STATUS OF TIGERS
IN THE SUNDARBANS OF BANGLADESH

2024

Bangladesh Forest Department
Ministry of Environment, Forest and Climate Change
Government of the People's Republic of Bangladesh

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Upholding the Legacy of Our Tigers

The Bengal tiger, as Bangladesh's national animal, embodies our cultural heritage and stands at the forefront of our conservation efforts. Safeguarding this magnificent species is crucial not only for the tigers themselves but also for the conservation of the Sundarbans mangrove ecosystem. Tigers are more than symbols of grandeur; they are essential to the balance and health of their forest ecosystems.

Tiger conservation is a pressing issue both nationally and globally, given their ongoing decline across many of their ranges. Key threats include habitat loss, declining prey, poaching for use in traditional medicine, global climate change and the pressures of a growing human population. The loss of tigers would be a significant blow to the ecosystems they inhabit. It is therefore our utmost duty to ensure their survival, especially as the Sundarbans represents the last stronghold of tigers in Bangladesh.

I am pleased to announce that the Forest Department is going to release the 3rd phase tiger status assessment report of the Sundarbans. This report follows the successful implementation of camera-trapping techniques funded by government of Bangladesh under 'Sundarbans Tiger Conservation Project'. I am excited to share that the latest estimates show a tiger population of 125 in the Sundarbans—an encouraging 9.65% increase since the 2018 survey. This positive development reinforces our commitment to continue our vigorous efforts in tiger conservation.

My deepest thanks and congratulations to all the officers, staff of the Bangladesh Forest Department, Village Tiger Response Teams (VTRT), researchers, and consultants who have contributed to this achievement. Their dedication and hard work have made this significant progress possible. I am confident that this report will offer valuable insights as we move forward with our tiger conservation efforts.

Syeda Rizwana Hasan

Dr. Farhina Ahmed
Secretary
Ministry of Environment, Forest and Climate Change
Government of the People's Republic of Bangladesh

Protecting Our National Treasure

The tiger, one of the most iconic animals on Earth, has been a major focus of conservation efforts over the past few decades. As Bangladesh's national animal, the tiger holds a special place in our heritage, and we are committed to conserve this vital part of our culture with all available resources. Tigers are critically endangered, making their conservation a global priority, not just for Bangladesh.

Among various methods for assessing tiger populations, camera-trapping has emerged as one of the most effective techniques globally. This report highlights the successful completion of our 3rd phase camera-trapping survey in the Sundarbans, a key tiger habitat in Bangladesh. We are proud that the Government of Bangladesh has invested in the Sundarbans Tiger Conservation Project, demonstrating strong national commitment to this good cause.

This latest assessment reveals an encouraging 9.65% increase in the tiger population since the 2018 survey. Tigers are dependent on well-managed habitats with adequate prey and undisturbed breeding areas. To meet the goals set out in the National Tiger Recovery Program and the Bangladesh Tiger Action Plan 2018-2027, it is essential to base habitat management on scientific data and protect both tigers and their prey from poaching.

We are dedicated to taking all necessary actions to conserve and protect the tigers of the Sundarbans. Moving forward, assessing the carrying capacity of this unique ecosystem will be crucial in setting realistic and effective targets for future tiger management.

I would like to extend my heartfelt thanks to all the consultants, field assistants, frontline staff, tiger conservation groups, and scientists who contributed to this important assessment. Combined efforts are vital to our ongoing conservation success.

Dr. Farhina Ahmed

Md. Amir Hosain Chowdhury
Chief Conservator of Forests
Bangladesh Forest Department

PREFACE

A positive update of our Sundarbans tigers

Bangladesh Forest Department has completed the 3rd assessment of tiger population in the Sundarbans, using the advanced and reliable method of camera-trapping. This technique, widely used in tiger range countries, helps estimate both the number and density of tigers. We are excited to announce that the first government-funded "Sundarbans Tiger Conservation Project" is making significant strides in ensuring a sustainable tiger population in this vital tiger habitat.

The Sundarbans, with its intricate network of tidal waterways, mudflats, and salt-tolerant mangrove forests, is globally renowned for its rich biodiversity and is home to one of the world's top five tiger populations. Accurate data on tiger numbers, prey availability, habitat conditions, and carrying capacity is crucial for effective conservation.

The latest analysis using the Spatially Explicit Capture Recapture method reveals a tiger density of 2.64 tigers per 100 km^2 of the Sundarbans. This figure is consistent with the 2018 estimate and shows a satisfying increase of about 9.65% in the tiger population, despite ongoing conservation challenges and climate change impacts. This positive trend indicates that our current conservation strategies are making a difference. By comparing the results of this latest assessment with those from studies conducted in 2015 and 2018, we can better understand trends and plan future conservation strategies.

With continued support from the government, scientists, local communities, and the dedicated frontline staff of the Forest Department, we are optimistic about achieving our goals for tiger conservation and ensuring their survival for future generations.

Md. Amir Hosain Chowdhury

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Special appreciation goes to Dr. Farhina Ahmed, Secretary, Ministry of Environment, Forest and Climate Change for her outstanding support during the project implementation. We deeply appreciate the contributions of Mr. Md. Amir Hosain Chowdhury, Chief Conservator of Forests; Mr. Md. Jahidul Kabir, Deputy Chief Conservator of Forests; Mr. Mihir Kumar Doe, Conservator of Forests, Khulna Circle; Mr. Kazi Md. Nurul Karim, DFO, Sundarbans East Forest Division; and the Assistant Conservator of Forests from Khulna, Chandpai, Satkhira, and Sarankhola ranges for their support throughout this project.

We also acknowledge the dedicated efforts of the technical committee members of the Sundarbans Tiger Conservation Project: Mr. Imran Ahmed, Conservator of Forests, Wildlife and Nature Conservation Circle; Mr. Nirmal Kumar Paul, DFO, Wildlife Management and Nature Conservation Division (WMNCD), Khulna; Professor Md. Anwarul Islam, CEO, WildTeam, Bangladesh; Chairman, Department of Zoology, Jahangirnagar University; Head, Forestry and Wood Technology Discipline, Khulna University; and Country Representative, IUCN-Bangladesh. Special thanks are due to Mr. Md. Zaheer Iqbal, DCF, RIMS; Mr. Md. Shariful Islam, ACF; Mr. Md. Sharifuzzaman, Wildlife and Biodiversity Conservation Officer; Ms. Ali Ashrafi Sultana, ACF, Mr. Md. Masudur Rahman, WBCO, Ms. Fa-Tu-Zo Khaleque Mila, Wildlife and Biodiversity Conservation Officer, and Mr. Md. Aminur Rahman, Department of Zoology, JU for their support and contributions to identifying tiger photographs.

The success of the survey depended heavily on the support of field staff from the Forest Department and WildTeam. We are particularly grateful to WildTeam, Bangladesh; and the Department of Entomology and Wildlife Ecology, University of Delaware, the Explorer Club Expedition Grant, USA for providing their valuable camera-traps and necessary supplies for the project. The field data collection was made possible through the hard work of the Village Tiger Response Team, Community Patrol Group, and other community members. We also acknowledge the contribution of logistics provider including the boatmen, sampan-drivers, and support crews of the accommodation boats during the survey.

