissmann & Groth 1992; Rocha 1996). The present study also found that *S. nodiflora* produces two types of cypselas within a capitulum. The cypselas produced from ray florets are heavier, elliptical, membranous with upwardly-pointing teeth along the margins and two short terminal awns while those from disc florets are lighter, cylindrical and tangentially compressed with 2 or 3 stiff terminal divaricate awns. Chauhan & Johnson (2009) stated that the heavier cypselas produced from ray florets could be related to the inclusion of additional carbohydrate resources by the plant to help in the plant emergence while Brandel (2007) attributed the presence of superior mass in the cypselas produced from ray florets to the pericarp wing which is developed as an alternative structure for dispersion. The present study shows that the differences in morphological features of these two types of cypselas favour spatial dispersion having different strategies which promote spreading in various sites. In a capitulum, the cypselas of disc florets detach first and disperse to farther sites while those of ray florets disperse later in the vicinity of mother plants. The morphological features such as marginal and terminal teeth in ray floret cypselas and terminal teeth in disc floret cypselas enable them to be dispersed by animals and humans. Further, wind during dry season and water during rainy season also disperse them farther away. Therefore, the morphological features of cypselas of *S. nodiflora* are adapted for dispersal by multiple vectors, the situation of which is referred to as "polychory" involving zoochory, anthropochory, anemochory and ombrohydrochory.

The present study shows that the cypselas of both ray and disc florets of *S. nodiflora* are viable and germinate within a week after their dispersal from the mother plants and produce new plants. This situation indicates that both types of cypselas do not have dormancy. Similarly, Bradford (1990) reported

that both cypsela types in this plant do not have any difference in the fruit coat permeability and hence germination responses between them are almost the same; both cypselas types germinate immediately after dispersal. On the contrary, Brandel (2004) reported some differences in germination rates of the two cypsela types in *S. nodiflora* and related these differences to the ability of cypselas to environment perception. Turner (1994) also reported that fresh cypselas of both types of florets germinate quickly in a wide range of conditions. The buried cypselas to 10cm depth in soil remain viable for one year. Chauhan & Johnson (2009) reported that in *S. nodiflora*, the cypselas germinate immediately but ray floret cypselas if buried in soil would remain dormant for several months and germinate when favourable conditions exist. The present study indicates that heterocarpy in *S. nodiflora* is a mixed strategy in which disc floret cypselas successfully germinate under different conditions in time and space and ray floret cypselas germinate in restricted environment, usually near mother plants or the same habitats. The ability of disc floret cypselas offers the chance to colonize new sites, free from sibling competition or other local sources of stress, whereas the remainder of the offspring stays in the same habitat (Imbert & Ronce 2001). Interestingly, both types of cypselas produce identical plants and also produce bimorphic cypselas within the capitulum during flowering period suggesting that they are genotypically identical but different only by morphology which is configured by environmental situations. The study suggests that *S. nodiflora* with bimorphic cypselas and the associated traits is able to grow as a widespread weed in different habitats and expand its distribution range. This plant is considered to be a menace in agro-ecosystems. But it is an important food source for bees, wasps, flies and butterflies. Therefore, it may be an important component of agro-ecosystems because it plays a significant role in sustaining communities of insects that contribute to crop growth. Nevertheless, the information detailed here on the reproductive system of this weed is important to plan a management control schedule.

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REVIEW

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Status of studies on zooplankton fauna of Arunachal Pradesh, India

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Abstract: This paper gives a brief review of the studies on zooplankton fauna of Arunachal Pradesh, the major shareholder of the eastern Himalaya biodiversity hotspot. Altogether, 66 species of zooplankton (45 Rotifera, 20 Cladocera, & one Copepoda) have been recorded along with their distribution in the state, wherever available. It is apparent that there is a lack of serious taxonomic studies on all three major groups of zooplankton from this Himalayan state. The urgency and importance of documenting the zooplankton fauna of this biogeographically unique and biodiversity-rich state is highlighted in view of the fragility of the ecosystem as well as the effect of climate change.

Keywords: Arunachal Himalaya, Cladocera, Copepoda, Rotifera, zooplankton.

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INTRODUCTION

Zooplankton is an important biotic component of aquatic ecosystems (Dadhick & Saxena 1999; Sinha & Islam 2002) acting as indicators of the trophic condition of an ecosystem (Gannon & Stemberger 1978; Sharma 1998). Changes in zooplankton abundance, species diversity, and community composition are considered as good indicators of environmental change (Sharma et al. 2008). Truly planktonic animals or zooplankton are dominated by three major groups in freshwaters, the Rotifera and the two groups of the subphylum Crustacea, namely, Cladocera & Copepoda. The present study, thus, concentrates on these three major groups.

Freshwater rotifers are represented by over 2000 species (Segers 2007, 2008) of which 419 species belonging to 65 genera are known from India (Sharma & Sharma 2017a). The Indian Rotifera diversity is relatively richer than other Southeast Asian countries like Thailand (Sa-Ardrit et al. 2013). Of the nearly 700 species of freshwater cladocerans known globally (Forro et al. 2008; Kotov 2013), 131 species in 47 genera have been reported from India (Chatterjee et al. 2013; Sharma & Sharma 2017b). Out of about 3000 species of freshwater copepods known globally, the Indian diversity is estimated to be nearly 200 species under 60 genera (Reddy 2017). Rotifera, Cladocera,, and Copepoda, thus, share roughly 21%, 18%, and 7% of their respective global diversity till date.

Studies on Indian zooplankton began more or less at the beginning of the 20th century. Studies on Indian Cladocera was initiated with the description of *Daphnia newporti* Baird, 1860 (now it is a 'species inquirenda'). The momentum, however, picked up with the publication of two papers on Indian Cladocera at the beginning of the 20th Century (Gurney 1906, 1907). Though Indian Rotifera studies started near the end of the 19th Century with the report of 47 species from Calcutta and its surroundings by Anderson (1989), a clear impetus in Rotifera studies from India is evident with the works of Murray (1906), who reported 32 species from the Sikkim Himalaya (now a part of northeastern India), followed by quite a number of publications. Works of Gurney (1906, 1907) at the beginning of the last century were the first reports on Indian freshwater Copepoda.

The progress of studies on Indian zooplankton, encompassing all facets, is well- documented (see Sharma & Sharma 2017a for Rotifera; Sharma & Sharma 2017b & Chatterjee et al. 2013 for Cladocera; Reddy 2017 for Copepoda). While these studies dealt with individual groups, a common observation by them is the non-homogeneity of the progress in space. All the biogeographic zones of the country are not equally studied including different ecosystems like hot springs and alpine regions. Also, studies from different regions as well as states of the country are disproportionate, a fact that can be attributed to the recorded low diversity in these groups in relation to global diversity. Within the Indian landmass, substantial work has been done from the northeastern region in terms of Rotifera and Cladocera while most of the studies on Indian copepods have been confined to the southern peninsula.

A similar trend of non-uniform coverage of all the states of northeastern India, too, is evident. Most of the zooplankton studies in the region have been confined to select states. About two-thirds (~280 species) of the Indian Rotifera are known from northeastern India. This rich rotifer diversity is mainly attributed to Assam (220 species), Manipur & Mizoram (162 species each), Meghalaya (161 species), and Tripura (152 species) (Sharma 2017a). There is no quantification of the rotifers from states like Arunachal Pradesh, Nagaland, and Sikkim though there are some occasional reports like those by Murray (1906) from Sikkim. Similarly, Assam (75 species), Meghalaya (58 species), Manipur (56 species), and Tripura (50 species) (Sharma 2017a) contributed to the relatively rich cladoceran diversity of the region. Not much is known about the Cladocera diversity of the remaining northeastern states except for sporadic reports. The copepod fauna of northeastern India as a whole is poorly studied with only a few reports (Reddiah 1964; Reddy 2013a,b) from the region. The only systematic study on the zooplankton fauna of Arunachal Pradesh is perhaps by Sharma et al. (2017a,b,) who reported seven species each of Rotifera and Cladocera from Tawang. But it neither mentioned the occurrence of other species in the district nor provided any details on the number and distribution of zooplankton in the state.

There is a complete dearth of studies exclusive to any of the three zooplankton groups from Arunachal Pradesh though it is a part of the eastern Himalaya global biodiversity hotspot (Myers et al. 2000) and is also among the 200 globally important ecoregions (Olson & Dinerstein 1998). Therefore, it is critically imperative to undertake comprehensive and dedicated studies on important aquatic faunal groups like zooplankton of Arunachal Pradesh that is ecologically fragile, especially due to the developmental pressure it is witnessing of late. This is upholded by the more sensitive nature of these tiny organisms. In this context, it is imperative to know the state of affairs of zooplankton fauna of

Arunachal Pradesh before undertaking a detailed study. This is what this study is aimed at, making a sincere effort to collate all the existing scattered information on zooplankton fauna of Arunachal Pradesh.

Arunachal Pradesh: the biodiversity mine

The state of Arunachal Pradesh (26.4–29.5 ^{0}N & 91.5–97.5 ^{0}E; 83,743km^{2}; Fig. 1) in northeastern India is uniquely situated in the transition zone between a) the eastern Himalaya & Indo-Burmese biodiversity hotspots, b) Palearctic & Oriental biogeographic region, and c) Himalaya & peninsular India. The state has an unmatched composition of biological diversity having representative elements of the different conjoining ecosystems as well as its own unique elements. Wide altitudinal range from 50 to >7000 m within the state has brought about a great diversity of habitat and forest types and climatic conditions from temperate to alpine or tundra that arguably support the evolution and existence of diverse forms of biota. The landscape is one of the richest in biological values in the world, high in endemism and holding a large number of rare and threatened species (Rao 1994; Baishya et al. 2001; Borang 2001). Frequent new discoveries and new records in almost all groups of flora and fauna from the state reinforces the above observations and the state can be rightly considered as a 'biodiversity mine' for its biodiversity potential.

This Himalayan state harbours a wide variety of both lotic and lentic freshwater biotopes, ranging from sub-tropical wetlands to hot-springs to high-altitude glacial lakes. The five major rivers, namely, Kameng, Subansiri, Siang, Dibang, and Lohit, along with another 123 rivers and streams (SAC 2009) constitute the lotic habitats accounting for 86% of the total wetland area of the state. The state has a total of 2,653 wetlands, natural as well as man-made, with a total area of 155,728ha that accounts for more than 2% of the total geographic area of the state. These vast wetland systems harbour diverse aquatic fauna including freshwater zooplankton, most of which are yet to be explored. There are about 1672 high altitude lakes (SAC 2009) in the state, most of which are set in some form of complexes like the Bhagajang Wetland Complex and Nagula Wetland Complex in Tawang District. The state also has a number of hot springs like Thingbu & Tsachu in Tawang, hot springs in Dirang, West Kameng District, and Kibitho & Walong in Anjaw District. There are records of zooplankton from these types of unique habitats from other parts of India as well as the world. For instance, Padhye & Kotov (2010) found two species of Cladocera in a hot water spring in the Western Ghats of India. Among all other organisms, the diaptomid *Arctodiaptomus jurisovitchi*, was the most widely distributed species recorded from high altitude mountain lakes at 4000–6000 m in the Khumbu Valley in

Figure 1. Location of Arunachal Pradesh in the eastern Himalaya biodiversity hotspot bordering Indo-Burma hotspot (adapted from Kamei et al. 2012)

the Nepal Himalaya (Manca et al. 1998).

Rotifera of Arunachal Pradesh

Rotifers are pseudocoelomate, multicellular, mostly microscopic organisms with size of about 40–250 µm. Though omnipresent, rotifers are primarily freshwater invertebrates, with about 95% of the species reported from freshwater habitats (Sharma 1996). At present, roughly a little over 2000 species of rotifers are known from the world and classified in to three main groups, the marine Seisonida (three species), the Monogononta (1,570 species), and the unique, exclusively parthenogenetic Bdelloidea with 461 clonal species (Segers 2007, 2008). Out of these, 419 species are known from India (Sharma & Sharma 2017a).

Though a majority of attempts on the systematics of Indian Rotifera are from the northeastern states (see Sharma & Sharma 2017a; Vanjare 2017), that from Arunachal Pradesh is very negligible. The first ever review of taxonomic studies on Indian Rotatoria (Sharma & Michael 1980) indicates no studies on rotifer fauna of Arunachal Pradesh till that time.

The report of three species of *Lepadella*, namely, *L. acuminata*, *L. ovalis* & *L. patella* by Sharma & Sharma (1987) was probably the earliest record of Rotifera from Arunachal Pradesh. While studying the distribution of lecanid rotifers in northeastern India, Sharma (1987a) recorded five species of *Lecane*, namely, *L. bulla*, *L. closterocerca*, *L. leontina*, *L. luna* & *L. lunaris*, from the state. Sharma (1987b) reported the occurrence of *Anuraeopsis fissa* from Arunachal Pradesh. While studying the zooplankton biodiversity of the amphibian habitats of Arunachal Pradesh, Sinha et al. (2002) recorded an additional 10 species of rotifers from eight districts of the state. At this time, altogether 19 species of rotifers are known from Arunachal Pradesh. Sharma & Sharma (2005), however, while studying the biodiversity of freshwater rotifers from northeastern India, reported the occurrence of 26 species of Rotifera in Arunachal Pradesh. But, no published information could be found for the remaining seven species, hence they are not considered.

Later, *Lecane quadridentata* and *Synchaeta oblonga* were added to the rotifer fauna of Arunachal Pradesh (Sharma 2008; Sharma & Sharma 2008). In the latest review on the diversity and distribution of Indian Brachionidae, Sharma & Sharma (2014a) mentioned the occurrence of 11 brachionid rotifers from Arunachal Pradesh including two new additions, namely, *Keratella serrulata* (Ehrenberg, 1838) & *Notholca squamula* (Műller, 1786). Recently, another 19 species were added to the rotifer fauna of the state by Barik et al. (2014), bringing the total number of Rotifera known from Arunachal Pradesh to 42 species. Reportedly, 76 species of rotifers are known from Arunachal Pradesh (Sharma & Sharma 2014b). This figure, however, is based on unpublished data and hence not incorporated. Recently, Sharma et al. (2017) recorded seven species of Rotifera from Tawang District of Arunachal Pradesh. Out of these, three species, namely, *Euchlanis triquetra* Ehrenberg, 1838, *Polyartha vulgaris* Carlin, 1843, & *Trichocerca cylindrica* (Imhof, 1891) are new additions to the state's Rotifera list. Thus, the number of rotifer fauna of Arunachal Pradesh has been restricted to 45 species pending validation of the additional species.

Cladocera of Arunachal Pradesh

Cladocerans are small crustaceans in the range of 0.2–6 mm. They inhabit most types of continental fresh and saline water habitats, occurring more abundantly in both temporary and permanent stagnant waters (Forro et al. 2008). Nearly 700 species of cladocerans are known globally (Forro et al. 2008; Kotov 2013). Systematic studies on Indian Cladocera was initiated by Baird (1860) describing *Daphnia newporti* Baird, 1860 (Species inquirenda, Chatterjee et al. 2013) from Nagpur and surrounding areas. About 131 species of freshwater Cladocera are known from India (Chatterjee et al. 2013; Sharma & Sharma 2017b).

Within India, the cladoceran fauna of the northeast is the best known (Sharma & Sharma 1990, 2011). Studies on Cladocera of Arunachal Pradesh, however, is virtually lacking except for some scattered reports. The first record of Cladocera from Arunachal Pradesh was the report of *Alona costata* (*Flavalona costata* Sinev & Dumont, 2016) from the Kameng division (Biswas 1964). This, however, did not get reflected in the successive review (Sharma & Michael 1987), monograph (Michael & Sharma 1988), and checklist (Chaterjee et al. 2013) on Indian Cladocera. *Flavalona costata* (*Flavalona* is the new generic name of costata-group of *Alona* sensu lato (Sinev & Dumont, 2016)) is not included in the present list pending confirmation of its occurrence in the Indian subcontinent where an endemic form *F. cheni* is available. While studying the planktonic diversity of amphibian habitats, Sinha et al. (2002) recorded five species of Cladocera from Arunachal Pradesh. These are *Bosmina longirostris* (O.F. Muller, 1776) sensu lato, *Alona guttata* Sars, 1862, *Moina micrura* Kurz, 1874, *Moinodaphnia macleayi* (King, 1853) and *Diaphanosoma sarsi* Richard, 1894.

Gupta et al. (2013) recorded the occurrence of *Sida*

crystallina (O.F. Müller, 1776) sensu lato in the Apatani Plateau of Arunachal Pradesh. Another chydorid, *Flavlona cheni* (Sinev, 1999), has been reported from Arunachal Pradesh (Sharma & Sharma 2013). Surprisingly, the latest checklist of Indian Cladocera (Chaterjee et al. 2013) did not mention the record of any Cladocera from Arunachal Pradesh. Seven more species of Cladocera have been reported (Barik et al. 2014) from the Tawang basin of the state. Out of these, *Macrothrix laticornis* (Jurine, 1820) sensu lato is not considered in this report as its record from India needs revalidation (Chatterjee et al. 2013). Recently, Sharma et al. (2017) recorded seven more cladocerans from Tawang, out of which the occurrence of two species, namely, *Chydorus pubescens* Sars, 1901 sensu lato & *Eurycercus lamellatus* (O.F. Müller, 1776) sensu lato, in India is doubtful (Chatterjee et al. 2013). These two species, however, are included in the present list as only a revision of the Indian population is required to validate the presence of one or more species of the genus. Thus, a total of 20 valid taxa of Cladocera are reported from Arunachal Pradesh.

Copepoda of Arunachal Pradesh

Copepods are the largest among the three major groups of zooplankton, ranging from 0.5–15 mm in size. These are claimed to be numerically the most abundant metazoans on earth and conservative estimates reveal that they may outnumber the abundance of insects (Schminke 2007). Approximately, 2814 species of freshwater copepods under 257 genera are known globally (Boxshall & Defaye 2008).

Scientific reports on Indian freshwater copepods began to appear with the works of Gurney (1906, 1907). Nearly 200 species of freshwater copepods are known from India (Reddy 2017). Investigations on copepod diversity of northeastern India/eastern Himalaya, however, is completely lacking (Battish 1992), though some recent studies on diaptomids are reported (Reddy 2013a,b). These include a description of *Neodiaptomus prateek* Reddy, 2013 from Assam and a record of the little known *Tropodiaptomus signatus* Kiefer, 1982 from Manipur. As such, our knowledge of Copepoda from the northeastern region, in general, and Arunachal Pradesh, in particular, is virtually nil. The only record of copepods from Arunachal Pradesh is that by Sinha et al. (2002) who reported three copepods, namely, *Heliodiaptomus cinctus*, *Eucyclops speratus*, and *Mesocyclops leuckarti*, from the amphibian habitats of the state. The latter two species, however, are not included in the present list as their occurrence in the Indian landmass awaits revalidation.

DISCUSSION

Scrutiny of available literature clearly indicates that virtually no taxonomic studies sensu stricto have been done on the zooplankton fauna of Arunachal Pradesh. Whatever is known about the zooplankton diversity of the state is ancillary to other studies; some are mentioned in the faunal inventories of other states, some in review of a particular taxon or a particular region, some in routine EIA studies, while others in either feeding behaviour studies of zooplankton consumers or limnological studies. Thus, there is a complete lack of comprehensive and exclusive studies on zooplankton fauna of Arunachal Pradesh.

Nonetheless, collation of whatever scattered reports that are available in the public domain reveals that zooplankton fauna of Arunachal Pradesh comprises of 45 species of Rotifera under 20 genera and 13 families, 20 species of Cladocera under 16 genera and 9 families, and only one species of Copepoda. As apparent, copepods are the least studied group (Table 1, Fig. 2) as only one species under one genera under one family is known so far from the state. This is purely an under-representation of the zooplankton diversity of the state which is otherwise well known for its rich and unique biodiversity. The poor zooplankton diversity of Arunachal Pradesh is in contrast to the established fact that within the Indian landmass, the highest diversity of Rotifera (Sharma & Sharma 2014b) and Cladocera (Sharma & Sharma 2011) have been documented from the northeastern region, which also includes this state. Low level of exploration

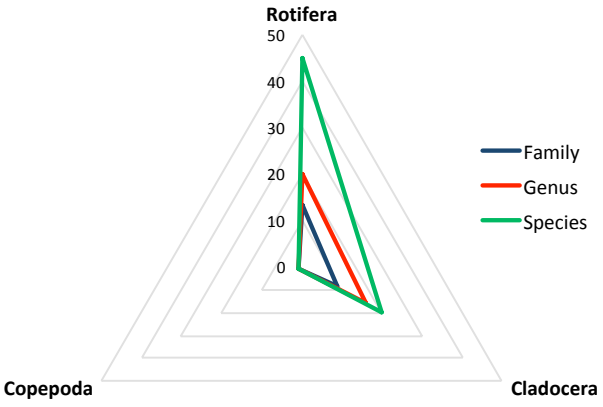

Figure 2. Composition of zooplankton fauna of Arunachal Pradesh depicting the number of species, genera & family known under each group

Table 1. Reported zooplankton fauna of Arunachal Pradesh

Taxa	District	Reference
Phylum: Rotifera		
Class: Eurotatoria		
Subclass: Monogononta Plate, 1889		
Order: Flosculariaceae Harring, 1913		
Family: Conochilidae Harring, 1913		
Conochilus hippocrepis (Schrank, 1803)	E. Kameng	Sinha et al. 2002
Family: Testudinellidae Harring, 1913		
Testudinella emarginula (Stenroos, 1898)*	Tawang	Barik et al. 2014
T. patina (Hermann, 1783)	Tawang	Barik et al. 2014
Family: Trochosphaeridae Harring, 1913		
Filinia pejleri Hutchinson, 1964	E. Siang	Sinha et al. 2002
Order: Ploima Hudson & Gosse, 1886		
Family: Brachionidae Ehrenberg, 1838		
Anuraeopsis fissa (Gosse, 1851)	NA	Sharma 1987b
Brachionus calyciflorus Pallas, 1766	E. Siang	Sinha et al. 2002
B. ahlstromi Lindeman, 1939	Papumpare	Sinha et al. 2002
B. quadridentatus (Hermann, 1783)	Tawang	Barik et al. 2014
Keratella serrulata (Ehrenberg, 1838)*	NA	Sharma & Sharma 2014
Notholca squamula (Müller, 1786)*	NA	Sharma & Sharma 2014
Platinous patulus (Muller, 1786)	E. Kameng	Sinha et al. 2002
Platyias quadricornis (Ehrenberg, 1832)	E. Kameng, E. Siang	Sinha et al. 2002
Family: Epiphanidae Harring, 1913		
Epiphanes brachionus (Rousselet, 1901)	Tawang	Barik et al. 2014
Family: Euchlanidae Ehrenberg, 1838		
Euchlanis dilatata (Ehrenberg, 1832)	Tawang	Barik et al. 2014; Sharma et al. 2017
E. triquetra Ehrenberg, 1838	Tawang	Sharma et al. 2017
Family: Lecanidae Remane, 1933		
Lecane bulla bulla (Gosse, 1851)	NA	
Tawang	Sharma 1987a;	
Sharma et al. 2017		
L. closterocerca (Schmarda, 1859)	NA	Sharma 1987a
L. curvicornis (Murray, 1913)	Tawang	Barik et al. 2014
L. flexilis (Gosse, 1886)	Tawang	Barik et al. 2014
L. inopinata Harring & Myers, 1926	E. Kameng, Papumpare, U. Subansiri, E. Siang	Sinha et al. 2002
L. leontina (Turner, 1892)	NA	Sharma 1987a
L. luna (O.F. Muller, 1776)	NA	Sharma, 1987a
L. lunaris (Ehrenberg, 1832)	NA	
Tawang	Sharma 1987a;	
Sharma et al. 2017		
L. papuana (Murray, 1913)	Tawang	Barik et al. 2014; Sharma et al. 2017
L. ploenensis (Voigt, 1902)	E. Kameng	Sinha et al. 2002
L. quadridentata (Ehrenberg, 1832)	NA	Sharma, 2008
L. signifera (Jennings, 1896)*	Tawang	Barik et al. 2014
Family: Lepadellidae Harring, 1913		
Colurella obtusa (Gosse, 1886)	Tawang	Barik et al. 2014
C. sulcata (Stenroos, 1898)*	Tawang	Barik et al. 2014
Lepadella acuminata (Ehrenberg, 1834)	NA	Sharma & Sharma 1987
L. cf. *nartiangensis* (Sharma & Sharma, 1987)*	Tawang	Barik et al. 2014
L. ovalis (Muller, 1786)	NA	Sharma & Sharma 1987
L. patella patella (Muller, 1773)	E. Siang (Sinha et al. 2002)	Sharma & Sharma 1987
L. quadricarinata (Stenroos, 1898)	Tawang	Barik et al. 2014
L. vandenbrandei (Gillard, 1952)*	Tawang	Barik et al. 2014
Family: Mytilinidae Harring, 1913		
Mytilina ventralis (Ehrenberg, 1832)	Tawang	Barik et al. 2014
Family: Notommatidae Hudson & Gosse, 1886		
Cephalodella gibba (Ehrenberg, 1830)	Tawang	Barik et al. 2014
Family: Scaridiidae Manfredi, 1927		
Scaridium longicaudum (Muller, 1786)	E. Kameng	Sinha et al. 2002
Family: Synchaetidae Hudson & Gosse, 1886		
Polyartha vulgaris Carlin, 1843	Tawang	Sharma et al. 2017
Synchaeta oblonga Ehrenberg, 1832	NA	Sharma & Sharma 2008
Family: Trichocercidae Harring, 1913		
Trichocerca bidens (Lucks, 1912)*	Tawang	Barik et al. 2014
T. cylindrica (Imhof, 1891)	Tawang	Sharma et al. 2017
T. porcellus (Gosse, 1886)	W. Kameng	Sinha et al. 2002
T. pusilla (Jennings, 1903)*	Tawang	Barik et al. 2014
T. weberi (Jennings, 1903)	Tawang	Barik et al. 2014
Phylum: Arthropoda		
Subphylum: Crustacea		
Class: Branchiopoda Latreille, 1817		
Order: Cladocera Latreille, 1829		
Family: Bosminidae Baird, 1845		
Bosmina longirostris (O.F. Muller, 1776) s.lat.	E. Kameng	Sinha et al. 2002

Taxa	District	Reference
Family: Chydoridae Dybowski & Grochowski, 1894		
Subfamily: Aloninae Dybowski & Grochowski, 1894		
Acroperus harpae (Baird, 1834) s.lat.	Tawang	Sharma et al. 2017
Alona affinis (Leydig, 1860) s.lat.	Tawang	Barik et al. 2014
A. guttata Sars, 1862	E. Kameng	Sinha et al. 2002
A. quadrangularis (O.F. Müller, 1776) s.lat.	Tawang	Sharma et al. 2017
Flavalona cheni (Sinev, 1999)	NA	Sharma & Sharma 2013
Karualona karua (King, 1853) s.lat.	Tawang	Barik et al. 2014
Leberis diaphanus (King, 1853) s.lat.	Tawang	Barik et al. 2014
Subfamily: Chydorinae Dybowski & Grochowski, 1894		
Alonella (*Nanalonella*) *nana* (Baird, 1843)	Tawang	Barik et al. 2014
C. parvus Daday, 1898	Tawang	Sharma et al. 2017
C. pubescens Sars, 1901 s.lat.	Tawang	Sharma et al. 2017
C. sphaericus (O.F. Müller, 1776) s.lat.	Tawang	Sharma et al. 2017
Family: Daphniidae Straus, 1820		
Daphnia tibetana (Sars, 1903)	Tawang	Barik et al. 2014
Family: Macrotrichidae Norman & Brady, 1867		
Macrothrix spinosa King, 1853	Tawang	Barik et al. 2014
Family: Moinidae Goulden, 1968		
Moina micrura Kurz, 1874	E. Kameng	Sinha et al. 2002
Moinodaphnia macleayi (King, 1853)	E. Kameng	Sinha et al. 2002
Family: Eurycercidae Kurz, 1875 sensu Dumont & Silva-Briano, 1998		
Eurycercus lamellatus (O.F. Müller, 1776) s.lat.	Tawang	Sharma et al. 2017
Family: Ilyocryptidae Smirnov, 1976 sensu Smirnov, 1992		
Ilyocryptus spinifer Herrick, 1882	Tawang	Sharma et al. 2017
Family: Sididae Baird, 1850		
Diaphanosoma sarsi Richard, 1894	E. Kameng	Sinha et al. 2002
Sida crystallina (O.F. Müller, 1776) s.lat.	L. Subansiri	Gupta et al. 2013
Class: Maxillopoda		
Subclass: Copepoda Milne-Edwards, 1840		
Order: Calanoida Sars, 1903		
Family: Diaptomidae Baird, 1850		
Heliodiaptomus cinctus (Gurney, 1907)	Papumpare, E. Siang	Sinha et al. 2002

of zooplankton fauna of Arunachal Pradesh is perhaps due to the mostly inaccessible terrain of the state and lack of experts in and around the state. The record of nine rare species of rotifers from the aquatic biotopes of Arunachal Pradesh, however, is an indication of the unique nature of zooplankton fauna that is yet to be explored in detail; a thorough exploration may reveal many more elements of biological, ecological, and evolutionary interest. Prevalence of the wide range of climatic conditions from temperate to alpine conditions and the phenomenal range of habitats owing to the unique biogeographic positioning of the state supports this hypothesis.

