Article

Conservation status of Bengal tiger *Panthera tigris tigris* in the earth's only mangrove tigerland: A review of efforts and challenges

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Abstract: Sundarban is the earth's largest contiguous 'mangrove forest' ('Bādābān') designated as protected or conservation areas including biosphere reserve, tiger reserve, core area, critical tiger habitat, primitive (wilderness) zone, national park, wildlife sanctuaries, buffer area and reserved forests, covering 10,277 km^2 forest area [4260 km^2 (41.45%) in India and 6017 km^2 (58.55%) in Bangladesh]. This natural biodiversity hotspot is the only mangrove tigerland and the 'last stronghold' of *Panthera tigris tigris* with a camera trap-based population estimate of 214 (100 in Indian Sundarbans and 114 in Bangladesh Sundarbans) supported by a creek (sign) survey. Globally, Sundarban is a prioritised class I tiger conservation landscape extending over 5304 km^2 or 51.6% of total terrestrial and aquatic mangrove habitat in the region, which is facing emergent conservation challenges due to natural and anthropogenic threats. Several conservation actions have been executed to stabilise and increase the tiger population. There is cause for 'cautious future optimism' since the trend of historically high rates of mangrove clearing and degradation has slowed down and tiger population in the Sundarban mangroves has slightly increased and remains stable during the last three enumerations (2018–2022) in India (the results of the current camera-based census in Bangladesh counterpart are to be announced on 29 July 2024), which can be attributed to some positive improvements of tiger habitat management.

Keywords: mangrove habitat; tiger conservation; natural and anthropogenic threats

1. Introduction

The Sundarban mangrove forests, a government property since 1817, came under the undivided Bengal forest management system in 1869. During late 1870s most of the mangrove forests was declared as reserved and protected forests under the forest Act, 1865 (Act VIII of 1865). A full-fledged forest division was created in 1879 in Khulna and scientific management was started during late 1890s. Since 1947, the Sundarban mangroves have been shared between India and present Bangladesh.

1.1. Location and boundaries

Sundarban lies on the Bengal delta and is demarcated by the rivers Baleswar (east) and Harinbhanga (west), in Bangladesh (21°27′30″, 22°30′00″N latitudes; 89°02′00″, 90°00′00″E longitudes), but the northern part of is not clearly defined and in the Indian part by the river Hooghly (west) and rivers Ichamati-Kalindi-Raimangal-Hariabhanga (east) in India (21°32′ to 22°40′N latitude; 88°05′ to 89°00′E longitude), the Bay of Bengal on the south, and imaginary Dampier-Hodges line (1829–1830) on the north.

1.2. Protected area network and impact zone

Before, during and after the British colonial period there was no real government's policy for management, protection and conservation of the mangrove tigers. It is only during early 1970s, an effective conservation network of 'protected areas' (PAs) has been notified in stages in the reserved and protected forests over 10,277 km^2 [4260 km^2 (41.45%) in India and 6017 km^2 (58.55%) in Bangladesh]. In India, the forerunner is the Sundarban Tiger Reserve (STR) over 2585 km^2 (1973), followed by a national park (NP)

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over 1330.12 km^2 (1984) and increased to 1520.78 km^2 (2003) with overlapping 1699.62 km^2 critical tiger habitat (CTH), declared in 2007, which is also known as core area of STR, preserved as inviolate for the purpose of tiger conservation, i.e., any anthropogenic activity strictly prohibited there except research. Within this area, a primitive zone (now better known as wilderness area) over 124.40 km^2 (e.g., the Kendo Island, a remote and undisturbed densely forested area at the Bay mouth) has been kept aside to act as gene pool. The reserve forest (RF) areas over 885.27 km^2 outside the core area have been earmarked as the buffer area, where fishing and honey collection are allowed with permits. The transition area in Indian Sundarbans is densely settled by about 4.5 million people, mostly farmers and fishermen.

In India, Sundarban Biosphere Reserve (SBR) was established in 1989 over 9630 km^2 (including 5366 km^2 deforested human settlement area known as 'transition zone') and 545.191 km^2 critically vulnerable coastal areas (CVCA) were also notified in February 1991. Only three PAs each in India [Sundarban NP, Sajnekhali (376.34 km^2) and West Sundarban (556.45 km^2) Wildlife Sanctuaries (WLS)] and Bangladesh [Sundarbans Reserve Forest (SRF) (1996): Sundarbans East (312.3 km^2), South (369.7 km^2) and West (715.0 km^2) WLSs] presently harbour tiger populations. In Bangladesh, ecological critical areas (ECA) and Sundarban Impact Zone (SIZ), an ecologically sensitive area, was notified in 1999 covering 30 km (10 + 20)—wide buffer to the north and east of SRF, which is inhabited by about 3.5 million people, most of whom are directly dependent on the natural resources of the Sundarbans.

1.3. Ecological and conservation significance

The Sundarban mangrove biome, often known as the mangrove forest or *mangal* (locally called 'Bādābān'), is a biodiversity hotspot, unique, fragile and highly productive ecosystem; on the contrary, it is the most hostile and dynamic habitat in the world marked by highly saline water and soil, swampy terrain, fluctuating climate and rainfall, frequent storms and extremely hot and humid environment, flooded habitats constantly under the influence of two high and two low tides, where the big cats have been struggling to survive through morphological and behavioural adaptations[1].

The mangrove tigers, being completely isolated in the island habitats, do not follow the same natural rules by which the mainland tigers govern their lives because in the Sundarbans ecosystem, the iconic big tigers have to face constant challenges, continuously adjust to new environmental conditions and struggle regularly for survival i.e., to live, hunt and breed. The Bengal tigers and Sundarban mangrove forests are intrinsically linked. The carnivorous tigers balance populations of the ungulate prey species like *Axis axis axis* and *Sus scrofa cristata*, which then balance plant species populations, allowing the mangrove trees to become the dominant vegetation in this flourishing Bengal delta. Without tiger the largest mangrove forests in the world would vanish shortly along with the globally highest blue carbon stock because it is estimated by UNESCO World Heritage forests that whereas Sundarban NP in SBR has stores of 60 million tonnes of carbon (Mt C), Bangladeshi portion of the Sundarbans has 110 Mt C during 2001–2020. Conservation efforts to protect the Bengal tiger, classified as "Endangered", are being continued in India and Bangladesh since 1972. Tiger, the national animal of both India and Bangladesh, is a symbol of marvelous, numinous, predominant and integral part of the mangrove ecosystem. Sundarban is a UNSECO's World Heritage Site in both India (NP: 1330.10 km^2; 1987) and Bangladesh (1395 km^2; 1997) and a Ramsar site in both the countries (Bangladesh No.560; 6017 km^2, 1992; India No.2370; 4230 km^2, 2019).