We acknowledge the technical advice provided by Dr. Murray G. Efford, Department of Mathematics and Statistics, University of Otago, New Zealand, and Late Mike Meredith, WCS Malaysia. Finally, we are grateful to Dr. Billal Habib, Professor, Wildlife Institute of India for his effort in validating the identification of tiger images.

Abu Naser Mohsin Hossain, PhD
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Executive summary

The Sundarbans mangrove forest, covering an area of 6,017 km^2, is the last stronghold of tigers in Bangladesh. This report presents the results of third tiger status assessment conducted from January 2, 2023 to April 25, 2023, and from November 1, 2023 to March 28, 2024. The survey covered 2,240 km^2 (*ca.* 50% of forest land) of Sundarbans using remotely triggered camera-traps deployed in 605 grids and conducted additional surveys of 1,306 km narrow rivers and creeks (*khal*) to estimate tiger population abundance.

The camera-traps were active for 31,482 trap-nights and captured 7,297 images of tigers. From these images, a total of 84 individual tigers were identified: 21 males, 62 females, and 1 unknown sex. One juvenile and 19 cubs, and one sub-adult were also detected. The Spatially Explicit Capture-Recapture model estimated density of 2.64 tigers per 100 km^2, resulting in a population of 125 tigers (95% *CI*: 100-156) for the Sundarbans.

This third tiger assessment indicates an overall positive trend in the tiger population, with a 9.65% increase from 2018 and a 17.92% increase from 2015 surveys. However, although the Khulna block shows an increase in tiger density, the Chandpai-Sarankhola and Satkhira blocks show declines, with Satkhira experiencing the most significant decrease. The low ratio of male to female tigers in the Khulna block (1 male to 12 females) suggests a need for more intensive camera-trapping and genetic monitoring to investigate potential issues like missing males or inbreeding in the population. Additionally, anthropogenic pressures, such as poaching of tigers and spotted deer, may have contributed to the reduced tiger density in Satkhira than previous estimate, highlighting the need for strengthening protection measures.

A series of recommendations is suggested to enhance the protection of tigers and their habitats. For improved protection, enhancement of the effectiveness of SMART and other regular forest patrols is advised, with supervision from senior forest officials and independent observers. Grasslands in the Sundarbans should be managed with biannual interventions, and elevated land should be established and maintained for emergency use by terrestrial wildlife, especially tigers and ungulates. To minimize variation in population estimate, it is recommended to conducting the next status assessment in a single winter session, with all logistical arrangements completed in advance. Additionally, incentivization and training of Village Tiger Response Team (VTRT) and other community-based organizations are needed to effectively address human-tiger conflict situations.

1. Introduction

Tiger, *Panthera tigris*, one of the most iconic and charismatic species on Earth, has garnered significant conservation attention over recent decades. Despite extensive efforts to protect them, over centuries tigers have lost 93% of their historical range globally (Sanderson et al. 2010). Currently, fewer than 6,000 tigers remain, distributed across 10 tiger range countries: Bangladesh, Bhutan, China, India, Indonesia, Malaysia, Myanmar, Nepal, Russia, and Thailand. In recent decades, Vietnam, Lao PDR, and Cambodia have lost their last tigers (GTF, 2023).

The increasing demand for natural resources has led to severe habitat degradation, extensive infrastructure development, and the negative impacts of human-induced climate change. These factors have placed unprecedented pressure on biodiversity, particularly affecting the already declining tiger population (McNeely 1997; Shahabuddin 2010). Currently, remaining tiger populations are restricted to relatively small and isolated forest patches (Walston et al. 2010).

The Sundarbans mangrove forest, straddling Bangladesh and India, is home to one of the largest populations of Bengal tigers (Aziz et al. 2018a; Jhala et al. 2011) and is classified as a Class III Tiger Conservation Landscape of global importance (Sanderson et al., 2006) (Fig. 1). The Bangladesh portion of the Sundarbans (hereafter Sundarbans), which covers 60% of the entire area, spans 6,017 km^2 and represents the last significant stronghold for tigers in Bangladesh.