Studies on organisms like zooplankton in these extreme aquatic habitats may throw light on their adaption, thus helping us to understand the evolution of cryptic species group complexes like those in Lecanidae, Brachionidae, and similar others in Cladocera as well as Copepoda. Further, zooplankton are considered as 'beacons of climate change' (Richardson 2008) and studying them from high altitude areas like those in Arunachal Pradesh may provide better insight into understanding climate change impacts. These are just the glimpses out of many such opportunities we are missing out by not exploring the zooplankton fauna of a unique and critical region like Arunachal Himalaya.

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SHORT COMMUNICATION

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First record of the endangered Arabian Tahr *Arabitragus jayakari* (Thomas, 1894) in the Hatta Mountain Conservation Area, Dubai, United Arab Emirates

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Abstract: The Arabian Tahr *Arabitragus jayakari* is endemic to the Hajar Mountains of Oman and the United Arab Emirates in the southeast of the Arabian Peninsula and is categorized as Endangered on the IUCN Red List of Threatened Species. Lack of scientific research from areas of its occurrence has been a challenge in determining its basic ecological aspects such as current distribution range, population status, and abundance. In the present study, we report a new distribution record for the Arabian Tahr from the Hatta Mountain Conservation Area in the Dubai Emirate through camera trap images. A total of 442 images (44 events) were obtained using three camera traps on 564 trap nights between March and December 2016. About 90% of the Arabian Tahr captures were recorded between 1100 and 1600 hr, indicating diurnal activity. This new occurrence record of the Arabian Tahr from this area is considered of high significance as it will drive in more studies and incentives towards the conservation and management of the species and the area as a whole.

Keywords: Arabian Tahr, *Arabitragus jayakari*, Hatta Mountain Conservation Area, camera trapping, Dubai Emirate, first record, UAE.

Information on species distribution and diversity pattern is crucial for understanding the ecological and evolutionary determinants of spatial heterogeneity in biodiversity (Ricklefs & Schluter 1993). Spatial congruence of species distributions has been studied in several taxa (Marquez et al. 1997; Gómez-González et al. 2004; Oertli et al. 2005), but remains poorly understood in certain mammalian communities, especially in herbivores, in the Middle East region. The ungulates of the Arabian Peninsula region, Arabian Oryx *Oryx leucoryx*, Arabian Ibex *Capra nubiana*, and gazelles *Gazella marica* & *G. arabica*, are generally poorly known among local communities and the general public. There is, however, a widespread impression that they are under severe threat because of overgrazing, lack of protection, and lack of knowledge, and that the animals are fragmented into small populations (Conservation Breeding Specialist

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Group 2001). Most of the gazelles have received little attention and their taxonomic status and relationships are uncertain.

Arabian Tahr is one of the two species formerly included in the genus *Hemitragus* that are disjunctly distributed in the southern slopes of the Himalaya (*H. jemlahicus*), and southeastern Arabia (*H. jayakari*). Hassanin & Douzery (1999) suggested that Tahr was probably of Eurasian origin and most closely related to Ibex, goat, and Bharal (*Pseudois*). More recent research on their molecular genetics (Ropiquet & Hassanin 2005), however, surprisingly concludes that *Hemitragus* is polyphyletic and that the Arabian Tahr is genetically most similar to the northern African Aoudad *Ammotragus lervia* and more distantly related to the other Tahr species.

The Arabian Tahr is currently classified as Endangered in the IUCN Red List of Threatened Species (Insall 2008). Its historic range covered an area of about 19,413km^2 (Insall 1999). A later analysis of the range by hectads 10km x 10km grid, reported Tahr as present in 8863km^2, absent in 3653km^2, and with an uncertain presence in 6924km^2 (Robinson 2005).

The population size of Arabian Tahr is speculated to be probably less than 2000 individuals (Munton 1978, 1985). There is no recent published population estimate of the species, though field surveys in Oman are ongoing. Though the population of the Tahr is assumed to be declining, accurate census proves difficult to be formulated due to the extremely rugged terrain of the area, low densities, and small group size. The optimum habitat of the Arabian Tahr comprises north facing slopes between 100–1800 m that are characterized by relatively high rainfall, cool temperatures, and diverse vegetation (Insall 1999).

The Arabian Tahr species has been categorized as critically endangered in the UAE (Hornby 1996). It has been reported from mountainous areas such as Jabal Hafeet in Abu Dhabi Emirate and from Wadi Wurayah in Fujairah Emirate, which included local reports from its immediate vicinities (Tourenq et al. 2009; Al Zaabi & Soorae 2015). On the other hand, a survey of Ru'us Al Jabal in Ras Al Khaimah Emirate reported that Tahr was absent in the area, which was confirmed as local communities also did not have any knowledge of the species (EPAA 2006).

Previous studies have established the presence of the Arabian Tahr in the UAE, in Wadi Wurayah in the Emirate of Fujairah and in Jabal Hafeet in the Emirate of Abu Dhabi. There were no previous reports of the Arabian Tahr from Hatta Mountain Conservation Area (hereafter Hatta MCA) since no study was conducted in the area.

It is difficult to study this species through direct observation or other traditional study methods as with other elusive species such as the Caracal *Caracal caracal*, Arabian Sand Cat *Felis margarita harrisoni*, and Gordon's Wildcat *Felis silvestris gordoni*, but such species are significant indicators of the ecological condition of the environment.

Camera trapping is a non-invasive method that causes minimum disturbance to the target species. It has been widely used for inventories, particularly of elusive mammals (Silveira et al. 2003; Rovero & De Luca 2007; Tobler et al. 2008a,b; Ahmed et al. 2016) to study their activity patterns and habitat use (Bowkett et al. 2008).

With this background and main objective, we aimed to document the presence of the Arabian Tahr in the Hatta MCA of Dubai Emirate by using non-invasive camera trapping.

Methods

The Hatta Mountain Conservation Area (Hatta MCA) in Dubai, UAE (24.760^{0}N & 56.111^{0}E), encompasses an area of around 27.43km^2 mainly consisting of mountainous rugged terrain with freshwater ecosystems (Fig. 1). Camera trapping was carried out between March and December 2016 in order to record the baseline status of biodiversity in the Hatta MCA (Fig. 1). Three camera traps (Bushnell™) were deployed on the trails at three different locations selected, based on the presence of indirect evidence (pellet groups of herbivore species) at Hatta MCA. Images taken using remotely triggered camera traps were used to ascertain the presence of different species in the area. Camera traps were mounted on rocks as it was difficult to mount them with tripods due to the ruggedness of the terrain and unpredictability of weather conditions in the area. The camera trap locations were recorded by a handheld (eTrex™) GPS receiver unit and ancillary information such as date, time, and temperature was recorded. Data analyses were done in MS Excel 2013 and Oriana (V 4.01). Image capture rates (R) were calculated as number of independent photographic events (N) divided by the number of camera nights deployed (T) as follows:

$R = N/T \times 100$

Results and Discussion

A total of 442 images of the Arabian Tahr (44 events) were obtained from 564 trap nights during the study period with a rate of 7.8 capture events per 100 trapping

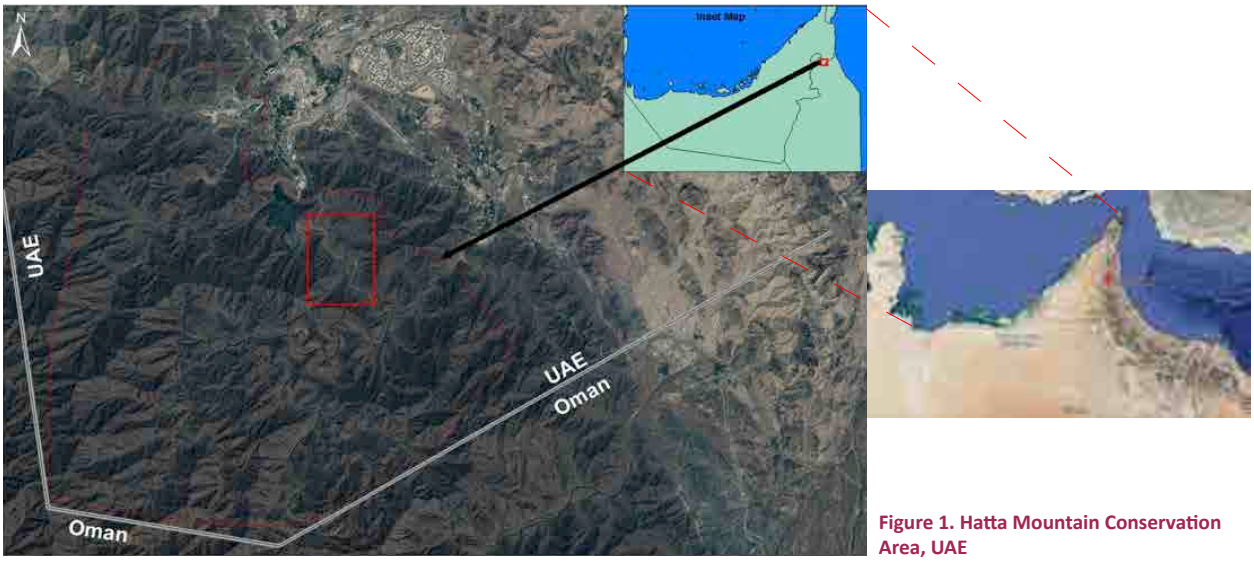

Figure 1. Hatta Mountain Conservation Area, UAE

nights. The first retrieved image of the Arabian Tahr was taken on 07 May 2016 at 1409hr, marking it as the first photographic record of the Arabian Tahr from the Hatta MCA (Image 1). The last image capture was recorded on 03 December 2016. Individuals were captured six times on 07 May 2016 on camera trap no. 2. Furthermore, camera trap no. 2 captured individuals at 14 different times, while camera trap no. 3 captured individuals at two different times. Camera trap no. 1 was unfortunately stolen, hence the absence of data.

In terms of the timing of images, about 90% of the captures were recorded between 1100 and 1600 hr, indicating a diurnal activity pattern. The remaining (10%) images were captured from 1600 to 1100 hr. We assume this activity pattern may be a result of the least human disturbance during the hottest hours of the day. The frequency of the Arabian Tahr recorded in camera

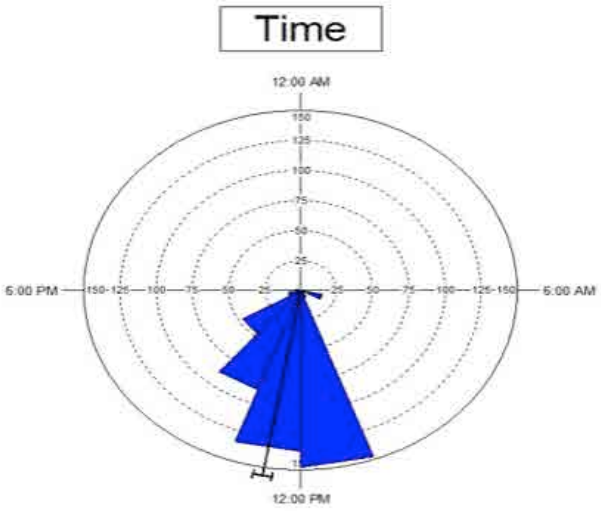

Figure 2. The frequency of Arabian Tahr recorded in camera traps along 24-hour cycles between March and December 2016

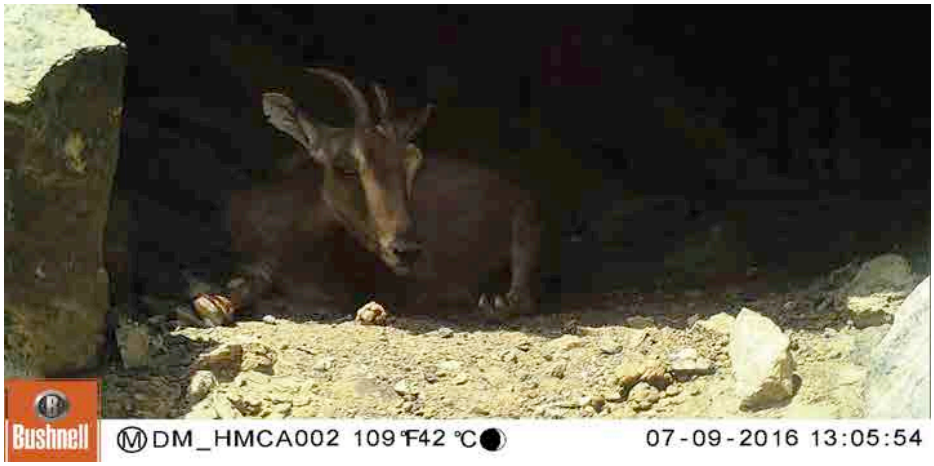

Image 1. First camera trap image of Arabian Tahr in Hatta Mountain Conservation Area

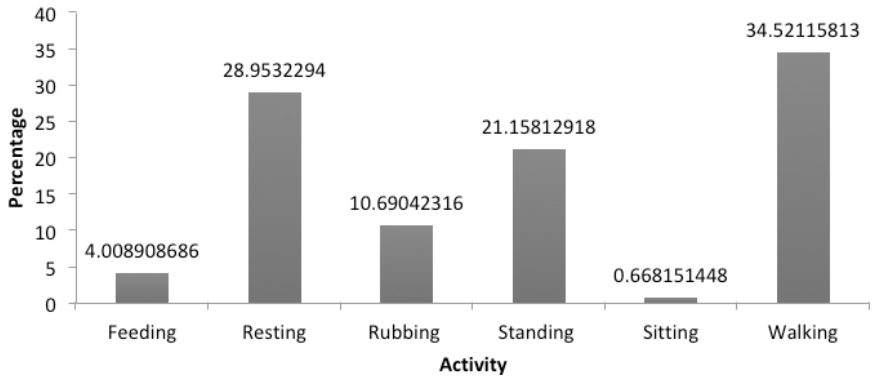

Figure 3. The activity of Arabian Tahr individuals as per images captured in Hatta Mountain Conservation Area

Image 2. Camera trap images of Arabian Tahr in Hatta Mountain Conservation Area

traps along 24-hour cycles is given in the circular plot (Fig. 2).

During the course of the study, the temperature stamped on the images ranged between 21 and 45°C with an average of 39.38±0.22°C (mean ± SE) between May and December 2016, which indicates that Arabian Tahr prefers medium to high temperature for its activities. The images show that the majority of individuals (34.52%) were photographed while walking, followed by resting, standing, and rubbing (Fig. 3).

Comparing the general body conditions such as build, size, and horns, we were able to record nine to 12 individuals through the camera trap images (Image 2). This population of the Arabian Tahr seems to be the largest in the UAE as compared to the two other populations recorded in the country. At Jabal Hafeet, a maximum of six individuals was recorded (Al Zaabi & Soorae 2015), while in Wadi Wurayah its presence has been documented without any estimate of the population (Tourenq et al. 2009) and there have been no records since 2012 (Al Bustan Zoological Centre and Environmental Agency – Abu Dhabi 2017). These two locations where the Arabian Tahr are recorded in UAE are not connected to the population found in Hatta MCA as these areas are not linked by any corridors.

The confirmed presence of this secretive animal in the Hatta MCA is highly significant as it will a) add to the knowledge base of the extent of the Tahr's range not just in the UAE but also in the whole Hajjar Mountain range, b) help in formulating an effective management plan for the conservation of this rare and charismatic species in the area as establishing spatial distribution of species is critical for designing appropriate conservation strategies, and c) strengthen the significance on the establishment of a protected area in species conservation.

With the confirmation of the Tahr population in the Hatta MCA, further studies can provide a better understanding of the different ecological characteristics and threats faced by the species in the area. The data generated will be valuable in all levels of the decision-making process and in ensuring the continued survival of this species in not only the national context but also in a transboundary, multinational management framework.

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Short Communication

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A winter roost count of the Short-eared Owl *Asio flammeus* (Aves: Strigiformes: Strigidae) at Porbandar, Gujarat, India

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Abstract: The Short-eared Owl *Asio flammeus* is a common to uncommon winter visitor to Gujarat. The species roosted in bushes of *Prosopis juliflora* in the grassland of Shiroda area, Odadar Village of Porbandar District. Communal roosts were identified by foot surveys between 9–17 November 2016. A total of 20 individuals co-existed with grazing cattle in the grassland of ca. 1km^2. At present due to their restricted nesting habits and nomadic nature, the species is vulnerable to habitat loss at their feeding and roosting grounds. Conversion of open habitats to agriculture, grazing, recreation, housing and tourism development are the current threats to the species in the wetland complex. The IUCN conservation status further confirms that though they are assessed as Least Concern, in spite of the species population constantly declining with global population estimated at 3,000,000 individuals which equates to 2,000,000 mature individuals. The present study is the first systematic attempt to count a roost in Gujarat.

Keywords: Gujarat, IUCN, Porbandar, Short-eared Owl, wetland, wintering roost.

The Short-eared Owl *Asio flammeus* is a widespread winter migrant to India (Blanford 1894). It prefers grassland and open country (Ali & Ripley 1987). In India, it is reported from Maharashtra (Jamdar & Shrivastava 1988; Chandrasekaran 1995), Madhya Pradesh (Pasha et al. 2004), Tamil Nadu (Thyagaraju 1933), Kerala (Jayson & Mathew 2002; Chandrasekhara & Nameer 2003), Gujarat (19 November 1993 specimen: The Field Museum), Rajasthan (5 January 1949 specimen: The Field Museum; Singh 1997), Karnataka (20 January 1941 specimen: The Field Museum), Uttar Pradesh (Grewal 2000), Andhra Pradesh (Kanniah & Ganesh 1993) and other states.

The Short-eared Owl has an extremely large range, and therefore it does not approach the thresholds for Vulnerable under the range size criterion (extent of occurrence <20,000km^2 combined with a declining or fluctuating range size, habitat extent/quality, or population size and a small number of locations or severe fragmentation) as well as under the population trend criterion (>30% decline over 10 years or three generations) and population size criterion (<10,000 mature individuals with a continuing decline estimated to be >10% in 10 years or three generations, or with a specified population structure) in IUCN conservation status evaluation. For these reasons the species is designated as Least Concern.

At present, due to their restricted nesting habits and nomadic nature, the species is vulnerable to habitat loss on their feeding and roosting grounds. Conversions of open habitats to agriculture, grazing, recreation, housing and tourism development are the current threats to the

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species in the wetland complex.

The Short-eared Owl is a common to uncommon winter visitor to Gujarat (Ganpule 2016). The species is usually present from September/October to March/April in the Indian Subcontinent (Grimmett et al. 1998; Ali & Ripley 2001; Srinivasulu & Srinivasulu 2007).

The species usually nests and roosts on the ground and prefers grassland habitat. It is often seen flying low like harriers; its opportunistic diet consists mainly of small mammals and rarely small birds. It is an active hunter, flying low over the ground (less than 6 feet) in search of prey; usually hovers and drops vertically pouncing on prey. The species is considered to be a highly migratory in the northern limits of its global range. Banding data shows 1,000-mile movements in 50 days. These movements also vary and large movements are often related to juvenile dispersals. The longevity record for a Short-eared Owl in the wild is 13 years (Rumet 2012).

Material and Methods

Observations and counts were recorded in November 2016 for nine days in the Shiroda region, located between Odadar and Mokar villages of Porbandar District (Fig. 1). It is located about a distance of 5km from Porbandar Somnath National Highway and connected by a tar road with Odadar and Mokar villages. The study area is Gosabara Mokarsagar Wetland Complex (here after Mokarsagar) which was declared an Important Bird and Biodiversity Area by the Bombay Natural History Society and Birdlife International in March 2017 (Rahmani et al. 2016).

Mokarsagar (21.565^{0}N & 69.764^{0}E) is the largest wetland of Porbandar District and spread across 106km^2. The wetland complex supports more than 20,000 waterbirds annually and thus is shortlisted as a potential Ramsar site as well as Biodiversity Heritage Site. Recently, a public interest litigation has been also filed in Gujarat High Court to declare it as a wildlife sanctuary.

The wetland complex is drained by the Bhadar River, the longest river of the Saurashtra region along with River Billeshwari (Minsar). Before the 1970s, the region was an intertidal mudflat due to the ingress of sea water through the mouth close to Gosabara (21.535^{0}N & 69.710^{0}E) which mixed with fresh water during the

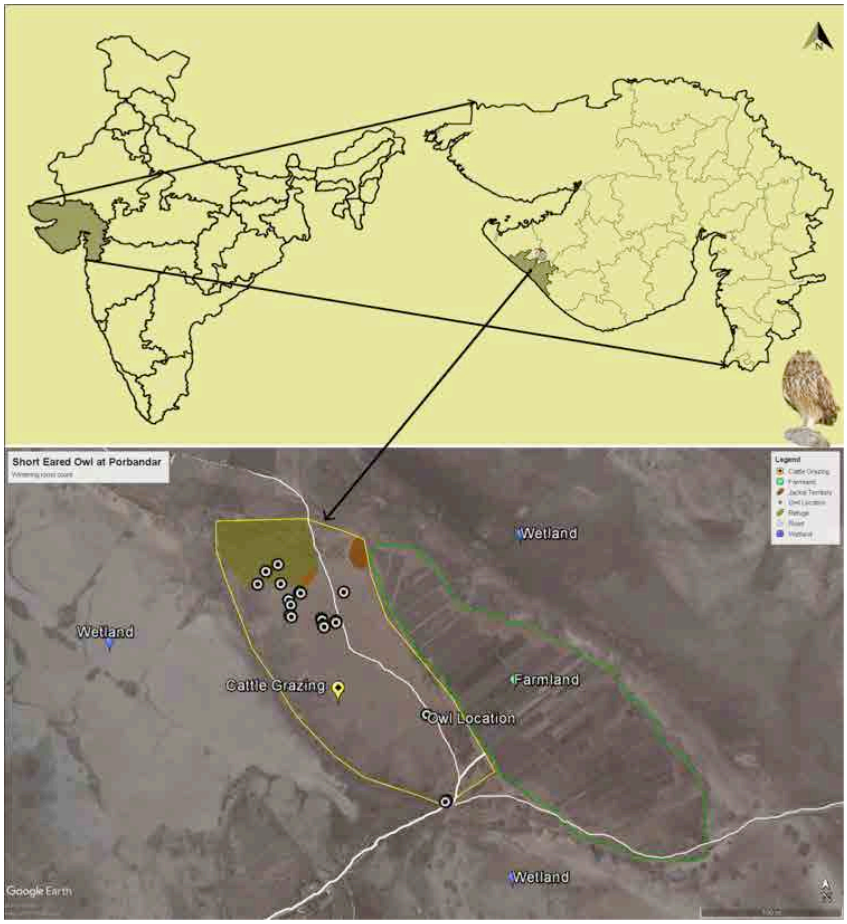

Figure 1. Study area (Shiroda island of Mokarsagar) of Short-eared Owl covering an area of 1km^2

monsoon season. The culvert was created near Gosa Village and resident fishermen used fixed oja nets for catching Prawns *Penaeus penicillatus* (Mansuri 1986). Gradually the tidal influx started impacting the soil and fresh water biota of the region. In order to prevent and control the impacting phenomenon Salinity Ingress Prevention Cell (SIPC), Gujarat, built structures across the creek such as tidal regulators (masonry wall) and bunds at different locations (Singh et al. 2014). These structures prevented the free flow of tidal ingress. As a result prawn fishing was stopped but the quality of agricultural soil improved.