1.4. Typical ecological setting of the tiger's habitat

The mangrove forests, belonging to the families like Rhizophoraceae, Sonneratiaceae, Avicenniaceae, Meliaceae, Palmae/Arecaceae, Combretaceae, Plumbaginaceae, Sterculiaceae and Myrcenaceae, exhibit diverse and dynamic systems and carry the distinction of hosting a viable tiger habitat in a typical ecological

setting, despite its reduction to almost half the size of the area that existed in the late 1800s due to large-scale reclamation. The habitat preference of the tiger is both pure and mixed vegetation. There is adequate mangrove forest cover, which is used by the tiger for hunting, hiding and procreation. However, it is generally observed that the *Heritiera fomes* (Sundari) and *Phoenix paludosa* (Hental) formations, which are not regularly inundated or inundated for a short period, form the prime tiger habitat. The islander tigers in the Sundarban mangroves suffer due to muddy terrain, unstable soil, and pneumatophores that stick out of the muddy ground like spikes at a height of 20–30 cm above soil to make hunting very difficult (about 20% success-rate), lack of sweet drinking water and habitat fragmentation, which are severely interfering into tiger's life cycle.

2. Materials and methods

2.1. Objectives of review

The goals of this review are to provide baseline information on techniques of monitoring tiger and prey populations in the Sundarban mangrove forests in both India and Bangladesh; their population structure and density; habitat use, carrying capacity, prey selection; tiger-human interactions; and conservation actions taken to curb the natural and anthropogenic threats and challenges.

2.2. Data collection methods

2.2.1. Secondary data

The secondary data were gathered by using an extensive literature (non-conventional, commercial or academic publishing, distribution channels and grey literature) review, including the working plans, management plans, official reports, policies, practices and procedures in vogue on the wildlife resources of the Sundarbans.

Data were also collected from the FD (Forest Department)'s archive and collated for preparing a database and facilitating field verification.

2.2.2. Primary data

Both quantitative and qualitative methods were used for collection of field data from time to time. Generally, data were gathered from multiple sources to strengthen reliability and consistency in results. The quantitative tools include field surveys, questionnaires and statistical data. The qualitative method involves observation, one-on-one interviews, focus groups (stakeholders) either individual or in a community setting and recorded manually or electronically. All quantitative data is based on and interpreted by qualitative judgment.

Intensive case studies also enabled in-depth exploration of intricate phenomena within some specific context at foundation, pre-field, field and final phases including up and down boat (mechanized) survey (rivers, streams, and creeks) at slow speed from 5:30 am to 5:30 pm for sighting and signs as well as camera trapping over 1264 km and 1649 km in Bangladesh and India respectively.

Age of the tigers was approximately determined by body size and appearance: (i) cubs for <12 months, (ii) juveniles for 12–24 months; and (iii) adults for above 24 months. All tiger images were separated from all the captured photographs. The images were screened on the basis of clarity of tiger flanks, which is important for individual identification. Each qualified image was labeled, stored and linked the left and right profiles with a unique identification number using camera station number. Individual tigers were identified uniquely based on stripe patterns on flanks, head, tail and limbs. Sex of the individual tiger is identified on the basis of external genitalia, body composition, pugmarks and behaviour.

3. Results

3.1. Monitoring tiger populations

3.1.1. Pugmark technique

Before technology took its due turn during the early 21st century, the traditional 'pugmark census' methods were relied on in the Sundarbans.

Indian Sundarbans: SBR

Studies on Bengal tigers in the Indian Sundarbans date back to 1970, when Chaudhuri, then the Divisional Forest Officer (DFO) of undivided 24-Parganas Forest Division, carried out ecological studies and on the basis of pug marks estimated 112–120 tigers in the Indian Sundarbans[2].

STR

Efforts were made by FD to estimate tiger numbers based on a single approach called pugmark (plaster cast) method for individual identification of footprints, attacks on humans, and interviews with local communities. Up to 2004, the tiger population estimate (census or monitoring) was based on this method, in which the fresh left hind pugmark impressions were collected from the field and analysed on the basis of eighteen parameters. In 1972, the first tiger census (partially conducted) estimated 135 tigers. In 1976, the total number was estimated to be 181 (Male 66, Female 72 and cub 43). The block-wise results of tiger enumerations in 1977 and 1984 are shown below (**Tables 1–3)**.

Table 1. Comparative estimates of tiger population in STR in 1977, 1983 and 2004 on the basis of plaster cast method.

Block	Year	Male	Female	Male:Female (Ideal 1:3)	Cub	Total
Pirkhali	1977	8	10	1:1.25	1	19
	1983	10	9	1:0.9	2	21
	2004	8	14	1:1.75	5	27
Panchamukhani	1977	4	5	1:1.25	5	14
	1983	10	12	1:1.2	-	22
	2004	6	13	1:2.16	4	23
Netidhopani	1977	4	5	1:1.25	3	12
	1983	1	2	1:2	-	3
	2004	3	5	1:1.6	1	9
Jhilla	1977	3	5	1:1.6	8	16
	1983	8	7	1:0.875	2	17
	2004	3	5	1:1.6	-	8
Arbeshi	1977	6	9	1:1.5	0	15
	1984	12	9	1:0.75	4	25
	2004	8	12	1:1.5	1	21
Khatuajhuri	1977	4	5	1:1.25	2	11
	1983	9	7	1:077	-	16
	2004	3	6	1:2	3	12
Chandkhali	1977	5	5	1:1	2	12
	1983	6	10	1:1.66	-	16
	2004	5	9	1:1.8	-	14

Table 1. (*Continued*).