A male tiger in Satkhira captured in camera-traps

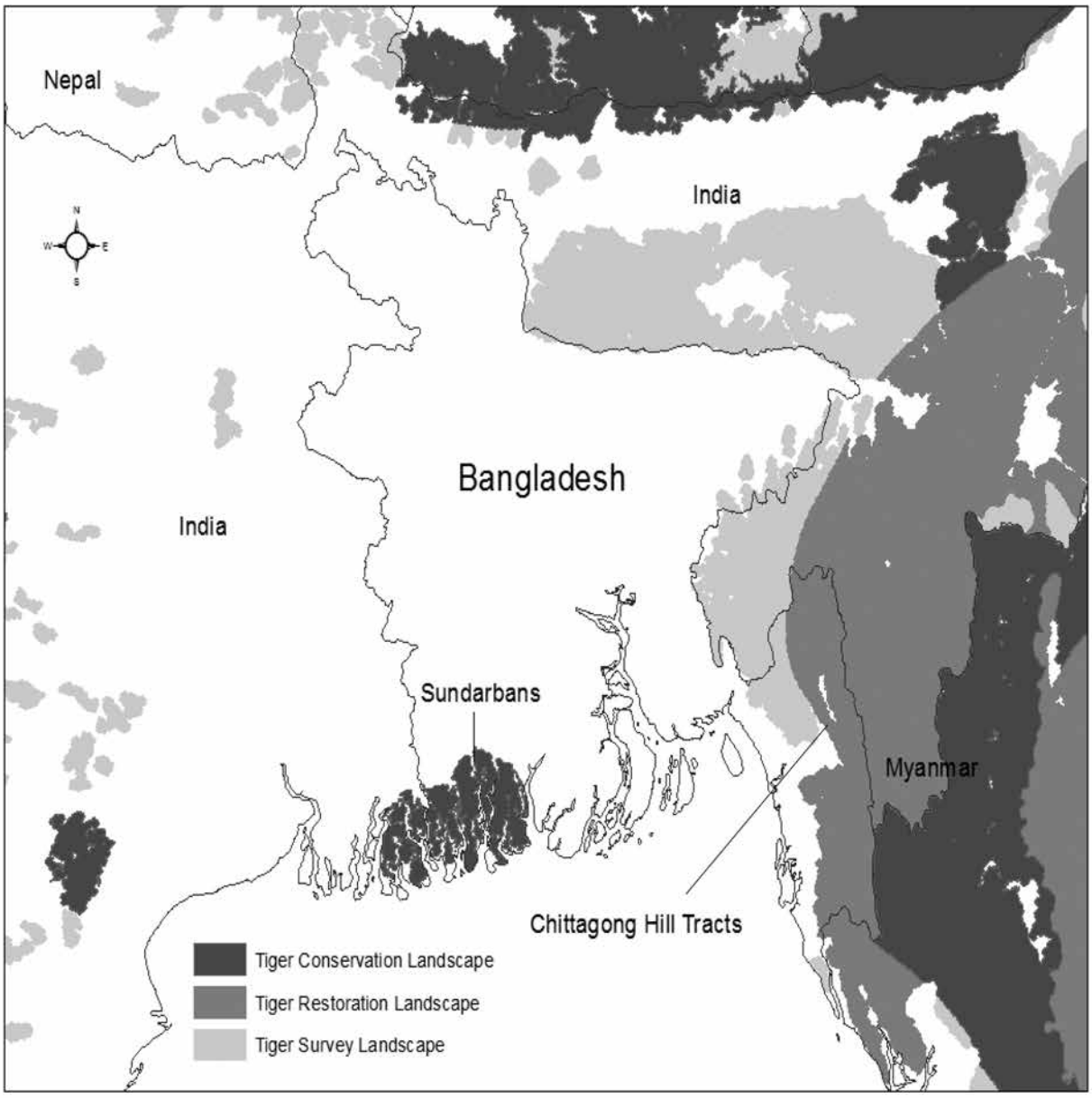

Figure 1 Tiger Conservation Landscapes in and around Bangladesh (prepared with data from Sanderson et al. 2006).

Historically, tigers were found throughout Bangladesh, but today, only a viable population remains in the Sundarbans (Ahmad et al. 2009). This population is crucial for global tiger conservation due to its significant potential for long-term survival. However, the Sundarbans, like other tiger habitats, faces serious threats, including poaching, retaliatory killings, and the human consumption of prey animals (Mohsanin et al. 2013; Saif et al. 2016; Aziz et al. 2017a).

Tigers are a keystone species in the Sundarbans and hold a deep cultural significance, with numerous myths and legends associated with them. Tigers play a key role in structuring and maintaining the ecosystem health of this fragile forest. Their loss could have a profound impact on the integrity and functionality of the ecosystem, which in turn would affect the livelihoods of millions of people living in the surrounding areas (Ahmad et al. 2009).

The survival of tigers in the Sundarbans is heavily reliant on a limited number of prey species where the spotted deer, *Axis axis* and wild boar, *Sus scrofa* account for 89% of the prey biomass to the tiger diet (Aziz et al. 2020). Tigers also occasionally hunt other species such as the barking deer, *Muntiacus vaginalis*, rhesus macaque, *Macaca mulatta*, and water monitor, *Varanus salvator*. Therefore,

effective management strategies to protect these prey species are crucial for tiger conservation in the Sundarbans (Ahmad et al. 2009; Aziz et al. 2020).

In 2010, at the historic St. Petersburg Tiger Summit, world leaders of tiger range countries pledged to double the wild tiger population by 2022 through the Global Tiger Recovery Program (GTRP) (Wikramanayake et al. 2011). In support of this commitment, Bangladesh has developed the National Tiger Recovery Program (NTRP) and the Bangladesh Tiger Action Plan (BTAP). These documents emphasize the importance of regular monitoring of tiger populations using reliable scientific methods to enable adaptive management (Ahmad et al. 2009).

The first systematic national survey in 2015 estimated 106 tigers (95% *CI*: 84-130) in the Sundarbans (Dey et al. 2015). Additionally, a DNA-based study estimated 121 tigers (95% *CI*: 84-158) by collecting genetic samples covering 1,994 km^2 of the Sundarbans (Aziz et al. 2017b). The updated BTAP (2017-2028) aims to preserve the current tiger occupancy across 6,017 km^2 and increase the tiger density from a baseline of 2.17 tigers/100 km^2 (Dey et al. 2015) to 4.50 tigers/100 km^2 within the next decade (Khan et al. 2018).

This 2024 tiger assessment in the Sundarbans employed motion-triggered camera traps, conducted four years after the second survey in 2018, to update the status of the tiger population, and monitor population trends compared to baseline estimates of the Sundarbans of Bangladesh.

Typical view of the Sundarbans landscape (photograph © M. Abdul Aziz)

2. Materials and Methods

2.1 The Sundarbans

The Sundarbans is situated south of the Tropic of Cancer and within the Ganges-Brahmaputra-Meghna delta, and consists of low-lying, vegetated islands with elevations between 0.9 and 2.1 meters above mean sea level, interspersed with a network of tidal waterways (Iftekhar and Islam 2004). The Sundarbans is a relatively recent formation, dating back approximately 6,000 to 7,000 years (Allison 1998; Allison et al. 2003). Its extent has varied significantly since its inception, influenced by a complex interplay of sea level changes, sedimentation rates, and neotectonic subsidence (Islam and Tooley 1999; Stanley and Hait 2000).

The Sundarbans, the world's largest mangrove forest, covers 10,263 km^2, with approximately 60% (6,017 km^2) in Bangladesh and the rest in India. Within Bangladesh, 4,267 km^2 is forested, with the remainder consisting of water bodies (Iftekhar and Islam 2004). The forest is bordered by dense human settlements and agricultural land to the north and east, and by the Bay of Bengal to the south. The Sundarbans features a complex topography of estuaries, rivers, and waterways, encompassing numerous low-lying, swampy forest islands of various shapes and sizes (Iftekhar and Islam 2004).

The major rivers in the region flow from north to south and are interconnected by narrow east–west channels and creeks (Islam and Wahab 2005). Three large rivers—Arpangassia (1.2–2.8 km wide), Sibsa (1.3–3.4 km wide), and Passur (1.4–3.1 km wide)—divide the forest into three main, isolated areas. Additionally, the Raimangal (1.5–2.8 km wide) and Haribhanga (2.9–4.4 km wide) rivers delineate the international boundary, splitting the forest between the Bangladesh and Indian Sundarbans (Aziz et al. 2018a). Historically, these major rivers have been used for the commercial navigation of cargo vessels for centuries.

The Sundarbans is home to around 330 plant species, 400 fish species, over 300 bird species, 35 reptile species, and 42 mammal species (Hussain and Acharya 1997). It also shelters several globally threatened species, including the Bengal tiger, the fishing cat, *Prionailurus viverrinus*, the Ganges river dolphin, *Platanista gangetica*), the Irrawaddy dolphin, *Orcaellabrevirostris*, the Indo-Pacific hump-backed dolphin *Sousa chinensis*, the finless porpoise, *Neophocaena phocaenoides*, the masked finfoot, *Heliopais personatus*, and the estuarine crocodile, *Crocodylus porosus* (Barlow 2009).