In Mokarsagar, there are four elevated inland islands which usually do not get submerged during the peak monsoon (because the islands lie at about 4–6 m above sea level and the Mokarsagar is at sea level). Shiroda is one amongst these four islands mainly used by the Odadar villagers for grazing livestock.

The wetland complex has been monitored since 2012 for water as well as terrestrial bird count, the frequency is once every month of the year. On 9 November 2016, during the survey in Shiroda, one Short-eared Owl was observed and photographed in the bushes close to the road (Image 1). The bird was not disturbed and count and observation plan was structured to survey the region for the total wintering population of the species.

It was assumed that the Short-eared Owl will be present on all of the four islands of Mokarsagar. Starting from Shiroda, all islands were surveyed for presence of Short-eared Owls. The region was diligently surveyed on foot (after Fuller & Mosher 1987). Randomly, 500m long transect lines (total nine) were conducted in the study area. Walking the transects and counting of roosting birds on both sides and locations were geo-tagged with Garmin eTrex® 30x Handheld GPS device. Apart from Shiroda, the Short-eared Owl was not found on any of the other islands of Mokarsagar. Thus, the data presented is from Shiroda only.

Table 1. Observation chart

Date	Time (hrs)	Comments
09.xi.2016	18:00	Area is mainly grassland with scattered *Prosopis juliflora;* location was also very close to a 'kacha' road less frequently used
10.x.2016	16:00–18:00	Bird was found at same place but remain stable and hidden.
11.xi.2016	18:15	Bird was spotted about 200m away from previous site from the road
13.xi.2016	16:00–18:00	Observed two pairs (4 individuals) from the road
14.xi.2016	16:00–18:00	Observed 12 individuals by foot survey
16.xi.2016	16:00–18:00	Observed 14 individuals by foot survey
17.xi.2016	16:00–19:00	Observed 20 individuals by foot survey

Observation and Discussion

The species was found to roost in bushes of *Prosopis juliflora* on Shiroda island. Realizing the fact that the species was spotted for the first time, an effort for identifying communal roosts was undertaken by going on foot surveys. A total 20 individuals (Table 1) were observed to co-exist with grazing cattle in the grasslands spread over an area of 1km^2 between November 9–17, 2016 (Table 2; Fig. 2). The species prefers bushes to hide (Image 2) but, when unknowingly disturbed by cattle herders, it flies to refuge areas as shown in Fig. 1. The refuge area covers 0.14km^2 with dense vegetation of *Proposis* spp. along with grasses.

The species was observed to co-exist with mammals like Golden Jackal *Canis aureus*, Bengal Fox *Vulpes bengalensis*, Jungle Cat *Felis chaus*, Nilgai *Boselaphus tragocamelus*, Wild Boar *Sus scrofa*, and domestic cattle *Bos domesticus*. The species was also observed to co-exist with 48 bird species (Table 2). No attempts were made to study its interactions with other species. Generally, it remains silent during wintering stage thus no call was observed.

The current sighting of the Short-eared Owl in

Image 1. Short-eared Owl on Shiroda Island

Table 2. Bird Species observed to coexist with Short-eared Owl

	Bird Species	Status in Gujarat (Ganpule 2016)
1	Common Quail *Coturnix coturnix*	Common winter visitor
2	Grey Francolin *Francolinus pondicerianus*	Common resident
3	Cattle Egret *Bubulcus ibis*	Common resident
4	Short-toed Snake-Eagle *Circaetus gallicus*	Common to uncommon resident
5	Eurasian Marsh-Harrier *Circus aeruginosus*	Common winter visitor
6	Pallid Harrier *Circus macrourus*	Common to uncommon winter visitor
7	Montagu's Harrier *Circus pygargus*	Common winter visitor
8	Shikra *Accipiter badius*	Common resident
9	Indian Thick-knee *Burhinus indicus*	Common resident
10	Yellow-wattled Lapwing *Vanellus malabaricus*	Common resident
11	Red-wattled Lapwing *Vanellus indicus*	Very Common resident
12	Kentish Plover *Charadrius alexandrinus*	Common resident and local winter migrant
13	Barred Buttonquail *Turnix suscitator*	Resident and fairly common resident
14	Chestnut-bellied Sandgrouse *Pterocles exustus*	Common resident
15	Rock Pigeon *Columba livia*	Very common resident
16	Eurasian Collared-Dove *Streptopelia decaocto*	Common resident
17	Greater Coucal *Centropus sinensis*	Common resident
18	Sykes's Nightjar *Caprimulgus mahrattensis*	Uncommon winter visitor
19	Indian Nightjar *Caprimulgus asiaticus*	Common resident
20	Green Bee-eater *Merops orientalis*	Common resident
21	Eurasian Kestrel *Falco tinnunculus*	Common winter visitor
22	Isabelline Shrike *Lanius isabellinus*	Winter visitor
23	Bay-backed Shrike *Lanius vittatus*	Common resident
24	Long-tailed Shrike *Lanius schach*	Common resident
25	Southern Grey Shrike *Lanius meridionalis*	Common resident
26	Black Drongo *Dicrurus macrocercus*	Very common resident
27	Rufous-tailed Lark *Ammomanes phoenicura*	Very common resident
28	Ashy-crowned Sparrow-Lark *Eremopterix griseus*	Very common resident
29	Indian Bushlark *Mirafraery throptera*	Common resident
30	Greater Short-toed Lark *Calandrella brachydactyla*	Common winter visitor
31	Sand Lark *Alaudala raytal*	Common resident
32	Crested Lark *Galerida cristata*	Common resident
33	Red-vented Bulbul *Pycnonotus cafer*	Very common resident
34	Sykes's Warbler *Iduna rama*	Common winter visitor
35	Common Tailorbird *Orthotomus sutorius*	Common resident
36	Plain Prinia *Prinia inornata*	Common resident
37	Lesser Whitethroat *Sylvia curruca*	Common winter visitor
38	Common Babbler *Turdoides caudata*	Very common resident
39	Large Grey Babbler *Turdoides malcolmi*	Very common resident
40	Jungle Babbler *Turdoides striata*	Common resident
41	Indian Robin *Copsychus fulicatus*	Common resident
42	Oriental Magpie-Robin *Copsychus saularis*	Common resident
43	Rosy Starling *Pastor roseus*	Very common winter visitor
44	Purple Sunbird *Cinnyris asiaticus*	Common resident
45	Paddyfield Pipit *Anthus rufulus*	Common resident
46	Long-billed Pipit *Anthus similis*	Common winter visitor
47	Tawny Pipit *Anthus campestris*	Common winter visitor
48	Indian Silverbill *Euodice malabarica*	Common resident

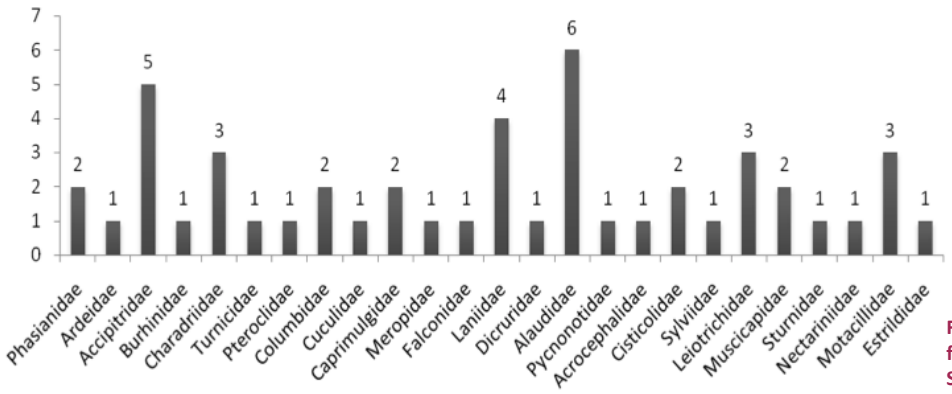

Figure 2. Bird Species of different families observed to coexist with Short-eared Owl

Image 2. Short-eared Owl in the bushes of *Prosopis juliflora*

Porbandar is the first published record for the district as it was not mentioned in previous checklists (Meena & Kumar 2014). Foot surveys were repeated for three days on the same transects and a maximum number of the owls were observed on the third day (i.e., 17 November 2016). Prey base and feeding ecology were not studied, however, we speculate that there is abundant prey at Shiroda Island & its adjacent farmlands, and the dense vegetation of *Prosopis juliflora* along with grass provide spaces roosting and sheltering. The present study is the first systematic attempt to count Short-eared Owls in Gujarat and reports the highest wintering roost congregation of the species.

Based on our limited study and data, we recommend that the management measures should maintain large contiguous tracts of wetland, and grassland habitat for the species and their prey. Controlled human disturbance and predation as well as possible, public education, and continued field research is required.

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Crocodiles of river Krishna: impact on agriculture, economy, and the sociology of human population in Sangli, Maharashtra, India

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Abstract: Krishna is one of the main rivers of the Deccan Plateau. It begins its course in the Western Ghats. A large human population relies on the river Krishna for agricultural irrigation, watering livestock (cattle), fishing and other activities. The presence of and attacks by the Mugger Crocodile *Crocodylus palustris* on humans and livestock are reported in the Krishna resulted in the formulation of the present research. Data collection comprised on-site observations and field interviews using a structured questionnaire. Attacks were found to occur mostly during winter and summer seasons. During winter, crocodiles bask in the sunlight on river banks and attack in self-defense. The summer season corresponds with their breeding period and attacks occur as the crocodiles protect their nests.

Keywords: *Crocodylus palustris,* human-animal interaction, human-crocodile conflict, impact, Mugger Crocodile.

The Mugger Crocodile *Crocodylus palustris* has inhabited the Krishna River in Sangli District of Maharashtra for a long period (Whitaker & Andrews 2003). Its population size has not been determined as no population survey has been carried out. In general, *C. palustris* is shy, but can become aggressive if disturbed in its natural habitat. The crocodile is a long-lived animal, late maturing with complex social hierarchy, easily unapproachable, and studies needs to be carried out over a long period of time and with considerable effort (Chihona2014).The preferred habitat is typically difficult to access. Human beings or livestock are not natural preys of crocodile but they are misidentified as they go down to the water and may appear to the crocodile as a natural prey item. The crocodiles may attack them as defense when human beings or livestock present a threat to the crocodile or its nest.

Extensive water extraction for consumption, irrigation and industrial use, coupled with a decrease in fish stocks in the wild has contributed to habitat loss for crocodiles throughout the world (Botha et al. 2011). Similarly, extensive fishing by fishermen has also affected the crocodiles' feeding habit with the result that the risk of competition for food (livestock and humans) has increased. The crocodiles of Krishna River are also affected by similar factors. Most crocodilians which occur near human population are potential predators of humans and livestock. The recovery of the wild population of crocodiles (Stuart Chihona, 2014) often increases at a large extent, as it increases the human, livestock-crocodile competition. Fishermen and livestock farmers are the most likely victims and hence they are likely to want to reduce crocodile numbers and kill crocodiles (Barnes 1996) or

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damage their nests and/or eggs in an attempt to reduce their numbers (Shacks 2006). Crocodile attacks can also be correlated with the number of crocodiles and condition or state of the habitat. Those rivers with slow flowing water and a flat substrate show presence of a large number of crocodiles (Atigre et al.2015) where the livestock get into the water and the crocodile attack can result. Competition for resources has been a matter of concern for most carnivores, with humans as well as crocodiles, as it affects distribution and behaviour of wildlife (Ehrlich 2009; Vanak & Gompper 2009; Combrinket al. 2011), due to either disturbance or shortage of resources. The shortage of resources coupled with the overpopulation of crocodiles has resulted in the migration of crocodiles from river Krishna to its tributaries, Warana and Kadavi (Patil et al. 2012).

All the above-mentioned potential threats to the crocodile population in the Krishna led to crocodile attacks on human in the last 12 to 15 years. According to the records of the sub-divisional forest office in Sangli, Maharashtra the first known crocodile attack on human occurred in April 2003. Many such attacks on humans and livestock are reported from the selected study area. The present research was initiated to study the impact of crocodiles on agriculture, economy and the sociology of local people in Sangli, Maharashtra.

The main focus of the research was to identify the levels of human-crocodile interactions, i.e., property damage (like crop fields), predation of livestock and attacks on humans. As the study area is densely populated with a heavy agricultural load of sugarcane plantations, the farming community frequently visits the river belt for agricultural purposes. Similarly, there is a large number of cattle domestication in the region. Thus, it is interesting to know how farmers manage the agriculture system and livestock management methods with crocodiles in close vicinity.

Materials and Methods

To identify the impact of crocodiles on agriculture, economy and sociology of human population from Sangli, Maharashtra, the study area was frequently visited from January to May of both years in 2016 and 2017. During these visits, farmers from various villages on the banks were interviewed to collect the research information regarding problem.

Study Area

River Krishna is the third longest river in India, measuring about 1400km. It originates at Mahabaleshwar (17.92^0 N & 73.65^0 E) in the extreme north of Wai Tahsil, Satara District, Maharashtra and meets the Bay of Bengal at Hamasaladeevi (15.95^0 N & 80.98^0 E) in Andhra Pradesh. The selected segment of study starts at Junekhed (17.07^0 N & 74.35^0 E) in Walwa Tahsil of Sangli District and ends at the Krishna-Warana confluence (16.83^0 N & 74.53^0 E) at Haripur near the city of Sangli. This river segment is about 50km long (Fig. 1). The villages on the left bank are Punadi, Nagrale, Shirgaon, Burli, Aamanapur, Anugadewadi, Dhangaon, Audumbar, Bhilawadi, Chopadewadi, Sukhwadi, Bramhnal, Mouje Digraj, Padmale, Sangli (Ganpati Mandir, Gaonbhag, Haripur Road) and Haripur. Villages on the right bank are Junekhed, Navekhed, Walwa, Nagthane, Suryagaon, Santgaon, Shantinagar,

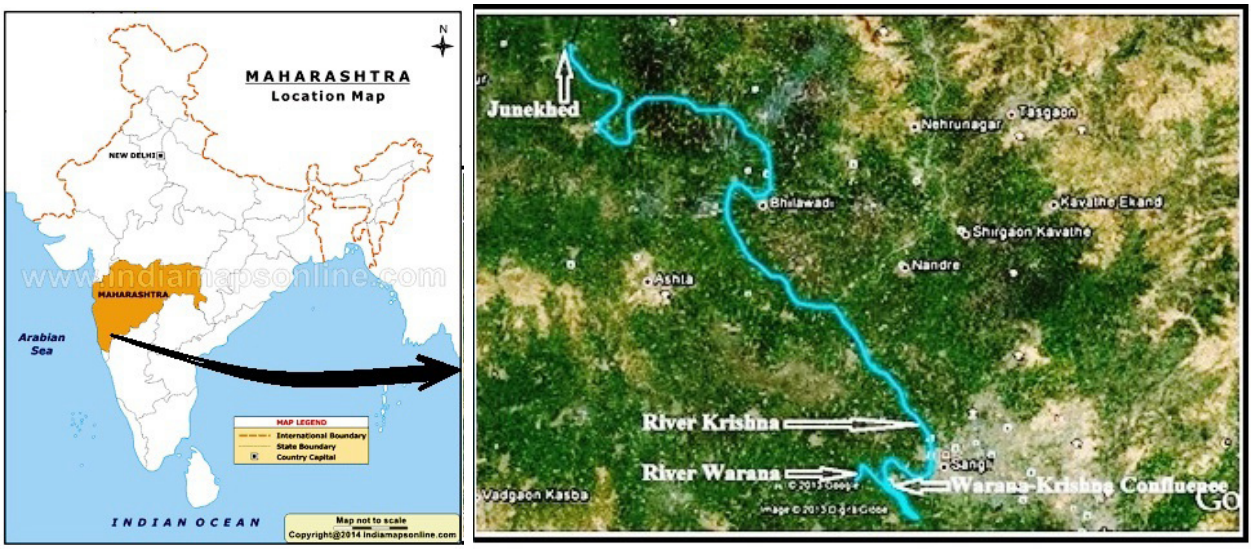

Figure 1. Study area as indicated by the arrows

Ankalkhop, Mardwadi, Karandwadi, Tung, Kasabe Digraj and Sangliwadi. According to 2011 census, the human population of Sangli District was 2,822,143 with density of 329 per km^2 (Directorate of Census Operations, Maharashtra, 2011). The villages Walwa and Bhilawadi are in developing stage with industrialization and there is less interactions while Sangli City is a District place with 447,774 populations and there is no interactions. The populations of all other villages of study area are dependent on agriculture or livestock and are affected by crocodiles.

Image 1. Crocodile observed in water at Bramhnal

Image 2. Two crocodiles observed on red soil at Bhilawadi

Interviews and personal observations

The methodology used included interviews of the people native to the study area together with personal observations made during the visits. Moore (1953), Charnock-Wilson (1970), Abercrombie (1978), and Whitaker (1978) have used this method for crocodile survey to obtain more information or to augment more detailed studies (Parker & Watson 1970) about the problem.

Frequents visits in the study area were carried out during late winter and summer seasons from January to May to identify the impact of the crocodile population on agriculture, economy and the sociology of human population. This is the breeding period of *C. palustris*. The crocodile lays eggs in the month of March in nest holes, which hatch in the last week of May. Farmers, women, cattle herders and wash girls who visit the river bank in the study area regularly were interviewed with the help of a questionnaire. Farmers' were asked about interference of crocodiles in their routine works of farming and cattle domestication. A total of 212 questionnaires from the people of the age group 15 to 70 years were collected and analyzed. Independent and random sampling methods were used for the selection of farmers from every village. The village guard (Kotwal), village revenue officer (Talathi), and the village headman (Sarpanch) were included in the surveys due to their responsibility in dealing with human-crocodile interactions in the study area.

Observations and Results

Crocodile sightings

During most of the surveys crocodiles were observed basking on the river banks in the study area. A population count was not done. Respondents who were daily visitors to the river reported the presence of crocodiles in Krishna and this was supported by researcher observation; photographs of basking crocodiles were taken during study visits (Images 1 & 2). Respondents reported that crocodiles could be observed about 50mfrom either river banks, more frequently observed basking on the grass, soil or few rocky surfaces. They also reported that more number of crocodiles are observed in recent 5–6 years than past and the size of crocodiles is also bigger.

Crocodile attacks on livestock and humans

Table 1 demonstrates that there were more crocodile attacks on livestock than on humans mainly in the summer months. Respondents reported that livestock (buffalo, cow, sheep and goat) are driven to the water to drink and most of the drinking sites are covered with a thick canopy. The density of the vegetation was directly proportional to the attacks on livestock, with few attacks noted in open spaces. The respondents, particularly the village guards noted that out of all these attacks on cattle very few were fatal; cattle were strong and large enough to escape from the crocodile jaws. There were more attacks on the cattle in the evening (82%), rather than during the morning (18%) (Table 3). The cattle herders needed to remain vigilant during this process, with some reporting that they held the tails of the animals to pull them away from possible attacks. Before the animals drank water, the cattle herders threw stones to chase the crocodiles away from the banks. Cattle were mostly attacked as they entered the river for drinking and therefore became an easy target for the crocodiles.

Sixteen (16) attacks on human were recorded in the study area from April 2003 to March 2017, of which six were female and 10were male. Out of these 16 incidents,

Table 1. Summary of the Mugger Crocodile survey and observations

Crocodile Survey			Observations		
Length of river surveyed	No. of villages visited	No. of respondents	River water used for	Reported crocodile attacks (April 2003 to March 2017)	Impact of crocodile attacks
50km	16	212	. Irrigation to crop plants . Watering and washing cattle . Washing clothes . By women . Bathing	. 16 on humans . 62 on cattle	. Loss of human life . Loss of cattle life . Loss of wealth for treatment . Damage to crops . Decrease in crop yield

Table 2. List of crocodile attacks on human

	Date of interaction	Place of interaction	Name of person	Gender	Remark
1	29.iv.2003	Kadam vasti Kasbe Digraj	Mr. Aniket Rajaram Kadam	Male	Dead
2	11.ix.2003	Sakharwadi, Bhilawadi	Mr. Ramchandra Bhiku Nalawade	Male	Dead
3	19.vii.2005	Chopadewadi	Mrs. Ratnaprabha Nayku Yadav	Female	Injured
4	16.iii.2007	Ankalkhop	Mr. Sunil Pandurang Bhosale	Male	Dead
5	28.vi.2008	Bhilwadi	Mr. Tanaji Keru Kamble	Male	Injured
6	28.viii.2008	Dhangaon	Mrs. Sunita Balaso Mohite	Female	Injured
7	17.x.2008	Bhilawadi	Mr. Ramchandra Nana Kamble	Male	Severely injured
8	13.ix.2009	Dhangaon	Mr. Mahadev Keshav Yadav	Male	Injured
9	13.xi.2010	Bramhnal	Mrs. Varsha Vinod Kamble	Female	Dead
10	02.vi.2011	Walawa	Mrs. Kalpana Babaso Khandekar	Female	Severely injured
11	11.iv.2011	Ankalkhop	Mr. Tushar Balaso Magadum	Male	Dead
12	17.ix.2013	Aamanapur	Mr. Shankar Bhau Pawar	Male	Injured
13	14.iv.2014	Bramhnal	Mrs. Sakhubai Dilip Kamble	Female	Severely injured
14	12.iii.2015	Bhilawadi	Mrs. Sushama Dadu Changdeo	Female	Dead
15	25.v.2015	Kasabe Digraj	Mr. Shivaji Nana Chougale	Male	Injured
16	05.iii.2017	Haripur	Mr. Keshav Damu Patil	Male	Severely injured

Table 3. Summary of observations

	Description	Observation
1	Time of the day when the cattles are driven to the river for water	82% in the evening 18% in the morning
2	Crop plantation in the study area	70% area covered with sugarcane 30% area with seasonal crops
3	Damage to crops by crocodile movements	10%of crops were damaged
4	Crocodile attacks on humans	37.5% (6) attacks caused death 25% (4) were severe 37.5% (6) were not severe

six (37.5%) caused death while 4 (25%) were severe and the remaining six (37.5%) were not severe (Table 2). Though the humans of all age groups were attacked, the humans above 60 years of age were severely harmed. Interestingly, in all of the crocodile attacks the victims' bodies (both humans and cattle) were recovered with no missing organs or body parts. This clearly indicated that the crocodiles had not attacked the humans or the livestock for food.

Damage to crop plants

The soil surface on both the banks of the river is covered with sugarcane plantation (70%) along with some seasonal crops (30%) such as groundnut, wheat, jowar and maize (Table 3). The basking period of *C. palustris* is during the winter when the farmers grow short-lived (three months) seasonal crops. The crocodiles come out of the water for basking and move to the nearby cropland. The majority of the respondents (87%) reported that crocodiles damaged the small or newly germinated crops (about 10% of crops in the 50m area) (Table3).

Discussion and Conclusions

There has been a remarkable increase in human-wildlife conflict worldwide (Woodroffe et al. 2007). The increase is linked to the risk factors associated with predator attacks on humans and livestock that range from fatal injuries to death (Ogada et al.2003). Positive

solutions for these negative interactions need a deep understanding of the local situation, anthropogenic factors and ecological aspects of the area. This will reduce negative attitudes towards the predators, and will serve to further maintain viable populations of predators, even creating good breeding sites for them to boost other areas (Chihona 2014). This will increase the chances for a predator such as *Crocodylus palustris* to retain its status in natural waters.

Villages close to the river are mainly affected by crocodile attacks. Livestock are mainly attacked when they enter the river for water as well as when they graze on river banks during the summer months. This can be correlated with the breeding season of the crocodiles in India. Mating occurs in late February or early March and the females lay eggs which are incubated in nest holes near the water edge for 80 to 90 days. Hatching occurs usually in late May (Patil & Atigre 2016) and the female carries her hatchlings in her mouth to the water (https://www.youtube.com/watch?v=XH3xQQ9_ZmI). The most interaction have occurred in the summer months which is the breeding season of *C. palustris* and they are protecting their nests.

The data showed that more than 60% of cases of attacks on humans resulted in severe injury or death since 2003. The social impacts on victims' families vary depending on the victim's familial responsibilities. For example, the loss of a parent, a breadwinner, means that the children drop out of schools, be forced to engage in activities like cattle herding for boys and house hold chores for girls. Furthermore, girls would be forced into premature marriages as they try to alleviate poverty in their homes. In the case of severe injuries in crocodile attacks, maximum income of the family is used for treatment and reduced workforce for agricultural activities.

This study did not measure the effects of crop raiding. All seasonal plants are sowed in the winter along with new sugarcane plantation, when crocodiles are seen basking on the banks. Crocodiles move out of water on to the land in the morning causing damage to the young crops resulting in economic losses to the farmers.

Although crocodiles have become a threat to the agricultural, economic and social scenario of the region, there were no reports or observations that they are harmed or attacked.

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Appendix 1. Questionnaire

Respondents' information

Place: Date:
Latitude Longitude:
Name of person:
Address:
Age: Education: Occupation:

Since when, you are staying nearby the habitat of crocodile?

Questions:

1. Have you seen any crocodile/s?
2. How many times?
3. How long are you watching a crocodile/s?
4. How many crocodile/s at a time you have seen?
5. What is the length of crocodile/s?
6. Have you seen eggs of crocodile/s? How many?
7. Have you seen young ones of crocodile/s? How many?
8. Have you seen a crocodile with young ones?
9. Have you heard the sounds of crocodile/s or its young ones?
10. Have you seen nest of crocodile/s?
11. How many crocodile/s live in one nest?
12. Do you know any crocodile -human conflict or attack on any other animal?
13. When? How many times?
14. Is anybody injured or died in crocodile/s attack?
15. Does Crocodile damage the crop plants?
16. If yes, How and When?
17. Give the quantitative data.
18. Have you heard about crocodile/s protection and conservation?
19. Is there a need of crocodile/s protection and conservation?
20. How to protect and conserve crocodile/s?
21. Have you any memorable event regarding crocodile/s?
22. Will you accept a crocodile park in your area?

