STATUS OF TIGER PREY SPECIES IN THE SUNDARBANS OF BANGLADESH



M. Abdul Aziz, PhD

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The Integrated Tiger Habitat Conservation Programme (ITHCP) is an initiative implemented by the International Union for Conservation of Nature (IUCN) and funded by German Cooperation via KfW Development Bank, which contributes to the global effort to double tiger numbers in the wild by 2022 by supporting landscape level conservation work benefiting species, communities, and habitats. Coordinated actions enhancing conservation skills, developing livelihoods, and improving governance and infrastructure are delivering results in terms of better protected tigers across these landscapes.

Under the ITHCP initiative, Wildlife Trust of India, WildTeam, and Jahangirnagar University jointly implemented the project “Protecting Tigers, People, and their vital habitats in the Sundarban delta in India and Bangladesh – Phase II”. Jahangirnagar University carried out this milestone research on assessing the status and distribution of the major prey species of tigers in Bangladesh Sundarbans. The active support of the Bangladesh Forest Department and IUCN Bangladesh is greatly acknowledged.





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EXECUTIVE SUMMARY

The Sundarbans, shared between Bangladesh and India, supports one of the five top tiger populations in the world. The Bangladesh Sundarbans, covering 6,017 km^2 accounting for 60% of the entire Sundarbans, constitutes roughly 60% of the national forest coverage of the country, and the only habitat having breeding populations of tigers. In the Sundarbans, tigers chiefly live on spotted deer *Axis axis* and wild boar *Sus scrofa*, with occasional cropping on rhesus macaque *Macaca mulatta*, barking deer *Muntiacus vaginalis*, water monitor *Varanus salvator*, and Malayan porcupine *Hystrix brachyura*. Monitoring these prey populations is a prerequisite to evaluate management actions for long-term conservation of tigers in this mangrove habitat. The Bangladesh Tiger Action Plan also highlighted the need for developing a protocol for assessing status, distribution, and size of tiger prey species in the Sundarbans. We have initiated this premier study to investigate major prey species of tigers in Bangladesh Sundarbans using a systematic and structured sampling framework. We have applied Pellet Group Count (PGC) method for spotted deer, wild boar, barking deer, and Malayan porcupine whilst the boat-based transect for rhesus macaque, and water monitor. A total of 808 PGC plots (each of 200 m^2) and 1,281 km of transects (255 independent river segments) were established covering the entire Bangladesh Sundarbans for data collection. Two survey teams comprising 10 research assistants have conducted field surveys for 9 months over two winter seasons between 2021 and 2023.

The estimated mean density of spotted deer was 35.44± *SE* 2.21 ind./km^2 of forest, with an extrapolated population of 136,604 (*r* = 128,104-145,105) individuals. The density was highest in the south-eastern regions of Sundarbans, with notably high densities in keora (73,52 ind./km^2), pasur-kankra (53.76 per km^2), gewa (50.35 ind./km^2), and baen (48.71 ind./km^2) forests. The mean density of wild boar was estimated as 15.75±*SE* 1.72 ind./km^{2}of forest, and extrapolated population of 47,515 (*r* = 42,326-52,704) individuals. The distributional pattern of this ungulate was found to be reversed of the spotted deer with higher densities on the south-western regions, and they preferred goran (33.01 ind./km^2), baen (28.60 ind./km^2), and goran-gewa (26.48 ind./km^2) forests. The mean group density of rhesus macaque was estimated as 2.97±*SE* 0.20 ind./km^2, and population of 152,444 (*r* = 134,039-170,930) individuals. This nonhuman primate was rather uniformly distributed throughout the Sundarbans. The mean density of barking deer, water monitor, and Malayan porcupine were 0.26±*SE* 0.14, 6.29±*SE* 1.71, and 5.30± *SE* 1.53 ind./km^2, and their population sizes were 818 (*r* = 452-1184), 25,124 (*r* = 22,701-28,127), and 12,241 (*r* = 8,995-15,747) individuals, respectively. The former two species were confined to the north-eastern region of the Sundarbans whilst the latter has relatively wider distribution with higher density across Sarankhola and Chandpai ranges. This study provided a baseline for future monitoring of the prey species in the Bangladesh Sundarbans.

Acknowledgements

This study would not have been possible without the support from many organizations and individuals. The financial support from the German Cooperation through the KfW Development Bank paved the way to initiate this study with excellent coordination of the International Union for Conservation of Nature (IUCN) that played a key role in successful execution of the project in Bangladesh Sundarbans.

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We were encouraged by useful information and consultations with Dr Adam C.D. Barlow from WildTeam, UK and Dr Yadvendradev Jhala from the Wildlife Institute of India on selecting the potential survey methodologies for this study. Their suggestions and guidelines were helpful.

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Long-term field surveys were supported by a team of trained local honey hunters, and fishermen sourced from villages located on the northern fringes of the Sundarbans. They were assisted by arm guards supplied by the forest department, and a team of staffs – cooks and drivers in accommodation boat, survey boats and speedboat, provided by vendors, the JRS Tours and Travels, and the Vromon Sundarban. Our field teams were accompanied for a while by Dr Ai Suzuki from Tokyo Metropolitan University, Japan, Dr Kris B. Prasada Rao of PEM from Denmark, and Professor Dr Md. Anwarul Islam from WildTeam.

My project team members – Md. Aminur Rahman, Md. Ameer Hamza put forward their best effort to field surveys and team management in very remote and challenging field conditions of Sundarbans. Research students including Sumaiya Naznin, Tamanna Binte Asma, Sumaya Khatun, Jakia Sultana, Aong Shew Nu Marma, Muntasir Ahamed, Dipto Kumar Das, Fatima Tasnim Nishat, Abdullah Al Mubassir, Md. Robiul Islam provided their valuable time in supporting field activities and data entry for the project.

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1. INTRODUCTION

1.1 Background

The Sundarbans, shared between Bangladesh and India, is recognised as one of the 11 Tiger Conservation Landscapes of global priority for long-term conservation of tigers (Sanderson et al., 2006). The Sundarbans is the largest mangrove forest in the world covering about 10,236 km^2 (Giri et al., 2007), and the only such habitat where tigers have been adapted to survive till today. The tiger population surviving in the Sundarbans is one of the five top largest populations in the world (Aziz et al., 2017).

Tiger is a Critically Endangered in Bangladesh, with the last remaining population in the Sundarbans (Ahmad et al., 2009). Tiger survives on a limited number of prey species in this forest, which is one of the major challenges for our tigers (Aziz et al., 2013). Specifically, prey abundance is considered as the single most important factor in determining the quality of tiger habitat, and closely linked with the existence of tigers. On ecological perspective, the carrying capacity, i.e., the number of tigers the Sundarbans habitat can support, is primarily depended on the density of the major prey species. Therefore, tracking changes in prey abundance is fundamental to evaluate the impact of tiger conservation actions in Bangladesh Sundarbans (Ahmad et al., 2009).



Fig. 1. Bengal tiger of the Bangladesh Sundarbans.

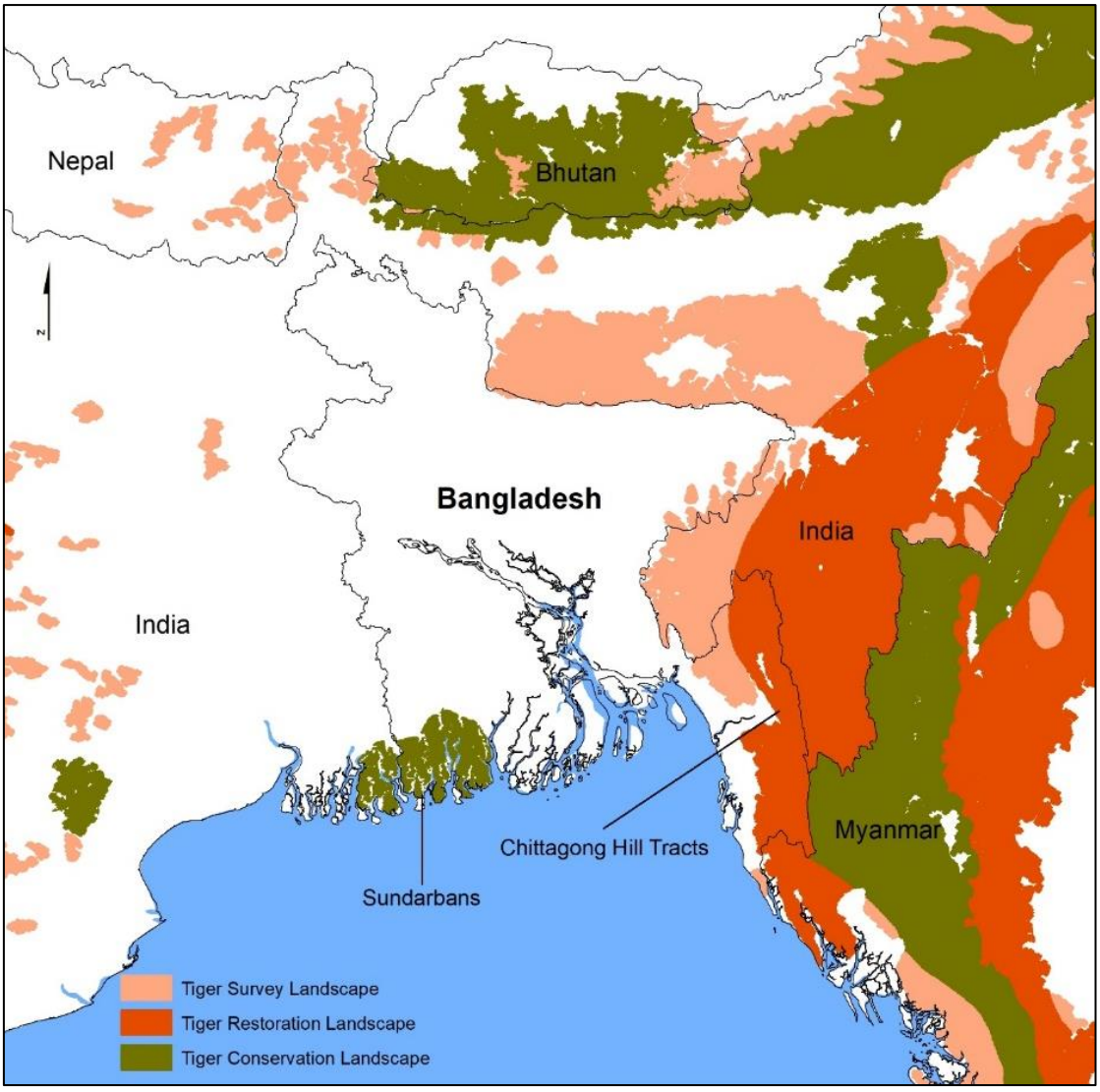


Fig. 2. Location of Sundarbans and other tiger landscapes in the region.

From an ecological viewpoint, tiger is the flagship species for this landscape, and plays a key role in structuring and maintaining the ecosystem health of this fragile forest. Conversely, the survival of tigers in Sundarbans entirely depends on its very limited number of prey species – mostly the spotted deer, and to a lesser extent the wild boar. Therefore, appropriate management actions for protecting these prey species are critically important for conserving the tigers. At the same time, these ungulates play a key role in influencing forest structure, and maintain the most important link between primary producers and tertiary consumer in the Sundarbans.

Tigers chiefly live on spotted deer *Axis axis*, and wild boar *Sus scrofa* which comprise 89% of its prey biomass in the Sundarbans (Aziz et al., 2020). This is the reflection of small variety of prey species in the Sundarbans landscapes, compared to tiger habitats elsewhere. Tigers were also known to hunt, to a lesser extent, the barking deer *Muntiacus vaginalis*, rhesus macaque *Macaca*

mulatta, and water monitor *Varanus salvator* (Aziz et al., 2020). Indeed, baseline status of these prey species are completely lacking for the Sundarbans.

Studies show that there is a strong relationship between tiger and prey population, where the latter is critical to the long-term survival for tigers (Karanth et al., 2004). This information is a prerequisite for developing management strategies targeting the protection of tigers, prey species and their habitats.
The Bangladesh Tiger Action Plan highlighted the need for developing a monitoring protocol on assessing the status, distribution, and size of tiger prey species in the Sundarbans (Ahmad et al., 2009; Khan et al., 2018). Monitoring of prey populations is also required to evaluate management actions for conserving large carnivores (Ahmad et al., 2009; Aziz et al., 2020). Despite this, there has been no initiative taken in assessing tiger prey abundance over the tenure of almost 10 years of first-generation tiger action plan (Khan et al., 2018). Furthermore, a recent situational analysis of tiger conservation in Bangladesh has reiterated the urgency of assessing the status of spotted deer, and wild boar populations in the Sundarbans (IUCN–Bangladesh, 2018).

Previous effort to assess tiger prey abundance began in 2002 under the auspices of the Sundarbans Biodiversity Conservation Project but the project has ended up prematurely in 2005. In 2009, another initiative was taken by the Sundarbans Tiger Project with an objective of developing a structured monitoring programme on prey species in the eastern Sundarbans (Smith et al., 2007). This project produced some preliminary data; however, it was not scaled up for full-fledged implementation. After about 20 years, we discovered that we could not make any major progress on this important research agenda towards understanding the tiger's prey abundance in the Sundarbans (Ahmad et al., 2009).

The Sundarbans mangrove forest is characterised by unique vegetation, topography, and elevation which might have undermined previous efforts of prey assessment. The application of typical distance sampling technique, used frequently elsewhere, was challenging in the Sundarbans, thereby Pellet Group Count (PGC) method was attempted for assessing ungulate populations (Deodatus and Ahmed, 2002; Smith et al., 2007). Because of the difficulty of seeing animals in dense vegetation in the tropical forests, researchers often attempted to assess herbivore populations from their dung piles which are easy to find, identify, and count (Ahrestani et al., 2018). Although the method has been introduced long back in 1930s in north America, researchers still find its value and applicability in challenging habitats across the continents (Ahrestani et al., 2018; Bennett et al., 1940; Fattorini and Ferretti, 2020; Plhal et al., 2014). To monitor prey populations, the PGC method is relatively simple to undertake, and are commonly used in estimating densities of ungulates (Acevedo et al., 2007; Alves et al., 2013; Campbell et al., 2004; Ferretti et al., 2011; Neff, 1968; Putman, 1984). The PGC method is based on recording faecal accumulation over a fixed amount of time in previously cleared plots, and then dividing the count by defecation rate of the species involved.

A wide range of herbivore population was assessed using the PGC method, which include, but not limited to, the mule deer *Odocoileus hemionus* in the United States (Collins and Urness, 1981), sika deer *Cervus nippon* in southern Scotland (Marques et al., 2001), white-tailed deer *Odocoileus virginianus* in Mexico (Camargo-Sanabria and Mandujano, 2011), roe deer *Capreolus capreolus* in Spain (Acevedo et al., 2010), Asian elephant *Elephas maximus* in Lao PDR (Hedges et al., 2013), African elephants *Loxodonta africana* in Mozambique (Young et al., 2009), gorilla *Gorilla gorilla* (Todd et al., 2008), and hare *Lepus americanus* (Hodges and Mills, 2008).



Fig. 3. An arial satellite view of the Sundarbans landscapes in Bangladesh.

This research project aims to investigate the status and distribution of tiger's major prey species of Bangladesh Sundarbans under the ITHCP initiative coordinated by the International Union for Conservation of Nature and funded by German Cooperation via KfW Development Bank. The umbrella project titled, "Protecting Tigers, People, and their vital habitats in the Sundarban delta in India and Bangladesh – Phase II", was implemented by the Wildlife Institute of India, WildTeam, and Jahangirnagar University. In particular, the Department of Zoology of Jahangirnagar University implemented the research component of this project with active support of the Bangladesh Forest Department and IUCN Bangladesh. We specifically aimed at (i) estimating density and abundance of tiger's major prey species; and (ii) assessing the spatial distribution of prey species in relation to forest types in the Sundarbans of Bangladesh.

2. THE SUNDARBANS

2.1. Management regime

The Sundarbans, the largest contiguous mangrove forest of the world, is located on the Ganges-Brahmaputra delta (Giri et al., 2007). The part of the Sundarbans in Bangladesh (21º30′–22º30′ N, 89º00′–89º55′ E) covers 6,017 km^2, of which 3994.71 km^2 is forest land, and the remaining area includes water bodies comprising rivers, creeks, and estuaries (IFMP, 1998). The Sundarbans is bordered on the south by the Bay of Bengal and on the north and east sides by a landmass dominated by human settlements (Hussain and Acharya, 1994). Two rivers, the Raimangal and the Harinbhanga, mark the international boundary between Bangladesh and India, and separate the Indian part of the Sundarbans.

For management purpose, the Bangladesh Sundarbans is divided into Sundarbans East Forest Division and Sundarbans West Forest Division. The east division is further delineated into Sarankhola Forest Range (1309.98 km^2) and Chandpai Forest Range (1000.21 km^2) whilst the west division into Khulna Forest Range (1613.45 km^2) and Satkhira Forest Range (1849.92 km^2) (Hussain, 1991). Ideally, the Sundarbans is managed as reserve forest, except three demarcated areas that were declared wildlife sanctuaries (WS) in 1996 for higher level protection of wildlife and their habitats. The sanctuaries, comprising Sundarbans West (715 km^2), Sundarbans South (370 km^2), and Sundarbans East (312 km^2), were collectively declared a UNESCO World Heritage Site in 1997. In 2017, the boundary of these WS has been extended to include additional areas from the reserve forest regions. Currently, the East WS encompasses 1,229. 20 km^2, South WS 753.10 km^2 and West WS 1,997.19 km^2, which together accounted a total of 52% of the total Bangladesh Sundarbans. Additionally, there are five river-based WS, specifically demarcated for the protection of cetaceans in the Sundarbans. These sanctuaries have a higher degree of legal protection compared to the reserved forest areas of Sundarbans.

The Sundarbans East and Sundarbans West Forest Divisions are administered by two separate Divisional Forest Officers (DFO) under a Conservator of Forest within Khulna circle of the Bangladesh Forest Department. An additional DFO oversees the Wildlife Management and Nature Conservation Division within the same circle. The entire Bangladesh Sundarbans was divided into 55 forest compartments for management purpose (Fig. 4). The regular activities are executed by 582 field management staffs stationed across 104 stations and guard posts (BFD, 2010).