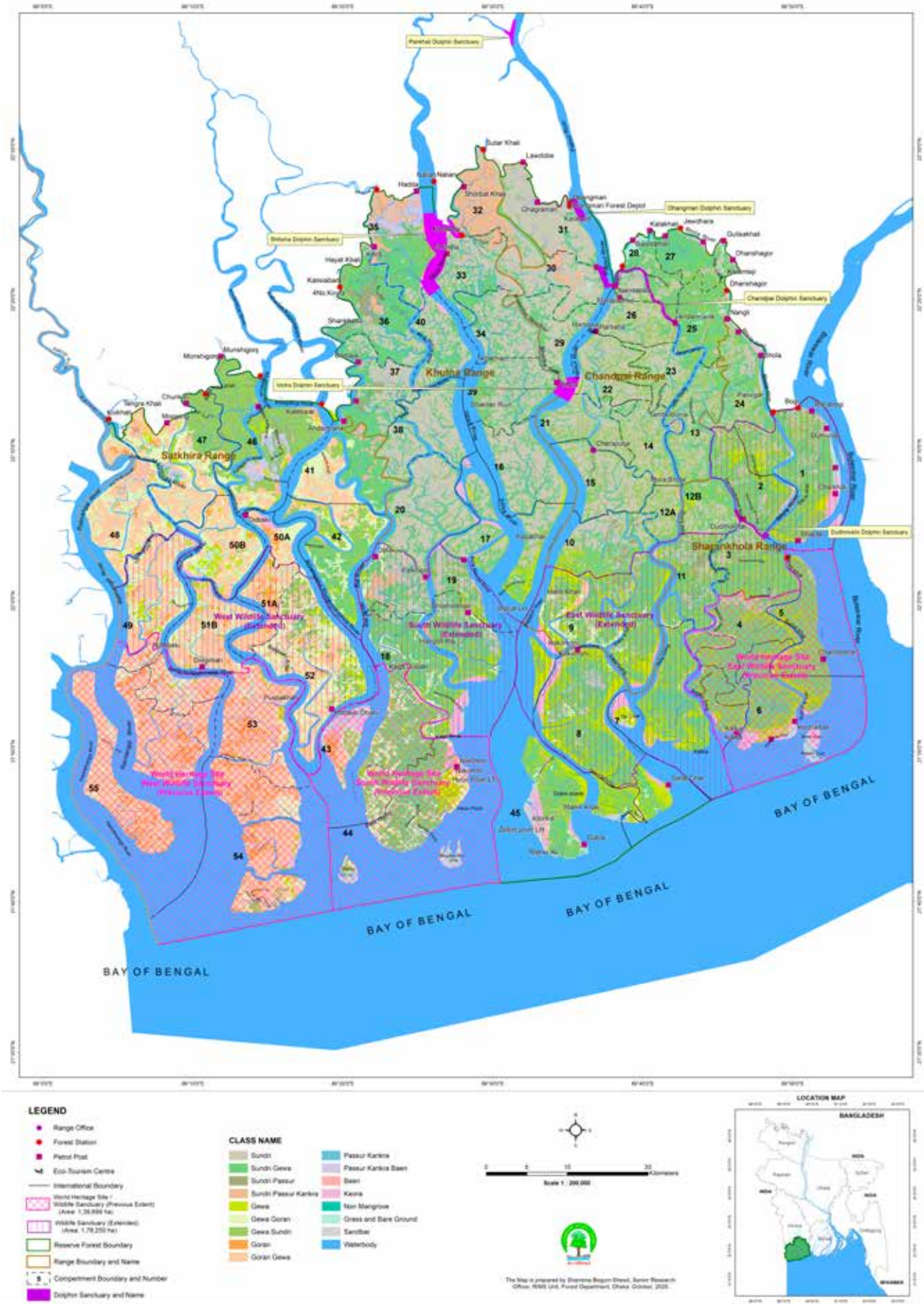

Figure 2 The Sundarbans of Bangladesh with Forest Camps, Wildlife Sanctuaries, and Forest Ranges.

In the Sundarbans, the dominant vegetation consists primarily of sundri, *Heritiera fomes* and gewa, *Excoecaria agallocha* trees, which together cover approximately 44% of the land area. Sundri trees alone account for about 18% of the land area. The distribution of vegetation is influenced by salinity. In the less saline eastern region, due to the influence of freshwater flow, sundri trees are prevalent. Conversely, the more saline western region is characterized by goran-gewa and gewa-goran vegetation.

2.2 Sample blocks

For this assessment, we established three survey blocks: Satkhira, Khulna, and Chandpai-Sarankhola. Satkhira block was further divided in to two sub-blocks: Satkhira South and Satkhira North. These sampling areas were selected following approaches used in Dey et al. (2015) and Aziz et al. (2018b).

Satkhira block

The Satkhira sampling block is situated within the Satkhira range, which is part of the Sundarbans West Forest Division. This range covers approximately 1,850 km^2 (Hussain 1992). The Raimangal River both isolates the southernmost island, Haldibunia, and marks the international boundary between Bangladesh and India. Due to narrow river channels, tigers frequently cross the border between Haldibunia and the Indian side of the forest (Naha et al. 2016). More than 50% of this range is covered by the Sundarbans West Wildlife Sanctuary.

For this survey, we divided the Satkhira block into two sub-blocks: Satkhira South and Satkhira North. The south block includes areas within the Sundarbans West Wildlife Sanctuary, such as Mandarbaria, Haldibunia, Puspakathi, and parts of Dobeki and Notabeki. The north block is outside the wildlife sanctuary and encompasses Kaikhali, Kodomtala, and Burigoalini. Its boundaries are defined by the Arpangassia River to the east, Kachikata to the south, the international border to the west, and surrounding villages to the north.

Khulna Block

The Khulna Block is located in the central part of the Sundarbans, within the Khulna Range. It serves as a transition zone between freshwater and saline water areas. This survey block encompasses 95% of the Sundarbans South Wildlife Sanctuary, with the exception of Kalir Char. Additionally, it includes a portion of the forest area under Gewakhali in the northern part, which lies outside the wildlife sanctuary. Similar to other parts of the Sundarbans, the Khulna Range is delineated by major rivers. The eastern boundary is defined by the Sibsa, Morjat, and Namud Samudra rivers. To the west, the boundary is marked by the Arpangassia and Boro Panga rivers.

Chandpai-Sarankhola block

The Chandpai-Sarankhola block is bordered by the Passur and Namud Samudra rivers to the west, the Baleshwar River to the east, and the upper part of the Shella River to the northeast. This block is the largest of all the sample blocks and encompasses major portions of the Chandpai and Sarankhola ranges within the Sundarbans East Forest Division. It is the least saline zone in the Sundarbans and has a higher biodiversity in terms of vegetation compared to other survey blocks (Barlow 2009; Sarker et al. 2019).

Team members checking camera-traps in the Sundarbans

2.3 Sampling framework

We employed a structured grid sampling approach, based on two previous surveys in the Sundarbans (Dey et al. 2015; Aziz et al. 2018b). We established 2 × 2 km grid cells across three survey blocks (Fig. 3). This consistent grid cell size facilitated logistical planning and resource allocation throughout the survey blocks. Camera-trapping surveys were conducted in the Satkhira South and Khulna blocks from January 2, 2023, to April 25, 2024. Moreover, surveys in the Chandpai-Sarankhola blocks took place from November 1, 2023, to March 28, 2024.