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SHORT COMMUNICATION

A new report on the clasper movements of a captive Sand Tiger Shark *Carcharias taurus* (Lamniformes: Odontaspididae) and a possible reason for the behaviour

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Abstract: Elasmobranchs present four clasper movements, which can be seen in different contexts from mating to no obvious reason. Three movements have been reported in *Carcharias taurus* and here the first occurrence of clasper flaring in this species is described. Clasper flaring was observed while other species were in a reproductive state and their aggressive behaviour towards the subject of this study was also observed.

Keywords: Agonistic behavior, *Carcharias taurus*, elasmobranch, Grey Nurse Shark, reproduction, reproductive behaviour.

Elasmobranchs have an external structure used to copulate, known as a clasper. This structure has the ability of movement by itself in order to facilitate copulation (Gilbert & Heath 1972). Four clasper movements have been described, as follows: flexion (movement of individual claspers backwards and forwards); splaying (the male contorting itself and opening his claspers up to 90^0 to the body axis); crossing (claspers crossed with tips posterolateral); and flaring (clasper flexed and bent forward with their distal ends spread) (Gordon 1993; Compagno 2001; Ritter & Compagno 2013).

In lamnoid sharks, the clasper skeleton is constituted of the clasper shaft on the anterior region and the clasper glans on the posterior part. This second region presents a structure called a clasper hook, which helps the male to anchor itself to the female during copulation (Gilbert & Heath 1972; Compagno 2001). Specifically in the Grey Nurse Shark *Carcharias taurus,* just the first three clasper movements have been reported (Gordon 1993; Compagno 2001); and it is believed that clasper flexion occurs in different contexts, from mating to without an obvious reason (Myrberg & Gruber 1974; Gordon 1993).

There are two hypotheses for the causation of these movements in elasmobranchs: an agonistic cause (Martin 2007) and a pre-/post-copulation behaviour related to sperm transportation (Gilbert & Heath 1972;

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Ritter & Compagno 2013). Although these theories could explain some of the reports, they are not applicable to all the circumstances. Therefore, here we report the first occurrence of clasper flaring in *Carcharias taurus* and present a new hypothesis for its causation, which would also explain why these two hypotheses have been made.

Materials and Methods

The subject of study

Our subject was an adult male *Carcharias taurus* that was 1.9m length, 80kg in weight and between 20-23 years old. This individual was housed in the Oceanarium tank at Aquário de São Paulo, São Paulo, Brazil, which is a 1,000m³ enclosure with depths varying from 1.4m in the superior area to 5m in the lateral areas.

Besides this specimen, the tank was inhabited by eight Nurse Sharks *Ginglymostoma cirratum*, two Brownbanded Bamboo Sharks *Chiloscyllium punctatum*, five Southern Stingrays *Hypanus americanus* and 10 bony fishes.

This was an opportunistic data collection, since the main objective of the research was to better understand the behavior of the subject. After the first observation of the clasper movements, a new focus has been given to the study. So, a focal all-occurrences sampling protocol was used due to the low frequency of the observed movements (Altmann 1974; Lehner 1996). We recorded the type of clasper movements, time of occurrence, duration and additional observations (such as other inhabitants' reproductive and aggressive behaviors).

Observations were made for 72 hours between January and April 2015; 36 hours of this total were realized between 09:00 and10:00 hr and the remainder, between 21:00 and 22:00 hr. At night time, the tank's light was turned off since the aquarium does not work at this period. So, the observation was made with the aid of a flashlight. However, considering that unexpected changes in the lighting intensity can cause stress in elasmobranchs (Powell et al. 2004), the lights were turned on for 30 minutes before all nocturnal observations. Since this study was purely observational, it was not considered necessary to ask for an ethical permission.

Results

Clasper flexion and splaying were not performed by the subject in this study. We, however, observed two clasper movements: clasper crossing (CC) (clasper crossed with tips posterolateral) and clasper flaring (CF). This last movement consists of the clasper crossed at 90º to the body axis while their tips bent downward and spread itself, showing up its clasper hook (Fig. 1) (supporting information), that has never been reported on this species before.

Clasper crossing was observed on four nights, counting a total of seven occurrences in this work, while clasper flaring was observed on six days, adding up to seven occurrences (Table 1). These movements were observed while two other species (*Ginglymostoma cirratum* and *Hypanus americanus*) were at a reproductive stage, and so, some aggressive behaviour of these inhabitants toward the subject of this study (Table 1) was observed.

Table 1. Description on occurrences of clasper movements in a captive *Carcharias taurus*. Additional observations are given on the context in which the behaviour has been performed.

Day	Hour	Clasper movements	Duration (seconds)	Additional observations
07.i.2015	21:44 21:56 21:59	CC CC CC	50 60 20	-The subject was contorting itself while doing these behaviours -The nurse sharks of the tank were stalking the subject at 21:53
09.ii.2015	21:21 21:22	CF CC	60 480	
05.iii.2015	21:04 21:45	CF CF	60 45	-Male nurse sharks were active and one of them performed CC at 21:01
09.iii.2015	21:40	CF	30	-After the clasper movements, the subject contorted itself for 20 seconds
16.iii.2015	21:53	CC	20	
14.iv.2015	21:33	CF	35	
15.iv.2015	21:47 21:47 21:48	CC CF CC	10 15 25	-Before the clasper movements, the nurse sharks stalked the subject -One male Southern Stingray performed clasper crossing at 21:11
24.iv.2015	21:53	CF	90	-One female Southern Stingray released one egg capsule at 21:17

CC - clasper crossing (clasper crossed with tips posterolateral); CF - clasper flaring (clasper crossed at ninety degrees to the body axis while their tips bent downward and spread itself, showing up its clasper hook).

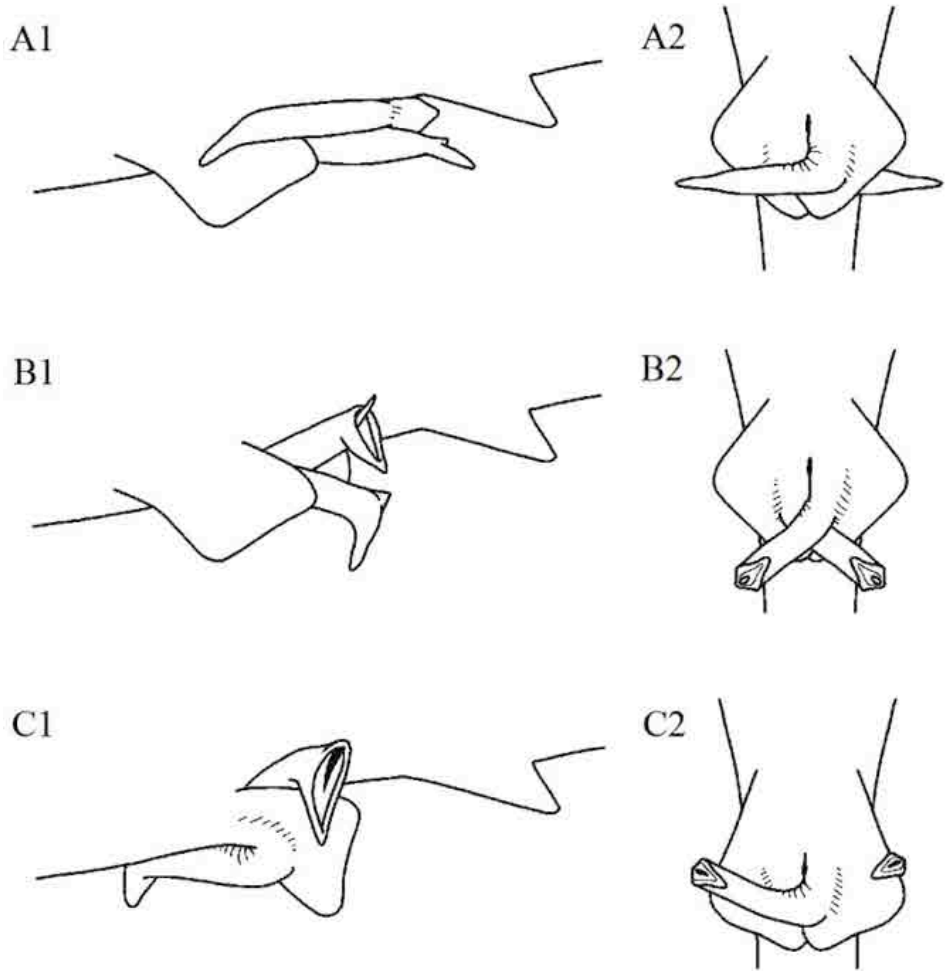

Figure 1. ***Carcharias taurus*** **clasper movements: A1 - crossing claspers (lateral view); A2 - crossing claspers (ventral view); B1 - clasper flaring showing up its hook (lateral view); B2 - clasper flaring showing up its hook (ventral view); C1 - clasper flaring at ninety degrees to the body axis while their tips bent downward and spread itself (lateral view); C2 - clasper flaring at ninety degrees to the body axis while their tips bent downward and spread itself (ventral view).**

Discussion

Clasper movements have been reported for various elasmobranch species: Bullhead Shark *Heterodontus francisci*, *Ginglymostoma cirratum*, *Carcharias taurus*, Gray Reef Shark *Carcharhinus amblyrhynchos*, Silky Shark *Carcharhinus falciformis*, Chain Catshark *Scyliorhinus rotifer*, Bonnethead Shark *Sphyrna tiburo*, Cape Shark *Squalus acanthias*, Whitetip Reef Shark *Triaenodon obesus*, Clearnose Skate *Raja eglanteria*, *Hypanus americanus*, Giant Manta Ray *Manta birostris* and Bat Ray *Myliobatis californica* (Myrberg & Gruber 1974; Klimley 1980; Tricas 1980; Gilbert 1984; Luer & Gilbert 1985; McKibben & Nelson 1986; Uchida et al. 1990; Gordon 1993; Carrier et al. 1994; Yano et al. 1999; Pratt & Carrier 2001; Chapman et al. 2003; Galván-Tirado et al. 2014). Most of these movements correspond to clasper flexion and, in some cases, clasper crossing.

During copulation, some species are known to expand and spread the tip of the inserted clasper to anchor the male securely to the female (Gilbert 1984; Luer & Gilbert 1985). Moreover, a *Triaenodon obesus* and a Flapnose Ray *Rhinoptera javanica* performed this behavior for a few minutes exactly after mating as witnessed by Uchida et al. (1990) in a captive environment. The expanded and spreading tip's condition observed on those studies are similar to those found in this work, besides the fact that our subject did not exhibit the behavior in a reproductive context.

In general, movements of claspers occur as a pre-copulatory behavior (Myrberg & Gruber 1974; Gordon 1993). Nevertheless, studies on *Sphyrna tiburo* and Grey Bamboo Shark *Chiloscyllium griseum* have reported these movements outside of mating events without being able to identify a cause for their occurrences (Myrberg &

Gruber 1974; Pratt & Carrier 2001). Martin (2007) has analysed agonistic behaviors in elasmobranchs and has pointed out that clasper flexion can be included in this classification despite its uncommon frequency.

During the mating season, agonistic behaviors are carried out as sexual conflict and may be directed toward conspecifics and other species which inhabit the same habitat (Gordon 1993; Martin 2007). In *Ginglymostoma cirratum*, aggressive behaviors are required to acquire and mate with females (Pratt & Carrier 2001) and can also be addressed in interspecific interactions (Henningsen et al. 2004).

The clasper movements here reported occurred at night, which agree with the nocturnal activity of the species (Compagno 2001; Hannon & Crook 2004; Barker et al. 2011). The manifestation of these movements occurred at the same time of pre-copulatory and aggressive behaviors of *Ginglymostoma cirratum*'s and *Hypanus americanus*'s specimens of the tank.

The Sand Tiger Sharks have been studied in captivity by Henningsen et al. (2004). These studies have reported that intrasexual conflicts can occur in a tank with only males of this species; they have also observed interspecific sexual conflicts of *Ginglymostoma cirratum* towards *Carcharias taurus*, which agrees with the findings of the present study.

Gordon (1993) stated that clasper flexion occurs in an elevated frequency when males start to perform pre-copulatory behaviors and, based on the study of Myrberg & Gruber (1974) with *Sphyrna tiburo*, stated the hypothesis that they might occur in different times of the year as well. Thus, this work presents not only the first evidence of clasper movements in grey nurse sharks in a different context from mating, but also as a new movement type.

In addition, our observations permit us to hypothesize that the claspers' displays are correlated with interspecific sexual conflicts, especially as a response to aggressive behaviors performed by the cohabitants, such as stalking, snapping and tailing. Probably, environmental stimuli present in the tank initiate physiological responses such as clasper movements. Additional research on clasper movements, however, is still needed. Studies in different facilities and with bigger captive populations should be carried out to permit a better understanding on this topic.

Another important question to consider is if there are any steroid hormones influencing these behaviors, since it is known that sexual conflicts are influenced by hormones, such as testosterone and progesterone (Henningsen et al. 2008). Attention should be paid to the restricted area in which such captive mature animals inhabit, which could affect the hormones' effects, since the most common tank has a semi-closed system (Mohan & Aiken 2004) that may result in a concentration of these hormones.

Conclusions

Carcharias taurus can perform at least four clasper movements. Besides clasper flexion, splaying and crossing, already described in the literature, this species can achieve a new mode, clasper flaring. Although this behaviour has already been seen in other species, this is the first report analyzing its occurrence without a reproductive context.

The results suggest that clasper movements are related to environmental stimuli, in a context different from mating. We believe that the convergence of reproductive behaviours of other species from the tank could have resulted in a physiological response in the subject that affected its behaviour. This would explain not only why the clasper movements are frequently seen in a captive context (since it normally has a closed system), but also why the movements here described occurred together with agonistic displays.

These results suggest the need to explore water sample analyses to better understand the stimuli that are released and that could affect the physiology behind behaviours and interspecific relationships in natural and artificial environments. These analyses would also improve captive husbandry techniques, since it could give us information on the need for keeping species apart at certain periods to avoid interspecific conflicts in confined environments.

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Short Communication

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New species of termite *Pericapritermes travancorensis* sp. nov. (Isoptera: Termitidae: Termitinae) from India

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Abstract: A new species of *Pericapritermes*, *P. travancorensis* sp. nov. (Isoptera, Termitidae, Termitinae), is described from Kerala, India, based on the characters of the king, queen, imago, soldiers, and workers. Morphological measurements of the king, queen, imago, soldiers, and workers are given with suitable illustrations. List of species of the genus *Pericapritermes* from the Oriental region is provided.

Keywords: Isoptera, Kottayam District, new species, *Pericapritermes,* Termitidae.

India is a region rich in termite diversity. Roonwal & Chhotani (1989) listed and comprehensively described 337 species of termites under 59 genera from the Indian sub-region (comprising of India, Pakistan, Nepal, Bhutan, Bangladesh, Myanmar, and Sri Lanka). Krishna et al. (2013) listed 290 species of termites belonging to six families and 54 genera from India. Mathew (2004) reported 56 species under 23 genera belonging to four families of termites from Kerala. The current termite fauna of Kerala can be estimated to be 66 species belonging to three families and 29 genera (Amina et al. 2016).

Silvestri (1914) described the genus *Pericapritermes* based on *Pericapritermes urgens*. The genus has been reported from the Ethiopian region by Snyder (1949) and Emerson (1955). The studies of Krishna (1968) transferred many species of the genus *Capritermes* with *Pericapritermes*, collected from Indo-Malayan region and New Guinea. Presently, *Pericapritermes* is known from the Oriental, Ethiopian, Palearctic, and Papuan regions (Thomas et al. 2008); Krishna et al. (2013) listed 40 species under the genus *Pericapritermes*. The oriental region contains 24 species in which six species are known from India (Table 3).

The soldiers of *Pericapritermes* are the most advanced in the *Capritermes* group in that their mandibles are robust and strong. The left is twisted and arched in the middle, with its apex blunt, and the right is flat, straight, and blade-like; in defence, they are locked together and released with a loud click, flipping the soldier several inches through the air (Thomas et al. 2008). The head is flat, the forehead is not steep, and the frontal gland is much reduced. The labrum of the soldier is straight at the anterior margin and with small anterio-lateral points. Imago has a large, oval fontanelle (Roonwal & Chhotani 1989). The apical tooth is shorter than the fused first plus second marginal tooth, the posterior margin of the fused first plus second marginal tooth is elongated

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and sinuate, and the third marginal tooth is prominent (Roonwal & Chhotani 1989). The members of this genus are soil feeders. Soil-feeding termites constitute 38.3% of Termitidae species, which dominate several subfamilies (Jones & Eggleton 2011). *Pericapritermes* build subterranean diffuse gallery systems that consist of clusters of small cells connected with tunnels, with the cells usually adjacent to underground hard materials.

Material and Methods

Specimens were collected from CMS College Campus, Kottayam District of Kerala State, southern India, which is situated between 9.596^{0}N 76.520^{0}E. The area is characterized by humid tropical climate with a mean annual rainfall around 3,600mm, and temperature ranging from 20–37 ^{0}C. CMS College Campus contains 35 acres of protected land. The tropical climate of this region supports rich biodiversity.

Collection and Identification of Termites

All the termites encountered in the colony were collected using an aspirator and preserved in 80% alcohol. Measurements and photographs were taken using Labomed Luxeo 4D binocular microscope with attached camera and PixelPro software at magnification 8X–35X. Morphological terminology, measurements, and indices for describing soldiers, workers, and imago follow Roonwal & Chhotani (1989), and Sands (1998). Important measurements and indices used in the study were total body length with wing, total body length without wing, length of head to lateral base of mandibles, maximum width of head with eye, maximum diameter of compound eye, maximum diameter of lateral ocellus, minimum eye-ocellus distance, maximum length of labrum, maximum width of labrum, length of left mandible, length of right mandible, maximum length of Pronotum, maximum width of Pronotum, minimum length of postmentum, maximum width of postmentum, minimum width of postmentum, minimum length of hindwing without scale, minimum length of forewing without scale, head width/head length index, and mandible length/head length index. The population study was done using direct count method.

Museum details

The holotype and paratypes are preserved in 80% alcohol and deposited in the Zoology Museum, Department of Zoology, CMS College, Kottayam, Kerala, India.

Pericapritermes travancorensis sp. nov. (Image 1)

urn:lsid:zoobank.org:act:E49C1081-D644-4E51-877A-E147BD91B7C1

Material examined

Holotype: CMSZMAI-101, Soldier, 08.xi.2015, CMS College Campus, Chungam, Kottayam, Kerala, India, 9.596^{0}N & 76.520^{0}E, 2.97m, coll. Jobin Mathew.

Paratypes: CMSZMAI-102, Soldier; CMSZMAI-103, Imago; CMSZMAI-104, King; CMSZMAI-105, Queen; CMSZMAI-106, Worker; 08.xi.2015, CMS College Campus, Chungam, Kottayam, Kerala, India, 9.596^{0}N & 76.520^{0}E, 2.97m, coll. Jobin Mathew.

Diagnosis

Five species of *Pericapritermes* were known from India. Diagnostic characters of the soldiers from India with their distribution are given in the Table 4. *Pericapritermes* found in the Indian subcontinent classified as large, medium and smaller species. *P. dunensis* was the only species coming under the medium group (Roonwal & Chhotani, 1989) *P. travancorensis* sp. nov. is a medium sized termite showed affinity with *P. dunensis*. *P. dunensis* was described from Dehra Dun, India; and has later been reported from Meghalaya, Arunachal Pradesh, Uttar Pradesh West Bengal and Bhutan (Roonwal, M.L. & Sen-Sarma, 1960; Roonwal & Chhotani, 1989). Imago of *P. dunensis* have body length with wings 14.10-15.10 mm, body length without wings 7.40-8.00 mm and length to the base of mandibles 0.90-1.00mm. Whereas In *P. travancorensis* sp. nov. body length with wings 10.77-11.23, body length without wings 5.58 – 6.45 mm and length to base of mandibles 0.78-0.82. *P. travancorensis* sp. nov. can be easily distinguished from *P. Dunensis* by larger soldier and mandible of the soldier. In this species right mandible is equal or slightly longer than left (Tables 1 & 3). The imago of the *P. travancorensis* sp. nov. smaller than the *P. Dunensis*, fontanelle large and sub-squarish. Moreover *P. dunensis* confined to the northeast of India.

Description

Holotype: Soldier

Head-capsule yellowish-brown, uniformly coloured, antennae yellowish darker anteriorly, labrum and pronotum pale with yellowish tinge, left mandible blackish, right mandible reddish-brown, legs and abdomen pale yellowish; head and body sparsely hairy; total body length 7.10 mm; head-capsule sub-rectangular, sides sub-straight (length to base of mandibles 2.63 mm, width 1.4 mm, index width/length 0.56 mm); in profile frons sloping in front and

shallowly depressed medially, median suture present, not extending up to fontanelle, fontanelle minute, circular, situated anteriorly, occipito-fontanelle distance 1.87 mm; antennae 14-segmented, segment 4 smallest; labrum fleshy, anterior margin depressed medially, antero-lateral corners produced into small, pointed tips; mandibles strongly asymmetrical, longer than half the length of head-capsule, left mandible strongly twisted at middle, with a spoon like tip, right blade-like tip pointed and weakly out curved apically, longer than left mandible (length: left 1.73 mm, right 1.74 mm, index left mandible length/head-length 0.66mm) (Fig. 1D); postmentum long club-shaped, weakly narrowed at waist (length 1.16 mm, max. width 0.42 mm, width at waist 0.28 mm) Pronotum saddle shaped, anterior margin convex, posterior margin with a weak median notch (length 0.35 mm, width 0.82 mm) (Figs. 6–12, Table 1).

Table 1. Table showing the various measurements of CMSZMAI-101 holotype of *P. travancorensis* sp. nov. (in mm)

Characters	Soldier
Total body Length (Without wings)	7.10
Total Head Length	4.32
Head Width	1.40
Head Length (Without Mandibles)	2.63
Left Mandible Length	1.73
Right Mandible Length	1.74
Labrum Length	0.24
Labrum Width	0.29
Pronotum Length	0.35
Pronotum Width	0.82
Postmentum Length	1.16
Postmentum Width Maximum	0.42
Postmentum Width Minimum	0.28
Head W/Head L	0.53
Mandible L /Head L	0.66

Colony

The termite colony was found in porous laterite soil. The colony consists of clusters of small cells connected with tunnels, with the cells usually adjacent to small crevices of the laterite stones. The colony occupied an area of 3697cm^3 and was located between the depth of 3.6–9.6 cm from the surface. The royal chamber is an enlarged cell with smooth, almost polished, and quite clean inner surface. It contains the royal pair and a number of soldiers and workers. Maximum number of workers and soldiers were observed below 3.6cm. Foraging workers were noticed 1.5m away from the colony. The numbers of individuals of different castes of the colony were as follows: king - 1, queen - 1, imago - 5, workers - 1265, soldiers - 119, immature workers – 1153, and immature soldiers - 86.

Paratype: Imago

Head dark brown, postclypeus, labrum, antennae and legs brownish-yellow, pronotum dark brown paler anteriorly, abdomen dark brown above and yellowish below; head and body with a coat of fine short hairs and several long hairs; total body-length with wings 10.77–11.23 mm and without wings 5.58–6.45 mm; head-capsule subcircular (length to base of mandibles 0.78–0.82 mm, width with eyes 1.18–1.23 mm); fontanelle

Image 1. *Pericapritermes travancorensis* sp. nov. soldier

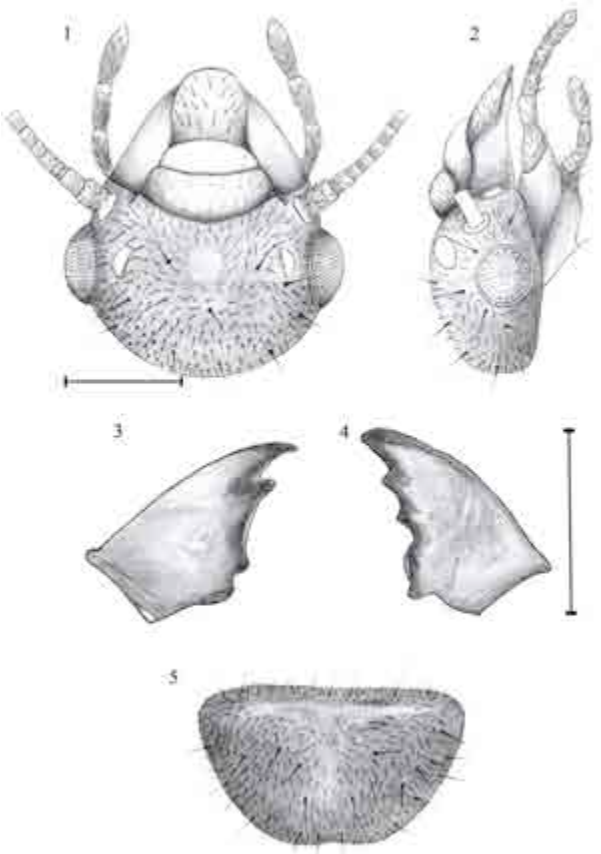
Table 2. Table showing the various measurements of CMSZMAI-102, 10 Soldiers; CMSZMAI-103, 4 Imagos; CMSZMAI-104, 1 King; CMSZMAI-105, 1 Queen; CMSZMAI-106 soldier, 10 workers of *P. travancorensis* sp. nov. (in mm). Measurements are based on 1 king, 1 queen, 4 imagos, 10 soldiers, and 10 workers.