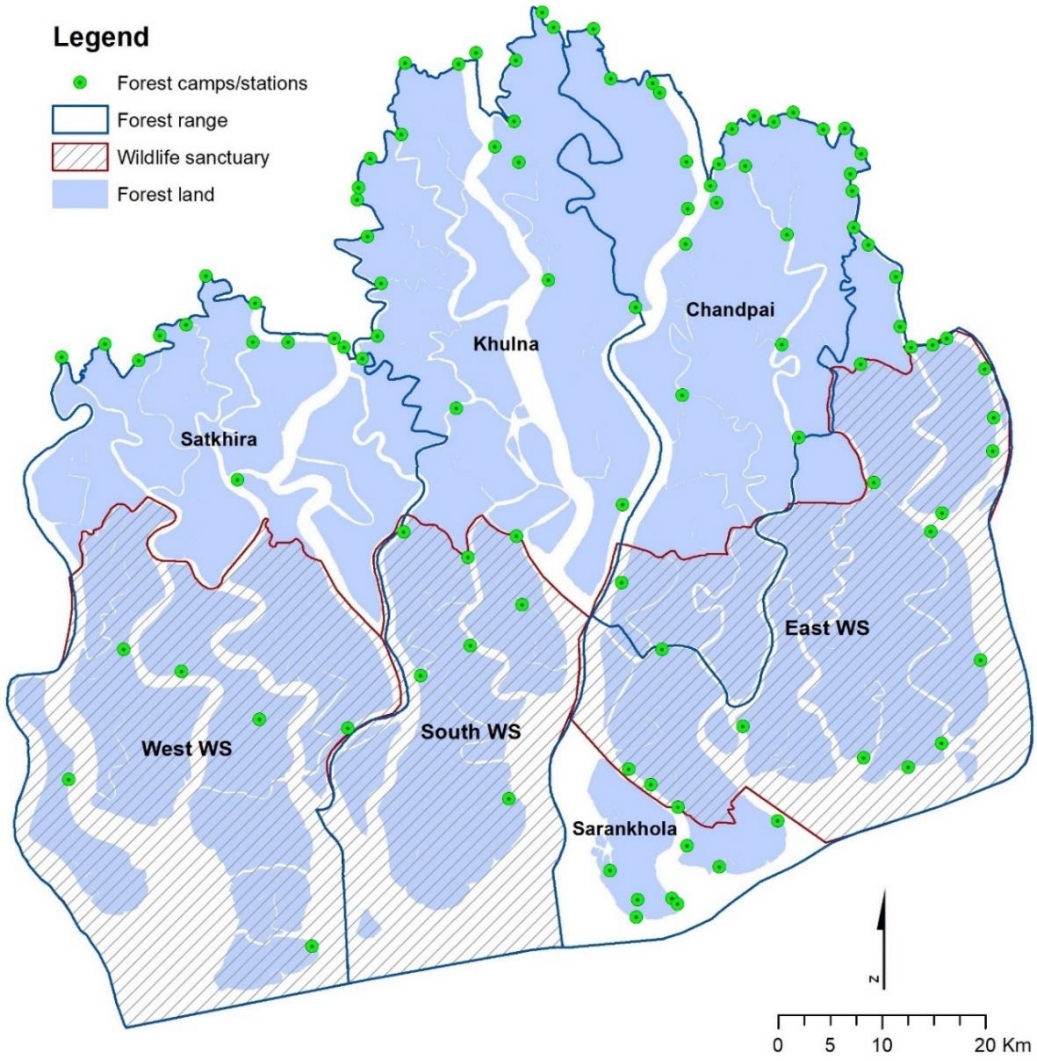


Fig. 4. Protected area and forest posts in Bangladesh Sundarbans.

2.2. Major wildlife

The Bangladesh Sundarbans is home to a wide variety of species of mammals, reptiles, birds, amphibians, insects, crustaceans, and a range of aquatic lifeforms. The Sundarbans is one of the most biologically diverse mangrove forests in the world, supporting 528 species of vascular plants, 322 species of fishes, 8 species of amphibians, 35 species of reptiles, over 315 species of birds, and 42 species of mammals (Islam and Wahab, 2005; IUCN–Bangladesh, 2001). This diverse assemblage of wildlife plays a crucial role in maintaining the ecological balance of fragile ecosystems of this mangrove swamps.

The Sundarbans has been in the focus for tigers over centuries, perhaps largely due to the mystery ingrained with the ‘man-eating’ behaviour of tigers in the Sundarbans. However, apart from the presence of this magnificent largest cat

in the Sundarbans, the mangrove swamps are also the last home for a range of iconic wildlife species, including, a few to name, the northern river terrapin *Batagur baska*, king cobra *Ophiophagus hannah*, spoon-billed sandpiper *Eurynorhynchus pygmeus*, masked finfoot *Heliopais personata*, mangrove pitta *Pitta megarhyncha*, ruddy kingfisher *Halcyon coromanda*, fishing cat *Prionailurus viverrinus*, Oriental small-clawed otter *Aonyx cinerea*, and smooth-coated otter *Lutrogale perspicillata*. Sadly, we have lost several large mammals from this forest during the latter half of the twentieth century, including the Javan rhinoceros *Rhinoceros sondaicus,* the swamp deer *Cervus duvauceli*, hog deer *Axis porcinus*, and wild buffalo *Bubalus arnee* ((Blower, 1985; Chaudhuri and Choudhury, 1994; Curtis, 1933; Hendrichs, 1975).

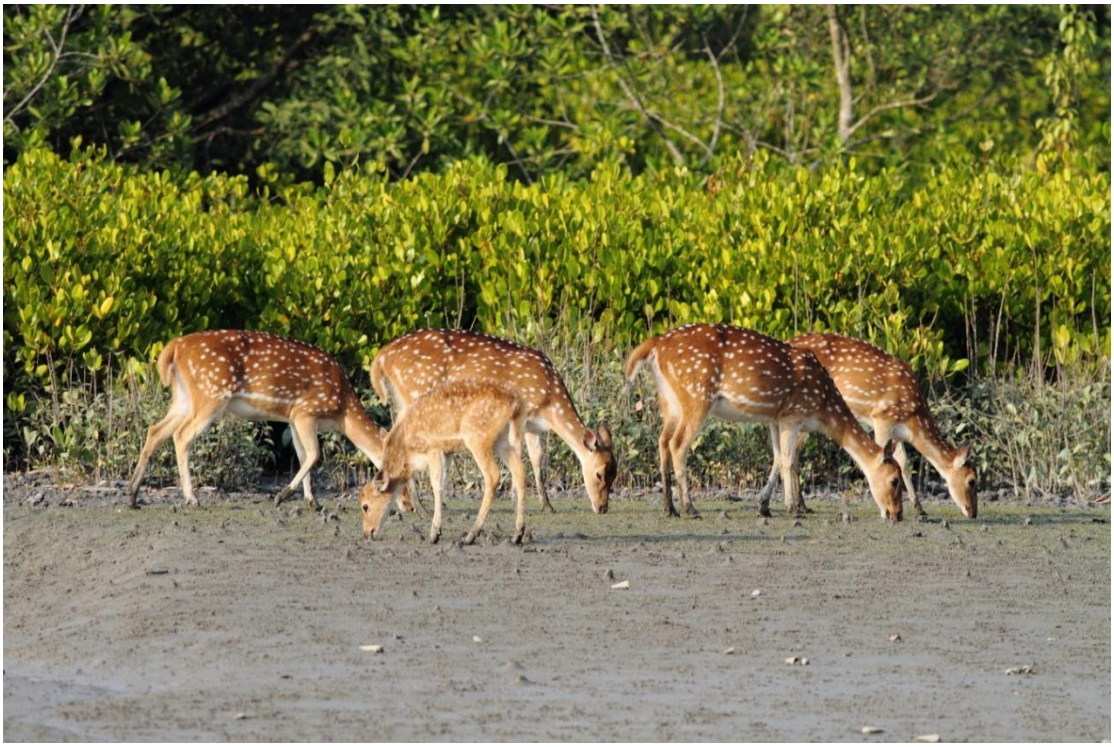


Fig. 5. Herd of spotted deer in Bangladesh Sundarbans.

2.3. Vegetation and forest types

The vegetation of Sundarbans predominantly comprises mangrove trees, which have adapted to saline water and tidal estuaries. The most common species of the forest is the sundri *Heritiera fomes*, gewa *Excoecaria agallocha*, goran *Ceriops decandra*, keora *Sonneratia apetala*, and nipa palms *Nypa fruticans*. Other important mangrove species include passur *Xylocarpus mekongensis*, kankra *Bruguiera gymnorhiza*, baen *Avicennia officinalis*, and amur *Amoora cuculata*. A study shows that the sundri and gewa comprises 84% of the entire forest cover, reflecting their dominance in the Sundarbans (Iftekhar and Saenger, 2008).

The Sundarbans is characterised by a maritime climate with a very seasonal weather patterns (Iftekhar and Islam, 2004b). Most of the Sundarbans is less than 1 m above the sea level (Canonizado and Hossain, 1998), and consists of vegetated islands that are inundated regularly by two high and low tides, each day with a mean amplitude of 3-4 m (Chaffey et al., 1985; Gopal and Chauhan, 2006). The forest floor is hugely interconnected by networks of grounded roots and upward spikes of pneumatophores, the critical features of the Sundarbans forests. The canopy of the forest hardly reaches more than 10 m.

Distribution of plant species and their composition in pure or mixed patches is highly influenced by salinity in waters. The vegetation patches in terms of species associations are widely variable in size and combinations. The northern and eastern parts receive more upstream river flow than the western regions, the floristic composition and growth is therefore varied across the regions. A comprehensive study by the Bangladesh Forest Department (2012) shows that about 99% of the forest area is composed of 13 forest types. It is noteworthy that except for the two forest types, the major types are characterised by the presence of one or both species of sundri and gewa (Table 1).



Fig. 6. Typical view of a narrow creek with keora and nipa palms in the Sundarbans.

Table 1: Major Forest types according to species association in the Bangladesh Sundarbans (BFD, 2012)**.**

Forest types	Area (ha)
Baen	1136.54
Gewa	21,453.90
Gewa-goran	32,574.71
Gewa-sundri	73,504.62
Goran	7,831.31
Goran-gewa	54,655.30
Keora	10,602.53
Passur-kankra	274.99
Passur-kankra-baen	2,524.93
Sundri	74,264.06
Sundri-gewa	102,273.58
Sundri-passur	2,368.43
Sundri-passur-kankra	7,083.99
Non-mangrove	362.23
Forest (total)	**390,911.11**
Grass and bare ground	4,856.13
Sandbar	1,217.84
Waterbody	221,005.41
Bangladesh Sundarbans	**617,990.49**

2.4. Salinity

The water salinity in the Sundarbans is a significant abiotic factor due its proximity to the Bay of Bengal and the network of rivers that flow through the region. The forest is situated in the estuarine zone where freshwater from the rivers meets the saline waters of the Bay of Bengal. This creates a dynamic and complex ecosystem with varying salinity levels. However, salinity levels exhibit seasonal variations. During the dry season, from November to April, when the river flow is reduced, salinity tends to be higher. In contrast, during the monsoon season, stretching from June to September, when the river discharge is higher, salinity levels remain relatively lower. The Sundarbans has a gradient of salinity levels from the freshwater zones near the rivers to the more saline areas close to the Bay of Bengal (Fig. 7).

Three broadly defined ecological zones have been recognised based on the very complex correlation of varying degree of residual salinity, fresh water flushing physiography, and their influence on the composition, and characteristics of species which inhabit the ecosystem (Chafeey et al., 1985). They are freshwater zone, the moderately saltwater zone, and the saltwater zone, occurring roughly from the north-east to south-west (Fig. 7). However, the boundaries of these zones are not stable and can be affected by the seasonal changes of freshwater flow from the upstream rivers. The freshwater supply in the Sundarbans has declined significantly since the Farakka barrage

was created in India in 1975, whilst the freshwater zone is converting to moderate saltwater zone and moderate saltwater zone to saltwater zone (Iftekhar and Saenger, 2008). Generally, the salinity gradually increases as one moves towards the outer edges of the Sundarbans. The varying salinity levels in the Sundarbans influence the distribution of plant species and animal lifeforms inhabiting the forest and aquatic ecosystems.

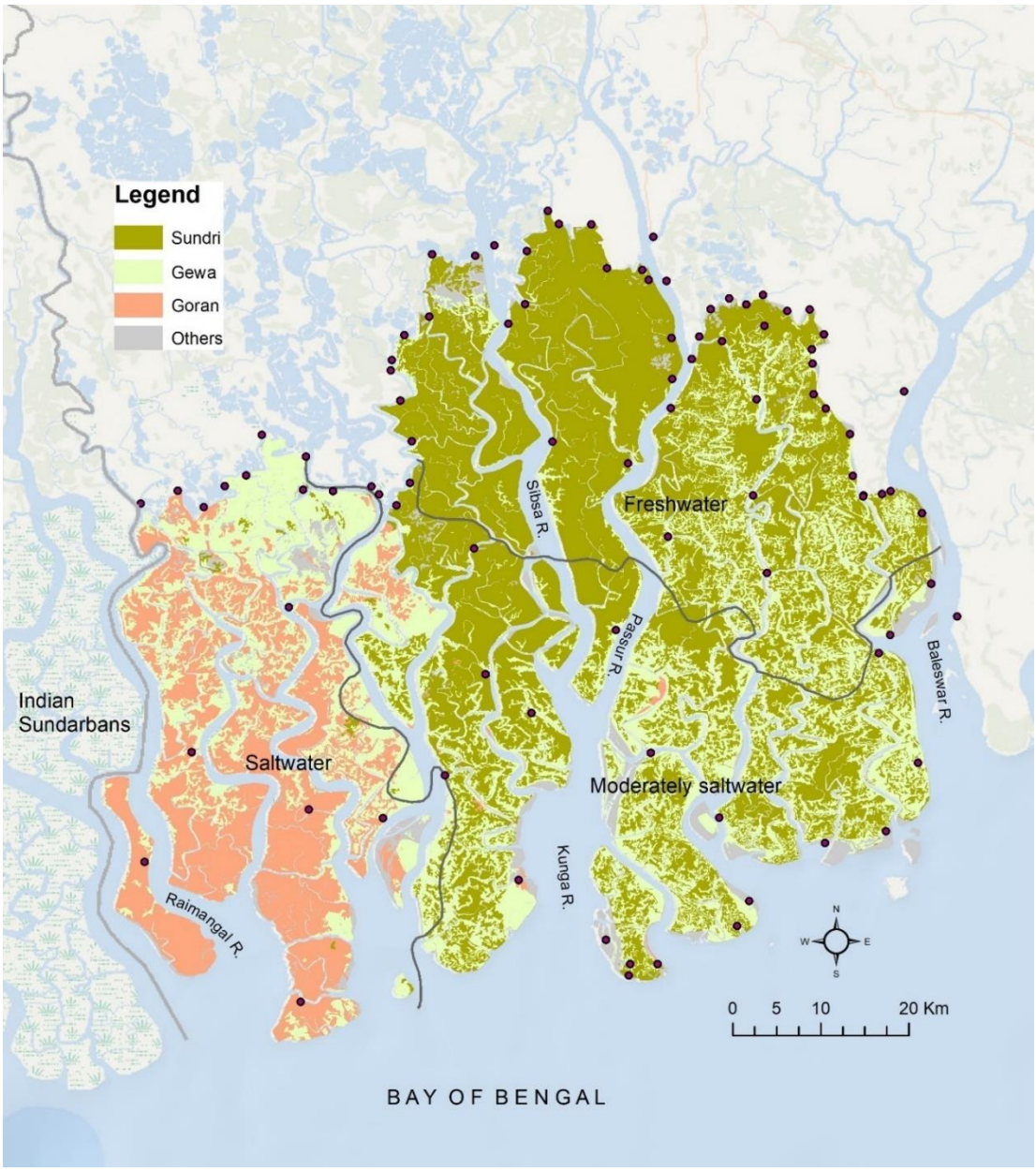


Fig. 7. Major vegetation types and salinity zones in the Bangladesh Sundarbans (reproduced from Chaffey et al. 1985 and IRMP 2010).

2.5. Climate

The climate of Sundarbans is influenced by its geographical location and proximity to the Bay of Bengal. The Sundarbans experience a tropical monsoon climate, characterised by high temperatures, humidity, and abundant rainfall throughout the year. The region has four distinct seasons: winter (December to February), summer (March to May), monsoon (June to September), and post-monsoon (October to November). The average temperature ranges from 25°C to 35°C during the summer months. In winter, temperatures can drop to around 10°C to 20°C. The Sundarbans experience high humidity levels, especially during the monsoon season when it can reach up to 90%. Humidity remains relatively high throughout the year. The Sundarbans receives heavy rainfall due to its proximity to the Bay of Bengal and the influence of the southwest monsoon. The annual rainfall ranges from 1,500 to 2,500 mm, with the highest precipitation occurring during the monsoon season. The monsoon season brings intense rainfall and frequent thunderstorms. The region is susceptible to regular tropical cyclones originating from the Bay of Bengal. These cyclones cause significant damage to the region, including strong winds, storms surges, and heavy rainfall. The Sundarbans is also vulnerable to the effects of climate changes, including rising sea levels. This poses a long-term threat to the ecosystem and its diverse wildlife.

3. PROFILE OF TIGER'S PRINCIPAL PREY SPECIES

2.1 Spotted deer

Head-body length: 90-140 cm
Height at shoulder: 90 cm (M), 70 cm (F)
Tail length: 10-25 length
Antler's length: 50-100 cm
Weight in kilogram: 70-90 (M), 40-60 (F)
Gestation period: 210-225 days
Lifespan: 9-11 years



Fig. 8. A male spotted deer in the Sundarbans.

The spotted deer is a beautiful animal with a spotted body and short tail. It is also known as chital as well as axis deer. Colloquially, the male with antlers is called *singel* by the 'forest people' of the Sundarbans (Fig. 8). German naturalist Johann Christian Polycarp Erxleben first described and gave the Latin name of this deer in 1777. It lives in the grasslands and forests of the Indian subcontinent comprising herds of up to 100 individuals or more. The spotted deer is native to Bangladesh, India, Nepal, Pakistan, and Sri Lanka.