Block	Year	Male	Female	Male:Female (ideal 1:3)	Cub	Total
Chamta	1977	8	8	1:1	-	16
	1983	19	12	1:0.63	-	31
	2004	11	12	1:1.09	3	26
Harinbhanga	1977	4	4	1:1	-	8
	1983	4	4	1:1	-	8
	2004	4	6	1:1.5	3	13
Matla	1977	4	5	1:1.25	2	11
	1983	7	7	1:1	1	15
	2004	6	8	1:1.33	2	16
Chhotohardi	1977	4	4	1:1	3	11
	1983	6	5	1:0.83	1	12
	2004	3	10	1:3.33	2	15
Gosaba	1977	5	7	1:1.4	1	13
	1983	12	10	1:0.83	1	23
	2004	4	8	1:2	2	14
Mayadwip	1977	6	7	1:1.16	3	16
	1983	14	9	1:0.64	-	23
	2004	4	6	1:1.5	2	12
Bagmara	1977	9	10	1.1.11	3	22
	1983	14	6	1:0.42	1	21
	2004	11	13	1:1.18	3	27
Gona	1977	3	3	1:1	1	7
	1983	5	6	1:1.2	-	11
	2004	4	6	1:1.5	2	12
Total	1977	77	92	1:1.19	36	205
	1983	137	115	1:0.83	12	264
	2004	83	133	1:1.6	33	249
	1989	126	109	1:0.86	34	269
	1992	92	132	1:1.43	27	251
	1996	95	126	1:1.32	21	242
	1997	99	137	1:1.38	27	263
	1999	96	131	1:1.36	27	254
	2001	93	129	1:1.38	23	245

Table 2. Estimates of tiger population in 24-Parganas (South) Forest Division on the basis of plaster cast method in 1984 (no census operation in 1970s).

Block	Male	Female	Male:Female (ideal 1:3)	Cub	Total
Herobhanga	2	3	1:1.5	-	5
Ajmalmari	7	3	1:0.42	1	11
Dulibhasani	2	-	-	-	2
Chulkati	3	2	1:0.66	-	5
Total	14	8	1:0.57	1	23

Table 3. Comparative estimates of tiger population in 24-Parganas (South) Forest Division on the basis of plaster cast method during 1997–2004.

Year	Male	Female	Male:Female (ideal 1:3)	Cub	Total
1997	13	16	1:1.23	6	35
1999	9	16	1:1.77	5	30
2002	7	13	1:1.85	6	26
2004	7	14	1:2	4	25

3.1.2. Bangladesh Sundarbans: SRF

Estimates of tiger population in the Bangladesh Sundarbans during 1975–2004[3] are given below:

(i) 350 (field survey in compartments 3, 4, 5, 6, 29, 30, 31, 46, 47, 48, 49, 50);

(ii) 425 (sample field survey in 1982);

(iii) 450 (pugmark study);

(iv) 430–450 (field survey in 110 km^2 area of Sundarbans South WLS);

(v) 359 (interview);

(vi) 362 (pugmark census in 350 km^2 of different compartment);

(vii) ca.500 (pugmark study).

3.2. Camera trapping technique

3.2.1. Indian Sundarbans

The first study was carried out in STR by Karanth and Nichols[4] from October 1998 to February 1999 and the results are shown in table below (**Tables 4–7**).

In 2010 camera trapping has been done in only few points on experimental basis.

Table 4. Results of camera trap survey of tigers in STR during October 1998 to February 1999.

Efforts	Results
Total number of trapping points	62
Sampling efforts	1086 trap-nights
Number of sampling occasions	18
Camera trap polygon area	539.9 km^2
Estimated buffer width Wˆ	2.00 km
Estimated sampled area Aˆ (Wˆ)	832.0 km^2
Total of effective photographic captures of tigers	8
Number of individually identified tigers (Mt + 1)	6
Catch per unit effort	1.10 tiger captures/100 trap-nights
Capture-recapture model used to estimate population size	Mb
Estimated number of tigers in the sampled area Nˆ (SE [Nˆ])	7 (3.82)
Estimated animal density for tigers in the sampled area Dˆ (SE [Dˆ])	0.84 (0.46) tigers/100 km^2

Table 5. Results of camera trap survey of tigers in the Sundarban landscape since 2012[5–8].

Year	Minimum number of adult	Minimum number of cub	Total	Remarks
2012–2013	89	2	91	Survey in entire Sundarban by WWF
2013–2014	62	-	62	All-India tiger estimation, 2014
2014–2015	31	7	38	Survey in 24-Pargans (south) FD and Basirhat range of STR
2015–2016	81	4	85	Survey by WWF in entire landscape
2016–2017	87	4	91	Survey in entire landscape

Table 6. Demography of tiger individuals captured in SBR (2016–2017 to 2020–2021)[9].

Unit	2016–2017	2017–2018	2018–2019	July, 2021
I. STR				74
1. Sajnekhali WLS	14	15	10	
2. Basirhat range	14	13	19	
3. NP (west) range	19	18	20	
4. NP (east) range	16	20	24	
II. 24-Parganas (South) Division	24	22	23	22
Total	87*	88	96	96

*Two individuals captured in Basirhat range were recaptured in Sajnekhali WLS (89 – 2 = 87) and cubs were excluded from the total count.

Table 7. Sampling efforts for ground surveys in the Indian Sundarbans during 2022 all-India tiger estimation, phase I, conducted from 5 December 2021 to 6 January 2022, in STR and from 8 January to 10 February 2022 in the 24-Parganas (South) FD[10].

Number of trails	Total length (in km)	Number of plots	Images of individual tigers captured
315	1,339	595	100

3.2.2. Bangladesh Sundarbans

Five adult and sub-adult tigers were camera-captured in the southern part of Sundarban East WLS during the period from October 2005 to January 2007; the extrapolated figure for total Sundarban landscape ca.200[11]. Dey et al.[12] identified a minimum tiger population to be 83 and maximum up to 130 individuals using 66 tiger presence points in the Bangladesh Sundarbans. In 2015, Bangladesh FD published the first-ever estimate of tiger population (total 106 tigers in the Bangladesh Sundarbans), which was based on rigorous scientific study using the camera-traps. None of the previous population estimates by the BFD had followed any scientifically valid method, so this result was taken as the baseline for future monitoring. A DNA-based population of 121 tigers was, however, estimated during 2014–2015 by sampling over 1994 km^2 of Bangladesh Sundarbans[13]. The summary of the camera trapping efforts and outputs in three forest blocks of Bangladesh Sundarbans in 2018 is placed below in **Table 8**.