Characters	King	Queen	Imago	Soldier	Worker
Total body length (with wings)	-	_	10.77–11.23	_	_
Total body length (without wings)	6.36	17.82	5.58–6.45	6.29–7.30	4.48–5.33
Total head Length	1.27	1.28	1.26–1.34	4.18–4.43	1.26–1.36
Head width	1.23	1.22	1.18–1.23	1.35–1.51	0.93–1.06
Head length (without mandibles)	0.82	0.79	0.78–0.82	2.49–2.73	0.74–0.83
Left mandible length	_	_	_	1.65–1.83	_
Right mandible length	_	_	_	1.71–1.87	_
Maximum diameter of eye	0.25	0.24	0.24–0.30		_
Eye ocilla distance	0.13	0.11	0.11–0.13		
Ocellar diameter	0.11	0.12	0.11–0.13		
Labrum length	0.30	0.31	0.29–0.31	0.22–0.26	0.34–0.36
Labrum width	0.29	0.32	0.29–0.32	0.27–0.31	0.41–0.43
Pronotum length	0.64	0.63	0.61–0.68	0.29–0.39	0.19–0.24
Pronotum width	1.12	1.16	1.04–1.16	0.74–0.92	0.53–0.62
Postmentum length	0.27	0.26	0.26–0.30	1.14–1.19	0.27–0.33
Postmentum width (maximum)	0.32	0.35	0.34–0.39	0.40–0.45	0.25–0.30
Postmentum width (minimum)	0.34	0.33	0.32–0.36	0.26–0.30	_
Head width / Head length	1.5	1.54	1.46–1.54	0.55–0.59	1.24–1.35
Mandible length /Head length	_	_	_	0.65–0.73	_
Fore wing length	_	_	8.47–9.10	_	_
Hind wing length	_	_	7.75–8.46	_	_

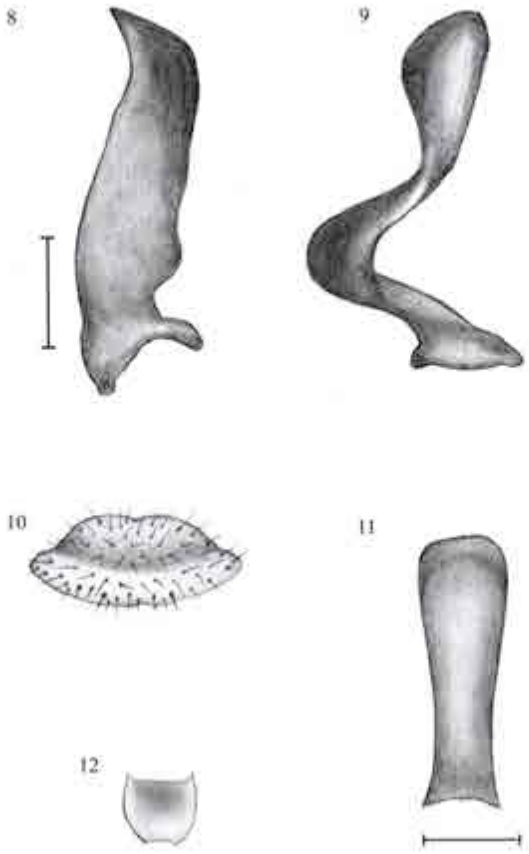
golden yellow, slightly depressed around fontanelle; epicranial suture indistinct; eyes round, strongly projecting, nearly equidistant from antennae and ocelli, (max. diameter 0.24-0.30 mm); ocelli oval, 0.11–0.13 mm long; eye ocillar distance 0.11–0.13 mm; postclypeus swollen, hairy; antennae with 15 segments; segment 3 shortest; 4 longer than 5 and 5 subequal to 3; mandibles with a prominent apical teeth and a pair of teeth basaly; pronotum flat, length 0.61–0.68 mm, width 1.04–1.16 mm, anteriorly weakly notched medially and posteriorly slightly emarginated; postmentum subsquarish length 0.26–0.30 mm, width 0.34–0.39 mm; wings brownish, membrane with distinct cubitus, media, and radius veins, in forewing and hindwing media arising from radius inside wing-membrane near to the wing scale, forewing-length 8.47–9.10 mm, hindwing-length 7.75–8.46 mm; body dimensions and colouration of king similar to imago but with slightly enlarged paler abdomen;total body length of queen 17.82 mm, abdomen whitish with yellowish tinge nearer to the sclerite (Figs. 1–5, Table 2).

Paratype: Soldier

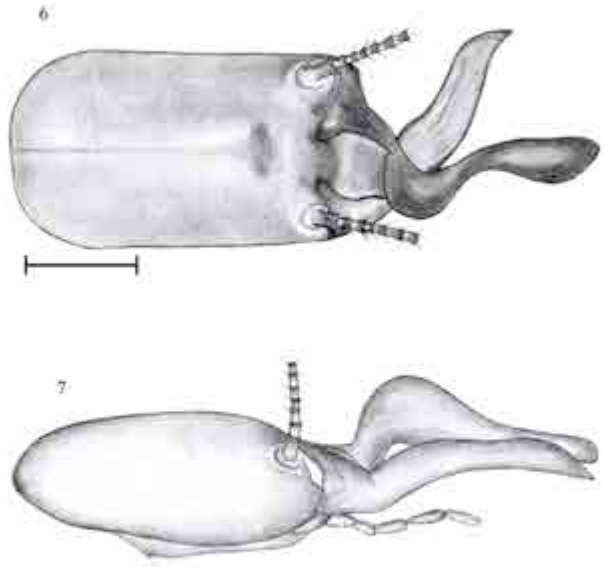
Colour and characters same as holotype; total body length 6.29–7.30 mm; head-capsule sub-rectangular, sides sub-straight (length to base of mandibles 2.49–2.73 mm, width 1.35–1.51 mm, index width/length 0.55–0.59 mm); in profile frons sloping in front and shallowly depressed medially, median suture present, not extending up to fontanelle, fontanelle minute, circular, situated anteriorly, occipito-fontanelle distance 1.80–1.99 mm; antennae 14-segmented, segment 4 smallest; labrum fleshy, anterior margin depressed medially, antero-lateral corners produced into small, pointed tips; mandibles strongly asymmetrical, longer than half the length of head-capsule, left mandible strongly twisted at middle, with a spoon like tip, right blade-like tip pointed and weakly out curved apically, longer than left mandible (length: left 1.65–1.83 mm, right 1.71–1.87 mm, index left mandible length/head-length 0.65–0.73 mm) (Fig. 1D); postmentum long club-shaped, weakly narrowed at waist (length 1.14–1.19 mm, max. width 0.40–0.45 mm, width at waist 0.26–0.30 mm) Pronotum saddle shaped,



Figures 1–5. *Pericapritermes travancorensis* sp. nov. Imago head: 1- dorsal; 2 - lateral; 3 - left mandible; 4 - right mandible; 5 - Pronotum. Scale bars: 0.5mm.



Figures 8–12. *Pericapritermes travancorensis* sp. nov. Soldier: 8 - right mandible; 9 - left mandible; 10 - pronotum; 11 - postmentum; 12 - labrum. Scale bars: 0.5mm.



Figures 6–7. *Pericapritermes travancorensis* sp. nov. Soldier head: 6 - dorsal; 7 – lateral. Scale bars: 0.5mm.

anterior margin convex, posterior margin with a weak median notch (length 0.29–0.39 mm, width 0.74–0.92 mm) (Figs. 6-12, Table 2).

Paratype: Worker

Head-capsule pale yellowish, antennae yellowish paler basely, pronotum and legs creamish, abdomen pale, intestinal contents clearly visible; head sparsely and body moderately hairy; total body length 4.48–5.33 mm; head capsule sub-circular (length to base of mandibles 0.74–0.83 mm, max. width 0.93–1.06 mm); fontanelle indistinct; antennae with 14 segments; segment 4 shortest; post clypeus swollen, length half of width; Pronotum saddle-shaped; length 0.19–0.24 mm, width 0.53–0.62 mm; anterior margin rounded, posterior margin with a median notch (Table 2).

Etymology

The name *travancorensis* was taken from the name of the area from where the specimens were collected. The specimens were collected from the CMS College

Table 3. Described *Pericapritermes* species, type localities and distribution from oriental region

	Species	Type locality	Distribution
1	*P. assamensis* (Mathur & Thapa, 1965)	West Bengal	India
2	*P. brachygnathus* (John, 1925)	Sumatra, Indonesia	Malaysia, Indonesia
3	*P. buitenzorgi* (Holmgren, 1914)	Java, Indonesia	Malaysia, Indonesia
4	*P. ceylonicus* (Holmgren, 1911)	Peradeniya, Sri Lanka	Sri Lanka
5	*P. dolichocephalus* (John, 1925)	Selangor, Malaysia	Malaysia, Indonesia
6	*P. dunensis* (Roonwal & Sen-Sarma, 1960)	Dehradun, Uttarakhand	India
7	*P. durga* (Roonwal & Chhotani, 1962)	Cherrapunji, Meghalaya	India
8	*P. fuscotibialis* (Light, 1931)	Hong Kong, China	China
9	*P. gutianensis* Li & Ma, 1983	Fujian, China	China
10	*P. hepuensis* Gao & Yang, 1990	Guangxi, China	China
11	*P. latignathus* (Holmgren, 1914)	Tjibodas, Java	Bangladesh, Indonesia, Thailand, Vietnam, China, Malaysia
12	*P. Modiglianii* (Silvestri, 1922)	Sumatra, Indonesia	Indonesia
13	*P. mohri* (Kemner, 1934)	Buitenzorg, Indonesia	Indonesia, Malaysia
14	*P. nitobei* (Shiraki, 1909)	Maruyama, Taiwan	Sumatra, Indonesia
15	*P. paetensis* (Oshima, 1920)	Luzon, Philippines	Philippines
16	*P. parvus* Bourguignon & Roisin, 2008	Irian Jaya, Indonesia	Indonesia
17	*P. perparvus* (Holmgren, 1911)	Sri Lanka	Sri Lanka
18	*P. planiusculus* Ping & Xu, 1988	Guizhou, China	China
19	*P. semarangi* (Holmgren, 1913)	Semarang, Java	Bangladesh,Thailand, Malaysia, Indonesia, China
20	*P. speciosus* (Haviland, 1898)	Borneo Malaysia	Indonesia, Malaysia
21	*P. tetraphilus* (Silvestri, 1922)	Rangamati, Bangladesh	India, Bangladesh, China, Burma
22	*P. topslipensis* Thakur, 1976	Coimbatore, Tamil Nadu	India
23	*P. wuzhishanensis* (Li, 1982)	HainanIsland, China	China
24	*P. travancorensis* sp. nov.	Kerala, India	India

Table 4. Diagnostic characters of soldiers of the different species of *Pericapritermes* from India with their distribution

	Name	Characters	Distribution
1	*P. assamensis*	Head capsule yellowish-brown, darker anteriorly, head length without mandibles 2.09-2.28 mm, head-width 1.19–1.27 mm, left mandible length 1.19–1.27 mm, pronotum width 0.72–0.91 mm.	Assam, West Bengal
2	*P. dunensis*	Head capsule yellowish-brown to brown, head length without mandibles 2.30–2.50 mm, head-width 1.30–1.45 mm, left mandible length 1.43–1.70 mm, pronotum width 0.80–0.88 mm.	Meghalaya, Arunachal Pradesh, Uttar Pradesh West Bengal
3	*P. durga*	Head capsule yellow to pale brown, head length without mandibles 2.45–3.05 mm, head width 1.45–2.00 mm, left mandible length 1.45–2.00 mm.	Meghalaya, Arunachal Pradesh Manipur
4	*P. tetraphilus*	Head capsule yellow to reddish-yellow, head length without mandibles 2.45–3.06 mm, head width 1.48–1.70 mm, left mandibles length 1.60–1.84 mm, pronotum width 0.90-1.13 mm.	Assam, West Bengal, Madhya Pradesh
5	*P. topslipensis*	Head capsule pale yellow to deep straw yellow, head length without mandibles 2.5–2.75 mm, head width 1.32–1.41 mm, left Mandibles length 1.45–1.48 mm, pronotum width 0.85–0.90 mm.	Tamil Nadu, Karnataka
6	*P. travancorensis* sp. nov.	Head capsule yellowish-brown, head length without mandibles 2.39–2.73mm, head width 1.35–1.51 mm, left mandible length 1.65–1.83 mm, pronotum width 0.74–0.92 mm.	Kerala (Kottayam District)

campus, a 200 year old College. CMS College was the first college in the Kingdom of Travancore.

Distribution

Pericapritermes travancorensis sp. nov. is currently known from the CMS College campus, Kottayam, Kerala, India.

Key to the soldiers of the Indian species of *pericapritermes*

1 Smaller species: Head-length with mandibles less than 4.0mm 2
- Head length without mandibles 2.09–2.28mm, head width 1.19–1.27 mm, mandible length 1.32– 1.37mm.....*P.assamensis*

2 Medium sized species: Generally smaller in size. Head-length with mandibles 4.00–4.50 mm 3
- Head length without mandibles 2.30–2.50 mm, head width 1.30–1.45 mm, Left mandible length 1.43–1.70 mm..... *P. dunensis*
- Head-length with mandibles 4.18–4.43 mm, head length without mandibles 2.49–2.73 mm, head width 1.35-1.51 mm, left mandible length 1.65–1.83 mm ..... ***P. travancorensis* sp. nov.**

3 Generally larger in size. Head-length with mandibles 4.5–5.0 mm, head length without mandibles 2.45–3.05 mm, head width 1.45–2.00 mm, left mandible length 1.45–2.00 mm. Anterio-lateral corners of labrum small 1
- Body weakly hairy, with fewer longer hairs 4
- Head-capsule generally larger, head length without mandibles 2.45–3.06 mm head width 1.48–1.70 mm. Left mandible-length 1.60–1.84 mm, Antennae with segment 4 subequal to 2 ..... *P. tetraphilus*
- Head-capsule generally smaller, head length without mandibles 2.5–2.75 mm, width 1.32–1.41 mm left mandible length 1.45–1.48 mm Antennae with segment 4 shorter than 2 ..... *P. topslipensis*

4 Body densely hairy with many long hairs, Labrum with anterior margin convex and antero-lateral corners minute. Segment 4 of antennae shorter than 2. Pronotum not emarginate anteriorly ..... *.P. durga*

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SHORT COMMUNICATION

A checklist of vascular epiphytes of El Cometa Lagoon, Pantanos de Centla Biosphere Reserve, Mexico

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Abstract: This study presents an updated checklist of vascular epiphytes found in the highly-conserved mangrove forest surrounding El Cometa Lagoon inside Pantanos de Centla Biosphere Reserve, Mexico. In order to perform this task, 25 sampling units were established at the study site and were visited at two stages, once in 2014 and next in 2016. Inside each sampling unit, all the epiphyte species found on host trees with a diameter at breast height 10cm were recorded. The complete epiphyte species list included 25 species belonging to 18 different genera. The richest family was Orchidaceae with nine species and the richest genus was *Tillandsia* with seven species. Additionally, the total epiphyte richness found in this study was among the highest reported for mangrove forests in Mexico. Epiphyte studies in mangrove forests are uncommon; therefore, this list is the first step to identify vascular epiphytes in the region and contribute to its proper conservation.

Keywords: Floristics, mangrove forest, Orchidaceae, Tabasco, *Tillandsia*.

Abbreviations: Pantanos de Centla Biosphere Reserve - PCBR, diameter at breast height - DBH.

Vascular epiphytes are represented by 27,614 species worldwide, which constitute 9% of the total vascular plant diversity (Benzing 1990; Zotz 2013). Some of the most important angiosperm epiphyte families are Orchidaceae, Bromeliaceae, Araceae, and Piperaceae, while the most important fern-allies families are Polypodiaceae, Aspleniaceae, and Dryopteridaceae (Zotz 2013). Mexico harbours approximately 1,650 vascular epiphyte species (Espejo-Serna 2014) and about 8.8% of them (146 species) are found in mangrove ecosystems (Carmona & Hernández 2015). It has been suggested that epiphytes are uncommon in mangrove forests due to: 1) the characteristics of the dominant host trees (e.g., type of bark, architecture, and presence of alkaloids and tannins), 2) the high temperatures frequent in

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these ecosystems, and 3) the exposure to brackish conditions (Benzing 1990; Zimmerman & Olmsted 1992; Zotz & Reuter 2009). Several studies, however, have reported exactly the opposite, i.e., a high epiphytic diversity in certain mangrove forests (Carmona-Díaz et al. 2004). In Mexico, from the six mangrove species that can be found (i.e., host trees), the most common are *Rhizophora mangle* L., *Laguncularia racemosa* (L.) C.F. Gaertn., *Avicennia germinans* (L.) L. and *Conocarpus erectus* L. (Tomlinson 2016).

Mangrove forests are ecosystems of great economic and ecological importance in the tropical and subtropical coasts of the world (Tomlinson 2016). These ecosystems also harbour high functional diversity and productivity (Zaldívar-Jiménez et al. 2004; Rog et al. 2017). Mangrove forests are also very important ecosystems for carbon cycling dynamics because they are among the highest carbon sinks in terrestrial ecosystems (an average of 937tC ha^{-1}) (Donato et al. 2011; Alongi 2012).

Mangroves are one of the most studied coastal ecosystems in the world (Rioja-Nieto et al. 2017). Nevertheless, few studies have evaluated the epiphyte ecology and diversity in mangrove forests (Gómez & Winkler 1991; Robertson & Platt 2001; Zotz & Reuter 2009; Cach-Pérez et al. 2013; Jiménez-López et al. 2017; Sousa & Colpo 2017). According to these studies, higher epiphyte diversity has been related to: (1) host trees with larger sizes (Jiménez-López. et al 2017; Sousa & Colpo 2017), (2) the lower canopy stratum (Cach-Pérez et al. 2013; Jiménez-López. et al 2017), (3) higher host tree densities (Cach-Pérez et al. 2013; Sousa & Colpo 2017) and (4) areas with higher precipitation (Cach-Pérez et al. 2013; Sousa & Colpo 2017).

The main objective of this study was to enlist the epiphyte species found in one of the most conserved subtropical mangrove forests in southern Mexico. The study was performed in a mangrove forest (Rzedowski 1978) located around El Cometa Lagoon inside Pantanos de Centla Biosphere Reserve (PCBR), Tabasco State, Mexico (Fig. 1). The dominant host trees were *Rhizophora mangle* L. and *Bucida buceras* L. (Jiménez-López et al. 2017; Solórzano et al. 2018). Two different time periods were required to obtain an adequate sampling of the forest, 10 days in July 2014 and 23 days in November 2016. The sampling units were concentrated on the southeast area of the lagoon where one of the most conserved parts of the forest can be found. Twenty 50×25 field plots (1,250m^2 each) and five transects of 50×5m (250m^2) were used to sample the vegetation. The 20 plots were arranged following two gradients, a distance-to-the-lagoon and distance-to-the-biggest-channel, while using a minimal distance of 100m between plots (modified from Sousa & Colpo 2017; Fig. 1). The remaining five transects were located in the vicinity of some of the previous plots in rich epiphyte areas, in order to increase the probability of registering

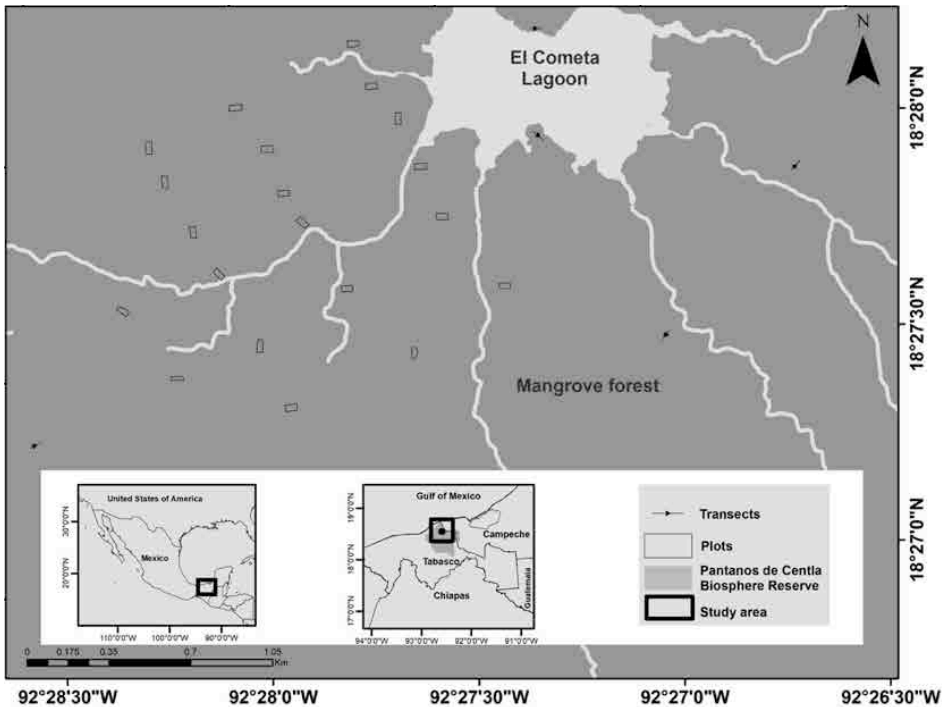

Figure 1. Study site and distribution of plots and transects, El Cometa Lagoon, Tabasco, Mexico

most of the epiphyte richness of the site. Due to the reported correlation between host tree size and epiphyte richness in mangrove forests (Cach-Pérez et al. 2013), the biggest host tree individuals were expected to harbor most of the epiphyte richness. Therefore, epiphyte individuals were collected only from the host trees that had a diameter at breast height (DBH, breast height=1.30m) ≥ 10cm (modified from Flores-Palacios & García-Franco 2006, 2008).

In order to identify the species, one to three epiphyte individuals that had a visible reproductive structure (i.e., either flower or fruit) were collected. When the individuals did not show any reproductive structure, they were collected and then grown ex situ in controlled conditions until they developed reproductive structures. Only afterwards the species was identified. Unfortunately, one species, *Myrmecophila* aff. *tibicinis*, did not show any type of reproductive structure during the study period; thus, its identity was not confirmed.

Every collected individual was pressed following conventional techniques (Lot & Chiang 1986) and was deposited in the HEM Herbarium of the Universidad de Ciencias y Artes de Chiapas. The species identity of every plant was determined using the specialized literature of Araceae (Croat 1983; Díaz-Jiménez et al. 2015), Cactaceae (Korotkova et al. 2017), Bromeliaceae (Ramírez-Morillo et al. 2004), Orchidaceae (Hágsater et al. 2005), and Polypodiaceae (Christenhusz et al. 2011; PPG I 2016) families and consulted with specialists (see Acknowledgements). Additionally, in order to obtain information about the vegetation types where each species can be found and their geographic distribution, the epiphyte collections at MEXU, HEM, CSAT, and UJAT herbaria were consulted. The scientific names of each recorded species followed Soto et al. (2007), while all species authors followed tropicos.org (https://www.tropicos.org) criteria.

In total, 25 epiphyte species (Appendix 1, Images 1 & 2) were reported. In terms of plant families, Orchidaceae was the richest family with nine species, followed by Bromeliaceae with eight species, and Polypodiaceae with four species (Appendix). The richest genus was *Tillandsia* L. with seven species, followed by *Trichocentrum* Poepp. & Endl. with two species. The number of species found in El Cometa Lagoon is equivalent to 17.13% of all the species reported in mangroves in Mexico (Carmona-Díaz & Hernández 2015). This means that in terms of vascular epiphyte richness, El Cometa Lagoon is currently ranked as the second richest mangrove forest in Mexico, after Sontecomapan (Magaña 1999; Valdez-Hernández 2000; Carmona-Díaz et al. 2004; Díaz-Jiménez 2007).

Currently, our checklist is the most complete epiphyte richness list of a mangrove forest inside Pantanos de Centla Biosphere Reserve (PCBR) and Tabasco. In previous efforts, a maximum of 23 species were reported inside PCBR (Gómez-Domínguez et al. 2014; Guadarrama-Olivera & Ortiz-Gil 2000; INE 2000); however, our checklist added nine more species to this list (Guadarrama-Olivera & Ortiz-Gil 2000; Gómez-Domínguez et al. 2014; Jiménez-López & Domínguez-Vázquez 2017; Jiménez-López et al. 2017). Additionally, our checklist added eight more species to the mangrove epiphyte richness of Tabasco State (Magaña 1999; Díaz-Jiménez 2007; Noguera-Savelli & Cetzal-Ix 2014).

We suggest that *Laelia anceps* L., a previously reported species (INE 2000), should be eliminated from the epiphyte checklist of the mangroves found in the region. We think this species was misidentified, because it is typically found in oak-forests between 1500–2200 m (Hágsater et al. 2005) and it is not registered in the present orchid list of Tabasco (González-Aguilar & Burelo-Ramos 2017). Additionally, the present checklist updated: 1) three species names of the Orchidaceae family, a) *Epidendrum flexuosum* G. Mey., previously *Epidendrum imatophyllum* Lindl., b) *Specklinia brighamii* (S. Watson) Pridgeon & M.W. Chase, previously *Pleurothallis brighamii* S. Watson, c) *Specklinia grobyi* (Bateman ex Lindl.) F. Barros, previously *Pleurothallis grobyi* Bateman ex Lindl., 2) one species in the Polypodiaceae family, *Microgramma lycopodioides* (L.) Copel, previously *Polypodium lycopodioides* L., and 3) one species in the Cactaceae family, *Hylocereus undatus* (Haw.) Britton & Rose and *Selenicereus undatus* (Haw.) D.R. Hunt, reported as two different species (INE 2000) has been unified as one species: *Selenicereus undatus* (Haw.) D.R. Hunt (Korotkova et al. 2017). It is worth mentioning that *Bromelia pinguin* L. (Bromeliaceae) and *Trigonidium egertonianum* Bateman ex Lindl. (Orchidaceae) were not reported in our study, but were listed in the previous checklists (INE 2000). Finally, the current checklist corrects some misidentifications made in previous studies (Jiménez-López & Domínguez-Vázquez 2017; Jiménez-López et al. 2017).

On one hand, it has been suggested that a higher host diversity results in a higher diversity of substrates, microclimates, and conditions available for the establishment of epiphytes (Cach-Pérez et al. 2013; Stein et al. 2014; Wagner et al. 2015). Therefore, this heterogeneity of conditions result in a higher niche variability that can host a higher epiphyte diversity. On the other hand, communities with highly variable host tree architecture and size have been associated with higher

Image 1. Vascular epiphytes of El Cometa Lagoon: 1 - *Aechmea bracteata*, 2 - View of inflorescence of *Catasetum integerrimum*, 3 - *Myrmecophila* aff. *tibinicis*, 4 - View of inflorescence of *Trichocentrum oerstedii*, 5 - *Tillandsia balbisiana*, 6 - *Selenicereus grandiflorus*, 7 - *Tillandsia fasciculata*, 8 - *Pleopeltis polypodioides*, 9 - *Anthurium schlechtendalii*, 10 - Flower of *Deamia testudo*, and 11 - Flower of *Encyclia alata*. © Derio Antonio Jiménez-López and Jorge Navarro-Ramos.

epiphyte richness (García-Franco 1996; Flores-Palacios & García-Franco 2006). Structurally homogeneous communities, however, have also been found to harbor high epiphyte richness (Sousa & Colpo 2017). In our study, host diversity was low, as two species, *Rhizophora mangle* L. and *Bucida buceras* L., were highly dominant (Solórzano et al. 2018). Thus, we consider this study as an example of a relatively homogeneous community in terms of diversity that harbors high epiphyte diversity.