The spotted deer is a medium-sized ungulate, with males heavier than females. They are sexually dimorphic. The upper parts of both sexes have bright golden to rufous coat, speckled with white spots. The throat, abdomen, insides of legs, ears and rump have white fur. Males have magnificent antlers which is absent in female. Antlers are three-tined which grow up to 100 cm. Antlers can regrow if they are broken during fighting.

The spotted deer eats a variety of plants. They prefer grasses, young shoots, foliage, and fruits. In Sundarbans, spotted deer are found to congregate in the meadows of the Katka, Khachikhali, Jamtola, Kokilmoni, and Mandarbaria. Fruits and leaves of *Sonneratia,* and *Imperata* grass are their favourite food items. The spotted deer play an important ecological role in their habitats as seed dispersers as well as the principal prey of tigers in the Sundarbans.

3.2 Wild boar

Head-body length: 90-200 cm
Height at shoulder: 80 cm
Tail length: 15-40 cm
Weight: 60-100 kilogram
Gestation period: 115 days
Lifespan: 10-14 years



Fig. 9. Wild boar in the pneumatorphores of the Sundarbans.

The wild boar is the largest of all pigs which live in forest habitats. The term *boar* is used to designate the male of the domestic pig, guinea pig, and various other mammals. The wild boars have stocky and powerful bodies with harsh, bristly hair on the top and much softer hair underneath. The wild boar inhabits a wide range of habitats, occurring in the western and northern Europe and north Africa to India including the Andaman Islands and China.

The wild boar is black or brown in colour with grizzled hair (Fig. 9). The piglets are lighter brown, with stripes on their coat for camouflage. Generally, adult

females and their young live in groups except for the old males which generally remain solitary. The wild boar possesses sharp tusks, with males having longer one that protrude from the mouth. Rival males fight using their tusks to get access to females for mating. The litter size varies widely, with up to 10 piglets.

The wild boars are mainly nocturnal. They are omnivorous and eat on roots, seeds, bulbs, nuts, and other plant parts from the forest floor. They are also adapted to eat carrion, earthworms, invertebrates, bird's eggs, and small mammals. Wild boars are very swift and can be dangerous even though they are normally unaggressive.

3.3 Barking deer

Head-body length: 95-110 cm
Height at shoulder: 50-60 cm
Tail length: 12-20 cm
Weight in kilogram: 25-30 (M), 20-25 (F)
Gestation period: 180-210 days
Lifespan: 17-30 years



Fig. 10. Barking deer on the riverbank in the Sundarbans.

The barking deer is a small-sized deer occurring in Asian countries. They are known as barking deer due to its nature of making sound resembling of a barking dog. Local people call it *maya horin*, the name probably given because of its alluring face. It occurs in twelve countries of south-central and south-east Asia including Bangladesh, Bhutan, Cambodia, China, India, Lao PDR, Myanmar, Nepal, Pakistan, Sri Lanka, Thailand, and Vietnam.

The barking deer is reddish brown or sometimes dark brown (Fig. 10). The upper canine of males is longer that projects from the mouth which is used in fighting with rival males. The males have short antlers with a single branch whilst the female has small knobs in place of antlers. The base of antlers extends onto the face of the deer from which another common name was given the *rib-faced deer*.

The barking deer inhabits a wide variety of habitats which include plains and rugged mountains, dense and open forests, evergreen and deciduous areas, old-growth, and secondary forests, and even grass, and cropland near woodlands. In Bangladesh, it is found in most of the NE and SE hill forests including Sundarbans mangrove swamps.

3.4. Water monitor

Length: 1.5-2 m
Weight: 20-50 kilogram
Lifespan: 11-25 years
Breeding season: April-October
Incubation period: 6-7 months
Clutch size: 10-40 eggs

The water monitor is a large varanid reptile native to south and southeast Asia. It lives close to water with range of forest and riparian habitats, ranging from primary forests, agricultural areas, and mangrove swamps. The habitats considered to be the most important to this lizard include mangrove vegetation, tidal flats, swamps, and riverbanks. They inhabit both saltwater and freshwater habitats across Bangladesh, India, Myanmar, and Sri Lanka.

The water monitor has a muscular body, with long, powerful, laterally compressed tail. They have very long neck and elongated snout. This lizard is characterised by their dark brown or blackish colouration with yellow spots on their underside which tend to disappear gradually with age. It has blackish band with yellow edges extending back from each eye.

The water monitor has powerful jaws, serrated teeth, and sharp claws which they use for predation and defence. This animal is amphibious in nature, and excellent swimmer. They are diurnal and hide or rest in trees, under bushes, large roots, or cavities under logs. To escape danger, they may jump from trees into rivers or creeks.



Fig. 11. Water monitor is adapted to mangrove habitat of Sundarbans.

The water monitors are carnivores and consume a wide range of prey species such as fish, crabs, frogs, snakes, rodents, and birds. They also eat turtles, and crocodile eggs. The water monitors often eat carrion. They have a keen sense of smell and can smell a carcass from far away.

The water monitor is one of the most exploited varanids for use in fashion accessories worldwide. Loss of habitat and hunting has exterminated water monitors from most of the mainland India and southeast Asia (André et al., 2013). Water monitors play a key role in their ecosystem as they are one of the large land carnivores where they inhabit.

3.5. Rhesus macaque

Head-body length: 47-64 cm
Tail length: 20-30 cm
Weight in kilogram: 11 (M), 8.5 (F)
Gestation period: 166 days
Lifespan: 27-40 years

Of the 10 species of nonhuman primate found in Bangladesh, rhesus macaque is the only species that occurs in the Sundarbans mangrove forest. Colloquially, it is known as *banor*. It is the most widely distributed nonhuman primate species of Bangladesh and occurring all types of forests including many urban habitats. They are found coexisting with humans across its range. It is native to India, Nepal, eastern and southern China, and northern Southeast Asia.



Fig. 12. Rhesus macaque – the only nonhuman primate found in the Sundarbans.

The rhesus macaque is brown or grey in colour. The face and rear are pink. This nonhuman primate eats a wide variety of foods comprising fruits, seeds, roots, leaves, and bark (Fig. 12). They also eat insects and small animals which they encounter. The monkey spends much of their active time on the ground, although they are good climbers as well as swimmers.

The rhesus macaque lives in groups comprising several adult males and females including their young. Male monkey leaves the group at maturity whilst the female tends to remain in the group with their parents. A single group living in temples or in urban habitats may range from 50 to 200 or more. In natural environment, the usual group size varies from 12 to 20. The group consists of multiple males and females including babies, and infants, where males are the dominant sex. Female usually produce one baby each year which is raised by its mother.

3.6. Malayan porcupine

Head-body length: 56-74 cm
Tail length: 6-11 cm
Weight: 10-18 kilogram
Gestation period: 90-112 days
Lifespan: 27 years

The Malayan porcupine is a species of rodent but relatively large compared to other rodent species in the family Hystricidae. They have short legs covered

with brown hairs. There are four claws on the front and five on the hind legs of the porcupine. Both legs have smooth soles. Three subspecies of porcupines live in south and southeast Asia.



Fig. 13. Malayan porcupine in the Sundarbans.

The Malayan porcupines are stout-bodied rodent covered with quills which are modified hair. These quills are rigid structures and sharply pointed which are used in defence and fighting. The quills which are on their upper body parts are rough black with white or yellow stripes (Fig. 13).

The Malayan porcupines are terrestrial, and forages at night. They live in a wide variety of habitats including forests, agricultural areas or even in open areas near forests. Porcupines live in small groups and are found to occupy dens near rocky areas or in the holes of trees or root systems. They may also dig out burrows, from which a network of trails penetrates surrounding habitat. Porcupines can also swim. They remain inactive during the day. Porcupines are considered ecosystem engineers, and play an important role in seed dispersal, habitat creation, and bark stripping.

The Malayan porcupines feed on a range of plant materials which include roots, tubers, bark and fallen fruits. They also eat carrion, insects, and large tropical seeds. Porcupines may give birth two litters in a year.

4. METHODS AND MATERIALS

4.1. Background

We reviewed previous efforts of prey surveys and conducted expert consultations for selecting suitable survey methods for the Sundarbans. We adopted two candidate methods for assessing tiger prey species: Pellet Group Count (PGC) and distance sampling. The PGC method has been widely used for survey of ungulates (Barnes and Smith, 1995; Neff, 1968; Webbon et al., 2004), which was also tested in the Bangladesh Sundarbans (Deodatus and Ahmed, 2002). Distance sampling using *khal* (small rivers, and creeks) as transect was used in the Indian side of the Sundarbans (Roy et al., 2016). Although a preliminary estimate of prey species is available from Indian parts, however, reliable estimate is lacking for Bangladesh Sundarbans. Before implementing these methods in our study, we have piloted PGC method, and boat-based transect to assess their suitability in the Bangladesh Sundarbans. We have created 40 PGC plots and 40 km boat-based transect distributed across 5 sample units in the Chandpai Range. Our results showed that the applicability of boat-based transect was extremely challenging for counting spotted deer, wild boar, barking deer, and Malayan porcupine, due to low visibility owing to dense riverbank vegetation across the 80% of the transect length surveyed (Fig. 14). However, detection of rhesus macaque, and water monitor was reasonable across the transects travelled by boat. Conversely, creating 200 m^2 PGC plot (2.5 m x 40 m) for counting pellet groups of ungulates including Malayan porcupine was successful with 98% recovery of pellet accumulation in the sampled plots. The PGC method also provided more robust data on habitat conditions (additional data on tiger pugmark, human presence, vegetation, etc.) which was otherwise challenging during boat-based transect. Therefore, we decided PGC method for surveying all ungulates including Malayan porcupine whilst the boat-based transect for rhesus macaque, and water monitor.

The mosaic nature of rivers, creeks, and forest islands make the Sundarbans only accessible only by boat. Therefore, our extensive surveys and stay in the Sundarbans was made possible by one accommodation boat (Alorkol, with accommodation capacity of 12 people), 2 survey boats (locally called *sampan*) and 1 speedboat. Ten research assistants (local fishermen and honey hunters) including two biologists, having previous experience of conducting tiger scat sampling and camera-trapping in the Sundarbans, were sourced for this project. The survey team was supported by 4 boat drivers, 2 cooks, and 1 general assistant. All survey works were carried out by 2 survey teams, each with 4 surveyors, assisted by 2 armed guards and 1 boat driver. Accommodation boat was used for night stay and cooking whilst survey boats were used to reach out the remote survey plots and narrow watercourses for boat-based transect survey.



Fig. 14. The poor visibility due to dense riverbank vegetations poses a huge challenge for distance sampling.

During survey, each team left in the early morning with sampan boat and returned to the accommodation boat in the evening. Breakfast and lunch were pre-prepared and taken from accommodation boat while leaving in the morning so that the teams could continue surveys without waste of time while travelling long-distance for meal every day. The speedboat was used for emergency support in case of sickness (always kept ready in case of any accidents due tiger to attack; fortunately, that hadn't happened!) and food supply for the team. Knife, bear spray/pepper spray, whistles, and sticks were carried with each team for first-layer of defence in case of immediate safety issues, in addition to the armed guards. Each team members were trained for specific activity in the field so that everyone remained focused on their assigned roles and being aware about safety issues.



Fig. 15. Local boat (sampan) used in the surveys.

4.2. Sampling framework

The entire forest land of the Sundarbans is occupied by tiger (Aziz et al., 2019), so by the prey species (Aziz et al., 2020). It is also plausible that spatial distribution and density of prey species varies across the gradient of vegetation types and other factors such as elevation, topography, level of human presence, and the level of protection. Therefore, we aimed at surveying the entire forest land of the Sundarbans in order to produce a robust baseline of prey species, and to investigate the spatial distribution so that management actions could be prioritised. We, therefore, established our sampling framework where the entire Sundarbans was delineated into 65 sample units (Fig. 16), an approach adopted from a previous tiger monitoring study (Barlow et al., 2008). Also, the relationship between prey data, intended to be produced in this study, could be established with that of tiger track-set index to improve the efficacy of the long-term tiger monitoring programme of the Sundarbans (Barlow et al., 2008). Within each sample unit, we created our PGC plots and established boat-based transects, where sampling intensity (i.e., number of plots or km of transect) was distributed as best as possible considering the area of the sample units. A detailed list of sample unit, number of PGC plots, and length of boat-based transects, distributed across forest range, sanctuary and reserve forests was presented in the Table 2.

Table 2: Distribution of sampling efforts across the Bangladesh Sundarbans.

Sample Unit	Number of PGC plot	Transect length (km)	Forest Range	Management status
1	6	12.80	Sarankhola	East WS
2	12	22.40	Sarankhola	East WS
3	12	15.00	Sarankhola	East WS
4	18	31.60	Sarankhola	East WS
5	10	10.10	Sarankhola	East WS
6	22	26.86	Sarankhola	East WS
7	13	32.10	Sarankhola	East WS
8	12	28.70	Sarankhola	East WS
9	10	21.20	Sarankhola	East WS
10	9	6.50	Chandpai	East WS
11	10	13.70	Chandpai	East WS
12	9	18.70	Chandpai	Reserve forests
13	12	16.49	Sarankhola	East WS
14	7	10.40	Sarankhola	Reserve forests
15	13	13.20	Chandpai	Reserve forests
16	9	12.80	Chandpai	Reserve forests
17	11	22.90	Chandpai	Reserve forests
18	8	11.20	Khulna	Reserve forests
19	10	5.90	Khulna	South WS
20	16	18.20	Khulna	South WS
21	15	22.30	Khulna	South WS
22	18	20.80	Khulna	South WS
23	18	16.70	Khulna	South WS
24	6	20.80	Chandpai	Reserve forests
25	7	16.70	Chandpai	Reserve forests
26	10	24.50	Chandpai	Reserve forests
27	8	12.60	Sarankhola	Reserve forests
28	8	2.20	Chandpai	Reserve forests
29	6	12.70	Chandpai	Reserve forests
30	10	8.22	Chandpai	Reserve forests
31	9	9.60	Chandpai	Reserve forests
32	7	13.60	Chandpai	Reserve forests
33	9	19.30	Chandpai	Reserve forests
34	11	28.00	Khulna	Reserve forests
35	16	44.51	Khulna	Reserve forests
36	11	18.60	Khulna	Reserve forests
37	14	22.70	Khulna	Reserve forests
38	14	29.90	Khulna	Reserve forests
39	15	24.70	Khulna	Reserve forests
40	13	24.00	Khulna	Reserve forests

41	12	24.68	Khulna	Reserve forests
42	12	15.30	Khulna	Reserve forests
43	13	23.70	Satkhira	Reserve forests
44	16	14.70	Satkhira	Reserve forests
45	15	24.50	Khulna	South WS
46	20	26.80	Khulna	South WS
47	7	23.60	Sarankhola	Reserve forests
48	21	27.20	Khulna	South WS
49	17	28.40	Satkhira	Reserve forests
50	15	36.50	Satkhira	Reserve forests
51	13	20.90	Satkhira	Reserve forests
52	16	24.30	Satkhira	Reserve forests
53	15	26.30	Satkhira	Reserve forests
54	18	8.35	Satkhira	West WS
55	11	17.70	Satkhira	West WS
56	16	13.00	Satkhira	Reserve forests
57	15	31.60	Satkhira	Reserve forests
58	14	17.90	Satkhira	West WS
59	14	23.30	Satkhira	West WS
60	13	17.60	Satkhira	West WS
61	13	14.80	Satkhira	West WS
62	12	27.60	Satkhira	West WS
63	17	22.10	Satkhira	West WS
64	5	14.00	Satkhira	West WS
65	14	18.20	Satkhira	West WS

Of the 65 sample units delineated, the mean area was 63.38± *SD* 14.41 km^2 with a range from 40.86 km^2 to 101.09 km^2. The Satkhira range has the highest number of sample unit (19), followed by Khulna (18), Chandpai (15) and Sarankhola (13) range. Of note, the number of sample unit across range is tentatively proportional to the area of each range.

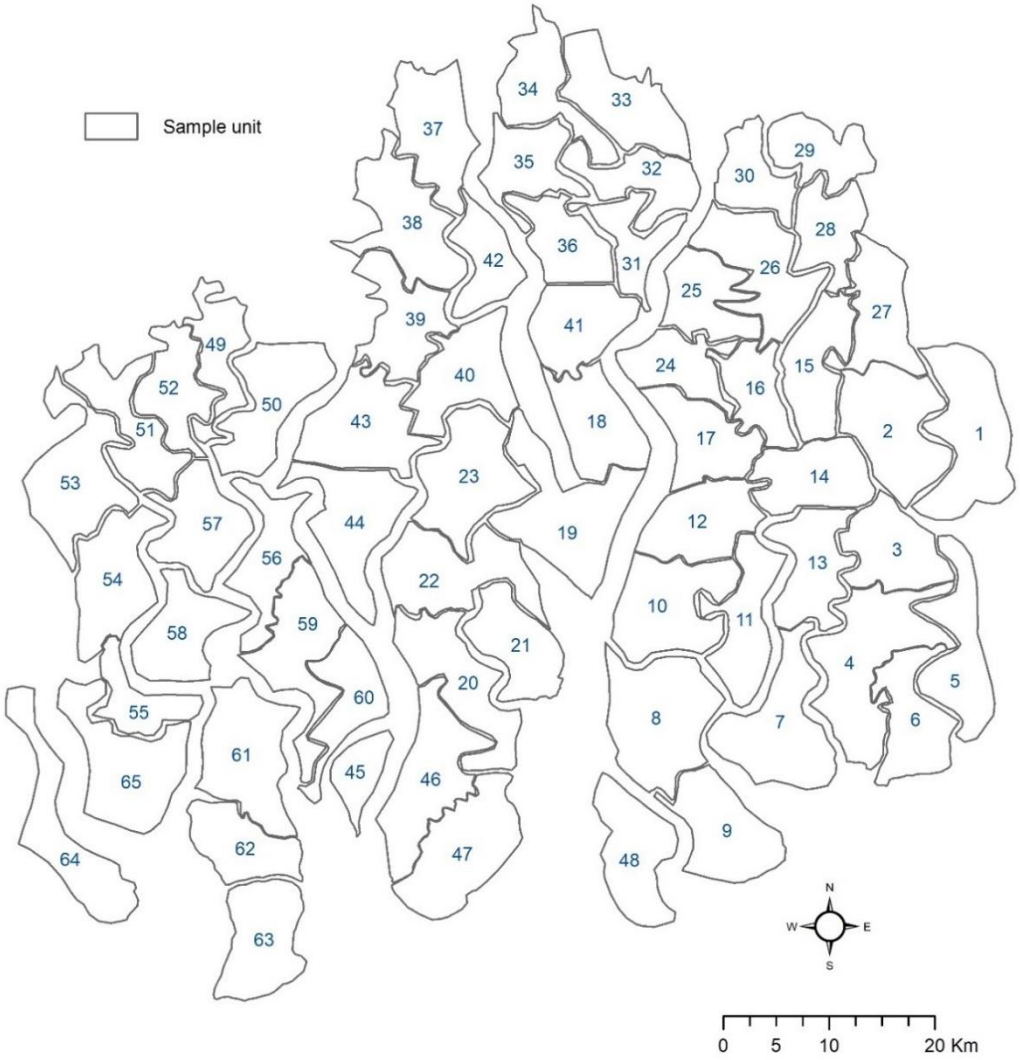


Fig. 16. Sample units used for PGC survey, and boat-based transects in Bangladesh Sundarbans.