Table 8. Summary of the camera trapping efforts and outputs in three forest blocks of Bangladesh Sundarbans in 2018[14].

Parameters	Satkhira	Khulna	Sarankhola	Overall
Total number of camera trap stations	253	96	187	536
Number of days sampled	102	69	78	249
Number of such stations captured tiger images	146	21	98	265
Total number of tiger images captured	1675	78	713	2466
Total identified adult tiger individuals	36	4	23	63
Male tigers	6	1	2	9
Female tigers	22	3	19	44
Sex-unidentified tigers	8	0	2	10
Number of cubs	2	0	3	5
Number of juveniles	3	0	1	4
Maximum occasion of captures in a station	14	9	9 (n = 2)	14
Maximum individual captured in a station	3	3	4	4
Maximum capture of an individual	30 (n = 2)	18	33	33
Maximum relocations of an individual	21	12	22	22
Total camera-trap nights	10,965	4762	8681	24,408
Minimum camera-trap area (km^2)	1208	165	283	1656
Effective camera-trap area (km^2)	1421	516	1405	3342

A comparative statement of distribution of tiger population in the sample blocks in 2018 and 2015 is shown below in **Table 9**.

Table 9. Comparative distribution of tiger population in 2018 and 2015 in the sample blocks[14].

Serial No.	Forest block	Year	Area (km^2)	Individuals
1	Satkhira	2018	1208	36
		2015	366	13
2	Khulna	2018	165	4
		2015	588	7
3	Sarankhola	2018	283	23
		2015	309	18
Overall		2018	1656	63
		2015	1265	38

Currently, there were approximately 210 tigers in the whole Sundarbans forest, with 114 (extrapolated) in the Bangladesh Sundarbans estimated on the basis of camera trap survey[15].

3.3. Tiger density

3.3.1. Indian Sundarbans

The tiger density is variable in different enumerations units. For example, in 2016 the first joint exercise in STR and 24-Parganas (South) Division was done. The results are shown in **Table 10** below.

Table 10. Tiger density in different enumeration units in SBR in 2016[7–9].

Enumeration unit	Area covered (km^2)	Tiger density/100 km^2
24-Parganas (South) FD	546.62	5.46*
STR		
NP (east) range	523.67 km^2	2.09
NP (west) range	580.34 km^2	3.07
Sajnekhali WLS	413.42 km^2	1.79
Basirhat range	403.83 km^2	3.56

*In 2012, the tiger density was 5.24 in Ramganga range and 4 in Raidighi range.

3.3.2. Bangladesh Sundarbans

During 2007, Khan[16] estimated an average of 3.7 tigers/100 km^2, whereas Aziz et al.[13] provided a density estimate of 2.85 ± SE 0.44 tigers/100 km^2 (95% CI: 1.99–3.71 tigers/100 km^2. The lowest density was recorded from Khulna range.

4. Discussion

4.1. Global status

The IUCN's latest assessment[17] estimates between 3726–5578 wild tigers (not including cubs) remaining in Asia, with an average of 4500 individuals. Some 3140 of the 4500 are estimated to be adult tigers.

4.2. Difference between Sundarbans and mainland Bengal tiger

The mangrove tigers are different from the mainland tigers in many ways, which are significant for their conservation in terms of ecological role played by them. Following Singh et al.[18], a comparison between Sundarbans and mainland Bengal tiger landscape in India may be made here in below.

Table 11. Comparison between Sundarbans and mainland Bengal tiger landscape in India.

Ecological parameter	Sundarbans tiger landscape	Mainland tiger landscape
Morphology	Small size and body weight 80-110 kg	Large size and body weight 160 kg
Prey species	Small size prey (chital and wild boar)	Large size prey (sambar and nilgai)
Habitat	Mangrove forest	Tropical forest
Competitor	None	Leopard
Density	4.3/100 km^2	16/100 km^2

4.3. Tiger enumeration

4.3.1. Outdated pugmark technique

The erstwhile tiger estimation by pugmark method was field-friendly and cost effective, but criticized as deficient, prone to human error and runs the risk of overestimation. Critics of the technique believed that an individual tiger's pugmark changes in shape and size over different substrates (soil texture, moisture and depth). Here the tides also wash away the footprints. Another source of variability is the variation between different tracers' abilities to trace the features of the pugmark on the tracing sheet. There are logistical constraints in the Sundarbans. Above all, in the sloppy, slushy silt, most pugmarks look like formless holes punched in the mud.

Khan[19] opined that different 'estimates' of the total number of tigers in the Sundarbans of Bangladesh mainly based on 'pugmark census' or interviewing, which are not scientific and does not fit to any of the conceptual framework of population sampling methods. The pugmark census assumes that tigers are individually identifiable from their pugmarks, which is not the case, so these 'estimates' cannot even be considered as indices of relative abundance.

4.3.2. Double-sampling method

This is the new method adopted by the Wildlife Institute of India in tiger census. The primary stage involved a ground survey by the Forest Department. Under this Forest Department, staffs collect evidence of the tiger's presence like pugmarks, scat, scratches on trees, or other such unmistakable signs of tiger presence. The next stage involves the camera trapping.

A. Camera trapping in Indian Sundarbans

The mangrove habitat of Sundarbans is unique. The normal approaches to tiger density estimation from camera trap population estimates are not applicable here. It is not possible to derive the effectively trapped area calculations from the usual half mean maximum distance moved by recaptured tigers. Therefore, home ranges are estimated from tagged tigers. The radius of home range is used to determine the effectively sampled area from the camera trap polygon to calculate density estimates from camera traps, which is applied to all tiger-occupied areas of Sundarbans. The extent and relative abundance of tigers throughout the TR is found through sign surveys in channels.

Due to the difficulty of walking in the Sundarbans mangrove forests and locating game trails for setting camera traps, camera traps could be deployed in a systematic grid-based approach used across India. Instead,

camera traps were set up at strategic locations, near fresh and brackish water ponds, using attractants to lure tigers to our camera stations. Initially, fishing nets were also used to orient the approaching tigers to get proper flank photographs for uniquely identifying each tiger from its stripe patterns.