We set up a pair of trail cameras in each grid cell, ensuring one camera-trapping station per cell. During the first year of the survey, we used Cuddeback X-Change™ model 1279 at 137 stations and ScoutGuard 2060-X at 50 stations in the Satkhira South Block. In the Khulna Block, we had 122 stations, where we used Cuddeback X-Change™ model 1279 at one set of stations and ScoutGuard 2060-X at the other set. However, due to poor performance of the Cuddeback cameras, we switched to a different brand after reviewing the photos recorded during the winter of 2023. We chose the GardePro T5WF, along with ScoutGuard 2060-X, for the 2023-2024 season. In this season, we set up camera-traps at 279 stations in Chandpai-Sarankhola and 66 stations in Satkhira North.

To maximize the probability of detecting tigers, we followed established protocols used in the Sundarbans and elsewhere (Karanth et al. 2017; Aziz et al. 2018b). Each survey effort consisted of three teams, each led by a team leader and deputy team leader, with additional team members including data collectors, field assistants, and one or two armed guards for safety. Camera-traps were set between 40-45 cm above ground to capture the best quality tiger photographs. In the other two blocks, we adjusted the camera height based on tide marks, setting them between 55 cm and 65 cm to account for varying elevations. Each camera-traps and memory card were named and numbered to help with archiving and analysis, which relied heavily on the precise geolocations of capture-recapture events of tigers.

Figure 3 Locations of camera-traps within 2 x 2 km grid cells across four survey blocks of the Sundarbans.

2.4 *Khal* survey

In addition to the camera-trapping exercise, we conducted a survey of the *khal* (small rivers and canals) across the Sundarbans for 75 days, from December 2022 to February 2023. The survey focused on detecting tiger crossing signs (tiger track sets), signs of tiger prey, and human disturbances, covering 65 previously designated sample units (Barlow et al. 2008). Survey was carried out by two teams, each consisting of staff from the Bangladesh Forest Department and WildTeam. A total of 1,306 km of *khal* were surveyed along established river courses (Barlow et al. 2008). The collected tiger sign data were overlaid onto a 10 × 10 km^2 grid to estimate tiger occupancy, allowing us to calculate population abundance and compare our results with previous assessments (Dey et al. 2015; Aziz et al. 2018b). For this analysis, we calculated naïve occupancy area by excluding grid squares without tiger signs, and rivers wider than 1 km, which were considered non-habitat (Aziz et al. 2017b). However, we included rivers which were crossed by tigers during the survey (Fig. 4).

2.5 Data analysis

We began by sorting through 1.1 million images captured by our camera-traps to isolate the tiger images. A team of experts, including consultants and wildlife biologists from the Bangladesh Forest Department, identified each individual tiger based on distinctive features such as markings on their right and left flanks, facial marks, and other unique characteristics.

We determined the sex of the tigers based on the presence or absence of visible scrotum in the tiger images. Additionally, we categorized tigers into age classes based on their body size, nose pigmentation, and overall appearance: cubs <12 months, juveniles 12-24 months, sub-adults 14-36 months, and adult >36 months old.

We created the spatial detection history and camera operation matrix for each individual tiger using the CamtrapR package (Neidballa et al. 2016) in R separately for each block. For estimating tiger density within each block and overall, we utilized the SECR (Spatially Explicit Capture Recapture) package in R, applying a Maximum Likelihood framework based on a multi-session approach. This approach is suitable when there are multiple independent blocks with no exchange of individuals (Efford 2011; Efford 2024). The SECR is widely recognized as the gold standard for estimating animal density and abundance (Efford et al. 2008).

For the analysis, we defined the minimum camera-trap areas for each block by drawing polygons around the outer line of camera-trap locations. We then created habitat masks in the SECR package which involved expanding the minimum camera-trapping area by 4 × σ, where σ represents the movement parameter derived by averaging the displacement of each individual tiger from its original capture location. The camera-trap data from Satkhira North were excluded from the final analysis because they violated the assumption of demographic closure. Surveys in Satkhira South were conducted in 2022, while those in Satkhira North were conducted in 2024, with capturing several individuals in both survey blocks.

We ran several models in SECR—including the null model, the behavioral response model, and individual heterogeneity model, with varying sigma values—to fit different detection (g^0) and density (D), as well as spatial movement parameters (σ). The best-fitting model was selected based on the lowest Akaike Information Criterion (AIC) value among the candidate models. All analysis were performed in R, and maps were generated using ArcGIS Pro 3.1.

3. Results and Discussion

3.1 Tiger density and population abundance

The tiger detection data were collected using 605 pair of motion-triggered camera-traps, deployed in the 2 × 2 km grid cells across three sample blocks of the Sundarbans. A total of 7,297 tiger images were captured by camera-traps by investing 31,482 camera-trap nights over nine months during 2023-2024. Among the total camera-traps stationed, 61% detected tigers, comprising 50% in Satkhira, 48% in Khulna and 74% in Chandpai-Sarankhola block. A total of 84 individuals of adult tigers was uniquely identified comprising 21 tigers in Satkhira, 13 in Khulna and 50 in Chandpai-Sarankhola sampled blocks. The sex of the identified tigers includes 21 males, 62 females, and 1 unknown. One juvenile, one sub-adult, and 19 cubs were also recorded in camera-traps, with highest in the Chandpai-Sarankhola areas (Table 1).

Table 1 Summary of the camera-trapping effort and outputs in the Sundarbans.

Parameters	Satkhira block	Khulna block	Chandpai-Sarankhola block	Overall
Total number of camera trap stations used	204	122	279	605
Number of days sampled	119	84	115	318
Total camera-trap nights deployed	10,600	6,807	14,075	31,482
Number of camera-trap stations captured tiger images	103	59	206	368
Total number of tiger images captured	1,068	432	5,797	7,297
Total individuals of adult tigers identified	21	13	50	84
Male tigers	6	1	14	21
Female tigers	15	12	35	62
Sex-unidentified tigers	0	0	1	1
Number of tiger cubs	1	2	16	19
Number of tiger juveniles	0	0	1	1
Maximum occasion of captures in a single station	8 (*n*=2)	10 (*n*=2)	14 (*n*=2)	14
Maximum individual captured in single station	4 (*n*=2)	3 (*n*=2)	4 (*n*=4)	4
Maximum capture of a single individual	37	20	28	37
Maximum relocations of a single individual	26	16	25	26
Minimum camera-trap area (km^2)	738	443	1,059	2,240
Effective camera-trap area (km^2)	1,144	855	1,775	3,774

The overall tiger density in the Sundarbans was estimated at 2.64 ± *SE* 0.30 tigers/100 km^2 (95% *CI*: 2.12-3.30), by fitting learned response model, using a half-normal detection function within a maximum likelihood framework. The block-wise analysis provided the highest tiger density of 3. 22 ± *SE* 0.46 (95% *CI*: 2.43-4.26)/100 km^2 for Chandpai-Sarankhola block. This was followed by Satkhira block with 2.09± *SE* 0.53 (95% *CI*: 1.29-3.40) tigers/100 km^2 and Khulna block with 1.85 ± *SE* 0.53 (95% *CI*: 1.07-3.20) tigers/100 km^2 (Table 2). Using the 4,728 km^2 naïve area occupied by tigers and overall estimated density, the total tiger population of 125 tigers (95% *CI*: 100-156) was extrapolated for the Sundarbans (Fig. 4).