4.3 Pellet Group Count

The density and abundance of spotted deer, wild boar, barking deer, and Malayan porcupine was assessed by using PGC method. The PGC method is a useful tool to estimate population densities in a non-invasive way, without needing to capture or handle the animals. This method has been widely used to assess ungulate numbers from eighties (Plumptre and Harris, 1995; Rowland et al., 1984) to recent times (Fattorini and Ferretti, 2020; Plhal et al., 2014), particularly in areas of low visibility and in large-scale studies (Massei et al., 1998). The PGC method involves counting the number of animal droppings, or 'pellet' in a sample plot, and then using this count to estimate the population density of the animals.

To establish the location of a PGC plot, random points were generated within each sample unit. However, due to extensive networks of rivers, creeks, and swamps, a number of the sample locations were shifted to nearest suitable forest land for creating PGC plots. After selecting PGC plot location, large visible trees were marked with red paint and GPS (Garmin GPSMAP 64xs) locations were recorded for ease of revisit during count. The PGC plot direction was established as a compass bearing perpendicular to the adjacent river course. Each plot started at the high-water mark from the river edge and was composed of 40 m x 5 m (similar to strip transect) (Fig. 17). Hence, area of each PGC plot was 200 m^2. Using measuring tape, we put stick at every 10 m along the middle line, and 4 sticks in each corner of the plot so that the boundary of marked plot could be easily recognised during revisit. After the PGC plot is established, all existing pellet groups within the plot area were carefully removed. Start and end GPS locations of PGC plots were recorded.

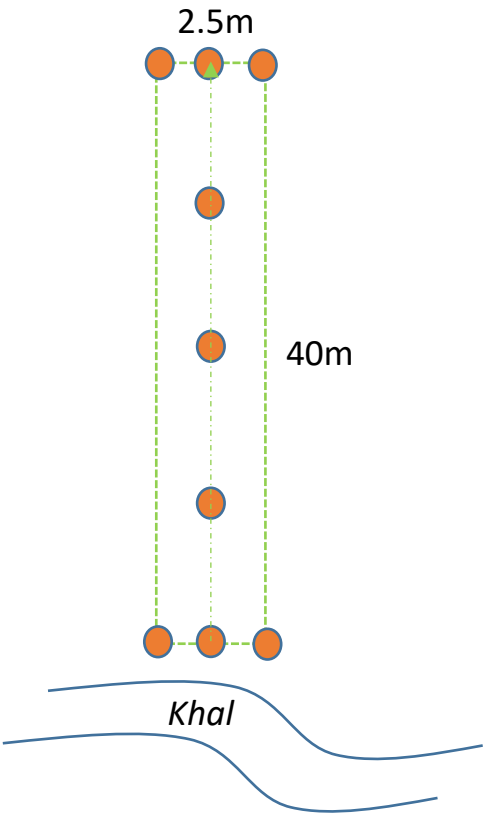


Fig. 17. Layout of PGC plot.

By investigating the size, shape, and moisture of pellet, each of study species could be easily identified, except the lack of a clear visible differences between spotted deer and barking deer pellets. To avoid any confusion in identifying pellets of these two ungulates during the survey, we have studied their pellets beforehand both in captivity and in wild habitat of Sundarbans (Table 3). This allowed us to carefully identify pellet groups during PGC survey (Chapman 2004, this study). Species identification was aided by pellet photographs to avoid any confusion (Fig. 18).

Datasheet was prepared in local language so that our assistants can fill it up with a minimum knowledge and effort. They were trained with data-filling exercise during pilot study to make them familiar with data recording details.

Table 3: Salient features of pellets of spotted deer and barking deer

Characteristics	Spotted deer	Barking deer
Size and shape	Usually small, cylindrical, or oval-shaped, and typically measure around 1-2 cm in length.	Cylindrical and often have a small point at one end. Mostly found in clumps and adhere to each other.
Texture and colour	Pellets have a compact texture. Dark brown to black in colour in fresh condition. May turn lighter and eventually fade to grey or white as they dry out.	Pellets were of firm consistency, black or dark brown and glossy when fresh because the surface was moist.
Number	Maximum number was found 105, with the mean of 73.5±17.35 in one pellet groups.	Largest number of individual pellets in one pile was 125, and the overall mean was 56±70.



Fig. 18. Pellets of spotted deer, barking deer, Malayan porcupine, and wild boar (clockwise from top to left).

4.4. Estimating daily defecation rate

The conversion of pellet count data into density requires the rate of defecation per day by per individual of study species. To do so, we determined defecation rate for spotted deer in the captive facility established at Andharmanik and Kalabogi Ecotourism Centres located within the Sundarbans (Fig. 19). In Andharmanik, 3 individuals (1 male, 2 female) and in Kalabogi, 8 individuals (4 male, 4 female) were observed directly for recording the frequency of defecation for 48 hours. During observation, assistants were posted, 1 observer assigned to 1 individual deer, outside of the facility to record each defecation event over time. Additionally, each facility was swept once in a day to remove all droppings, so that next day counting would give a total number of defecations within 24 hours' time by all individuals in the cage. These two sets of data were used to determine a conclusive defecation rate of 23 defecations per day by per individual spotted deer. Of note, these deer were fed natural food collected from the nearby forest, therefore we assumed that their defecation event was normal.

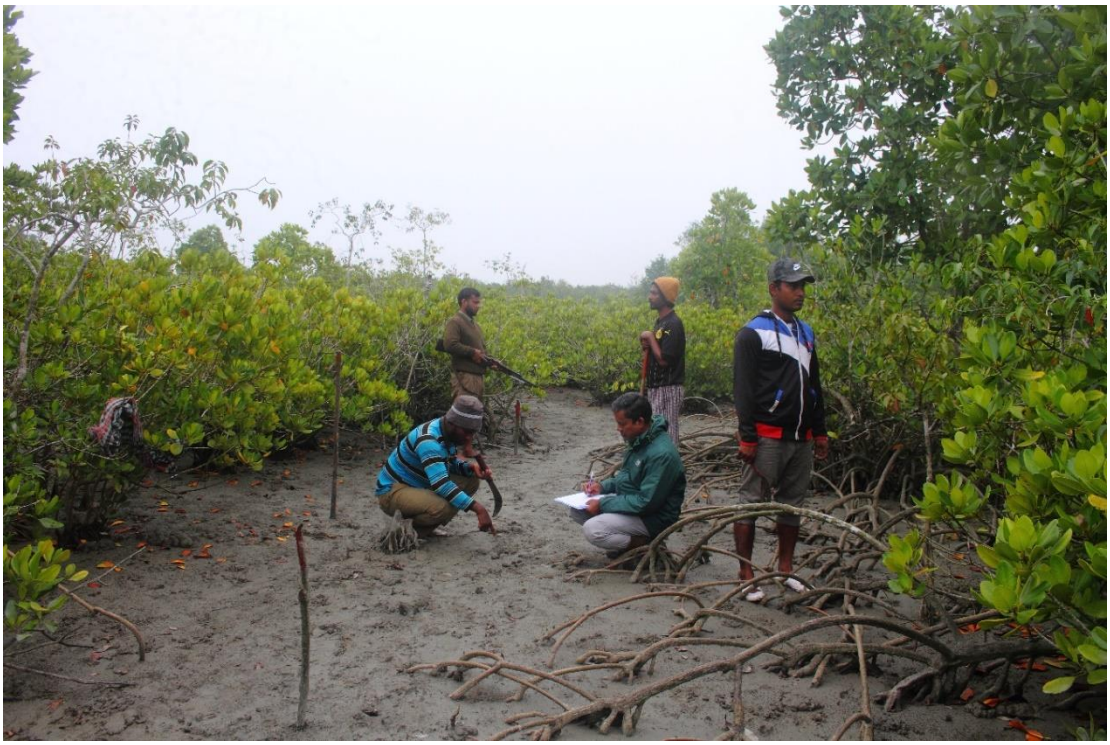


Fig. 19. Recording data in a PGC plot at Mandarbaria of Bangladesh Sundarbans.

Similarly, we have determined defecation rate for barking deer and Malayan porcupine in a private captive facility of the country, where 3 individuals of barking deer (1 male, 2 female), and 1 individual of porcupine were observed and recorded defecations for a week. The animals were fed by natural plants and vegetables, so assuming their normal defecation events. However, given

the inconsistent defecation rate due to small sample size, we used published defecation rate of Reeves' muntjac *Muntiacus reevesi* (closely related species of *Muntiacus vaginalis*), with 8.2 pellet groups by per animal per day (Chapman, 2004). In case of Malayan porcupine, 1 defecation per day by per animal was estimated and used in this study. For wild boar, we have used defecation rate of 6.7 pellet groups by per individual per day from a similar study (Fattorini and Ferretti, 2020), due to nonavailability of this animal at in-country facility.

4.5. Pellet data collection and analysis

We conducted field surveys over two dry seasons: 2nd November 2021 – 28th February 2022, and 1st October 2022 – 25th February 2023. The first season was composed of training of field assistants, piloting candidate survey methods, and implementation of pellet count methods partially. The second season was to finish the surveys of pellet count plots and conducting boat-based transects.

To estimate the density of spotted deer, barking deer, wild boar, and Malayan porcupine from PGC count data, four pieces of information were needed: number of pellet groups deposited daily by per individual of each species (defecation per day by per individual), time period when pellets are deposited (number of days between creating plot and counting pellet groups), number of pellet groups in PGC plot, and the area sampled. These data were then put into the equations (I and II) for estimating density of the animal species.

We counted faecal accumulation over a mean of 28 days (r = 13-35 days). During this short interval, pellet groups had nearly 100% survival, except extreme weather conditions of heavy downpours during seasonal storms and cyclones. We recorded the date of plot establishment, identification number of sample unit and plot, start and end GPS locations of each plot, forest types (name of tree species and their abundance in %), sign of inundation, pugmarks (tigers), and footmarks (prey species). During revisit, we recorded plot counting date, signs of human presence (pawprint, collection of non-timber forest products, fishing, etc.), tiger pugmarks, and prey footprints, and the number of pellet groups of the prey species. Two independent teams counted pellet groups from opposite end of the plot without sharing count data, and both counts were compared once counting is done. If any discrepancies occurred in counts between two teams, a third count was made to ensure a consistent number of pellet groups in each plot.

Forest type in each PGC plot was assessed based on major tree species found within the plot (% of major individual tree species with >10 cm diameter at breast height). For mixed classifications, the more dominant tree species were reported first, followed by the less common one, up to a maximum of four species. For example, if a PGC plot is dominant by sundri with some gewa, it was classified as sundri-gewa. Using field recorded data, we finally classified each PGC plot by allocating to major forest types used in the updated SRF classes (BFD, 2012).

With an effort of nine months field surveys, we managed to create a total of 808 pellet sample plots (317 plots in first season and 491 plots in second season) across 65 sample units of the Sundarbans. The mean number of plots per sample unit was 12.43 ± SE 0.48, ranging from 5 to 22 plots (Fig. 20). Due to inundation of plots by unexpectedly high tide during cyclone, data from 6% PGC plots were not utilised in analysis.

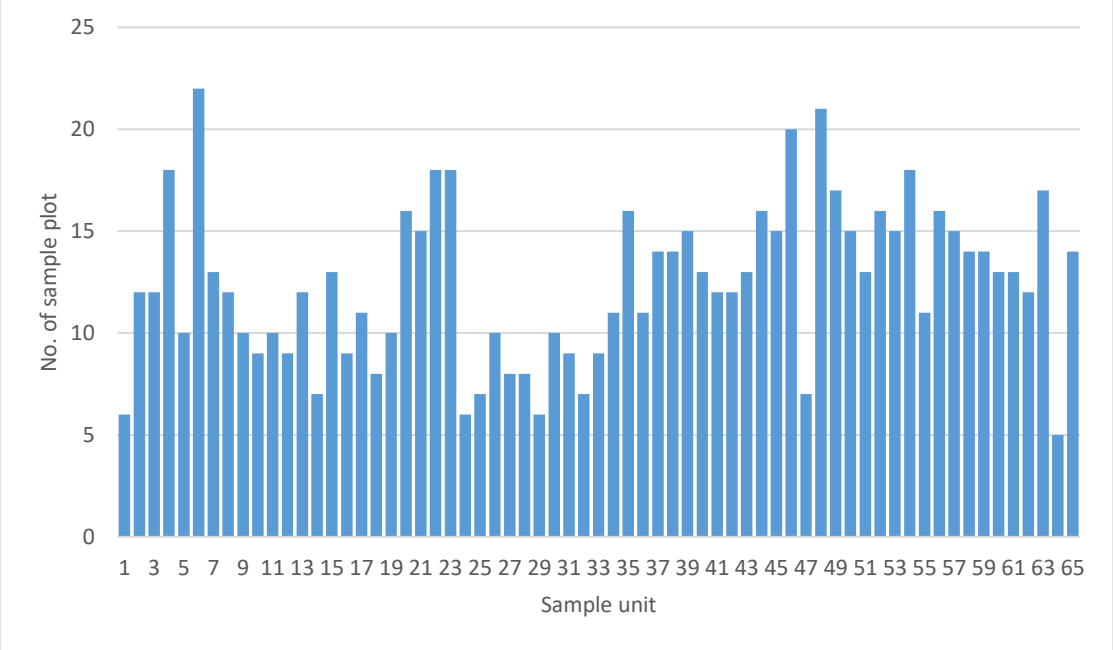


Fig. 20. Number of PGC plots across sample units in Bangladesh Sundarbans.

We pooled PGC count data together from two seasons for analysis. The mean number of pellet groups in each sampled plot was used to calculate pellet group density (pellet group/ha) using the following formula:

$$\text{Pellet group density} = \frac{No.\ of\ pellet\ groups}{Area\ of\ each\ plot} \times 10{,}000 \quad \text{.....(i)}$$

These values were combined to calculate mean pellet group density for the prey animals. Then, pellet group density was converted into animal density (individual/km^2) by dividing the total number of pellet groups recorded on a sample unit with the mean defecation rate and number of days over which pellet groups were accumulated (Mayle, 1996):

$$\text{Prey density} = \frac{Observed\ pellet\ group\ density\ per\ time\ period}{Defecation\ rate\ x\ time\ period} \quad \text{.....(ii)}$$

For assessing population abundance, density of each sample unit was assigned to any of nine forest types of the Sundarbans. The pooled density was then used to extrapolate population abundance for entire forest land of Bangladesh Sundarbans. However, population abundance for barking deer and Malayan porcupine was estimated using the area of their occurrence only, instead of entire forest lands.

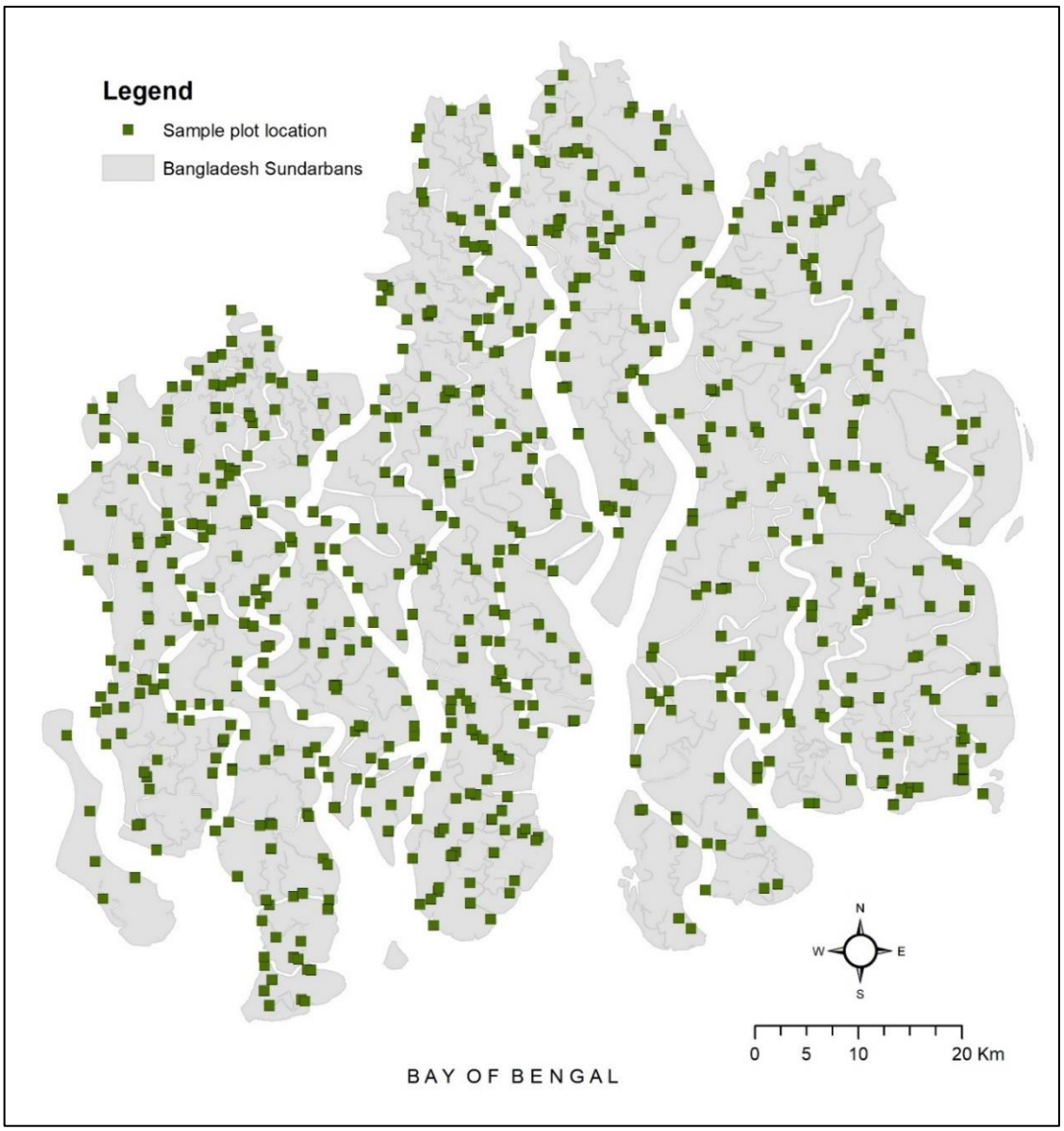


Fig. 21. Distribution of PGC plots in Bangladesh Sundarbans.