The camera trapping technique using the mark-recapture framework is statistically more reliable than the traditional method of counting pugmarks. But, in practice, population estimates of tigers based on the above technique suffer from problems such as high cost of equipment (Tk 3.27 crores for 200 special cameras in Bangladesh), risk of camera theft and low precision of density estimates especially in areas of low tiger density because the technique relies on sampling tigers at only a few predetermined locations where camera traps are set.

(i) Installation of cameras

Cameras may well be left in dense forests for several days to capture images of individual tigers. But impractical to put in cameras at every place that's likely to possess tigers, and even in places where they're installed, there's no certainty that the tiger would walk into a camera's range.

Supported the bottom survey locations were chosen for installing cameras. These cameras are heat and motion-sensitive. They lie idle till they detect any motion or a sudden change in temperature which implies they capture nearly anything that moves i.e., other animals, even birds. Each tiger is understood to possess a really unique stripe pattern. This can be accustomed to differentiate one tiger from the other.

To demystify the mangrove tigers, for the first time in 2000, remote cameras were deployed in the Indian Sundarbans[4]. But the scenario of camera trapping in Sundarbans is not like it is in other parts of the globe, where it has already been completed with success. The pioneering study based on camera trapping by conservationists was not able to give any convincing result about tigers- the study had limitations as camera traps were set up around freshwater ponds due to lack of forest trail in thick mangrove vegetation. On the basis of field surveys, carried out from October 1998 to February 1999, Karanth and Nichols[4] reported the tiger density of 0.84 tigers/100 km^2. The photographs of six different tigers obtained by camera traps showed differences in stripe patterns that permit unambiguous identification of the individuals. But no estimates of prey abundance were provided. The data set of captures was small (SBT 101 – 106 = 6 inclusive of a cub less than one year of age [SBT 105]). In the Sundarbans, periodic tidal phases are the biggest threat for camera trapping as high tides always create the risk of inundation of camera-trap equipment. Rough weather conditions are also an issue to address before starting similar investigations.

During this first camera-trap survey, 3–4 cameras were set around each sweet water pond (n = 15 [Jhingakhali, Jhillamukh, Burirdabri, Balkhali, Duttachera, Sajnekhali, Sudhannyakhali, Choragazi, Deulbharani, Dhopni, Chamta, Maraboni, Keorasuti, Haldibari and Begukhali), but they could not set traps at 14 other ponds within or surrounding the same polygon either for logistical reasons or disturbance by intruders with attendant risk of theft to the equipment. They made two estimates of the sampled area for Sundarbans: the first one using a 'small' value of $\hat{W}$ = 2.00 km and a second one using a 'large' value of $\hat{W}$ = 5.00 km. The first value corresponds to a situation where the home range size of tigers is expected to be approximately 12 km^2, with mutually exclusive ranges; the latter value corresponds to a situation where the home range size is expected to be approximately 78 km^2, with possibly overlapping home ranges. The estimates of the area effectively sampled by our camera-trapping system, derived using these two alternative approaches are 832 km^2 and 1240 km^2, respectively. They termed these two values as the 'lower' and 'higher' estimates of sampled area size. The estimated mean tiger density $\hat{N}$ derived using the smaller sampled area estimate works out to 0.84 tigers/100 km^2, with a 95% confidence interval CI(N) of 0.84–3.60 tigers/100 km^2 (this higher density value is the one reported in the summary provided earlier). The corresponding values of

lower tiger density derived using the larger estimate of the sampled area are N̂ = 0.56 tigers/100 km^2 and CI(N) = 0.56–2.42 tigers/100 km^2.

Karanth and Nichols[4] further noted that the statistical inferences, on which the tiger population density estimates for the Sundarbans were derived, are relatively less robust than those they had made in other study areas, for the following reasons:

1) The capture probability per sampling occasion was relatively lower in the Sundarbans when compared to other study areas: Sundarbans $p = 0.077 < p = 0.11–0.22$ at other study areas except at Bandipur ($p = 0.055$).
2) The inability to select from among competing capture-recapture models due to lack of recaptures and relatively few individual animals captured. They could only use the simple removal model M*b* with their data.
3) The lower number of tiger captures per unit effort (CPU) of 1.10 tiger captures/100 trap nights at the Sundarbans as opposed to CPU's of 14.5 in Kaziranga, 10.83 in Kanha, 8.69 in Ranthambore, 8.12 in Nagarahole, 5.32 in Pench, 4.94 in Bhadra and 3.37 in Bandipur. Only Namdapha with 0 captures/100 trap-nights had a lower catch per unit effort than the Sundarbans.
4) Problems were associated with the estimation of the sampled area due to the sampling design and the lack of data on distances between recaptures of individual tigers. If the sizes of home ranges were small and the ranges were exclusive in the Sundarbans (buffer distance <2.00 km), there might be a possibility that some individuals in the sampled area had zero probability of being photo-captured. In that case, the true population size in the sampled area might be higher than the estimated size, by a few individuals.

According to them, the data for Sundarbans were suggestive of a relatively low-density population with a mean tiger density (D̂) value in the range of 0.6–3.6 tigers/100 km^2. The approximate prey densities required to support these tiger densities may vary in the range of 2.4–14.8 ungulate prey/km. According to them, the data for Sundarbans were suggestive of a relatively low-density population with a mean tiger density (D̂) value in the range of 0.6–3.6 tigers/100 km^2. The approximate prey densities required to support these tiger densities may vary in the range of 2.4–14.8 ungulate prey/km^2. They were unable to obtain data on the prey densities for physical constraints. However, they suggested the estimated densities of major tiger prey species (chital, wild pig and rhesus macaque) possibly using thermal imaging or any other alternative technique. They were unable to obtain data on the prey densities for physical constraints. However, they suggested the estimated densities of major tiger prey species (chital, wild pig and rhesus macaque) possibly using thermal imaging or any other alternative technique.