Table 2 Identified individual tigers, their sex, and density parameter estimates within SECR model for the Sundarbans.

Camera-trapping block	No. of adult tigers captured, M_{t+1}[a]	Sex of tiger individuals detected[b]		Tiger density, *D (SE)*[c]/100km^2 ($CI_{95\%}$)	Probability of detection, g0 *(SE)*	Movement parameter, σ *(SE)* km
		♂	♀			
Satkhira[d]	17	4	13	2.09 (0.53) (1.29-3.40)	0.010 (0.002)	5.82 (0.78)
Khulna	13	1	12	1.85 (0.53) (1.07-3.20)	0.028 (0.011)	2.92 (0.42)
Chandpai-Sarankhola[e]	50	14	35	3.22 (0.46) (2.43-4.26)	0.006 (0.001)	4.57 (0.46)
Overall[d]	80	19	59	2.64 (0.30) (2.12-3.30)	0.07 (0.014)	4.62 (0.35)

Note

[a]M_{t+1} : Unique adult tigers photo-captured in camera-traps

♂: Male, ♀: Female

[b]Cub: Cubs were not included in SECR analysis

[c]D : Model averaged density

g0 : Detection probability at home range center

σ : Movement parameter

[d]Satkhira & overall: North sampled tigers (*n*=4) were excluded in SECR analysis due to the violation of demographic closure; total 80 individuals from three sample blocks were used in the final analysis.

[e]Chandpai-Sarankhola: Sex remains unknown for 1 tiger

A female tiger with her cub captured in camera-traps in the Sundarbans.

Figure 4 Location of tigers and tiger signs detected in camera-traps and khal surveys overlaid on 10 x 10 km grid cells of the Sundarbans.

The SECR learned response model was found as best-fit compared to the null model, which was anticipated given the use of lures at the traps. This model accounts for changes in detection parameters following the first capture, where both parameters (*g*0 and sigma) are influenced by the initial capture event (Efford et al. 2009). However, we used the individual heterogeneity model due to better performance for the Satkhira data.

Overall, the 2024 population estimate represents an increase of 17.92% compared to the initial 2015 estimates and an 9.65% increase from the last 2018 estimate. From 2015 to 2024, there has been a general rise in tiger density, indicating a positive trend over time (Fig. 5). This trend suggests that tiger populations may be recovering from the significant decline from the population estimates ranged between 300 and 500 tigers (Barlow 2009) (Fig. 6). The earlier decline was attributed to poaching activities that occurred prior to or during the first phase of tiger assessments in 2015 (Aziz et al. 2017a; Saif et al. 2015).

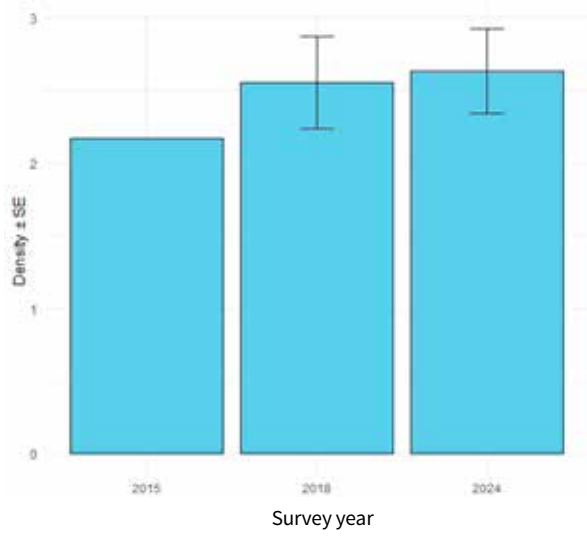

Figure 5 Overall tiger density (with standard error, except for 2015 where no standard error was reported) of the Sundarbans during 2015, 2018 and 2024.

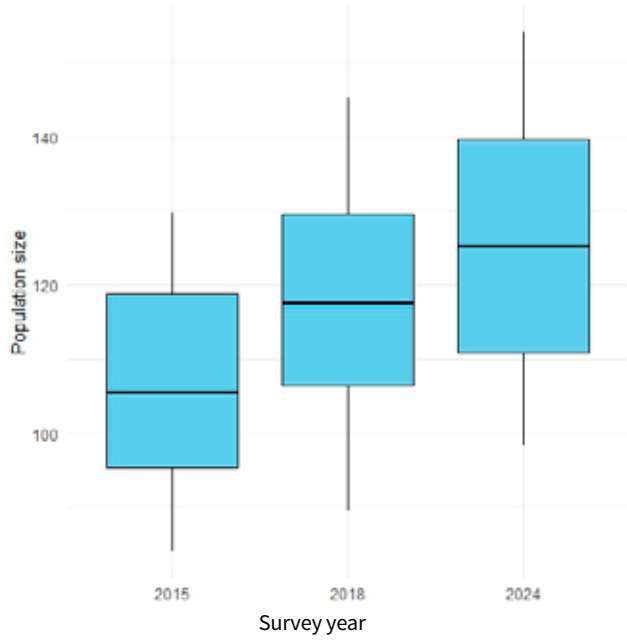

Figure 6 Tiger population size estimates with 95% confidence intervals of the Sundarbans during 2015, 2018 and 2024.

Table 3 Comparative results of tiger surveys conducted during the year of 2015, 2018, and 2024 in the Sundarbans of Bangladesh.

Sample block	Year of assessment[a]	Sample area (km^2)	Number of tiger individuals detected	Tiger density ($D \pm SE$)/100 km^2)
Satkhira	2024	738	21	2.09 ± 0.53
	2018	1,208	36	2.74±0.46
	2015	366	13	2.77±0.78
Khulna	2024	443	13	1.85± 0.53
	2018	165	4	1.20±0.64
	2015	588	7	1.08± 0.04
Chandpai-Sarankhola	2024	1,059	50	3.22± 0.46
	2018	283	23	3.33±0.71
	2015	309	18	3.70± 0.91
Overall	2024	2,240	84	2.64±0.30
	2018	1,656	63	2.55±0.32
	2015	1,265	38	2.17[b]

[a]*Data for 2015 and 2018 surveys are referred to Dey et al. 2015, and Aziz et al. 2018, respectively*

[b]*Standard error was not reported*

Although tiger density across the Sundarbans shows an overall upward trend, variations in tiger density trends are evident among the three sampled blocks (Fig. 7). Specifically, the Khulna block exhibits a positive trend in tiger density, whereas the Chandpai-Sarankhola and Satkhira blocks show negative trends, with Satkhira having higher negative trend compared to the others. The one-way ANOVA analysis reveals significant differences in tiger density between the sampled blocks (F (2, 3) = 144.43, p = 0.001). A recent report indicates that the Khulna range has a notably higher density of spotted deer compared to other ranges in the Sundarbans, which may have contributed to the increased tiger density in these areas (Aziz 2023). However, the differences between years were not statistically significant (F (1, 3) = 1.02, p = 0.387). These results underscore that anthropogenic pressure, such as direct poaching of tigers and their prey animals, might have played a crucial role in influencing tiger densities in the Sundarbans (Aziz et al. 2017b; Saif et al. 2017; Hossain et al. 2018).