4.6. Boat-based transect

Boat-based distance sampling technique was followed to investigate rhesus macaque, and water monitor in the Sundarbans. Distance sampling is widely used method for estimating animal parameters assuming that visibility is

reasonable and target animal could be counted reliably (Buckland et al., 2001; Greenwood and Robinson, 2006). To this end, we followed navigable narrow creeks as transect with less than 100 m wide so that observed animal could be spotted, and each individual animal be counted before they disappear into the vegetation. In case of counting macaque groups accurately, we halted our survey boat until a precise counting of all members of the group was made.

Boat-based transect was conducted during the winter season, starting from 1st October 2022 to 25th February 2023. Surveys were carried out by 2 survey teams. Each team was provided with printed map of the sample unit, demonstrating the *khals* to be surveyed (annex Fig. 44). We selected survey *khals* following the framework employed in a tiger monitoring programme (Barlow et al. 2008), where the *khals* were chosen based on <100 m of width having sufficient navigation and at least 1 km of navigable watercourse. The *khals* were selected in a way so that the transects would be as representative as possible, and evenly distributed for each sample unit. The number of sample unit, khal name, survey length, and geographic location of each *khal* surveyed were annexed in Table 4.

4.7. Data collection and analysis

During boat-based transect survey, each team member took position on board for their assigned responsibility. Two team members sat on deck of the boat, one with binoculars (Nikon Monarch S, and Prostaff 7s), and another with rangefinder (Bushnell Prime 1700) for detection of prey animals (Fig. 22). We recorded survey tracks, starting and ending GPS locations of each transect, and number and locations of each animal spotted. The perpendicular distance of animal was measured by rangefinder, and detection of animal was aided by binoculars wherever needed. The speed of the survey boat was maintained around 5 km per hour for reasonable detection of the target animals. A predesigned datasheet was used to record data on distance to animal from the boat, distance to forest edge and distance to water mark on the riverbank. The number of animals spotted, their age, and sex structure wherever possible, and activity patterns (e.g., feeding, walking, swimming, etc.) were recorded in the datasheet. The third and fourth members of the team were assigned to write data in the sheet, and to take photographs of animals and their habitats. While measuring the perpendicular distance of the animal, the nearest latitude and longitude of the spotted animal was recorded.



Fig. 22. Measuring animal distance with rangefinder during boat-based transect survey.

A total of 1,281 km of transects distributed over 255 independent river segments were travelled covering the entire Sundarbans of Bangladesh for data collection (Fig. 23, 24). The mean length of transect was 5.03±*SE* 0.17 km (*n* = 255, *r* = 1.1 – 17.8 km). The mean transect length per sample unit was 20.14±*SE* 0.99 km (*n* = 65, *r* = 2.2 – 44.51 km). The distribution of transect across sample units is shown in the Fig. 23.

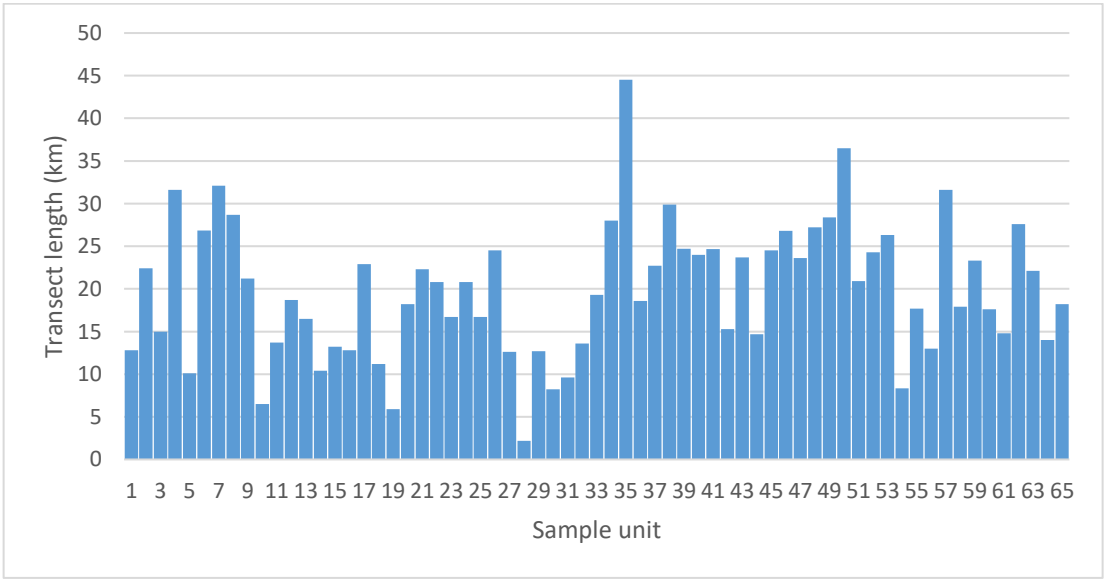


Fig. 23. Boat-based transect distributed across sample plots in Bangladesh Sundarbans.

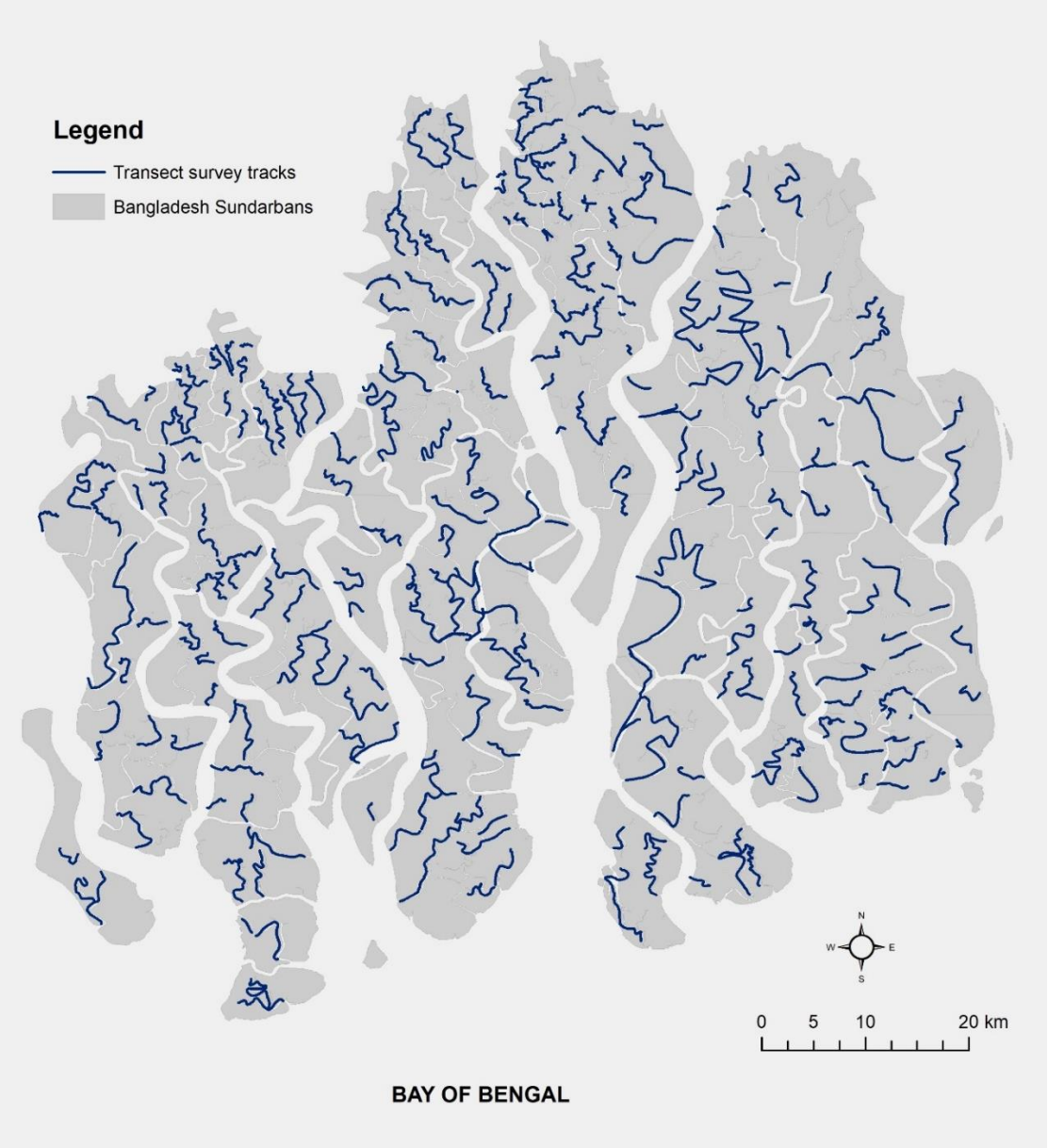


Fig. 24. Boat-based transects (blue lines) implemented in Bangladesh Sundarbans.

To begin with analysis, we plotted our data for rhesus macaque and water monitor (Fig. 25, 26). This enabled our observations of unusually large distances to be identified and excluded from the analysis, by truncating the outlying 5% observations following standard statistical procedure (Greenwood and Robinson, 2006). Therefore, we used sighting data detected within the 21 m of perpendicular distance for rhesus macaque and 33 m for water monitor, and the data beyond these cutoff values were removed from the analysis (Fig. 25, 26).

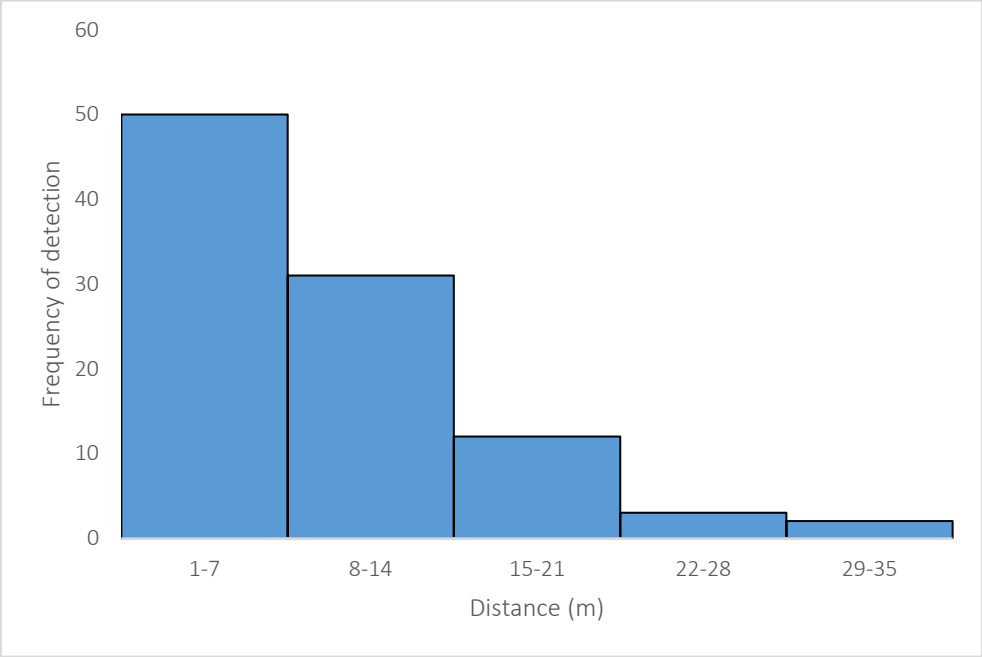


Fig. 25. Detection of rhesus macaque during boat-based transect in Bangladesh Sundarbans.

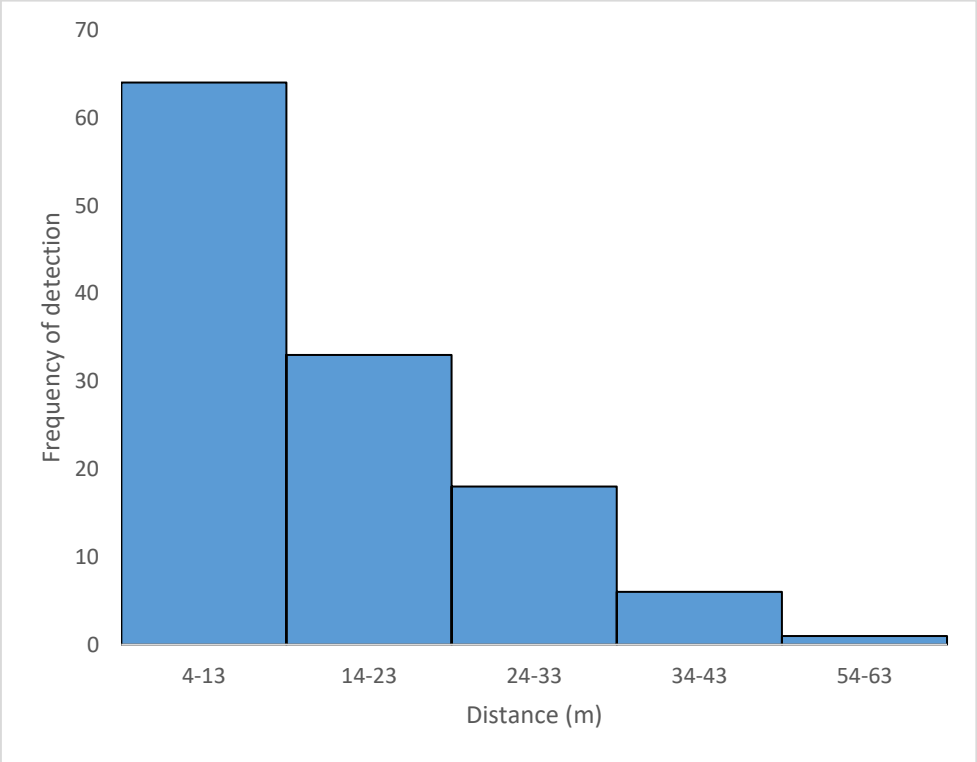


Fig. 26. Detection of water monitor during boat-based transect in Bangladesh Sundarbans.

Assuming the half-normal detectability function for our data (Greenwood and Robinson, 2006), after examining in histograms (Fig. 23), the density of rhesus macaque and water monitor was estimated using following formula:

$$D\ \text{hat} = n \sqrt{\left[2n \,/\, \pi \sum_{i} (x_i^2)\right] \,/\, (2L)}$$

where,

n = total number of animals detected

x_i = perpendicular distance of the i^{th} animal detected from the transect line

L = length of transect

5. RESULTS AND DISCUSSION

We managed to establish and revisit a total of 808 PGC plots distributed within 65 sample units covering the entire Bangladesh Sundarbans. The area of each plot was 200 m^2, consisting of 2.5 m width and 40 m length. The mean number of plots per sample unit was 12, ranging from 6 to 22, depending on the relative area of the sample unit. Average exposure time for pellet accumulation before counting was 28 days. We have successfully counted a total of 754 PGC plots whilst the rest were abandoned due to inundation by unexpectedly high tide in December 2021 and October 2022.

For investigating rhesus macaque and water monitor, a total of 255 boat-based transects was surveyed, accounting for a cumulative distance of 1,281 km watercourses across 65 sample units. The average length of each transect was 5.03 ± *SE* 0.17 km (1.1-17.8 km). The average cumulative length of transects across 65 sample unit was 20.14± SE 0.99 km (2.2-44.51 km). Unavailable navigable watercourses have led to limited transect coverage for several sample units.

5.1. Density and distribution of spotted deer

We grouped PGC data for estimating mean, range- and sanctuary-wise density for Bangladesh Sundarbans. The mean density was estimated as 35.44± *SE* 2.21 ind./km^2 of forest. The highest density was recorded in Khulna range (44.54± *SE* 6.17) and the lowest in Satkhira (29.14± *SE* 5.12) (Fig. 27). For sanctuaries, the highest density was in the South WS (37.32± *SE* 7.07) followed by East WS (36.53± *SE* 5.89), and West WS (31.79± *SE* 9.14) (Fig. 28). The cumulative density of three sanctuaries against reserve forest region showed that the density between reserve forest (35.68± *SE* 2.08) and protected area (35.16± *SE* 4.16) has no significant difference (Fig. 29). Using the mean density of spotted deer by taking account of forest types and respective land area of 3,909.11 km^2 (BFD, 2012), an extrapolated spotted deer population of 136,604, ranging from 128,104 individuals to 145,105 individuals, was determined for the Bangladesh Sundarbans.

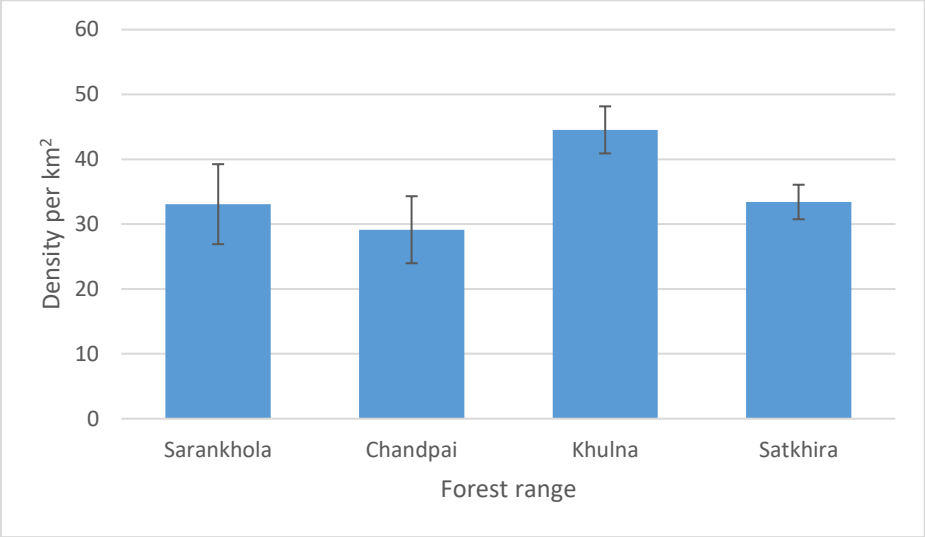


Fig. 27. Range-wise estimates of spotted deer in Bangladesh Sundarbans.