Tillandsia was the genus with the highest species number; however, this was not surprising, as this species has been reported as tolerant to dry in high radiation conditions (Cach-Pérez et al. 2013; Chilpa-Galván et al. 2013). Physical conditions in mangrove forests (such as radiation, nutrients, and temperature) can be relatively extreme (Mikolaev et al. 2016). Mangroves usually eliminate salt through their leaves, which provokes a saline environment on the parts that epiphytes usually colonize (Tomlinson 2016). This salt condition can affect some epiphyte survival and growth rates (Zotz & Reuter 2009). Nevertheless, some epiphytes have adapted to survive under the saline conditions found in mangrove forests (Gómez & Winkler 1991).

No species was found to have a protected status under the Mexican legislation NOM-059-SEMARNAT-2010 (SEMARNAT 2010). *Tillandsia brachycaulos*, a frequently

Image 2 . Vascular epiphytes of El Cometa Lagoon: 1 - Flower of *Epiphyllum hookeri* subsp. *guatemalense*, 2 - View of plant of *Epiphyllum hookeri* subsp. *guatemalense*, 3 - *Microgramma nitida*, 4 - *Notylia barkeri*, 5 - View of *Phlebodium decumanum*, 6 - *Phlebodium decumanum* on *Acoelorrhaphe wrightii* H. Wendl. & Becc., 7 - *Microgramma nitida*, 8 - *Prosthechea boothiana*, 9 - *Tillandsia brachycaulos*, 10 - *Tillandsia bulbosa*, 11 - *Tillandsia dasyliriifolia*, and 12 - *Tillandsia streptophylla*. © Derio Antonio Jiménez-López and Jorge Navarro-Ramos.

found species in this study, however, is included under the Least Concern category in the Red List (UICN 2017). This species was found preferably at low heights (1–2 m over ground height), where lower radiation and temperatures can be found (Mondragón et al. 1999; Cach-Pérez et al. 2013; Jiménez-López et al. 2017).

The present checklist represents an additional effort to register all the epiphyte diversity in the region. Furthermore, this information highlights the need to consider epiphytes among the plant diversity of mangrove forests and include them in the conservation strategies inside PCBR and Tabasco, Mexico.

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Appendix 1. Checklist of the epiphyte species found in El Cometa Lagoon, Tabasco, Mexico.

POLYPODIOPSIDA
Polypodiaceae

***Microgramma nitida* (J. Sm.) A.R. Sm.**
Distribution in northern & central America: Mexico (states of Campeche, Chiapas, and Tabasco), Belize, Guatemala, El Salvador, Panama, Nicaragua, and the Honduras.
Distribution: Mangrove forest, freshwater swamp forest, dry deciduous forest, and lowland evergreen rain forest.
Material examined: This study, D.A. Jiménez-López 43 (HEM); Campeche: Calakmul, Demetrio Álvarez M. and C. Jiménez J. 4334 (MEXU); Chiapas: San Fernando, Jorge Martínez-Meléndez 2185 (HEM);. Ocosingo: E. Martínez S. 7961 (MEXU) and D.E. Breedlove 33976 (MEXU); Tabasco: Frontera, A. Novelo R. 4419 and 4405 (MEXU), A. Novelo R. and L. Ramos 2501, 2794, & 3078 (MEXU);. Huimanguillo: C. Cowan 3257 (CSAT).

***Phlebodium decumanum* (Willd.) J. Sm.**
Distribution in northern & central America: Mexico (states of Campeche, Chiapas, Quintana Roo, and Tabasco), Honduras, and Guatemala.
Distribution: Mangrove forest and lowland evergreen rain forest.
Material examined: This study, D.A. Jiménez-López 49 (HEM); Campeche: Calakmul, E. Martínez R. et al. 30257 (MEXU); Chiapas: Ocosingo, E. Martínez S. 8002 (MEXU); Quintana Roo: Othón P. Blanco, Silvia Torres 43 & 68 (MEXU).

***Pleopeltis polypodioides* (L.) E.G. Andrews & Windham**
Distribution in northern & central America: Mexico (states of Chiapas and Tabasco), Guatemala, Belize, El Salvador, Honduras, Costa Rica, and Panama.
Distribution: Mangrove forest and montane forest.
Material examined: This study, D.A. Jiménez-López 58bis (HEM); Chiapas: La Trinitaria, D. E. Breedlove 22348 (MEXU). Pueblo Nuevo Solistahuacán, A. Reyes-García 1638 (MEXU).; Tabasco: Tenosique, Eizi Matuda 3572 (MEXU).

***Vittaria lineata* (L.) Sm.**
Distribution in northern & central America: Mexico (states of Chiapas and Tabasco), Guatemala, Belize, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama.
Distribution: Mangrove forest, lowland evergreen rain forest, and montane forest.
Material examined: This study, D.A. Jiménez-López 50 (HEM); Chiapas: Acacoyagua, María Evangelina López-Molina 411 (HEM); Cacahoatan: Manuel Martínez-Meléndez et al. 5462bis, 5602 and 5539 (HEM); Ocosingo: E. Martínez S. 10121 (MEXU); Tabasco: Teapa, C. Cowan 3079 (CSAT).

MONOCOTYLEDONS
Araceae
***Anthurium schlechtendalii* Kunth**
Distribution in northern & central America: Mexico (states of Chiapas, Tabasco, Quintana Roo, Yucatán), Belize, Guatemala, Nicaragua, Honduras, and Costa Rica.
Distribution: Mangrove forest, dry deciduous forest, lowland evergreen rain forest, and montane forest.
Material examined: This study, D.A. Jiménez-López 40 (HEM); Campeche: Calakmul, J. Calónico Soto and D. Álvarez 23750 (MEXU); Hopelchén, Pascual Alvaro M. and Diego Pérez L. 201 (MEXU); Chiapas: Chicoasén, Angelita López Cruz 866 (HEM); Ocosingo, Gabriel Aguilar and D. Álvarez M. 3679 (MEXU), Gabriel Aguilar and Miguel Méndez M. 10143 (MEXU), Gabriel Aguilar et al. 6937 (MEXU) and G.A. Salazar et al. 8841 (MEXU); Ocozocuautla, I. March and R. Martínez C. 16 (MEXU); San Fernando, R.A. Palestina 1622 (MEXU) and Angelita López Cruz 820 (HEM); Villa Corzo, Emerit Meléndez López 62 (HEM); Tabasco: Frontera, A. Novelo R. and M. A. Ordoñez L. 4406 (MEXU); Tacotalpa, C. Cowan et al. 3421 (CSAT); Quintana Roo: José María Morelos, Demetrio Álvarez et al. 10458 (MEXU); Yucatan: Muna, C. Chan 2375 (MEXU).

Cactaceae
***Deamia testudo* (Karw. ex Zucc.) Britton & Rose**
Distribution in northern & central America: Mexico (states of Chiapas, Tabasco), Guatemala, Belize, El Salvador, Honduras, and Nicaragua.
Distribution: Mangrove forest, freshwater swamp forest, and grassland.
Material examined: This study, D.A. Jiménez-López 41 (HEM); Chiapas: Ocosingo, J.P. Abascal A. et al. 350 (MEXU); Tabasco: Frontera, A. Novelo R. and Ramos V.L. 3011, 2772 and 2453 (MEXU); Tenosique, C. Cowan 3292 (MEXU).

***Epiphyllum hookeri* subsp. *guatemalense* (Britton & Rose) Ralf Bauer**
Distribution in northern & central America: Mexico (Tabasco state), Guatemala, and El Salvador.
Distribution: Mangrove forest.
Material examined: This study, D.A. Jiménez-López 36 (HEM); Chiapas: Acacoyagua, Angelita López-Cruz 296 (HEM).

***Selenicereus grandiflorus* (L.) Britton & Rose**
Distribution in northern & central America: Mexico (states of Chiapas and Tabasco), Honduras, and Nicaragua.
Distribution: Mangrove forest, freshwater swamp forest, and dry deciduous forest.
Material examined: This study, D.A. Jiménez-López 114 (HEM); Chiapas: Ocosingo, E. Martínez S. 21327 (MEXU). Tuxtla Gutiérrez, Héctor Hernández Macías 1684 (MEXU). Tabasco: Frontera, A. Novelo R. y M.A. Ordoñez L. 4400 (MEXU), A. Novelo R. et al. 4212 (MEXU).

Bromeliaceae
***Aechmea bracteata* (Sw.) Griseb.**
Distribution in northern & central America: Mexico (states of Campeche, Chiapas, Quintana Roo, Tabasco and Yucatán), Guatemala, Belize,

Honduras, and Nicaragua.
Distribution: Mangrove forest, freshwater swamp forest, semi-evergreen rain forest, dry deciduous forest, and lowland evergreen rain forest.
Material examined: This study, D.A. Jiménez-López 33 (HEM); Campeche: Calakmul, E. Martínez S. et al. 27671 (MEXU); Hopelchén, Demetrio Álvarez et al. 8912 (MEXU); Chiapas: Ocosingo, Gabriel Aguilar and Raúl Arcos M. 11399 (MEXU) and E. Martínez S. 21026 (MEXU); Reforma, Pedro Tenorio et al. 19363 (MEXU); Quintana Roo: Felipe Carrillo Puerto, J. Calónico Soto and E. Martínez S. 22497 (MEXU); José María Morelos, Demetrio Álvarez and A. Ramírez A. 10888 (MEXU); Tabasco: Frontera, M.A. Guadarrama O. and N. Muñiz Ch. 6553 (UJAT) and A. Novelo R. and Ramos V.L. 2510 (MEXU); Jonuta, M.A. Guadarrama O. et al. 6888 (UJAT); Yucatan: Tekax, Guillermo Ibarra Manríquez et al. 4120 (MEXU).

Tillandsia balbisiana **Schult. f.**
Distribution in northern & central America: Mexico (states of Chiapas, Quintana Roo, Tabasco, and Yucatan), Guatemala, Honduras, and Panama.
Distribution: Mangrove forest, dry deciduous forest, semi-evergreen rain forest.
Material examined: This study, D.A. Jiménez-López 48 (HEM); Chiapas: Ocosingo, E. Martínez S. 18588 (MEXU); Quintana Roo: Puerto Morelos, Edgar Cabrera 22 (MEXU); Tabasco: Frontera, A. Novelo R. et al. 4240 y 4420 (MEXU); Yucatan: Valladolid, Edgar Cabrera 11555 (MEXU).

Tillandsia brachycaulos **Schltdl.**
Distribution in northern & central America: Mexico (states of Campeche, Chiapas, Tabasco, and Yucatan), Guatemala, El Salvador, and Honduras.
Distribution: Mangrove forest, semi-evergreen rain forest, and dry deciduous forest.
Material examined: This study, D.A. Jiménez-López 44 (HEM); Campeche: Calakmul, Celso Gutiérrez Báez 5216 (MEXU); Chiapas: Chicoasén, E. Martínez S. 24179A (MEXU); Tabasco: Frontera, A. Novelo R. and L. Ramos 2337 (MEXU) and G. Ortíz 5053 (MEXU); Yucatan: Valladolid, Edgar Cabrera 11556 (MEXU).

Tillandsia bulbosa **Hook.**
Distribution in northern & central America: Mexico (states of Campeche, Chiapas, Quintana Roo, and Tabasco), Guatemala, and Honduras.
Distribution: Mangrove forest and dry deciduous forest.
Material examined: This study, D.A. Jiménez-López 45 (HEM); Campeche: Calakmul, E. Martínez S. 35007 (MEXU); Chiapas: Ocosingo, E. Martínez S. 18162 (MEXU); Quitana Roo: Cozumel, Edgar Cabrera 3453 (MEXU); Tabasco: Frontera, A. Novelo R. and L. Ramos 2972 (MEXU).

Tillandsia fasciculata **Sw.**
Distribution in northern & central America: Mexico (states of Campeche, Chiapas, and Tabasco), Guatemala, Belize, El Salvador, and Honduras.
Distribution: Mangrove forest, pine forest, and montane forest.
Material examined: This study, D.A. Jiménez-López 118 (HEM); Campeche: Calakmul, E. Martínez S. 27211 (MEXU), Erika M. Lira C. 160 (MEXU) and Estela Madrid N. 37 (MEXU); Chiapas: Cintalapa, Nayely Martínez-Meléndez 2221 (HEM); La Concordia, Nayely Martínez-Meléndez 121 (HEM); La Trinitaria, Eizi Matuda 38651 (MEXU); Pantepec, J.M. Lázaro Zermeño 678 (MEXU); Siltepec, Nayely Martínez-Meléndez 1151 (HEM); Tabasco: Balancán, Fernando Menendez 295 (MEXU).

Tillandsia streptophylla **Scheidw. ex C. Morren**
Distribution in northern & central America: Mexico (states of Campeche, Chiapas, Quintana Roo, and Tabasco), Guatemala, and Honduras.
Distribution: Mangrove forest, freshwater swamp forest, and lowland evergreen rain forest.
Material examined: This study, D.A. Jiménez-López 38 (HEM); Campeche: Hopelchén, Demetrio Álvarez M. 8916 (MEXU); Chiapas: Ocosingo, Demetrio Álvarez M. and A. Chambor 4854 (MEXU) and E. Martínez S. 7058 (MEXU); Quintana Roo: Puerto Morelos, G. Davidse 20062 (MEXU); Tabasco: Balancan, Eizi Matuda 3305 (MEXU); Comalcalco, G. Ortíz 2030 (MEXU). Frontera, A. Novelo R. 4426 (MEXU); Huimanguillo, F. David Barlow 30 (MEXU).

Tillandsia dasyliriifolia **Baker**
Distribution in northern & central America: Mexico (states of Tabasco and Yucatan) Belize, and Guatemala.
Distribution: Mangrove forest and dry deciduous forest.
Material examined: This study, D.A. Jiménez-López 32 (HEM); Campeche: José María Morelos, Demetrio Álvarez M. 11314 (MEXU); Tabasco: Frontera, M. A. Guadarrama et al. 6683 (UJAT); Yucatan: Progreso, C.L. Lundell and A. Lundell 7391 (MEXU).

Tillandsia usneoides **(L.) L.**
Distribution in northern & central America: Mexico (states of Campeche, Chiapas, Quitana Roo, and Tabasco), Guatemala, Belize, Honduras, Nicaragua, Costa Rica, and Panama.
Distribution: Mangrove forest, dry deciduous forest, oak-pine forest, and dry deciduous forest.
Material examined: This study, D.A. Jiménez-López 115 (HEM); Campeche: Palizada, Eizi Matuda 3828 (MEXU); Chiapas: La Trinitaria, D.E. Breedlove 14496 (MEXU); Mapastepec, Eizi Matuda 2044 (MEXU); Motozintla, Eizi Matuda 5532 (MEXU). Quintana Roo: Othón P. Blanco, G. Carnevali 5151 (MEXU). Tabasco: Cardenas, S. Zamudio 382 (CSAT). Frontera, A. Novelo R. 3253 (MEXU). Jonuta, M.A. Guadarrama O. 6832 (UJAT).

Orchidaceae
Campylocentrum micranthum (Lindl.) Rolfe
Distribution in northern & central America: Mexico (states of Campeche, Chiapas, and Tabasco), Guatemala, Belize, Honduras, and Nicaragua.
Distribution: Mangrove forest and dry deciduous forest.
Material examined: This study, D.A. Jiménez-López 116 (HEM); Zona Arqueológica de Becan, Campeche, Edgar Cabrera 8409bis (MEXU); Chiapas: Ocosingo, Gabriel Aguilar M. and Miguel Méndez M. 10139 (MEXU); Tabasco: Tacotalpa, C. Cowan et al. 3485 (CSAT).

Catasetum integerrimum **Hook.**
Distribution in northern & central America: Mexico (Tabasco State), Honduras, and Nicaragua.
Distribution: Mangrove forest and lowland evergreen rain forest.
Material examined: This study, D.A. Jiménez-López 35 (HEM); Chiapas: Ocosingo, Gabriel Aguilar 11403 (MEXU); Tabasco: Frontera, Novelo R. and L. Ramos 3127 (MEXU).

***Brassavola grandiflora* Lindl.**
Distribution in northern & central America: Mexico (Tabasco State), Guatemala, and El Salvador.
Distribution: Mangrove forest.
Material examined: This study, D.A. Jiménez-López 46 (HEM).

***Encyclia alata* (Bateman) Schltr.**
Distribution in northern & central America: Mexico (Campeche, Chiapas, and Tabasco) and Honduras
Distribution: Mangrove forest, dry deciduous forest, and lowland evergreen rain forest, grassland, and freshwater swamp forest.
Material examined: This study, D.A. Jiménez-López 37 (HEM); Campeche: Calakmul, D. Álvarez M. 652 (MEXU) and E. Martínez S. 30081 (MEXU); Chiapas: Ocosingo, E. Martínez S. 6380 (MEXU); Tabasco: Cárdenas, M.A. Magaña and R. Curiel 974 (CSAT); Huimanguillo, M.A. Magaña and R. Curiel 970 (CSAT); Tacotalpa, C. Cowan et al. 3420 (CSAT); Teapa, A. Sol et al. 1094 (UJAT) and S. Zamudio 55 (CSAT).

***Myrmecophila* aff. *tibinicis* (Bateman) Rolfe**
Distribution in northern & central America: Mexico (Tabasco State).
Distribution: Mangrove forest.
Material examined: This study, D.A. Jiménez-López 47 (HEM).
Myrmecophila tibinicis is, however, distributed in Mexico (states of Campeche, Chiapas, Tabasco, and Yucatan), Belize, Nicaragua, and Costa Rica.

Notylia barkeri Lindl.
Distribution in northern & central America: Mexico (states of Chiapas and Tabasco).
Distribution: Mangrove forest, lowland evergreen rain forest, and tropical rain forest.
Material examined: This study, D.A. Jiménez-López 39 (HEM); Chiapas: Ocosingo, Samuel Levi et al. 418 (MEXU).

***Prosthechea boothiana* (Lindl.) W.E. Higgins**
Distribution in northern & central America: Mexico (Tabasco State).
Distribution: Mangrove forest.
Material examined: This study, D.A. Jiménez-López117 (HEM); Tabasco: Frontera, Novelo R. and L. Ramos 3126 (MEXU).

***Trichocentrum oerstedii* (Rchb. f.) R. Jiménez & Carnevali**
Distribution in northern & central America: Mexico (Tabasco State).
Distribution: Mangrove forest and freshwater swamp forest.
Material examined: This study, D.A. Jiménez-López 34 (HEM); Tabasco: Frontera, Novelo R. and L. Ramos 2802 (MEXU).

Trichocentrum ascendens (Lindl.) M.W. Chase & N.H. Williams
Distribution in northern & central America: Mexico (states of Campeche, Chiapas, Tabasco, and Yucatan), Honduras, Nicaragua, and Belize.
Distribution: Mangrove forest and lowland evergreen rain forest.
Material examined: This study, D.A. Jiménez-López 42 (HEM); Chiapas: Ocosingo, Gabriel Aguilar 9783 (MEXU); Tabasco: Huimanguillo, M.A. Magaña and S. Zamudio 139 (CSAT); Teapa: J. Calólico et al. 34913 (MEXU).

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Note

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Two moth species of Lasiocampidae (Lepidoptera: Lasiocampoidea) recorded for the first time in Bhutan

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Bhutan is one of the most isolated countries in the world situated at the eastern end of the Himalayan mountains. The country is surrounded by India to the south, east and west and to the north by Tibet (Autonomous region of China). The country covers an area of 38,394km^2. The landscape ranges from subtropical plains in the south to the Himalayan heights in the north. The northern region of Bhutan consists of eastern Himalayan alpine shrub and meadows reaching up to glaciated mountain peaks. In central Bhutan, the forest type consists of eastern Himalayan subalpine conifer forests in higher elevations and eastern Himalayan broadleaf forests in lower elevations. In the south, the Shiwalik Hills are covered with dense Himalayan subtropical broadleaf forests, alluvial lowland river valleys, and mountains up to around 1,500m. The foothills descend into the subtropical Duars Plain of Bhutan neighbouring the Indian Duars. Thus, the forest of Bhutan harbours a rich diversity of flora and fauna, especially in terms of invertebrate fauna. The least studied group of invertebrates in Bhutan is the moths whose data is still lagging behind.

The Lasiocampidae Harris, 1841 which are commonly known as the Lappet moths are among the families of moths which are poorly studied in Bhutan. The family Lasiocampidae consists of 1,952 species (224 genera) worldwide (van Nieukerken et al. 2011). The members of the family are generally large species with deep forewings and rounded hind wings; abdomen protruding well beyond the wings (Holloway 1987). The Lasiocampidae fauna of the country have been poorly studied. Earlier works on the fauna were conducted by Hampson (1892), Dudgeon (1901), Dierl (1975), and recently by Hauenstein et al. (2011). So far, a total of 42 species of Lasiocampidae have been recorded from Bhutan.

Material and Methods: The study was conducted at different locations of four districts (Tsirang, Dagana, Sarpang, Gelephu) in southern Bhutan. The collection of moths was undertaken opportunistically, as well as by

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setting up light traps at night using fluorescent lamps and Mercury vapour lamp. Moths were observed overnight in all the locations from July 2010 to August 2015. The moths were photographed using a DSLR camera and specimens were collected and killed using ethyl acetate fumes. Later the specimens were sorted, pinned, labelled and identified to species level in the laboratory. These voucher specimens are deposited in the Invertebrate Referral Collection Centre (IRCC), National Biodiversity Centre, Thimphu (Bhutan).

Identifications are based on the keys and descriptions provided by Hampson (1892), Holloway (1987), Zolotuhin & Witt (2000), and Zolotuhin & Pinratana (2005).

Results and Discussion: In total, we identified 10 species of Lasiocampidae, which belong to seven genera from Tsirang, Sarpang, Dagana and Gelephu districts of southern Bhutan. Two species namely *Kunugia siamka* Zolotuhin, 2002 and *Alompra roepki* Tams, 1953 are new records for Bhutan. Some earlier work done by G.S. Dudgeon (1901) in the early 19th century reported 14 species from Bhutan. Later, W. Dierl (1975) recorded an additional five species of Lasiocampidae based on the collections of Bhutan Expedition 1972 by the Natural History Museum in Basel, Switzerland. Recently, A. Hauenstein and his colleagues have reported 42 species of Lasiocampidae from Bhutan based on the collections made by A. Hauenstein and V.V. Sinjaev from 2003 to 2009 from different places of Bhutan (Hauenstein et al. 2011).

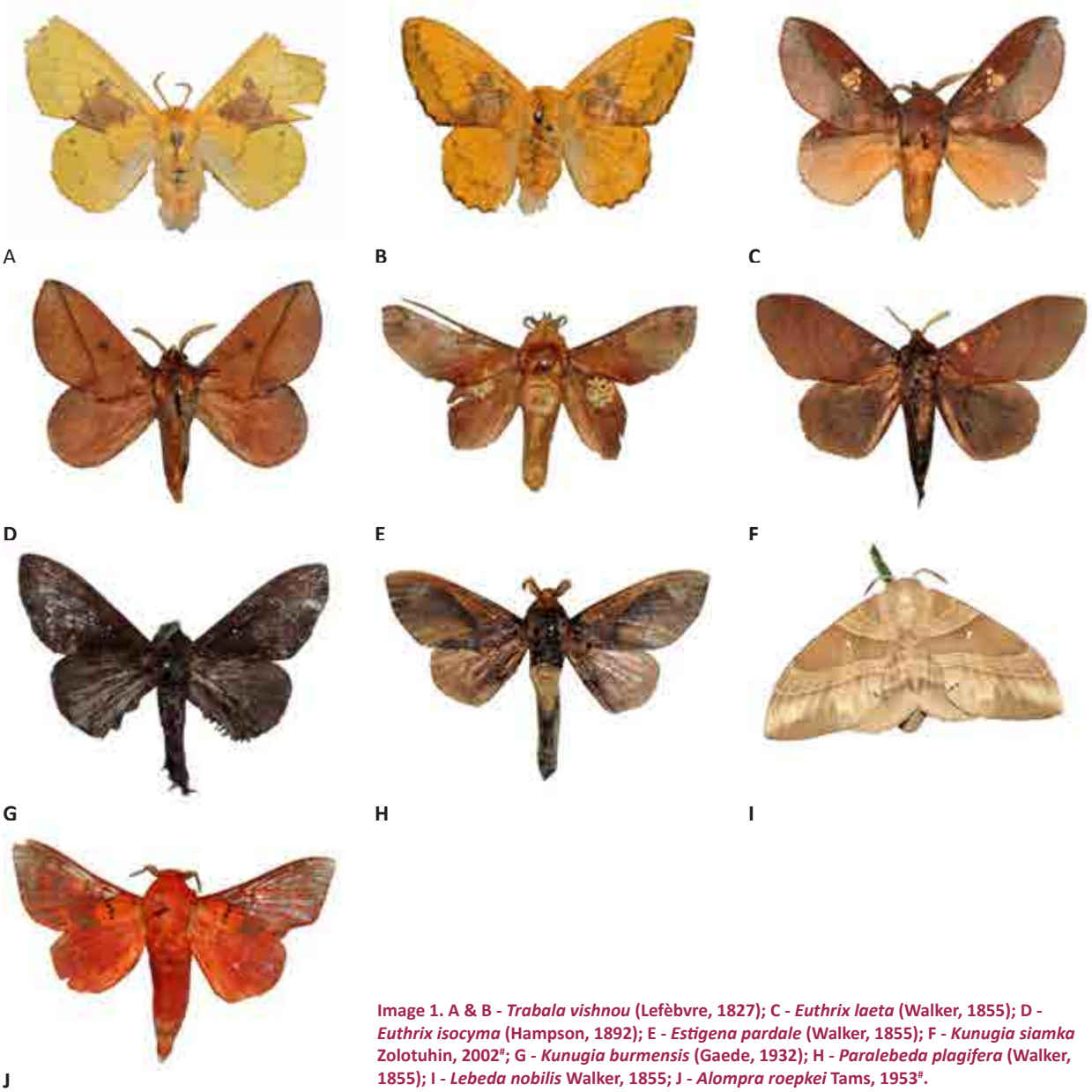

Image 1. A & B - *Trabala vishnou* (Lefèbvre, 1827); C - *Euthrix laeta* (Walker, 1855); D - *Euthrix isocyma* (Hampson, 1892); E - *Estigena pardale* (Walker, 1855); F - *Kunugia siamka* Zolotuhin, 2002#; G - *Kunugia burmensis* (Gaede, 1932); H - *Paralebeda plagifera* (Walker, 1855); I - *Lebeda nobilis* Walker, 1855; J - *Alompra roepkei* Tams, 1953#.