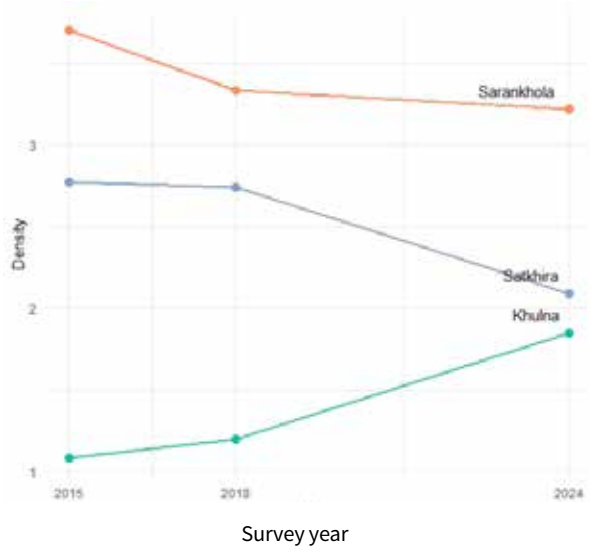

Figure 7 Trends in tiger density of three survey blocks from 2015 to 2024 in the Sundarbans.

The increasing trend of tiger population in Khulna block is encouraging (Fig. 7). However, a concern for tigers in the Khulna block is the highly skewed sex ratio, with only one male tiger detected compared to 12 female tigers (Table 1). In a second assessment conducted in 2018, we observed a similar pattern, finding just one male tiger in the region against three females across the entire Khulna block (Aziz et al. 2018b). To address this imbalance, a short-term, intensive camera-trapping (to investigate if there are additional male tigers but we missed) and genetic monitoring (e.g., investigating inbreeding or genetic depression) of the population should be implemented (Aziz et al. 2018a). This approach could offer valuable insights into the unusual sex distribution and help guide genetic management strategies for this tiger population, isolated by wider Arpangassia and Sibsa rivers (Aziz et al. 2018a).

3.2 Tiger relative abundance

A total of 1,001 tiger track sets were recorded from 1,306 km of surveyed *khal*, yielding a median rate of 0.57 tiger track sets per km of *khal*. Among the four forest ranges, Sarankhola exhibited the highest relative tiger abundance at 1.09 track sets/km, followed by Chandpai at 0.64 track sets/km, Khulna at 0.48 track sets/km, and Satkhira at 0.43 track sets/km. Overall, the relative abundance of tigers has slightly increased compared to the 2017 survey, which recorded 0.54 tiger track sets/km of *khal*. However, a notable decrease was observed in the Satkhira range (Fig. 8).

Tiger signs were detected in 64 out of 65 sample units, and camera traps confirmed the presence of tigers in the sample unit where signs were not recorded. These findings suggest that tigers occupied 100% of the forest landscape of the Sundarbans.

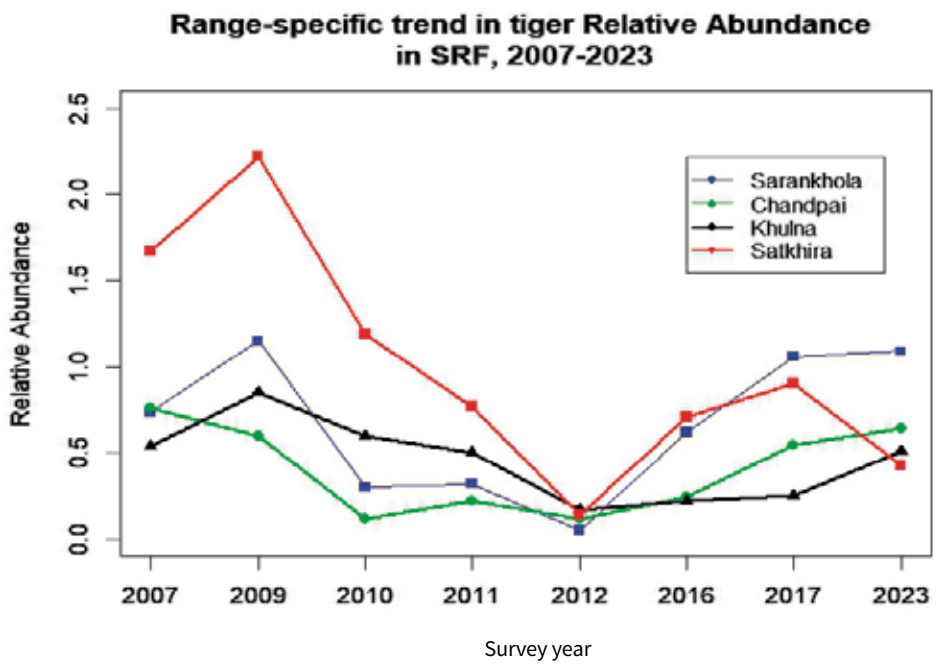

Figure 8 Trends in tiger relative abundance across four ranges of the Sundarbans between 2007 and 2023.

The results of *khal* survey largely align with the tiger density estimates from the camera-trapping survey. However, a notable concern is the decrease in relative tiger abundance in the Satkhira range. This declining trend was also reflected in the tiger density estimates and highlights the need for strengthened protection measures. It is advised implementing a monitoring program to investigate the factors contributing to the decline of tigers in this region and to address these issues immediately.

Spotted deer (top) and wild boar (bottom), the main prey animals of tigers of the Sundarbans (photographs © M. Abdul Aziz).

4. Recommendations

Avoid challenges for a successful tiger survey

- To ensure a successful tiger survey, it's crucial to address several challenges associated with camera-trapping. This method involves technical difficulties related to equipment, requires significant time for adequate sampling, and demands considerable resources. Therefore, all logistical arrangements (especially camera-traps), team arrangement, and budget allocation should be carefully planned and secured well in advance of the survey.
- The next status survey should be conducted within a single winter season (October – March) with allocating a minimum of 800 camera-traps and adequate resources to reduce variations in tiger population data. To achieve this, planning, and selection of survey areas, along with all necessary logistical and financial support should commence at the beginning of the fiscal year.
- Develop a dedicated team of biologists within the Bangladesh Forest Department in partnership with research institutions and universities for future tiger monitoring in the Sundarbans.

Improve tiger protection measures

- Forest camps and stations in and around the Sundarbans need to be more vigilant and proactive (Hossain et al. 2016). This requires a modest number of well-trained staff, basic training, and essential logistics to ensure effective and regular forest patrolling within their designated areas.
- The SMART patrol system should be continuously revised and enhanced through regular skill-building training, data analysis, and reporting. A dedicated group of frontline staff should be developed to allow for regular rotation between patrol teams and sessions. An independent observer could be assigned to each patrol team during operations to provide technical assistance and boost efficiency among team members.
- Additionally, building a community-based intelligence network is crucial for identifying hidden deer and tiger poachers. This network will help in managing wildlife crimes more effectively. Follow-up actions should include producing proper evidence and documentation of crimes to ensure successful prosecution. Coordination with other law enforcing agencies is also critical to ensure effective implementation of relevant laws in curbing forest and wildlife crimes.