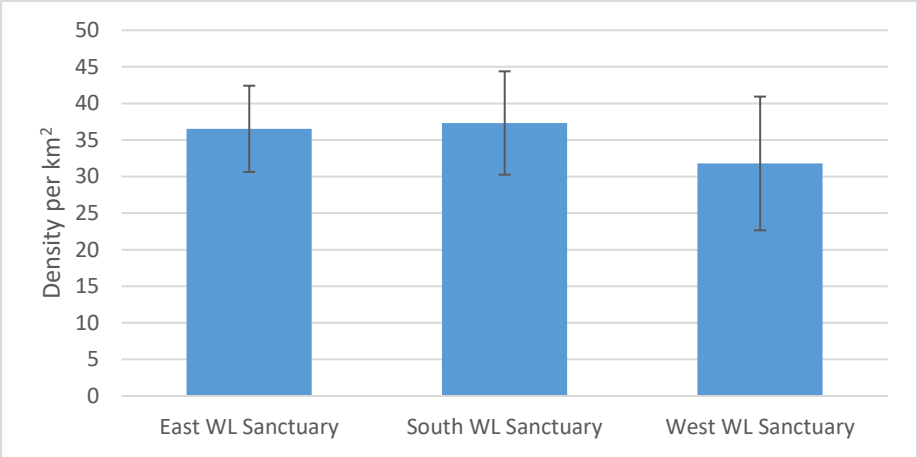


Fig. 28. Spotted deer density in wildlife sanctuaries of Bangladesh Sundarbans.

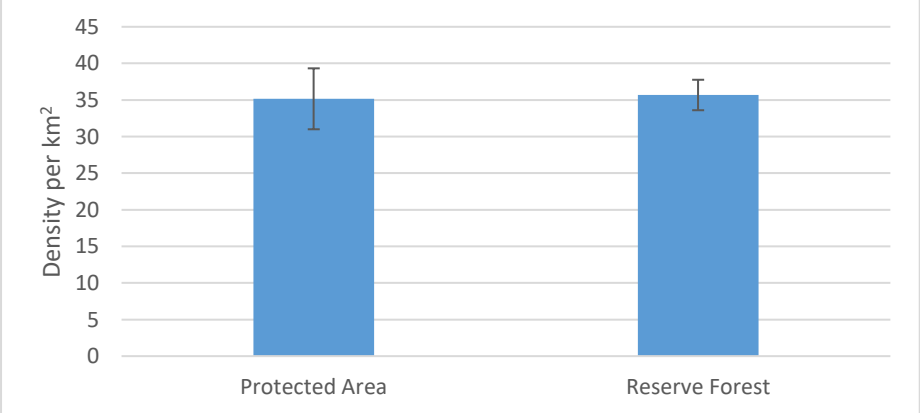


Fig. 29. Spotted deer density in protected area, and reserve forests in Bangladesh Sundarbans.

The spatial density of spotted deer was not uniform across all sample units as well as the Sundarbans (Fig. 30). Exceptionally higher densities (>60 ind./km^2) were found in the sample unit of 6 (Kachikhali, forest compartment 6), 19 (Pashakhali, forest compartment 17), 20 (Hangsha Raj, forest compartment 18), 22 (Patkosta, forest compartment 19), 24 (Charaputia, forest compartment 21), and 31 (Vodra, forest compartment 29). The sample unit 4 (Betmar, forest compartment 4), 7 (Chaprakhali, forest compartment 7), 21 (Bhromorkhali, forest compartment 18), 31 (Bhodra, forest compartment 29), 32 (Morapassur, forest compartment 30), 42 (upper Arua Sibsa, forest compartment 42), and 62 (between Mandarbaria and Jhalakathi khal, forest compartment 54) have reasonable deer densities (>50 ind./km^2). The combination of extensive grassland and scattered patches of Keora forests stretching over the areas of Kachikhali, Katka, Nilkamal, Kokilmoni, and Mandarbaria provide excellent grazing grounds to spotted deer, which may lead to higher densities of spotted deer in these areas.

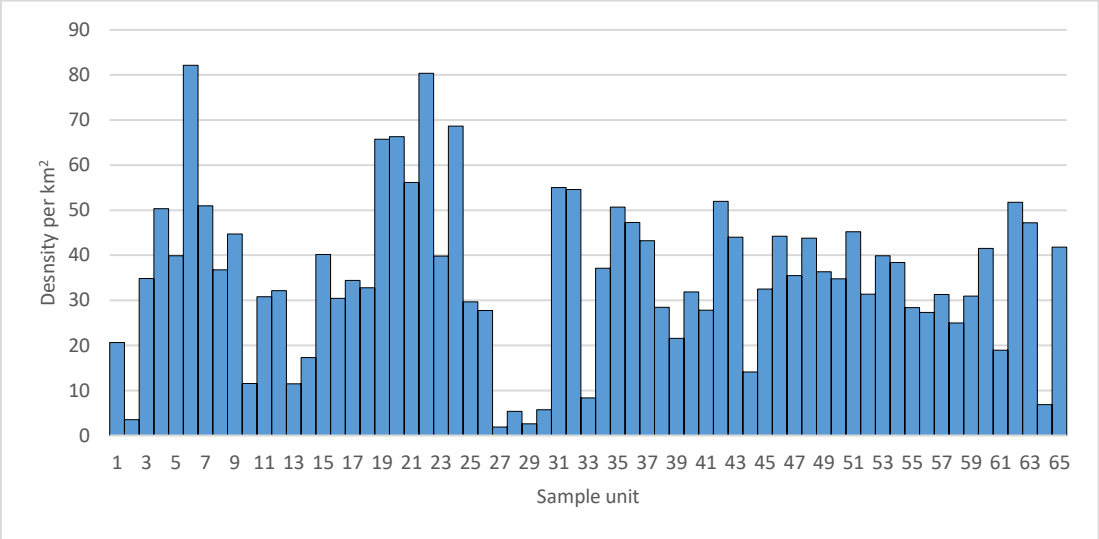


Fig. 30. Spotted deer density across sample units in Bangladesh Sundarbans.

Our results showed that a total of 13 sample units, accounting for 20% sample units, has the density of >50 ind./km^2 (Fig. 30). Overall, the south and southeastern regions have the highest density of spotted deer compared to north and northeast. Of note, sample units 2 (Dudmukhi, forest compartment 2), 27 (from Nangli to Mora Bhola, forest compartment 24), 28 (Dhanshagor, forest compartment 25), 29 (Jewdhara, forest compartment 27), and 30 (Baiydamari, forest compartment 28) contained a very low density of the spotted deer. These regions may require improved level of protection and management actions (Fig.31).

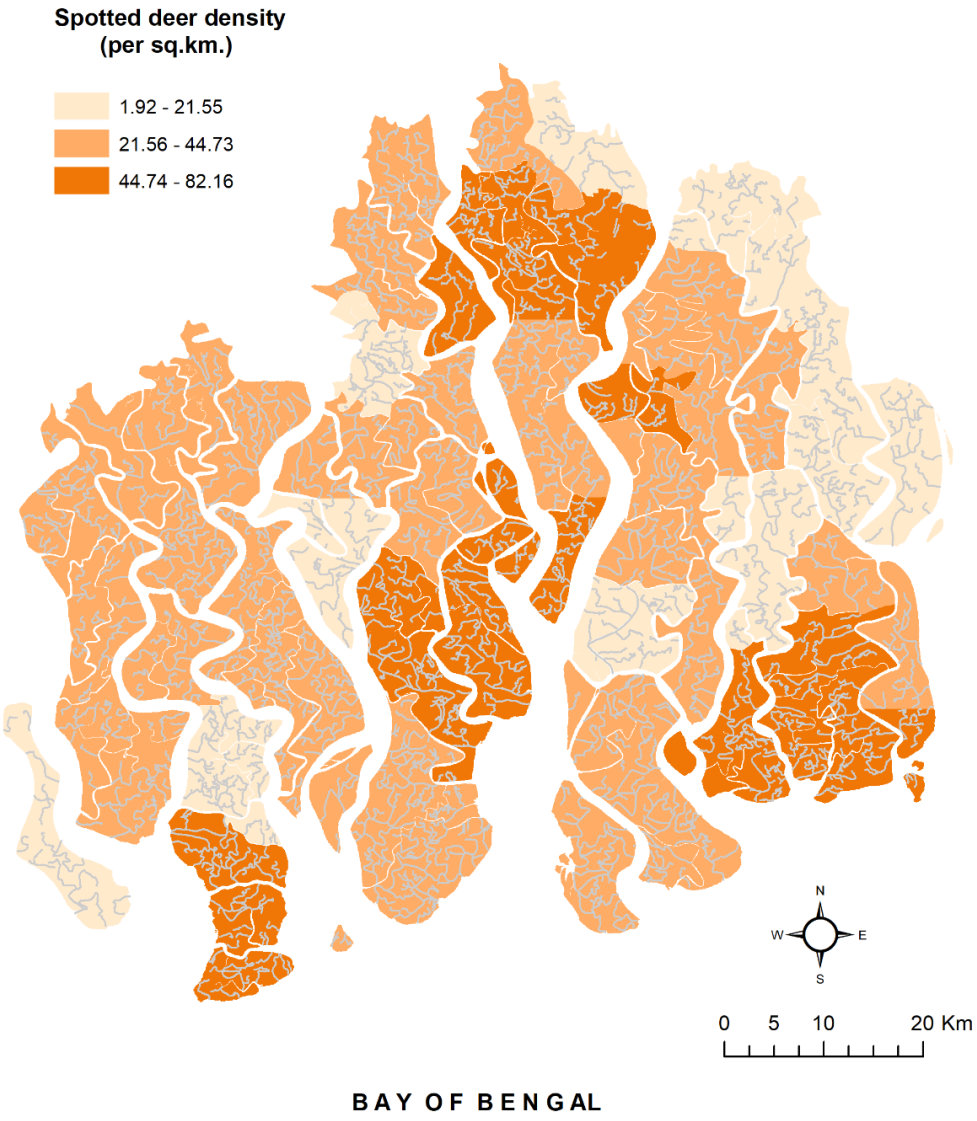


Fig. 31. Density and distribution of spotted deer in Bangladesh Sundarbans.

The density of spotted deer varied across the major habitat types of the Sundarbans, with highest in keora (73.52 ind./km^2) followed by passur-kankra (53.76 ind./km^2), gewa (50.35 ind./km^2), and baen (48.71 ind./km^2). The lowest density was found in sundri-pasur-kankra (9.95 ind./km^2) forests (Fig. 32). It is reasonable to expect high deer density in the Keora forest where stretches of extensive grasslands along with scattered keora patches provide excellent grazing grounds for this ungulate.

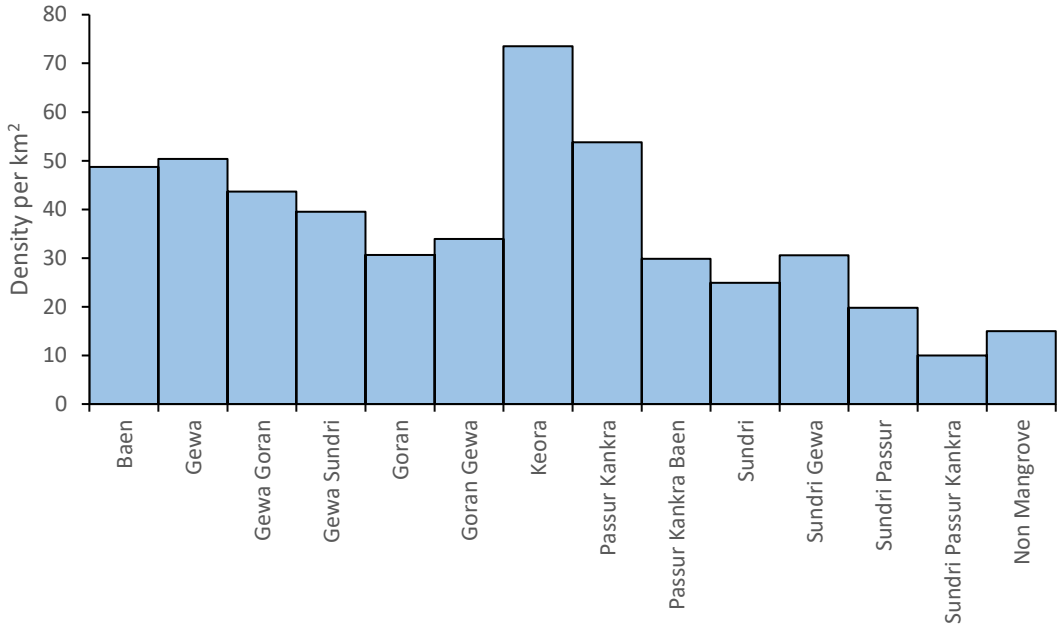


Fig. 32 Spotted deer density across habitat types of Bangladesh Sundarbans.

In Nagarhole National Park, southern India, Ahrestani et al. (2017), by using PGC method, estimated spotted deer density as 46.11 ind./km^2, and 128.15 ind./km^2, respectively for dry deciduous forest, and moist deciduous forests. These estimates are higher than the density of Sundarbans mangrove forests. Several population estimates, instead of density parameters, are available for spotted deer in the Bangladesh Sundarbans, including 80,000 (Hendrichs, 1975) and 83,000 (Dey, 2004). However, methods used in these studies appeared to be biased due to arbitrary measurement of animal distance (Khan, 2011). However, Dey (2004) had used PGC method in 27 plots, without reporting mean density of the animal. An overall density of large mammalian prey species (spotted deer, wild boar, and rhesus macaque) in Katka-Kachikhali was estimated as 27.9 ind./km^2 (Khan, 2011). The Project Tiger estimated a population of 31,000 individuals in Indian parts of the Sundarbans back in 1990s (Mallick, 2011), although, methods used in this study remains unclear. Recently, Roy et al. (2016) estimated spotted deer density at 5.24 ± *SE* 1.23 ind./km^2 using distance sampling method in the Indian parts; this estimate is much lower than our results. This estimate could not be compared directly because the method employed in our study is different. However, the lower density in distance sampling (Roy et al., 2016) could be related to the low detection rate due to dense riverbank vegetation, which was reflected in boat-based transect in our pilot study. Also, distance sampling estimates can be biased, either upward or downward, if assumptions of transect sampling are not fully met (Buckland et al., 2001). It is also plausible that vegetation types, dominated by goran-gewa in the Indian Sundarbans, as appeared in the

Satkhira range of Bangladesh (Indian part is adjacent to Satkhira range), could have negative impact on the density estimates of spotted deer. We found relatively low density of spotted deer in the Satkhira range of Bangladesh, where goran/goran-gewa are dominating forest types.

5.2. Density and distribution of wild boar

The mean estimated density of wild boar was 15.75± *SE* 1.72 ind./km^2 of forest, with the highest density in Satkhira range (33.94± *SE* 4.18), followed by Chandpai (9.46± *SE* 1.89), Sarankhola (8.47± *SE* 1.61), and Khulna (6.30± *SE* 1.26) (Fig. 33). For sanctuaries, the highest density was in West WS (10.53± *SE* 1.97) followed by South WS (9.01± *SE* 1.73), and East WS (6.01± *SE* 1.41) (Fig. 34). The density in the reserve forest region was highest (22.12± *SE* 2.64) compared to the cumulative density of wildlife sanctuaries (8.32± *SE* 1.02) (Fig. 35). Based on the mean density and the total forest land of 3,909.11 km^2 (BFD, 2012), we estimated a population of 47,515, with a range from 42,326 to 52,704 wild boars for Bangladesh Sundarbans.

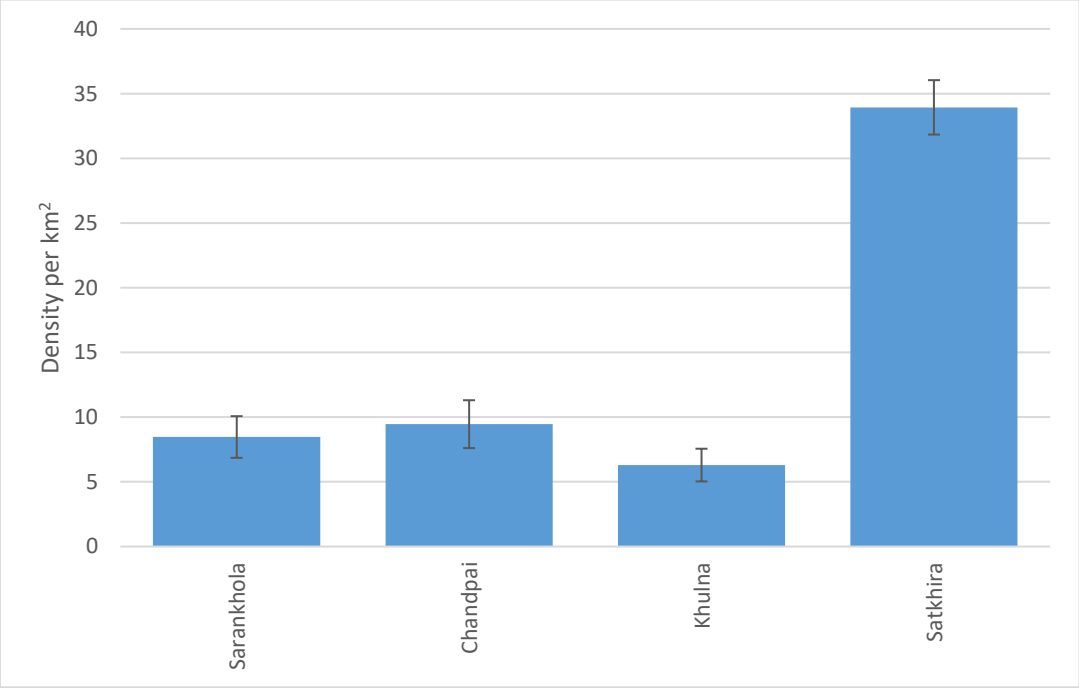


Fig. 33. Range-wise wild boar density in Bangladesh Sundarbans.