To avoid controversies, the forest authorities handed over the 2004 survey data for statistical analysis to a government department dealing with statistical analysis. However, instead of adopting scientific procedures, the department published the report without consulting the forest officers. In 2006, Indian Statistical Institute claimed that the number of tigers is not more than 75, the report, however, was not accepted and the results were not brought out officially. The findings were full of errors. For example, a tiger cannot be simultaneously present at two locations at a distance of a hundred km.

No tiger estimation was done in the Indian Sundarbans in 2006 as at that time; the new protocol for sampling this hostile and unique tiger habitat had not been developed. The second and third assessments were carried out in 2010 and 2014 which included the Sundarban tigers. The information generated by three earlier cycles of tiger status evaluation exercises resulted in major changes in policy and management of tiger populations and provided scientific data.

In STR, during the year 2010–2011, an attempt was made to estimate the tiger population and density by using camera (Moultrie Digital) traps in a mark recapture framework with closed population estimators at Netidhopani and the area covered was 220 km^2. Since the Sundarban is a unique habitat with six hourly tidal effects, it is extremely difficult to locate regularly used game trails for setting the camera traps. Therefore, it was decided to use lures and baits (meat or egg) to attract the tigers to camera traps. Due to this limitation the cameras could not be set systematically across the study area but were sparsely spaced near attractants of fresh water ponds. In all, 102 photos were taken using camera traps recording the presence of 12 different tigers (10 adults and two cubs). But, due to limited sampling, a reliable estimate of mean maximum distance moved could not be made for density estimation. Nor the camera configuration provided a robust design for using the modern approaches of spatially explicit likelihood and Bayesian approaches to density estimation. After the study, density was estimated at 4.3 individuals/100 km^2 and the number of tigers estimated to be 70 within a range of 64–90 tigers in STR after extrapolation[20].

In 2011, the first initiative was taken when WWF-India, Sundarbans programme, entered the forest of Lothian WLS, located at the southern corner of SBR. The entire division was divided into 4 km^2 grid, each grid having a pair of cameras facing each other for better and additional frames that will help to identify the animals being captured. The cameras run on battery and are fitted with heat and motion sensors. They switch on automatically when animals tread near them. The cameras need to be installed in places having a reasonable possibility of being crossed by the animals. Relatively high ground is required to install them so that these are not damaged by the high tides. Moreover, the camera traps have to be installed at a height of less than four feet to shoot the animals because they generate infra-red rays that turn the camera on whenever they hit an obstacle. Recapturing is the essence of the exercise. It helps to know how frequently a tiger has been passing a particular area. Even though it usually takes three weeks to recapture an animal, it could take up to a month in the Sundarbans.

As a part of the study, first camera traps were deployed on an experimental basis. However, the exercise was washed out with loss of 20 units of camera traps due to inundation by high tides as an effect of the 'supermoon'. This huge loss is a reminder of the supremacy of nature and the might of the tides. It is necessary to understand the tidal cycles before preparing the final design of a camera-trapping exercise.

From the learning and experience in Lothian, the concept of 'highest point of high tide' was established, which states that camera-trapping should be started during the high tides because it facilitates finding places with low risk of submergence. With the experiences gained in Lothian, in January 2012, camera traps were first deployed in the tiger forest by the WWF staff in 24-Parganas Forest Division of SBR. Sometimes, a strange smell in the air and fresh pugmarks on ground during camera deployment confirms the presence of the felid species. In each trap station, olfactory attractant is applied as it is safe to attract a tiger with the use of olfactory lure. Otherwise, trying to track a tiger in Sundarbans is very dangerous, probably impossible.

Eventually, the camera-trapping exercise in the reserved forest became the biggest breakthrough in tiger conservation history in Sundarbans. Safe recovery of 98% camera traps after the entire exercise and the estimate of a minimum of 20 tigers from 24-Parganas Forest Division explains the success of the study[5], as the area was earlier believed to be a non-tiger habitat. This unique study provides necessary information to NTCA to establish standard protocol for camera trapping in Sundarbans and plays a vital role in the declaration of the 556 km^2 area of 24-Parganas South Forest Division as 'West Sundarbans WLS'.

The major outcomes that were direct or indirect consequence of information generated by the monitoring exercises were:

(1) Tiger landscape conservation plans,

(2) Designation and notification of inviolate critical core and buffer areas of tiger reserves,
(3) Identification and declaration of new tiger reserves,
(4) Recognition of tiger landscapes and the importance of the corridors and their physical delineation at the highest levels of governance,
(5) Integrating tiger conservation with developmental activities using the power of reliable information in a Geographic Information System database,
(6) Planning reintroduction and supplementation strategies for tigers and,
(7) To priorities conservation investments to target unique vulnerable gene pools[21].

All these provide an opportunity to incorporate conservation objectives supported with sound science based data, on equal footing with economic, sociological, and other values in policy and decision making for the benefit of the society.

(ii) Boat survey

This is, however, not translated into accurate predictions of tiger populations. It is argued that when the field staffs sailing the water, they cannot see beyond a certain point on the land and many areas thus remain uninvestigated. Thus, this is not a total count but only a tidal channel search and the inner mangrove forests were excluded due to lack of proper animal trails and fear of tiger attacks.

In 2010, the tiger population in the Indian Sundarbans was estimated in a mark re-capture framework with closed population estimators in an area of about 200 km^2. This set-up allowed estimating population size reliably. But due to the small number of camera stations (12) and uneven geographical spread of camera traps, it was not possible to obtain a reliable estimate of mean maximum distance (MMDM) moved by recaptured tigers nor use the spatially explicit models effectively. Models estimating effective trapping area attempt to estimate home range radius either by estimating MMDM or through centers of activity, in the case of the Sundarbans direct estimates of home ranges based on telemetry data were attempted. Home range radius was used from 95% fixed kernel area estimates of tiger home ranges as a buffer to the camera trap polygon for estimating effectively trapped area.

The telemetry data suggested that though tigers do cross wide channels, crossing of channels >1 km in width was rare. A habitat mask was, therefore, used wherein channels >1 km in width were considered barriers to movement over the short term duration of the camera trapping exercise. 10 adult tigers and two cubs were photo-captured. The best model selected by CAPTURE was model Mh (incorporating individual heterogeneity) and the population estimate was 11 (se 3) tigers. The home range radius of four satellite-radio tagged and camera trapped polygons, giving an area of 438 km^2. After applying a habitat mask bounded by channels >1 km the effective camera trapped area was 257 km^2. Tiger density was computed to be 4.3 (se 0.3) tiger per 100 km^2. Since the tiger occupied area of the STR was 1645 km^2 and the tiger signs were found throughout this area with a similar variation across STR as found within the camera trapped area, it would be possible to extrapolate this tiger density across the reserve without much loss of accuracy.