Manage grassland habitats

- The Sundarbans landscape has been facing severe climatic events, including increasingly intense cyclones and tropical storms, which have led to extensive inundation of forest floors. These conditions have had serious repercussions for wildlife, particularly concerning the recent deaths of hundreds of spotted deer—tigers' primary prey—caused by cyclone Remal this year. Tigers themselves may also have faced life-threatening risks due to the high-water levels during the cyclone. To mitigate these issues, we strongly recommend evaluation of recently built raised areas, such as freshwater ponds with raised banks and raised mound lands, designed to exceed the maximum water levels observed during cyclones Remal or Sidr. These raised areas should be distributed spatially across the Sundarbans.

- Compared to other tiger habitats in Asia, the Sundarbans' habitat diversity is limited. There are some scattered grassland patches in the southeast (Katka-Kachikhali), south (Nilkamal), and southwest (Mandarbaria) that should be managed through biannual cutting of sungrass and control of woody plant encroachment. These management practices will enhance habitat quality for ungulates, particularly the spotted deer.

Mitigate human-tiger conflict

- The Village Tiger Response Team (VTRT) model has proven effective in managing human-tiger conflicts in the Sundarbans, significantly reducing the impact on both humans and tigers. This successful approach should be supported through regular training, consistent communication, and the necessary resources to enhance the team's effectiveness and improve their well-being.

- Community-based initiatives and training should continue to promote safe harvesting practices of forest and aquatic resources. Existing nylon fencing to be monitored and maintained by Forest Department with engagement of local community. School-based youth programs should also be implemented and made more effective through the use of innovative educational materials, incentives, and active participation. Engaging the local community in these efforts will foster long-term support for the conservation activities in the Sundarbans.

Camera-trap survey team members in the Sundarbans.

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ANNEX

PHOTOGRAPHS OF THE UNIQUELY IDENTIFIED TIGERS OF THE SUNDARBANS

Photo-captured tigers in Satkhira block

STT001 RIGHT

STT002 RIGHT

STT003 RIGHT

STT004 LEFT

STT005 LEFT

STT006 LEFT

Photo-captured tigers in Satkhira block

STT007 LEFT

STT008 RIGHT

STT009 LEFT

STT010 RIGHT

STT011 RIGHT

STT012 LEFT

Photo-captured tigers in Satkhira block

STT013 LEFT

STT014 LEFT

STT015 LEFT

STT016 RIGHT

STT017 LEFT

STT018 RIGHT

Photo-captured tigers in Satkhira block

STT019 RIGHT

STT020 LEFT

STT021 RIGHT

PHOTO-CAPTURED TIGERS IN **KHULNA** BLOCK

Photo-captured tigers in Khulna block

KHT001 LEFT

KHT002 LEFT

KHT003 RIGHT with her cub

KHT004 LEFT

KHT005 RIGHT

KHT006 RIGHT

Photo-captured tigers in Khulna block

KHT007 RIGHT

KHT008 LEFT

KHT009 LEFT

KHT011 RIGHT

KHT012 LEFT

KHT013 LEFT

PHOTO-CAPTURED TIGERS IN **CHANDPAI-SARANKHOLA** BLOCK

Photo-captured tigers in Chandpai-Sarankhola block

PET001 RIGHT

PET002 LEFT

PET003 LEFT

PET004 LEFT

PET005 RIGHT

PET006 RIGHT

Photo-captured tigers in Chandpai-Sarankhola block

PET007 RIGHT

PET008 RIGHT

PET009 RIGHT

STT010 RIGHT

STT011 RIGHT

PET012 LEFT

Photo-captured tigers in Chandpai-Sarankhola block

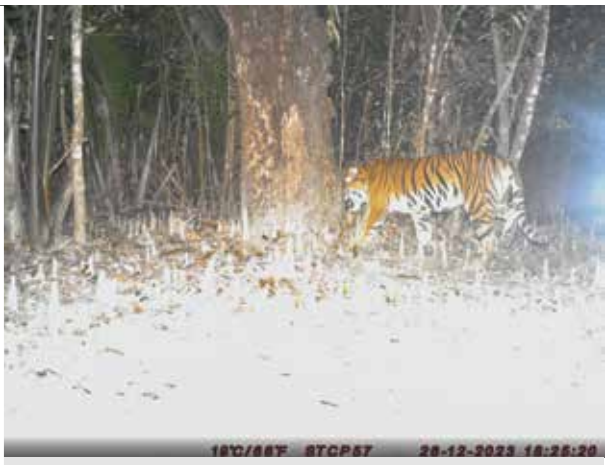
PET013 RIGHT

PET014 LEFT

PET015 LEFT

PET016 RIGHT

PET017 LEFT



PET018 LEFT

Photo-captured tigers in Chandpai-Sarankhola block

PET019 LEFT

PET020 LEFT

PET021 RIGHT

PET022 RIGHT

PET023 LEFT

PET024 LEFT

Photo-captured tigers in Chandpai-Sarankhola block

PET025 LEFT

PET026 LEFT

PET027 LEFT

PET028 LEFT

PET029 LEFT

PET030 RIGHT

Photo-captured tigers in Chandpai-Sarankhola block

PET031 LEFT

PET032 LEFT

PET033 RIGHT

PET034 RIGHT

PET035 LEFT

PET036 LEFT

Photo-captured tigers in Chandpai-Sarankhola block

PET037 LEFT

PET038 RIGHT

PET039 LEFT

PET040 LEFT

PET041 RIGHT

PET042 RIGHT

Photo-captured tigers in Chandpai-Sarankhola block

PET043 LEFT

PET044 LEFT

PET045 RIGHT

PET046 RIGHT

PET047 RIGHT

PET048 LEFT

Photo-captured tigers in Chandpai-Sarankhola block

PET049 RIGHT

PET050 LEFT

PHOTO-CAPTURED TIGER **CUBS** IN THE SUNDARBANS

Photo-captured tiger **cubs** in the Sundarbans

Cub 01 with mother Khulna

Cub 02 with mother Khulna

Cub 03 Satkhira

Cub 04 & 05 Chandpai-Sarankhola

Cub 06 with mother Chandpai-Sarankhola

Cub 07 Chandpai-Sarankhola

Photo-captured tiger **cubs** in the Sundarbans

Cub 08 with mother Chandpai-Sarankhola

Cub 09 with mother Chandpai-Sarankhola

Cub 10 with mother Chandpai-Sarankhola

Cub 11 & 12 Chandpai-Sarankhola

Cub 13, 14, & 15 Chandpai-Sarankhola

Cub 16, 17, & 18 Chandpai Sarankhola

Photo-captured tiger **cubs** in the Sundarbans

Cub 19 Chandpai-Sarankhola

Juvenile 01 with mother Chandpai-Sarankhola

Sub-adult 01 Chandpai-Sarankhola