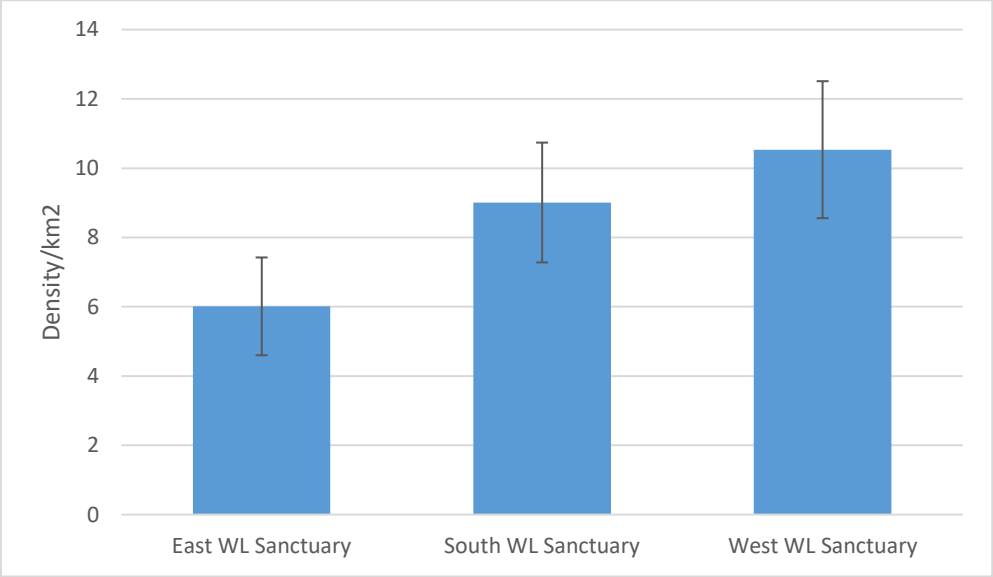


Fig. 34. Wild boar density in wildlife sanctuaries of Bangladesh Sundarbans.

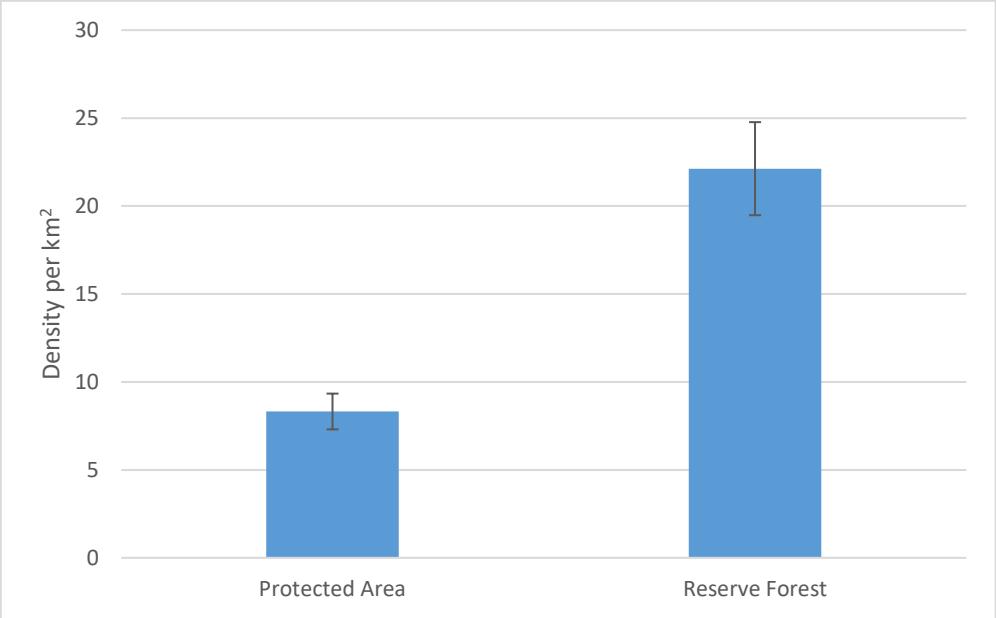


Fig. 35. Wild boar density for protected area, and reserve forest of Bangladesh Sundarbans.

The density of wild boar across sample units varied widely (Fig. 36). Our analysis showed that at least 10 sample units (15% of all sample units) has the highest density (>30 ind./km^2) of wild boar, and all of which are located within the Satkhira range (Fig. 35). Overall, the density of wild boar increases from east to west of the Sundarbans with notably higher density in the middle regions. In particular, sample units 51 (Chunkuri, forest compartment 47), 53

(Kachikata, forest compartment 48), 55 (Notabeki, forest compartment 55), 58 (Dingimari, forest compartment 51B), and 64 (Haldebunia, forest compartment 55) are preferably inhabited by wild boars. It is interesting to note that tigers cropped higher number of wild boars from the Satkhira range than the spotted deer, which was reflected in tiger diet proportions (Aziz et al., 2020). Perhaps, the frequent, and high-level inundation due to lower elevation of the forest land might be unsuitable for spotted deer, therefore the forest niche could be opened for wild boar, which may lead to reaching its optimum density in the west regions. It is also possible that a positive relationship exists between wild boar and goran/gewa-goran forest types in the Satkhira range which requires further investigation.

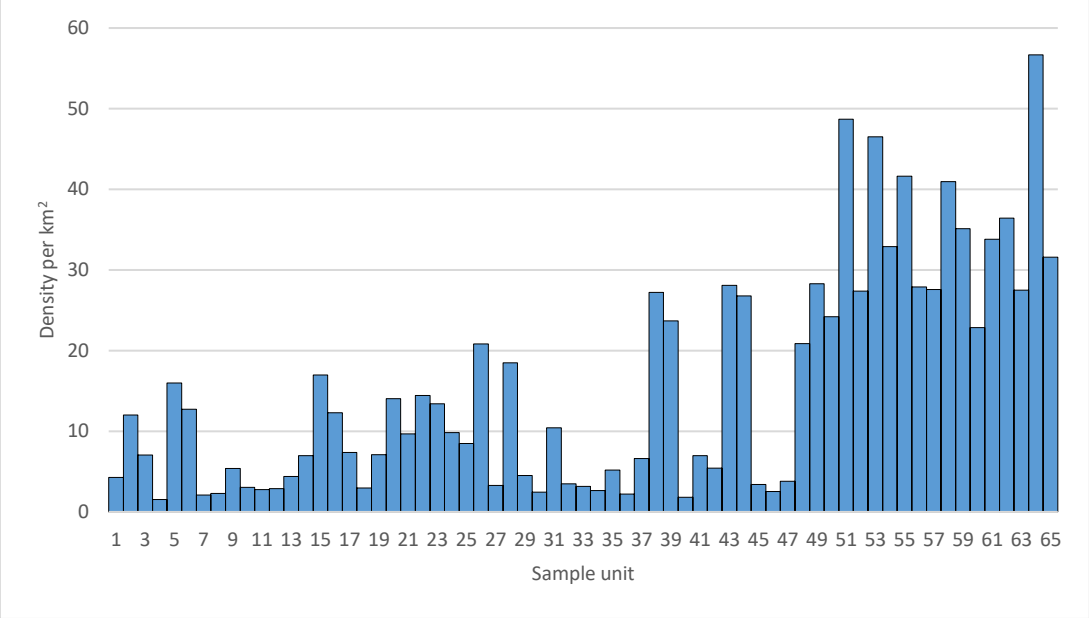


Fig. 36. Wild boar density across sample units of Bangladesh Sundarbans.

In most of the tiger reserve of south and southeast Asian countries, attentions were paid to count and monitors tigers, therefore population and density data on tiger's prey species are very limited. A study at Nagarhole National Park, southern India estimated, by using PGC method, wild boar density of 17.05 ind./km^2 in dry deciduous forest, and 16.32 ind./km^2 in moist deciduous forests (Ahrestani et al., 2018). In Bangladesh Sundarbans, Dey (2004) had estimated a total wild boar population of 28,000 by using pellet group data from 27 sample plots, without reporting any density parameters. A population of 31,000 was estimated by the Project Tiger during 1990s in Indian parts of the Sundarbans (Mallick, 2011).

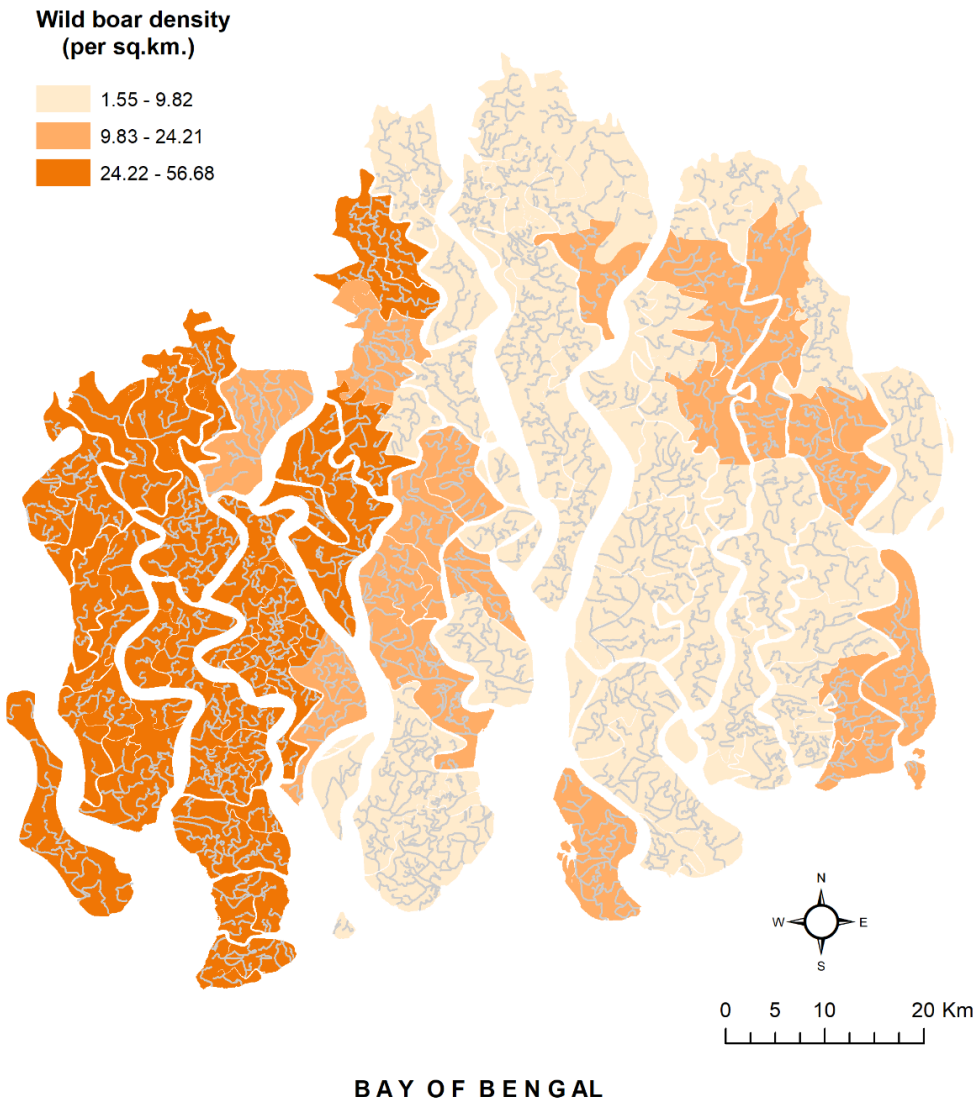


Fig. 37. Density and distribution of wild boar density in Bangladesh Sundarbans.

In this study, we found highest density of wild boar in the goran forest (33.01 ind./km^2), followed by baen (28.60 ind./km^2), goran-gewa (26.48 ind./km^2), and passur-kankra-baen (21.94 ind./km^2) among the others (Fig. 37). The least density habitat was the sundri-passur-kankra (1.65 ind./km^2) forest. However, without knowing the food habit of wild boar in the mangrove habitat, it is difficult to explain the high density in goran-gewa forest, which are abundant towards the west regions of the Sundarbans (Fig. 36).

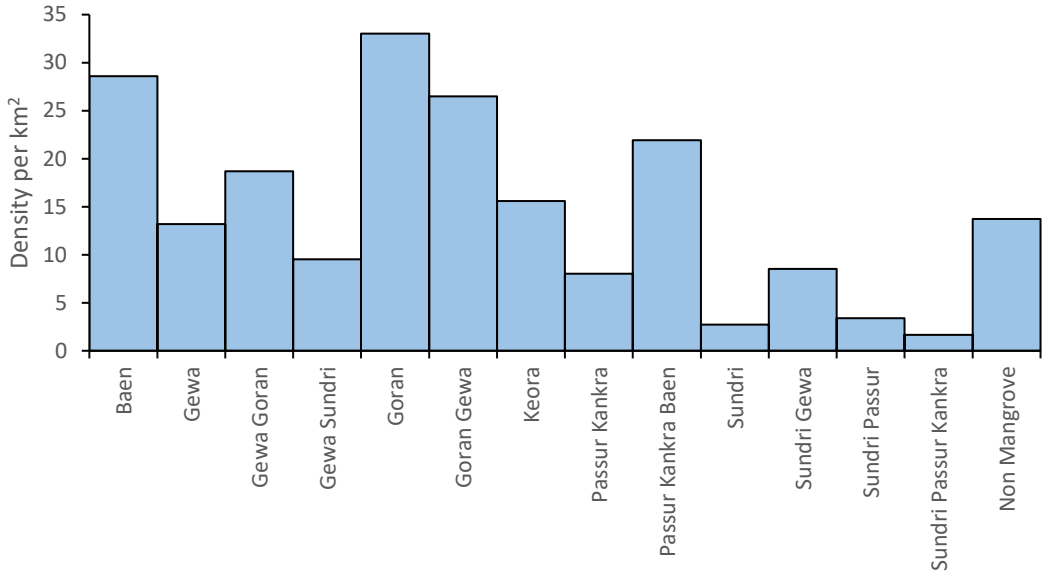


Fig. 38. Wild boar density across habitat types in Bangladesh Sundarbans.

5.3. Density and distribution of barking deer

The density and distribution of barking deer was assessed by PGC method. The estimated mean density was 0.31±*SE* 0.14 ind./km^2 of the Sundarbans. This estimate is exceptionally low comparing to the densities of spotted deer and wild boar. Their spatial distribution is also restricted towards the northeast region of Sundarbans. This density estimate may suffer from low detection, perhaps due to its rarity; therefore, the population might be underestimated.

We combined pellet data and boat-based transect data (*ad libitum* data were recorded) for analysis that provided a reasonable range of its distribution in Bangladesh Sundarbans. Precisely, barking deer was detected in 9 sample units (26, 28, 30, 32, 33, 34, 35, 37, and 46) which are located on north and northeast regions of Khulna and Chandpai range (Fig. 39). We could not detect this ungulate in the sample units distributed to Sarankhola and Satkhira range. Based on the forest land area of the Chandpai range, and Khulna range, an extrapolated population of 818 individuals, with a range from 452 to 1,184 individuals, was estimated for Bangladesh Sundarbans. Due to a small number of detections of this species, the estimated variance was relatively high, resulting in a wider range of population estimates.

Although we have detected barking deer only from the Chandpai range, and Khulna range, this rare ungulate is likely to be present in the Sarankhola range too. Conversely, our data along with long-term observations suggest that this deer could be absent in the Satkhira range, probably due to low elevation and higher level of inundation which might have limited its distribution on the western Sundarbans.

Very little information is available on this rare ungulate in the Sundarbans. The contribution of this ungulate to tiger diet is also proportionately very low, perhaps due to its rarity (Aziz et al., 2020). Sadly, Indian Sundarbans has already lost the last individual of barking deer (Sahgal et al., 2007). A previous pellet-based study in Bangladesh Sundarbans estimated 2,265 individuals of barking deer (Dey, 2004). It was reported from north and northeast regions, especially in the freshwater and moderately freshwater zones, but not in the high saline zone. The population was probably overestimated (Dey, 2004), because extrapolation was made considering the entire land area of Bangladesh Sundarbans, without considering its limited distribution.