Ideally, 2–4 additional camera trap replicate areas need to be sampled and additional data from radio collared tigers are needed to provide more accurate and precise estimates of tiger density. But till these are obtained, this first quantitative assessment estimates the number of tigers to be around 70 (64 to 90) tigers for STR (in 1645 km^2). Further refinement in methodology, involvement of other institutions is needed and mention must be made that the 2010 estimate is subject to further study and by better methodology.

Mallick[22] has recorded some interesting results. The most important outcome is that maximum tigers were sighted in Pirkhali block, but the frequency was highest here during the four months from January to April and then the sightings started reducing from May onwards recovering only in December. This may

indicate a periodical fluctuation of population in this block. Another remarkable feature is that Netidhopani is the second important sighting area in the region, but here also the sighting records were not uniform throughout the year, but fluctuates during the rainy and winter months. Arbesi block is the third important sighting area. Here most sightings were recorded in December. On the contrary, the sighting record in the adjacent Panchamukhani block is low throughout the year. Matla block may be termed as very low in terms of sighting, where from August to December no sighting record was available. Experience is almost similar in Chamta, Chhotohardi, Chandkhali and Gosaba blocks. But in the southern blocks of Gona, and Bagmara, sighting was almost negligible and in Mayadwip it was nil. Jhilla, Khatuajhuri and Harinbhanga blocks were not very important in terms of sighting. So, the northern belt of forest blocks the presence of tigers was mostly felt, whereas only one block in the central zone, i.e., Netidhopani, holds most of its residents throughout the year.

Unfortunately, the tigers are notoriously elusive, particularly so in the Sundarbans, for which direct sighting is rare. In most of the cases only the loners were sighted and occasionally a pair of two (male-female during mating time or mother-cub during rearing). However, rarely, up to five tigers have been sighted in the Sundarbans.

B. Bangladesh Sundarbans

Khan[16] conducted a camera-trap survey in the Sundarbans East WLS (total area of 312 km^2, covering only the southern part of the sanctuary, for more than 200 days from October 2005 to January 2007. The results were extrapolated from the core study area in Katka-Kochikhali, southeastern Sundarbans, to five additional sites like Hironpoint, Mandarbaria, Harintana, Chandpai, and Burigoalini (each survey site approximately 170 km^2) using indices of abundance. With the use of 10 camera-traps at 15 trap-points, field data provided a total of 829 photos, including seven photos of five individual tigers. A total of 5.0 (SE = 0.98) tigers (adults and sub-adults) are thus estimated in the core area with an estimated density of 4.8 tigers/100 km^2. Distance sampling surveys conducted on large mammalian prey species obtained overall density estimate 27.9 individuals/km^2 and a biomass density of 1037 kg/km^2. By combining the estimates of absolute density with indices of abundance, an average of 3.7 tigers/100 km^2 across the region was estimated, which given an area of 5770 km^2, would predict a minimum of approximately 200 tigers in the Bangladesh Sundarbans.

Later, Bangladesh-India joint tiger census project conducted the tiger census 2015 examining some 1500 images and footprints of tigers taken from the Sundarbans through camera trapping and found the horribly low figure of tigers. Experts observe that the loss of habitat, unchecked wildlife poaching, animal-human conflict in the forest and lack of management of forest are the main reasons behind the rapid fall in the tiger population. According to the Forest Department data, at least 49 tigers were killed in the last 14 years (2001–2014) since the illegal poaching of wildlife and tiger-human conflict is on the rise in the Sundarbans.

In the first phase of the Bangladesh-India joint tiger census project, completed in April this year beginning 1 November 2013, some 89 infrared cameras were used to capture tigers' movements within a 3000 km^2 area in the Bangladesh part of the Sundarbans. The second phase of the tiger census project using camera trapping methods began on 12 November 2014.

The encounter rate of human sign and sighting was higher in Bangladesh Sundarbans which is further exacerbated by the usage of river channels for transportation of commercial vehicles. The tiger population in the Bangladesh Sundarbans is much below the actual carrying capacity, while the Indian side has reached carrying capacity. The findings point to better management in the Indian Sundarbans.

Camera traps can also have drawbacks. The images captured are limited to space, as they can gather information only in the areas that are activated by sensors; which may leave us not being able to detect all the animals in the given area. If handled properly the data provided by the camera trapping survey is close to accurate data or may create several problems during the research if not handled properly. But after doing a thorough job the results can be satisfying as camera traps add a dimension to research like never before.

4.4. Tiger mortalities

4.4.1. Indian Sundarbans

A statement of tiger mortalities in the Indian Sundarbans based on gender and age classes is given below in **Table 12**.

Table 12. Tiger mortalities based on gender and age classes in the Indian Sundarbans.

Year	Male	Female	Unidentified	Age class
2011	2	0	1	3–10: 2; unknown: 1
2012	1	0	2	<1: 1; >10: 1; unknown: 1
2013	1	0	0	>10: 1
2015	2	1	0	1–3: 1; 3–10: 1; unknown: 1
2021	1	-	-	11–12: 1

Comparatively, maximum cases were reported from the central Indian and Eastern Ghats followed by Western Ghats, Shivalik hills and Gangetic plains, Northeast hills and Brahmaputra flood plains and lastly Sundarbans[23]. In the year 2008–2009 last tiger poaching (one) took place[22]. But there may be a possibility of unrecorded cases of poaching because the chronicles of seizure from Sundarbans between March 2009 and November 2010 revealed that poaching seems to be a silent killer. At least six persons were arrested from east Goraberia and Baruipur with tiger skins and skulls with the seizures showing from full grown big cats to cubs all fell prey to the poachers.