Thus, an updated checklist consisting of 44 species of the Lasiocampidae of Bhutan is provided in Appendix I.

Notes on the new records

Kunugia siamka Zolotuhin, 2002 (Image 1F)

Kunugia siamka Zolotuhin, 2002, Ent. Z. 112: 138, figs 8, 12. Type locality: Thailand, Chiang Mai, Doi Phahompok, 25km NW of Fang, 2,100m.

Material examined. IRCC/472, IRCC/473, 20.xi.2014, 23.xi.2014, 3 males, Tashipang, Mendrelgang, Tsirang (Bhutan) (26.950^{0}N & 90.114^{0}E, 1,247m); IRCC/474, 19.vii.2014, 1 male, Dagapela, Dagana (26.939^{0}N & 89.920^{0}E, 1,599m). coll. J.S. Irungbam.

Note: This species is recorded for the first time from Bhutan. The species is earlier recorded from northern Thailand, Laos, Malaysia (Zolotuhin 2002; Zolotuhin & Ihle 2008). The present record from Bhutan is a new range location and extension from its earlier known distribution.

Alompra roepkei Tams, 1953 (Image 1J)

Alompra roepkei Tams, 1953, Tijdschr. Plant. 59: 166, figs 3, 6, 8, 13. Type locality: [northern India] Assam.

Material examined. IRCC/469, 09.vi.2015, 1 female, Tashipang, Mendrelgang, Tsirang (Bhutan) (26.950^{0}N & 90.114^{0}E, 1,247m), coll. J.S. Irungbam.

Note: This species is recorded for the first time from Bhutan. The moth has a reddish-brown fasciae and is slightly larger than *Alompra ferruginea* Moore, 1872, which is smaller, darker, with narrower forewings. In the male, the forewings have convex margins centrally. The valve in *A. roepkei* is divided but it is bifid in *A. ferruginea* (Holloway 1987). The species was expected to be present as *A. ferruginea* was already found in Bhutan (Hauenstein et al. 2011). Holloway (1987) recorded the species in Borneo from 1700m at forested localities and it is rare.

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Appendix 1. An updated checklist on the Family Lasiocampidae of Bhutan based on Hampson (1892), Dudgeon (1901), Dierl (1975), Hauenstein et al. (2011) and the present study.
N.B. (*) denotes the species recorded during the study and (#) denotes the new records in Bhutan.

	Species	Local distribution	Global distribution
1	*Amurilla subpurpurea dharma* Hauenstein, Ihle, Sinjaev & Zolotuhin, 2011	Paro, Wangdue Phodrang, Trongsa.	Eastern Nepal.
2	*Baodera khasiana* (Moore, 1879)	Thimphu, Bumthang, Trongsa	Northern India, Nepal, southern China, Myanmar.
3	*Trabala vishnou* (Lefèbvre, 1827)* [Image 1 A & B]	Punakha, Wangdue Phodrang, Mongar, Samdrup Jongkhar, Tsirang, Dagana.	Northeastern Pakistan, Nepal, India, Sri Lanka, China, Taiwan, Thailand, Laos, Vietnam, Malaysia.
4	*Crinocraspeda torrida* (Moore, 1879)	Mongar.	Northern & central India, southern China, northern Thailand, Laos, northern Vietnam.
5	*Euthrix vulpes* Zolotuhin, 2001	Thimphu, Punakha, Trongsa.	Northern India, Nepal.
6	*Euthrix inobtrusa* (Walker, 1862)	Samtse.	Northern India, Nepal, central & southern China, Thailand, Vietnam, peninsular Malaysia, Sumatra.
7	*Euthrix laeta* (Walker, 1855)* [Image 1 C]	Tsirang, Dagana.	Nepal, India, Sri Lanka, Myanmar, China, Russia Far East, Korea, Japan, Thailand, Laos, Vietnam, Malaysia, Sumatra, Borneo, Philippines, Java.

	Species	Local distribution	Global distribution
8	*Euthrix isocyma* (Hampson, 1892) [Image 1 D]	Thimphu, Wangdue Phodrang, Mongar, Tsirang,	Northern India, Nepal, southeastern China, Myanmar, Thailand, Laos, northern Vietnam, Cambodia.
9	*Euthrix fossa* (Swinhoe, 1879)	Trongsa, Samdrup Jongkhar	Northeastern India.
10	*Eteinopla signata* (Moore, 1879)	Thimphu, Punakha, Wangdue Phodrang.	Northern India, Nepal, southern China, Thailand, Laos, Vietnam, peninsular Malaysia.
11	*Lenodora castanea* (Hampson, 1892)	Thimphu, Punakha, Bumthang.	Northern India, Nepal, southwestern China.
12	*Micropacha lidderdalii* (Druce, 1899)	Gasa, Thimphu, Punakha, Wangdue Phodrang, Trongsa.	Nepal, northeastern India.
13	*Radhica flavovittata* Moore, 1879	Mongar.	Northern India, Nepal, southern China, Taiwan, Myanmar, northern Thailand, Laos, Vietnam, Sumatra, Borneo, Peninsular Malaysia
14	*Radhica puana* Zolotuhin, 1995	Mongar.	Northern Thailand, Laos, Vietnam.
15	*Zolotuhinia bhutata* (Zolotuhin, 2000)	Punakha, Mongar.	Endemic to Bhutan.
16	*Estigena pardale* (Walker, 1855)* [Image 1 E]	Punakha, Tsirang.	Pakistan, India, southern China, Taiwan, Thailand, Vietnam, Malaysia, Java, Sumatra
17	*Estigena philippinensis swanni* (Tams, 1935)	Samdrup Jongkhar.	Pakistan, Nepal, India, Andaman Is., southern China, Thailand, Laos, Vietnam, Myanmar, Borneo, Sumatra, the Philippines.
18	*Gastropacha (Stenophylloides) moorei* Zolotuhin, 2005	Thimphu.	Nepal, India
19	*Paradoxopla sinuata sinuata* (Moore, 1879)	Thimphu, Trongsa, Mongar, Wangdue Phodrang.	Pakistan, northern India, Nepal, southern & northern China
20	*Kunugia ampla* (Walker, 1855)	Wangdue Phodrang.	India, Bangladesh, Southern China, Thailand, Laos, Vietnam, peninsular Malaysia.
21	*Kunugia fulgens* (Moore, 1879)	Trongsa.	Northern India, Nepal, southern China, Thailand, Vietnam.
22	*Kunugia placida* (Moore, 1879)		India, southern China, Thailand, Vietnam, peninsular Malaysia.
23	*Kunugia lineata* (Moore, 1879)	Paro, Thimphu, Trongsa, Punakha	Northern India, Nepal, Myanmar, southern & eastern China, northern Thailand, Laos, Vietnam.
24	*Kunugia siamka* Zolotuhin, 2002# [Image 1 F]	Tsirang, Dagana.	Northern Thailand, Laos, Malaysia.
25	*Kunugia burmensis* (Gaede, 1932)* [Image 1 G]	Tsirang, Thimphu	Myanmar, southern China, northern Vietnam, northern Thailand.
26	*Kunugia vulpina omeiensis* Tsai & Liu, 1964	Wangdue Phodrang	Northern India, southern China, Myanmar, Thailand, Laos
27	*Kunugia dzong* Hauenstein, Ihle, Sinjaev & Zolotuhin, 2011	Mongar.	Endemic to Bhutan.
28	*Dendrolimus himalayanus* Tsai & Liu, 1964	Paro, Thimphu, Punakha, Wangdue Phodrang, Trongsa, Bumthang.	Northern India, Nepal, southern China (Tibet).
29	*Paralebeda plagifera* (Walker, 1855)* [Image 1 H]	Paro, Punakha, Wangdue-Phodrang, Tsirang, Dagana.	Northern & central India, Nepal, southern & southeastern China, northern Thailand, Laos, northern Vietnam.
30	*Paralebeda femorata karmata* Zolotuhin, 1996	Paro, Thimphu, Trongsa, Bumthang.	Northeastern Pakistan, Nepal, India.
31	*Suana concolor* Walker, 1855	Trongsa.	India, Sri Lanka, Myanmar, southern China, Thailand, Laos, Vietnam, Malaysia, Sumatra, Java, Borneo, the Philippines
32	*Metanastria hyrtaca* (Cramer, 1779)	Punakha, Wangdue Phodrang, Samdrup Jongkhar.	Nepal, India, China, Myanmar, Thailand, Vietnam, Malaysia, Sumatra, Borneo
33	*Lebeda nobilis* Walker, 1855* [Image 1 I]	Tsirang.	Nepal, India, central & southern China, Taiwan, Thailand, Laos, Vietnam, peninsular Malaysia, Sumatra, Java
34	*Pyrosis hreblayi* Zolotuhin & Witt, 2000	Trongsa, Mongar.	Eastern Nepal.
35	*Arguda vinata nepalina* Kishida, 1992	Thimphu, Wangdue Phodrang, Bumthang, Trongsa.	Nepal, northeastern India, Myanmar, Southern China, Thailand, northern Vietnam, Malaysia.
36	*Arguda thaica* Zolotuhin, 2005	Mongar.	Northeastern India, Vietnam, Laos, Thailand.
37	*Syrastrena minor* (Moore, 1879)	Mongar.	Nepal, northern India.
38	*Syrastrena lajonquierei* Holloway, 1982	Thimphu, Trongsa, Punakha.	Nepal, Myanmar, northern Vietnam, Thailand.
39	*Bharetta cinnamomea* Moore, 1865	Haa, Wangdue Phodrang.	Nepal, India, southern China, Myanmar, Vietnam.
40	*Odonestis pruni oberthueri* Tams, 1935	Thimphu.	Northern India, Nepal, northeastern Myanmar, Vietnam.
41	*Argonestis flammans* (Hampson, 1893)	Mongar.	Nepal, India, southern China, northern Thailand, Vietnam, Laos.
42	*Kosala kadoi* Hauenstein, Ihle, Sinjaev & Zolotuhin, 2011	Paro, Haa, Thimphu, Wangdue Phodrang, Trongsa.	Endemic to Bhutan.
43	*Alompra ferruginea* Moore, 1872	Samtse.	Northeastern Himalaya, Borneo, Sumatra, Mindanao.
44	*Alompra roepkei* Tams, 1953# [Image 1 J]	Tsirang.	Northeastern Himalaya, Myanmar, northern Vietnam, Laos, Thailand, peninsular Malaysia, Borneo, Sundaland, the Philippines

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New nymphalid butterfly records from Jammu & Kashmir, India

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India is home to 461 species of butterflies belonging to the largest family Nymphalidae (Varshney & Smetacek 2015; Kehimkar 2016). A number of reports on the range extension of butterfly species are consistently pouring in from the states of Uttarakhand, Himachal Pradesh, and Punjab of the northwestern Himalaya, but the information on the distribution and range extension of butterflies in the northern Himalayan state of Jammu & Kashmir is scanty and equivocal. The Jammu region of Jammu & Kashmir offers a wide range of habitats from the alluvial plains of the Ravi and Chenab in the south to the moderately elevated Shiwaliks, Pir-Panjal, and Great Himalaya northwards, bordering Kashmir in the north and Ladakh in the northeast. While a good account of butterfly fauna is available for Kashmir (Home 1938; Mani & Singh 1962; Das et al. 1964; Das & Verma 1965; Qureshi et al. 2014) and Ladakh (Meinertzhagan 1927; Tshikolovets 2005; Sidhu et al. 2012; Sondhi et al. 2017), only a few records are available from the Jammu region (Sharma & Sharma 2017a,b, 2018). During the surveys conducted in the Jammu Shiwaliks, Sharma & Sharma (2017a) reported three new nymphalid butterfly species for the state and these included *Polyura agraria*, *Athyma perius* and *Lethe europa*.

Targeting a wide area, the butterfly surveys were conducted in different landscapes across sub-tropical and temperate climatic regimes, viz., Kalidhar and Dalhori forests, Rajouri District (west), Mansar-Surinsar-Manwal Range, Jammu, Samba, and Udhampur districts (south), Billawar-Basoholi-Bani, Kathua District (east), Batote-Bhaderwah, Ramban and Doda districts (north), and Paddar in Kishtwar District (far northeast) in an elevation range of 320–3,200 m (Fig. 1) from June 2016 to June 2018. During the explorations, we sighted five nymphalid butterfly species previously not reported from the state of Jammu & Kashmir. The species were photographed in the field and the geo-coordinates were recorded. The species were identified by consulting the available literature, viz., keys (Evans 1927, 1932), catalogue (Varshney & Smetacek 2015), field guides and books (Varshney 1983, 1993; Kunte 2006; Pajni et al. 2006; Singh 2010; Kehimkar 2014, 2016; Smetacek 2016; Sondhi & Kunte 2018), annotated checklist (van Gasse 2017), and online resources (Anonymous 2018a,b; Choker et al. 2018; Karmakar & Sarkar 2018; Kunte et al. 2018).

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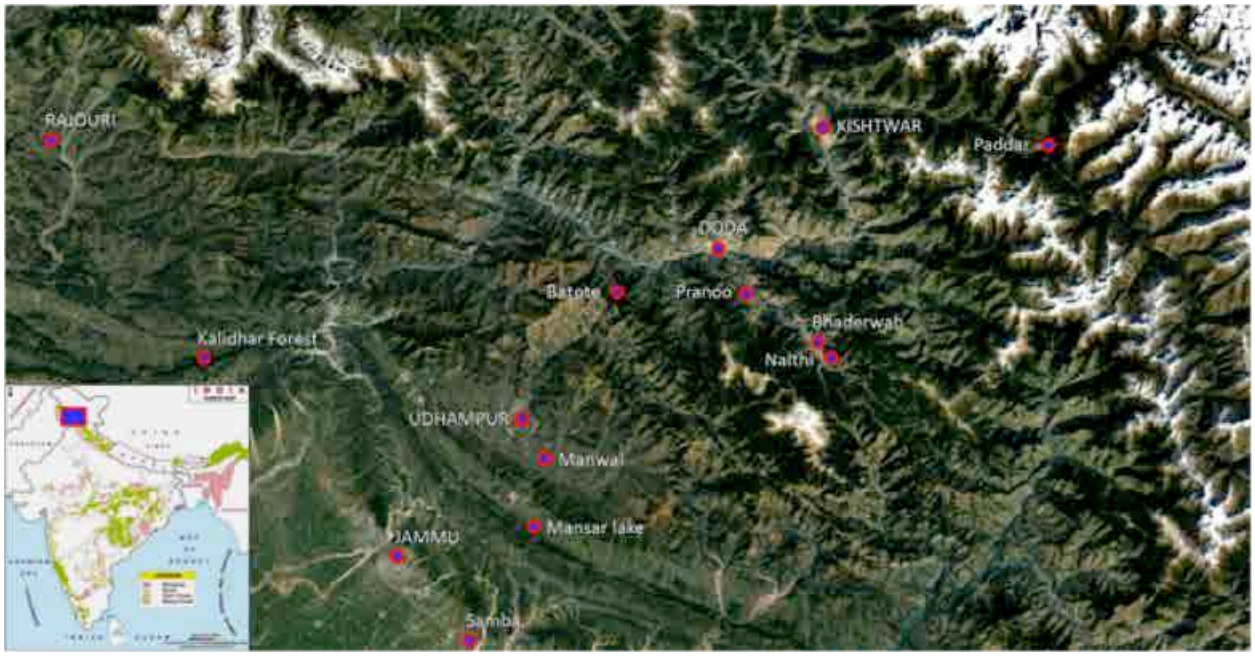

Figure 1. Map of the study area showing locations of butterfly records

Heliconiinae

***Vagrans egista* Kollar (Vagrant)**

Current known distribution until this study: India (Punjab, Himachal Pradesh, Uttarakhand to Arunachal Pradesh, West Bengal, and Odisha), Nepal, Bhutan, and Myanmar (van Gasse 2017; Kehimkar 2014, 2016; Varshney & Smetacek 2015; Anonymous 2018a).

Remarks: Three individuals were spotted nectaring on the water pepper plant *Polygonum hydropiper* L. along the banks of lake Mansar (32.693^{0}N & 75.149^{0}E, c. 665m), Samba District, on 22 October 2017. Five individuals were noted mud-puddling on the moist sandy bed of a seasonal stream near Manwal (32.801^{0}E & 75.140^{0}E, c. 575m) in Udhampur District on 28 October 2017 (Image 1). Three individuals were again sighted on the same day in an adjacent stream. The species, though widely distributed across the Himalaya with its known western distribution up to Himachal Pradesh (Kirti et al. 2016; Anonymous 2018a), was recorded for the first time from the state of Jammu & Kashmir.

Image 1 Vagrant *Vagrans egista*

***Acraea issoria issoria* Hubner (Himalayan Yellow Coster)**

Current known distribution until this study: India (Himachal Pradesh to Arunachal Pradesh), Nepal, Bhutan, and Myanmar (van Gasse 2017; Kehimkar 2014, 2016; Varshney & Smetacek 2015; Sondhi & Kunte 2018; Kunte et al. 2018).

Remarks: On the sunny evening of 04 June 2018, an individual of Himalayan Yellow Coster was spotted basking over a leaf of *Debregeasia hypoleuca* Gaudich (Image 2a) along a perennial stream near Batote (33.110^{0}N & 75.340^{0}E, c. 1,390m) on the Jammu-Kishtwar State Highway. On scanning the area further up along the stream, we noticed sluggish swarms of Himalayan Yellow Coster butterflies hovering and intermittently sitting over *Debregeasia hypoleuca* Gaudich and *Girardinia palmata* Blume shrubs-. Two days later, on 06 June 2018, a few pairs were observed mating (Image 2b) while a few others were spotted laying eggs On 19 June 2018, we visited the spot again and observed the ventral surface of *D. hypoleuca* Gaudich leaves loaded with eggs along with a few freshly emerged caterpillars (Image

2c). The species has its established distribution across the Himalayas from Arunachal Pradesh in the east up to Solan District of Himachal Pradesh in the far west (Kunte et al. 2018) until this reporting, thus confirming it as an addition to the butterfly fauna of Jammu & Kashmir.

Limenitinae

***Auzakia danava* Moore (Indian Commodore)**

Current known distribution until this study: India (Himachal Pradesh, Uttarakhand to Arunachal Pradesh, northern hills of West Bengal), Nepal, Bhutan, and Myanmar (van Gasse 2017; Kehimkar 2014, 2016; Varshney & Smetacek 2015; Anonymous 2018b; Sondhi & Kunte 2018).

Remarks: On the bright sunny afternoon of 23 October 2017, a female individual (Image 3a) was seen hovering over a gregarious *Mentha longifolia* L. growth near marshy slopes of Pranoo (32.113^{0}N & 75.575^{0}E, c. 1,020m), Bhaderwah. A male individual was spotted perched on a rocky boulder near Nalthi (32.937^{0}N & 75.712^{0}E, c. 2025m), Bhaderwah, on 18 May 2018 (Image 3b). The species has a widespread distribution across the Himalayas, with its western extent reported up to Bandli Wildlife Sanctuary, Mandi District, Himachal Pradesh (Anonymous 2018b). This is the first sighting of the species from this part of the northwestern Himalayas and thus is a new record for the state of Jammu & Kashmir.

Cyrestinae

***Pseudergolis wedah* Kollar (Himalayan Tabby)**

Current known distribution until this study: India (Himachal Pradesh to Uttarakhand, Sikkim, Arunachal Pradesh), Nepal, Bhutan, Bangladesh, and Myanmar (van Gasse 2017; Kehimkar 2014, 2016; Varshney & Smetacek 2015; Karmakar & Sarkar 2018; Sondhi & Kunte 2018).

Remarks: An individual was seen basking over a sandstone along a small rivulet near Dalhori (32.299^{0}N & 74.453^{0}E, c. 1125m), Rajouri, on 21 July 2017. A group of five individuals was again sighted in a dumpy vegetated location near Kalidhar (33.050^{0}N & 74.646^{0}E, c. 810m), Jammu District, on 20 October 2017 (Image 4). On the same day two individuals were again spotted basking over the leaves of *Ficus auriculata* Lour, two others sitting on dung, and one observed in continuous low flight. Taslima Sheikh also recorded the species from Chenani (33.041^{0}N & 75.279^{0}E, c. 1,185m), Udhampur District, on 14 August 2017. Karmakar & Sarkar (2018) have reported the westernmost extent of the species up to Mcleodganj in Kangra District, Himachal Pradesh, and this could be a possible missed record or a range

Image 2 a. Himalayan Yellow Coster *Acraea issoria issoria* (male)

Image 2b. Himalayan Yellow Coster *Acraea issoria issoria* (mating pair)

Image 2c. Himalayan Yellow Coster *Acraea issoria issoria* (eggs and caterpillars)

Image 3 a,b. Indian Commodore *Auzakia danava* (female and male)

Image 4. Himalayan Tabby *Pseudergolis wedah*

Images 5a,b. Common Jester *Symbrenthia lilaea* (wings closed and open)

extension of the species and thus is a new addition to the butterfly fauna of Jammu & Kashmir State.

Nymphalinae

***Symbrenthia lilaea* Hewitson (Common Jester)**

Current known distribution until this study: India (Himachal Pradesh to Arunachal Pradesh, West Bengal, and Odisha), Nepal, Bhutan, and Myanmar (van Gasse 2017; Kehimkar 2014, 2016; Varshney & Smetacek 2015; Choker et al. 2018; Sondhi & Kunte, 2018).

Remarks: An individual was first spotted basking over the leaves of *Ficus auriculata* Lour along the Jammu-Poonch National Highway near Kalidhar (33.052^{0}N & 74.633^{0}E, c. 720m) on 18 October 2017. Two individuals were sighted on the sandy bed of a seasonal stream close to Kalidhar Temple on 20 October 2017 (Images 5 a,b). Another individual was recorded among a group of Vagrant *Vagrans egista*, Common Leopard *Phalanta phalantha*, Lemon Emigrant *Catopsilia pomona*, Danaid Eggfly *Hypolimnas misippus*, Common Punch *Dodona durga*, and Common Beak *Libythea lepita* along a seasonal stream near Manwal (32.801^{0}E, 75.140^{0}E, c. 575m), Udhampur District, on 28 October 2017. Taslima Sheikh first recorded the species on 22 January 2016 (Choker et al., 2018) from Environmental Park, Jammu (32.729^{0}N, 75.904^{0}E, c. 475m). The species has so far been reported up to Datyar in Solan District of Himachal Pradesh (Choker et al. 2018) and thus is an addition to the butterfly fauna of Jammu & Kashmir State.

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Argostemma khasianum C.B. Clarke (Rubiaceae): a new record of a genus and species of flowering plant for the state of Arunachal Pradesh (India) and its lectotypification

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Eastern Himalaya is well known for its biological diversity, due to its varied topography, diverse altitudinal gradient, moderate to heavy rainfall and rich forest compositions. Among the eastern Himalaya, Arunachal Pradesh has comparatively species rich flora when compared with the adjoining countries like Bangaldesh, Bhutan, China, Myanmar, Nepal. These areas known as EH biodiversity hotspot (Brooks et al 2006). *Argostemma* Wall. is a genus of small perennial herbs in the family Rubiaceae belonging to the subfamily *Rubioidae* of the tribe *Argostemmateae*. This tribe is represented by two genera i.e., *Argostemma* Wall. and *Neurocalyx* Hook. (Robbrecht 1988; Sridith 1999a&b, Sridith & Puff 2000). The genus comprises 220 species (Mabberley 1997) that are distributed from Paleotropics to Africa. The type species of this genus, *A. sarmantosum* Wall., is from India. Approximately, 106 species are reported from Bhutan, India, China, Cambodia, Indonesia, Japan, Laos, Malaysia, Myanmar, Nepal, New Guinea, Philippines, Thailand and Vietnam (Sridith 1999a&b).

During a botanical exploration of the state to revise the Flora of East Kameng District, one interesting species of *Argostemma* with white coloured flowers and hairy peduncle was collected. After critical examination of the specimens and existing literature dealing with *Argostemma* of the Indian subcontinent and adjacent areas (Roxburgh 1864; Hooker 1880; Hajra et al. 1996; Pal 2013; Dash & Singh 2017) it was revealed that this genus has a new distribution record for the state. The species has been enumerated here along with its lectotypification, as more than one specimen existed among the original material.

Argostemma khasianum
C.B. Clarke in Hook.f., Fl. Brit. Ind. 3: 43. 1880.
(Images 1 & 2)

Type: India: Khasia Mts., F. De Silva et al. s.n. (Wallich Catalogue 8394B, p.p., K000031008) (K!- Lectotype designated here); 8394C-K001125382 (K!-Isolectotype designated here).

Perennial herb with dense matted roots. Stem erect, branched, up to 4cm long, internodes very short, glabrous or minutely hairy. Leaves in two pairs, pseudoverticillate, slightly anisophyllous elliptic, apex acute, base attenuate, 2.0–5.5 x 1.0–2.5 cm, sparsely pubescent on both surfaces; petiole 0.5–2.0 cm long, glabrous. Stipules very small, much reduced. Inflorescence 3–6 flowered, a laxed scorpioid cyme;

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Image 1. ***Argostemma khasianum.*** **A - U.K. Tiwari 47315 (ARUN); B - habit of plant; C - close up of flower**

peduncle 5.5–6.0 cm long, white, densely pubescent. Flowers 4–5-merous, actinomorphic. Calyx chartaceous, green; calyx lobes ovate, ca. 2–3 mm long, spreading, densely pubescent. Corolla star shaped, pubescent outside, tip of the corolla with 4–5 hairs, corolla lobes narrowly triangular, ca. 2mm long; corolla tube <1mm long. Stamens 4, inserted at the base of the corolla tube; filaments ca. 6–7 mm long, free; anther fused, extrose, forming a cone like; yellow with white apical appendage, basifixed, opening by longitudinal slits. Ovary pubescent; style filiform, ca. 8mm long, extrose, glabrous; stigma bilobate. Fruits globose, pubescent.