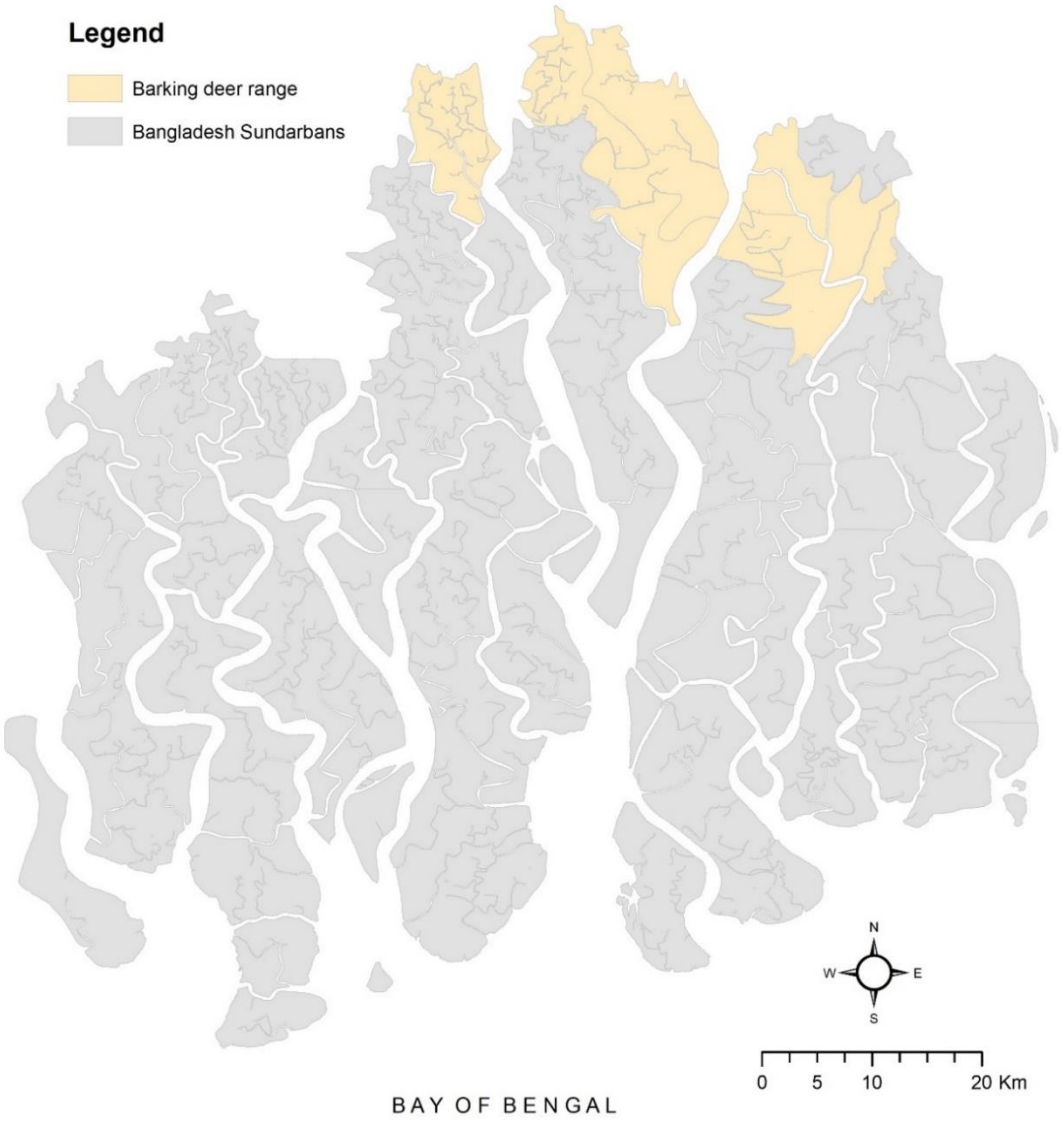


Fig. 39. Distribution of barking deer in Bangladesh Sundarbans.

5.4. Density and distribution of water monitor

The density and population status of water monitor were assessed by boat-based transect. The mean transect length was 5.03± *SE* 0.17 km (*n* = 255, *r* = 1.1km – 17.8 km) whilst the cumulative mean transect per sample unit was 20.14± *SE* 0.99 km (*n* = 65, *r* = 2.2 km – 44.51 km). The cumulative transect length conducted for the entire Bangladesh Sundarbans was 1,281 km. With this sampling effort, we estimated a density of water monitor at 6.29±*SE* 1.71 ind./km^2, and an extrapolated population of 25,124 (*r* = 22,701-28,127) individuals for Bangladesh Sundarbans. There were no previous studies on this monitor lizard in Bangladesh Sundarbans.

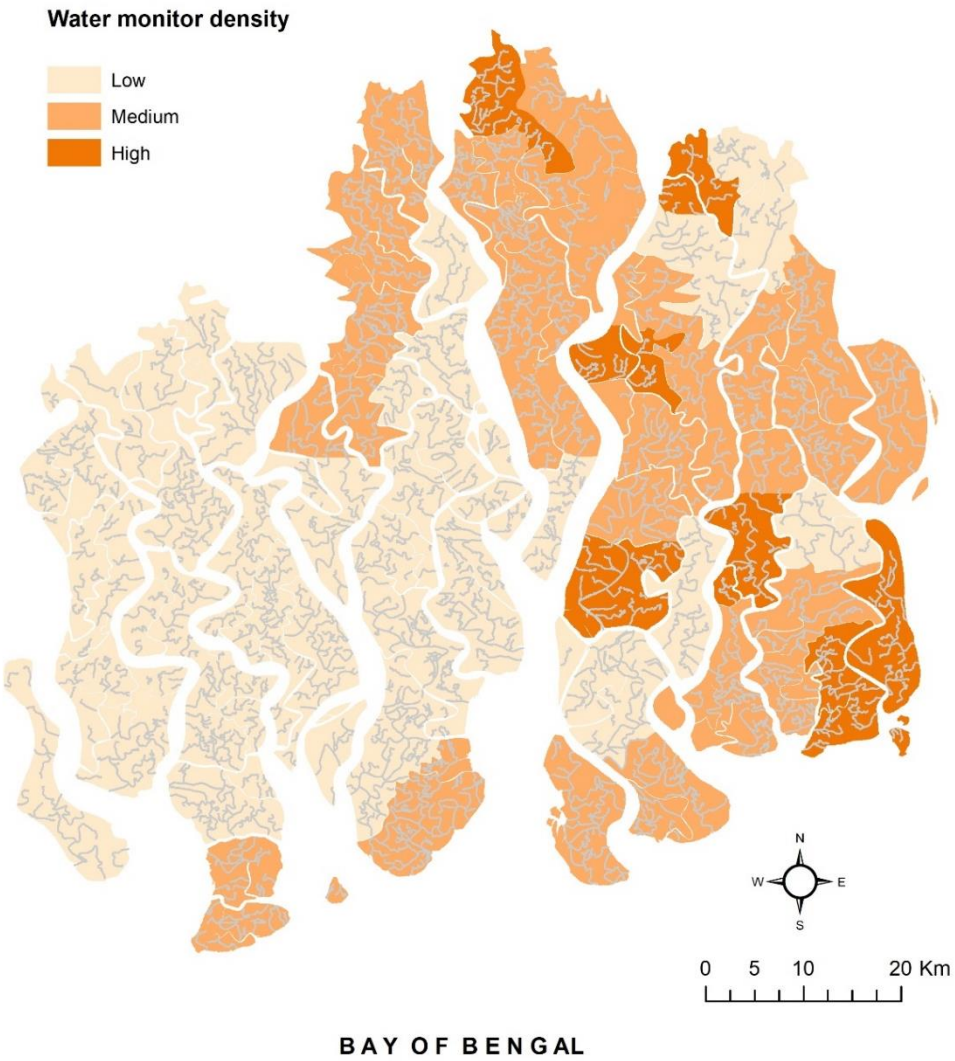


Fig. 40. Density and distribution of water monitor in Bangladesh Sundarbans.

Our results revealed a relatively high density of water monitor in the northeast regions than the western part of Sundarbans (Fig. 40). This lizard is known as an excellent scavenger and fond of carrion. During field survey, we found this monitor to be actively feeding on food wastes and decomposed fishes thrown from fishing boats, tourist launches, and cargo vessels, which appeared to be common across the riverbank of Passur, Sela, and southeastern coastal areas. The waste foods might have allured this lizard to forage along creeks and canals for easy meal, resulting in high detection rate in northeastern parts of the Sundarbans. It is also possible that they preferred moderate and freshwater zones of the Sundarbans, as they love to live in freshwater ponds and tanks in the country.

5.5. Density and distribution of rhesus macaque

The estimated group density of rhesus macaque was 2.97±*SE* 0.20 ind./km^2 and population density of 38.16 ind./km^2. The mean group size was 12.83± *SE* 0.71 (*n* = 98, *r* = 10-24). This nonhuman primate was detected in all sample units except the 64, which might be due to lower effort of transect or our survey teams could not encounter any groups during the survey (Fig. 41). Based on this overall distribution across the entire Sundarbans, a population of 152,444, with a range from 134,039 to 170,930 individuals, was extrapolated for Bangladesh Sundarbans.

Several studies estimated rhesus macaque populations, including 40,000 (Hendrichs, 1975), 126,220 (Gittins, 1980), and 51,000 (Dey, 2004) for Bangladesh Sundarbans. During 1990s, the Project Tiger estimated the population of rhesus macaque of 38,000 in the Indian Sundarbans (Mallick, 2011). However, sampling framework and survey coverage were not detailed in these studies, therefore no density parameters were reported. Our estimates thus could not be compared with these results.

The rhesus macaque is quite abundant, which are gregarious and found in groups of 10-24 individuals scattered throughout the forests. They were frequently found to congregate in tourist sites of Karamjal, Harbaria, Kalagachia and elsewhere for human foods; they migrate to the interior of forests during rainy seasons. An earlier study found a larger group size, 23.6±5.2 (*r* = 14-31 individuals) of rhesus macaque in Bangladesh Sundarbans (Hasan et al., 2013).

Our sampling method for estimating density and population size of rhesus macaque is explicit, supported by robust effort of survey coverage and intensity. Therefore, this estimate has a reasonable precision to qualify for a baseline population estimate, thus it could be useful for future monitoring.

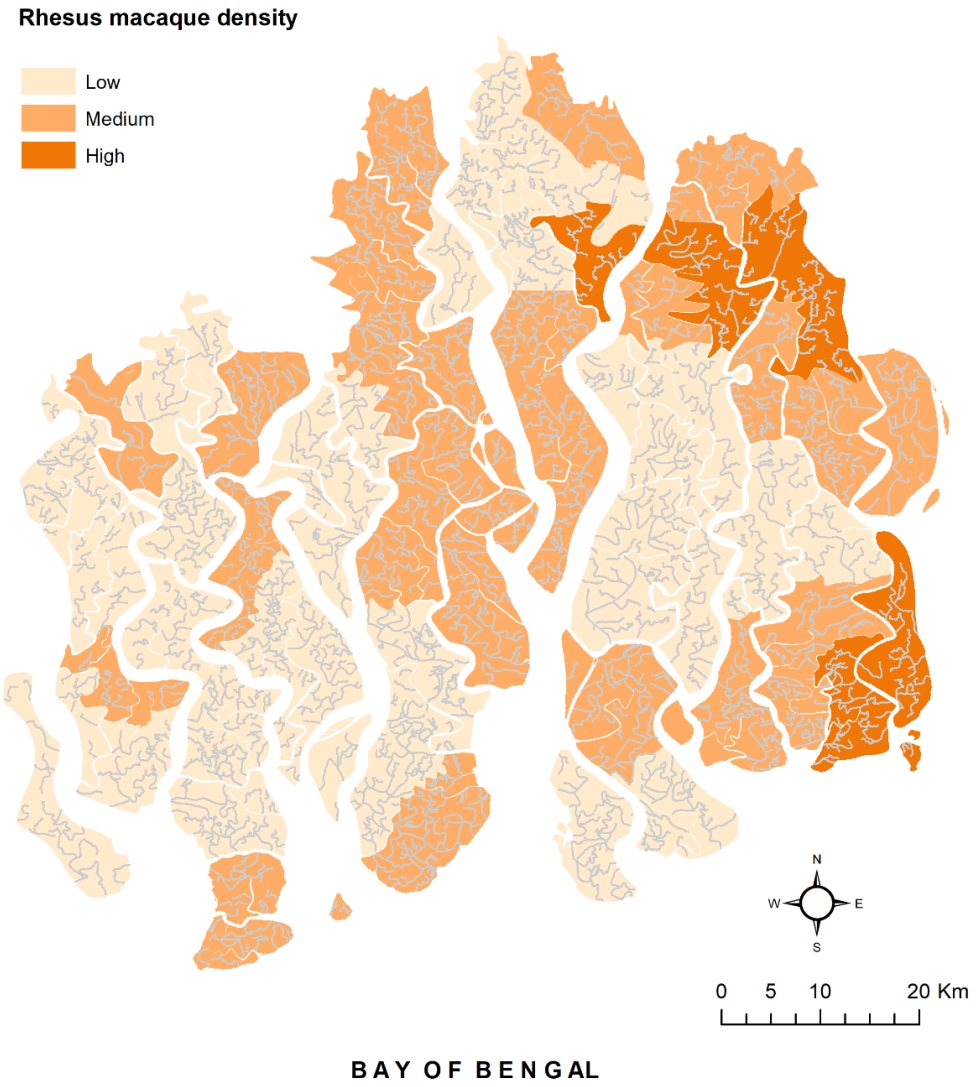


Fig. 41. Density and distribution of rhesus macaque in Bangladesh Sundarbans.

5.6. Density and distribution of Malayan porcupine

The PGC method was used to assess the density and distribution of Malayan porcupine in the Sundarbans. The density was estimated as 5.29±*SE* 1.53 ind./km^2 of forest. Our data showed that the distribution of this rodent is restricted to the Sarankhola and Chandpai range. Specifically, we have recorded its pellet groups in 1, 2, 3, 5, 6, 14, 15, 18, 26, 27, 29, 30, and 42 sample units (Fig. 42). However, we could not invalidate its presence in the northern region of Khulna range where a similar dry landscape exists.

Similar to the distribution of barking deer, its distribution is also likely to be linked to forest habitats with higher elevation along with drier areas and low rate of

inundation. Based on the land area of Sarankhola and Chandpai range, a population of 12,221 individuals, with a range from 8,995 individuals to 15,747 individuals, was estimated for Bangladesh Sundarbans, considering that these two ranges are occupied by the porcupine.

Our field observations suggest that this rodent prefers drier areas of forests having mature baen trees with short, crooked bole with inside holes which provide safe and secretive shelter. Therefore, the distribution appears to be restricted in forests having abundant baen trees and relatively drier areas. Due to low detection in our study, the density estimate is perhaps less precise.

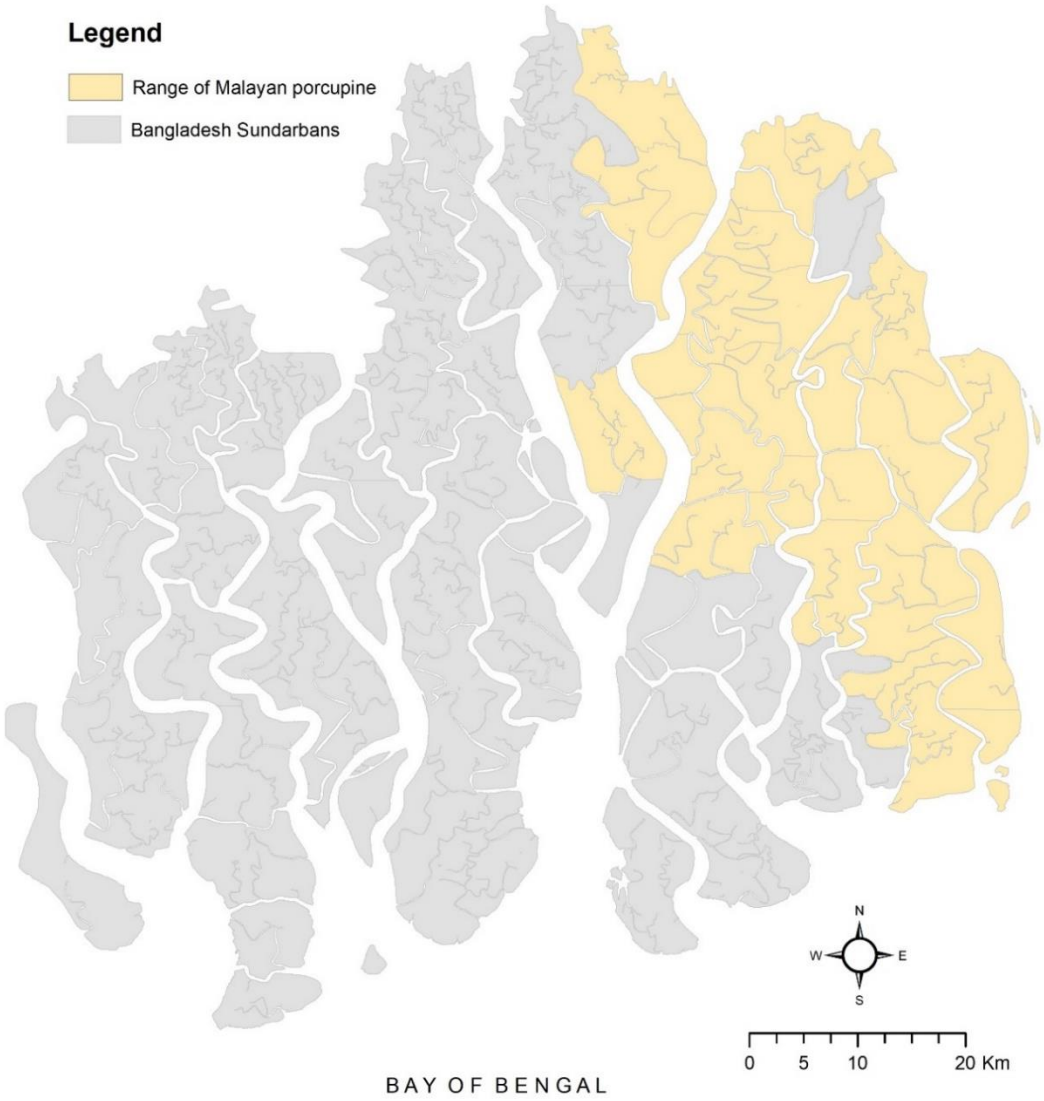


Fig. 42. Distribution of Malayan porcupine in Bangladesh Sundarbans.

6. WAY FORWARD

Using an explicit and robust sampling scheme, this study provided the first-ever baseline assessment of the density and distribution of tiger prey species in the Sundarbans of Bangladesh. It has also fulfilled an important activity of “develop methods for assessing prey occupancy, connectivity and population size” outlined in the Bangladesh Tiger Action Plan 2018-2027. The density parameters estimated in this study will be useful for understanding the ecological carrying capacity of tigers in the Sundarbans, where the latest or upcoming tiger census data can be used to supplement the analysis. These estimates could be used as a baseline for future monitoring of the prey populations in the Sundarbans.

Population monitoring, a prerequisite for adaptive management of wild animals in natural habitats, is critical for large carnivores like tigers and their prey species in the Sundarbans (Ahmad et al. 2009). Therefore, towards understanding tiger population dynamics in the Sundarbans, systematic and regular monitoring of its vital prey species through robust assessment is imperative.

The methods employed in this study could be replicated easily because creating plots and counting pellet groups or running a country boat for recording animals on the riverbank required a minimal level of technical skills. Wildlife biologists with some level of analytical skills and training will be able to lead the entire process, with the assistance of frontline staffs of the Sundarbans.

Future application of this approach is recommended once in three to five years interval, and it could be implemented as a simultaneous activity of tiger monitoring. This will allow us to better understand the population dynamics of prey species, as well as help assess the prey-predator relationship in the Sundarbans ecosystem.

Field activities in photographs



Fig. 43. Training and piloting of field methods with field assistants in Sundarbans.



Fig. 44. Activities of pellet survey and boat-based transect in Bangladesh Sundarbans.

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