Ecology: On moist stream side in evergreen forests; ca. 1,500m.

Flowering: June–July.

Taxonomic notes: Clarke (1880) while describing this species referred to *Argostemma verticillatum*, Wallich Catalogue 8394, which was collected by 'F. De Silva & C.' from Khasi hills. Wallich (1829–1849) while listing his catalogue had three sets under the number 8394, i.e., A, B & C. Where, 8394A referred to his specimen collected from Nepal (Nipal) and 8394B-C referred to F. De Silva's collections from Khasia Hills in India. All these specimens were previously identified as *Argostemma verticillatum*. Among these, Wallich Catalogue 8394B in parts, (K000031008, K001125380, K001125381) and 8394C in parts (K001125382) represent *Argostemma khasianum*. Of these, K000031008 is chosen as a lectotype because it contains more than one plant with both vegetative and reproductive parts, where as K001125380, K001125381 and K001125382 are chosen as isolectotypes.

Other specimens examined: 47315 (ARUN!), 07.vii.2016, India: East Kameng, from Bana to Yashing Top, 1,065m, coll. U.K. Tiwari); Wallich Catalogue 8394B - K001125380, K001125381 (K!), Khasia Hills, F. De Silva s.n. ; Wallich Catalogue 8394C K001125382, (K!), Khasia Hills, F. De Silva s.n. ; 5472 (K!) Khasia Hills, Clarke ; K000031014; K000031012; K000760233 (K!), Khasia Hills, Hooker & Thompson s.n. .

Image 2. *Argostemma khasianum*. A: De Silva, F. . H.I.8394 B (K000031008!)-Lectotype; Photo source: http://specimens.kew.org/herbarium/K000031008; © copyright of the Board of Trustees of the Royal Botanic Gardens, Kew.

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Amorphophallus longiconnectivus and *A. margaritifer*: additional aroids from Maharashtra with notes on the floral variations

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Genus *Amorphophallus* Blume ex Decne. comprises 203 species worldwide (The Plant List 2013). It is distributed in tropical Africa, Madagascar, tropical and subtropical Asia, Archipelago, Melanesia and Australia (Mayo et al. 1997). In India the genus is represented by 19 species and five varieties belonging to three sections, viz., *Amorphophallus, Conophallus* (Schott) Engl. and *Rhaphiophallus* (Schott) Engl., of which 13 species and three varieties are endemic to India (Jaleel et al. 2011, 2012, 2014).

As a part of taxonomic revision during our explorations in northeastern Maharashtra, we collected *Amorphophallus longiconnectivus* and *A. margaritifer* and reported the floral variations (Image 1). *A. longiconnectivus* and *A. margaritifer* show a range of variation which needs to be considered by future taxonomists before describing a new species. The specimens (A.R. Gholave & Kahalkar ARG-52, A.R. Gholave & Kahalkar ARG-59) have been deposited in Shivaji University Kolhapur (SUK).

Amorphophallus longiconnectivus

Bogner, Kew Bull. 50(2): 397.1995; Sivad. & Jaleel, Rheedea 8(2): 243.1998; Jaleel et al., Bangladesh J Plant Taxon. 18: 1–26. 2011.

Tuberous herbs. Tubers smooth, subglobose, 5–9 cm in diam. Leaf solitary; petiole smooth, 32–75 cm long, 1.2–2.3 cm in diam.; lamina 35–45 cm across., leaflets linear - lanceolate, 7–15 x 2–4 cm, acuminate at apex, base unequal and decurrent on rachis. Inflorescence solitary, long pedunculate; peduncle similar to leaf petiole, 52–108 cm long, 1.5–3 cm in diam.;cataphylls 2–3, 17–31 x 2–6 cm, pale pinkish. Spathe broadly ovate to broadly triangular, usually broader than long, 10.5–17.5 cm long, 1.5–4 cm in diam., tip acute, completely convolute, not differentiated in to basal tube and upper limb, pale green outside, pale purplish within, dark purplish verrucose inside at base. Spadix as long as spathe or slightly shorter than spathe; 10.5–17.5 cm

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long and 1–1.5 cm diam., stipitate, stipe 0.4–0.6 cm long; female zone 2.5–3 cm long; staminodial zone between male and female zone 1.5–2 cm long; neuters elongated, 3–6 mm long, 1–3 mm in diam., brown at curved tip. Male zone 5–8.5 cm long; appendix 1.5–3.4 cm long, clothed with sterile flowers and rarely with a scattered fertile stamens. Ovaries sub-globose, 1.5–2 mm in length, 2–3 mm in diam.,pale green, 2-3 locular with one basal ovule per locule; style very short, 1– 1.5 mm long; stigma 2–3 lobed, 1–2 mm in diam. Male flowers with 4–8 stamens; stamen 2–2.5 mm long, 1–1.5 mm in diam., yellowish-pink; filament short, thecae lateral, ellipsoid, 1.5–2.5 mm long; connective elongated, 1–1.5 mm long. Fruit berry, ellipsoid, 6– 9 mm long, 5–6 mm in diam., green when young, red at maturity, 2–3 seeded; seed ovoid, 6–7 mm long and 4–5 mm in diam.

Flowering & fruiting: June–September.

Chromosome number: 2n = 3x = 39 (Lekhak & Yadav 2011).

Distribution: India: Madhya Pradesh (Piparia, Khandwa) and Maharashtra (Tumsar, Bhandara District) (Fig. 1a).

Specimens examined: India, Madhya Pradesh; Khandwa District, Singar, 9.vii.2012, A.R. Gholave ARG - 3, 3.vii.2009, Lekhak & Shimpale 3862, SUK. Maharashtra; Bhandara District, Tumsar, Bamhani, 21.042^{0}N & 79.551^{0}E; 272m, 26.vi.2015, A.R. Gholave & Kahalkar ARG- 59, SUK.

Discussion: The genus *Amorphophallus* is highly variable in its spadix and floral morphology. These two species belong to *Amorphophallus* sect. *Rhaphiophallus*. There are nine species in this section and all are endemic to India except *A. sylvaticus* which is also reported from Sri Lanka (Jaleel et al. 2011).

Amorphophallus longiconnectivus was described by Bogner (1995) based on Haines's collection (1910) from Madhya Pradesh, Piparia District. Sivadasan & Jaleel (1998) studied the variations in the species. The spadix shows considerable variations with reference to size, shape, colour of neuters and appendix. Some morphological variations were observed in the population of the species at Bamhani Village, Bhandara District. Specimens from the above mentioned localities exactly matched with the description and illustration given in the protologues. On the basis of elongated neuters this species is easily distinguishable from other species in the genus. Variations are also reported from within a species. Green coloured hooked neuters, appendix covered with clothed sterile flowers (Image 1b), lemon coloured hooked neuters with sterile flowers (Image 1c). Elongated, green coloured, hooked neuters with brown coloured forked tip and very short appendix with a few sterile flowers (Image 1d), were variations noted in the same locality, i.e., Maharashtra; Bhandara District, Tumsar, Bamhani. Variations were seen in neuter structure e.g., very short blunt, golden neuters, (Image 1e & f) straight, faint golden coloured neuters with tip brown (Image 1g). In Gadchiroli, Maharashtra, individuals with blunt quadrangular neuters, half basal part moss green coloured, half upper part brown coloured neuters, male flowers arranged in groups, each group with 4-5 flowers were observed in the species' populations (Image 1h).

Amorphophallus margaritifer (Roxb.)

Kunth, Enum. Pl. 3: 34.1841; Hett. & De Sarker, Aroideana 19: 131.1996; Jaleel et al., Bangladesh J Plant Taxon. 18: 1–26. 2011. *Arum margaritiferum* Roxb., Fl.

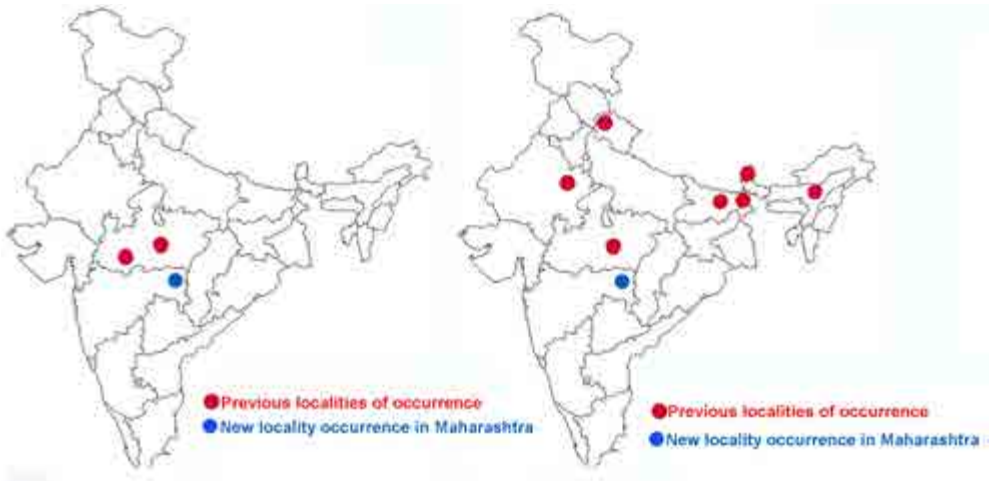

Figure 1. Map showing geographical distribution of (a) *A. longiconnectivus*, (b) *A. margaritifer*.

Image 1. a–h - *Amorphophallus longiconnectivus*: a - Habit, b–h - Spathe cut open to show variations in spadix and its parts; i–l. *Amorphophallus margaritifer*: i - Habit, j–l - Spathe cut open to show variations in spadix and its parts. Photo credit: a,b,c,d,f,I,j & k - © A.R. Gholave; e,g & I - © S.R. Yadav; h - © M.M. Sardesai.

Ind. (Ed., Carey) 3: 512. 1832; Wight, Ic. 3(1): 6, t. 795. 1844; *Plesmonium margaritifer* (Roxb.) Schott, Syn. Aroid.: 34.1856; Hook. f., Fl. Brit. India 6: 518.1893; Engl., Pflanzenr. IV 23C (48): 49.1911; C.E.C. Fisch. in Gamble, Fl. Pres. Madras: 1588. 1931.

Tuberous herbs. Tubers smooth, more or less sub-globose, 7.5–8.5 cm in diam.,5–6.5 cm in height. Leaf solitary, petiolate; petiole smooth,up to 24–85 cm long, 1–3.5 cm in diam., green to greenish-brown with greenish-white with regular elongated stripes; lamina

30–75 cm across, rachis smooth; 4–10 cm long, 3–13 mm in diam., leaflets linear-lanceolate, 8–27 x 1–4 cm, sub-marginal vein present, margins entire. Inflorescence long peduncled; peduncle 58–64 cm long, 1–1.2 cm in diam.; cataphylls-2, 11–17 x1–2 cm. Spathe broader than long, triangular, tip acute, 12–14.5 cm long,4–5 cm in diam., outside pale greenish, inside pale purplish, prominently verrucate at base within. Spadix 11.5–13.7 cm long as long as or slightly longer than spathe, stipitate; stipe green, 0.3–0.5 cm long, 0.5–0.8 cm diam.; female zone 2–3 cm long; staminodal zone between male and female zone, 3.5–4 cm long; staminodes congested, in 5–6 rows; male zone longer than female zone, 6–7 cm long, 0.5–1.5 cm in diam.; appendix absent. Ovaries pale-green,1.5–2 mm in diam., 1–1.5 mm long, 3-locular, one basal ovule per locule; style very short, 0.5–1.0 mm long; stigma yellowish, capitate, 1–1.2 mm high, ca. 2mm in diam., 2–4 lobed. Stamens many, compactly arranged in male zone, 1.5–2 mm long, pale brownish; staminodes loosely arranged, large, elongate- obovoid,0.8–1 cm long, 0.5–0.7 cm in diam., yellowish-white. Berries red at maturity, globose, 1–3 seeded.

Flowering & fruiting: May–August.

Chromosome number: 2n = 3x = 39 (Lekhak & Yadav 2011).

Distribution: India: Maharashtra, Madhya Pradesh, Uttar Pradesh, Rajasthan, Bihar, West Bengal, Sikkim and Assam (Fig. 1b).

Specimens examined: India: Jharkhand; Giridih District, Parasnath Hill, 630m, 23.vii.2012 A.R. Gholave ARG-7, 23.vii.2012, A.R. Gholave ARG – 8, SUK; West Bengal; 9.vi.1897, Prain, CAL Acc. No. 4968 & 4969; Maharashtra; 2.vii.2008 Kahalkar 3108, SUK; Bhandara District, Tumsar, Bamhani 21.042^{0}N & 79.551^{0}E; 272m, 26.vi.2015, A.R. Gholave & Kahalkar ARG-52, SUK.

Discussion

Amorphophallus margaritifer is unique as it lacks a spadix appendix. Jaleel et al. (2011) in his revision mentioned that Haines collected *A. margaritifer* from Chorbush, Nagpur; however, this place is not in Maharashtra and it is evident from the literature (Stafleu & Cowan 1976–1978). Haines worked in Chhota Nagpur area (today's Jharkhand & Chhattisgarh) and hence it is likely to be that he must have collected this species from Jharkhand rather than from Maharashtra. Specimens collected from Bhandara District, Maharashtra showed compact and rounded shaped neuters especially in premature condition (Image 1j), loosely arranged and elongated diamond shaped neuters were observed on mature inflorescences (Image 1k & 1l).

Conclusion

The genus *Amorphophallus* is highly variable in its spadix morphology. Variation is mainly observed in appendage colour and shape, neuter shape, size and colour, colour and interior of the spathe. The section is mainly characterised by staminodial zone /neuters between the male and female zone of the spadix. Many insects visit the inflorescence for feeding on neuters and at that time many flowers are pollinated. For attraction of insects inflorescence may be displaying these variations but these variations are not constant. These variations should be considered in future while delimiting the species.

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Cultivation of the Himalayan seasoning *Allium* in a remote village of Uttarakhand, India

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Himalayan Seasoning Allium or Strachey's Chive *Allium stracheyi* Baker (Family: Amaryllidaceae; vernacular: 'Faran', 'Jambu'), growing between 2000–4000 m in the western Himalaya, is a bulbous perennial herb that is commonly used as a spice and culinary herb. The pleasant aroma of Chives is favoured for flavouring and seasoning food items (Anonymous 2003), and this species is also useful in promoting digestion and in relieving cold and cough (Maikhuri et al. 2017). *Allium stracheyi* is enlisted as Vulnerable in the Red Data Book of Indian Plants (Dasgupta 1990). Ved et al. (2003) have also categorized it as Vulnerable in the western Himalayan states of Jammu & Kashmir, Himachal Pradesh, and Uttarakhand. Regional field information on its distribution and use categorized *A. stracheyi* under cultivation and low-pressure medicinal and aromatic plants in the Uttarakhand (Rawat 2005). In some parts of Uttarakhand, *A. auriculatum* Kunth is in cultivation and may be misidentified as *A. stracheyi* (Rawat 2005). Some authors have also mentioned 'Pharan' as *A. carolinianum* Redoute (Silori & Badola 2000). In some other reports, the vernacular for *A. stracheyi* is mentioned as Jambu (Negi 2012); however, the variation in local names may be due to different dialects. The foliage of *A. stracheyi* contains a higher quantity of carbohydrate, protein, vitamin C, vitamin E, and phosphorus as compared to its allied species such as *A. humile* Kunth and *A. rubellum* M. Beib. (Maikhuri et al. 2017).

The Himalayan Seasoning Allium is cultivated in several cold desert villages located in the buffer zone of the Nanda Devi Biosphere Reserve (NDBR) in districts Pithoragarh and Chamoli in Uttarakhand, India. Tolma (~2600–2800 m; 30.524^{0}N & 79.752^{0}E), a small, remote village located between the cold desert and a temperate region of NDBR in Chamoli District, western Himalaya, however, is well-known for traditional cultivation of this species for generations (Fig. 1, Image 1). According to natives, cultivation of *A. stracheyi* in Tolma may have begun in 1915–1920 as an innovative trial and the area under cultivation was not more than a common kitchen garden having an expansion of few metres. Some reports, however, state that prior to the closure of Indo-Tibet trans-border trade during the early sixties, *A.*

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stracheyi was exchanged with India by the Tibetan Lamas or other traders for bartering of daily need commodities, and possibly after 1960s, commercial cultivation of *A. stracheyi* was started in this region (Nautiyal & Nautiyal 2004). It is important to note that the cultivation of *A. stracheyi* is also acting as an anticipated measure for the conservation of its genetic resources (Pandey et al. 2008). Cultivation of *A. stracheyi* in Tolma Village is an interesting practice; therefore, the survey was conducted in 2015 for finding the cultivation status and economic benefits of *A. stracheyi*.

At present, a total of 20 out of 25 families in Tolma Village are cultivating *A. stracheyi* in a total of 1.10ha area. Of them, 17 have an average of 0.03ha area (0.02–0.06 ha) and three have an average of 0.18ha area (0.14–0.22 ha) under *A. stracheyi* cultivation. Being perennial, *A. stracheyi* is harvested twice a year (in June and September) and about 35.00kg dried leaf (foliage) is obtained from 0.02ha (equal to 1 'nali', 1 nali = 10 x 20 m area, 50 nali = 1ha; nali-vernacular) is a common parameter used for measurement of land) in a year. At the village level, during 2015–16, the prices (per kg) for Faran were close to about INR 350.00 (USD 5.44; INR 64.29 = USD 01, as on 19 September 2017). Therefore, the gross income of farmers having a minimum of 0.02ha area under cultivation was approximately INR 12,250.00 per year (USD 190.54) and those having a maximum of 0.22ha area under cultivation was approximately INR 134,750.00 per year (USD 2,095.97). Therefore, the estimated gross income from the cultivation of *A. stracheyi* in a hectare was INR 612,500.00 (USD 9,527.14). The gross income from cultivation of *A. stracheyi* in 0.02ha area was INR 8,750.00 in 2011. The price/kg for Faran at village level then was INR 250.00 while the estimated gross income from the cultivation of Potato *Solanum tuberosum* from 0.02ha was merely around INR 1,600.00 (Kuniyal & Sundriyal 2013). Therefore, cultivation of *A. stracheyi* is economically profitable than that of traditional crops. Marketing of this species, both at the local level and outside, is quite comfortable and in local fairs, approximately 10.00g Chive may be sold at INR 20–25. Sometimes, the expected produce in this village is booked by traders in advance; therefore, the tradition of cultivation and effortless trade of *A. stracheyi* is remarkable. The produce when dried, can be stored easily for a few months. Being a light and dried plant material, the transportation of the produce is easy and does not require special means.

Total cultivation cost in an established field (excluding the cost of planting material, as once this species is planted, it will flourish for many years; nearly 1.8 to 2.7 lakh plants may be required in a hectare) (Nautiyal & Nautiyal 2004), including the cost of farmyard manure, weeding, harvesting, and processing for *A. stracheyi*

Figure 1. Map of Uttarakhand showing the location of Tolma Village in Chamoli District (not to scale)

Image 1. Cultivation of *Allium stracheyi* in Tolma Village, Chamoli District, Uttarakhand

is around INR 140,000.00/ha/annum and the net profit is likely to be INR 472,500.00/ha/annum. After processing (chopping and preferably shade drying), average production per ha of *A. stracheyi* is estimated to be around 1,750.00kg (1.75 metric ton (MT); 1MT = 1,000.00kg). In some other mountain valleys located in the vicinity of NDBR, however, the production of *A. carolinianum* (Pharan — the species used similarly as *A. stracheyi*) and *A. wallichii* Kunth (Jambu) are reported to be 79.3 kg/ha/year and 102.8 kg/ha/year (Silori and Badola 2000) and around 2,431.00kg *A. stracheyi* (Jambu) from 3.45ha area (Negi 2012).

The cultivation of Himalayan Seasoning Allium in other villages such as Malari, Jhelum, Gamshali and Niti in Chamoli District and Martoli, Pachhu and Milam in Pithoragarh District in Uttarakhand is either sparse or not practiced by the majority of the families inhabiting the village, and harvesting from the wild is also common (Bhatt 1999). Since agro-climatic conditions vary in mountains areas, the information on production may vary. The villagers of Tolma, however, have been cultivating this species for generations and, therefore, their information on productivity may be considered as more reliable. Cultivation of *A. stracheyi* in Tolma Village is an excellent example of a traditional practice being upheld as a customary one, as well as being established as a profitable business. It was also interesting to note that out of the 20 families cultivating *A. stracheyi* in this village, only one has received any kind of financial support from government agencies for extension activities. Therefore, this is an exemplary practice for a MAP cultivation that is flourishing without any subsidy or support price. In addition to attractive economic benefits, *A. stracheyi* has its importance as a domestic culinary herb and indispensable gift. This village is also a source of planting material of this species for surrounding areas and nearby villages. On the other hand, cultivation of *Picrorhiza kurrooa* and *Saussurea costus* are some of the other examples of medicinal plant cultivation in Uttarakhand; however, in order to maintain the cultivation of these two species, intensive and extensive attempts were initiated at the policy, legal, and facilitation levels (Kuniyal et al. 2015; Kuniyal & Negi 2016).

The cultivation of *A. stracheyi* in this village is an excellent conservation practice. Also, some of the produce grown by villagers is stored for 4–6 months for domestic use during winter season. The post-harvest practices for *A. stracheyi*, however, are still traditional and the area under cultivation is nearly consistent from many years. Sometimes, the material chopped and dried traditionally also gets infected by diverse types of fungal/ bacterial infections. Therefore, for financial attractiveness, advancement in technology is essential (Buschke 2015). It is suggested that the traditional method of chopping and drying must be replaced with

new and less destructive methods. Studies are required to standardize suitable moisture content in dried materials. Better post-harvest processing, attractive packaging, and organic branding will also help the farmers in terms of increased economic returns as compared to their current income. In the advent of more attractive and new food crops like Pea (*Pisum sativum*), challenges may occur for maintaining this practice. Attempts for establishing exact scientific identity of similarly used cultivated Allium in Uttarakhand and their area expansion are also suggested. Microclimatic conditions for cultivation of *A. stracheyi* in this village are suitable and the flavour of Tolma's Faran is much favoured; therefore, this village may also act as an excellent research site for initiating the work on development of improved varieties.

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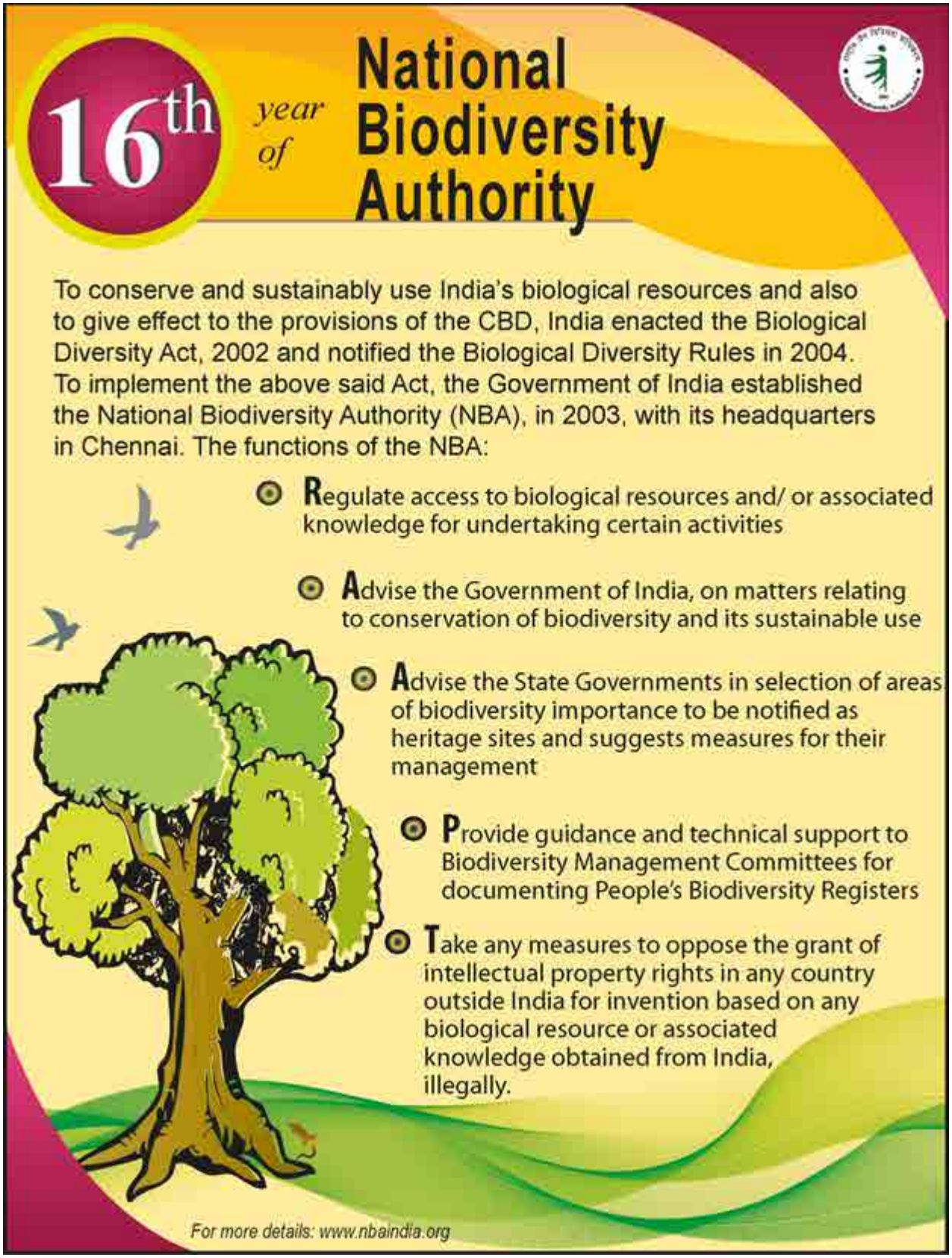

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