4.4.2. Bangladesh Sundarbans

Following independence in 1971 the Bangladesh Wildlife (Preservation) (Amendment) Act, 1974 banned tiger killing in Bangladesh for the first time. But poaching continued surreptitiously in the village as well as the forests. In 2012 the new Wildlife (Preservation & Protection) Act of Bangladesh introduced tougher punishments for tiger killing (7 years imprisonment); however, this law is not sufficient to combat poaching without effective enforcement measures.

During 2008–2012, a total of eight tigers were killed in the villages (WildTeam, mimeo). In this perspective, Saif et al.[24] identified five categories (village residents, poachers, hunters, trappers and pirates) of people involved in killing tigers, each with different motives, methods and networks. Village residents kill tigers predominantly for safety, whereas others kill in the forest professionally or opportunistically. Poachers kill tigers for money, but for others the motives are more complex. The motives of local hunters are multifaceted, encompassing excitement, profit, and esteem and status arising from providing tiger parts for local medicine. Pirates kill tigers for profit and safety but also as a protection service to the community. The emerging international trade in tiger bones, introduced to the area by non-local Bangladeshi traders, provides opportunities to sell tiger parts in the commercial trade and is a motive for tiger killing across all groups.

4.5. Prime prey enumeration

4.5.1. Chital or spotted deer (*Axis axis axis*)

Chital is the principal prey species of tiger in both Indian and Bangladesh Sundarbans. This species, like the tiger, lives on the edge of its natural range in the Sundarbans. They are most abundant in those habitats where extensive grassland and scattered forests of *Sonneratia* sp. occur. Open grassland and *Keora* appear to be favoured habitat and they have preference for *Keora* leaves and fruits. This habitat is available in all the PAs in the tigerland.

In the Bangladesh Sundarbans, spotted deer sign and sighting encounter rate was more or less uniform across the landscape with pockets of higher encounter rates in the Sarankhola and Khulna ranges. Hard size of the spotted deer varies considerably with the season and availability of food and water. Reza[25] recorded a total of 889 groups in Katka-Kachikhali, with varying group size 2–137 (mean 7.36), group density 9.56 groups/km^2, species density 70.4 individuals/km^2 and biomass and metabolic biomass were 3870 kg/km^2 and 2903.2 kg/km^2. The density increased subsequently by 7.4 kg/km^2 and biomass by 411.75 kg/km^2 and the reasons were attributed to reduced poaching due to departmental protection.

Dey[26] recorded about 83,000 deer in the Bangladesh Sundarbans with a varying density in different habitats such as 3–4 in *Heritiera fomes;* 6–7 in *Excoecaria agallocha-H. fomes;* 10–13 in *H. fomes-E. agallocha;* 12–14 in *H. fomes-Xylocarpus mekongensis-Bruguiera gymnorrhiza* and *E. agallocha* forest; 15–16 in *E. agallocha-Ceriops decandra-X. mekongensis;* 14–18 in *X. mekongensis-B. gymnorrhiza-Avicennia officinalis;* 43–55 in *C. decandra-E. agallocha-Sonneratia apetala;* and 112–195 in *Sonneratia apetala-E. agallocha* open grassland associations. The population density decreases with the increase in canopy closure because such closure is affected by tree heights and canopy widths and takes into account light interception and other factors that influence microhabitat. The deer density was lowest (2–4/km^2) in pure *H. fomes* where canopy closure was 70%–80% and highest in *S. apetala-E. agallocha*-open grassland associations with canopy closure 40%–50%.

The radio-tracking based home range of both males and females varied from 140 to 200 in April–September, which is their peak breeding season, although the chital breed throughout the year, but population decreased in October–January and population remained more or less stable during March–July with average male:female:fawn ratio 15:60:25 as against the peak season's ratio of 15:50:35. The home range of the males increased during the peak breeding season (295 to 410 ha), whereas the female's home range increased to 1.5 times higher than the rest of the year. A male shared overlap home ranges of 4–5 females during the rutting period.

Chital was captured throughout the Indian Sundarbans landscape with highest concentration of photo-captures in Sajnekhali WLS. Two of the capture hotspots in this sanctuary coincide with the location (Dobanki camp) where chital had been released in the late 2000s.

4.5.2. Barking deer (*Cervus muntjak* Zimmerman, 1780)

Barking deer is a solitary species appearing to be confined to the north and north-east in the Bangladesh Sundarbans. Although observed around Dhangmari, Karamjal, Jhongra stations in Chandpai range, they are not seen in southern Sundarbans. In contrast with the spotted deer, this species appears to avoid grassland and is thus better suited to the denser woodland in habitats to the north. Dey[26] recorded a population of about 2150 with variable density like 1–2 km^2 in *H. fomes;* 2–3 in *H. fomes-E. agallocha* and *X. mekongensis-B. gymnorrhiza-A. officinalis* forest; 3–5 km^2 in *E. agallocha-X. mekongensis-B. gymnorrhiza;* and 4–5 km^2 in *E. agallocha-H. fomes* forest. Both males and females have tusks-like upper canine teeth,

which are longer, well developed and distinctly visible from a distance in males. The territorial males use them along with their short antlers for fighting against each other.

The home range also varied from 45 to 90 ha during November-February but during the rutting period, a male's home range increased from 80 to 170 ha. During the breeding season a female's home range increased to 1.25 times larger than that of the non-breeding season. A male shared his home range with those of 2–3 females during the rutting period. Whereas the spotted deer are active mostly during day time, the barking deer are more active during the night.

Barking deer is also a major ungulate prey of the tiger in the Bangladesh Sundarbans[27].

4.5.3. Wild boar (*Sus scrofa cristatus*)

Wild pigs were distributed throughout the Sundarban landscape. Prevalence of more capture hotspots in SBR concurs with higher sightings of wild pig during boat transects in this area. The habitat of the wild boar is the tangled mass of Garan, whose extensive breaks harbour the sounders. Population status of the wild boar was studied in the Bangladesh Sundarbans. Reza[25] recorded a total of 133 wild boar groups in Katka-Kachikhali, with varying group size 1–15 (mean 2.21), group density 3.58 groups/km^2, species density 7.9 individuals/km^2 and biomass 300 kg/km^2. The mean biomass and the metabolic biomass were reported as 330.22 kg/km^2 and 247.67 kg/km^2 respectively. Dey[26] recorded 28,000 wild boars in the Bangladesh Sundarbans.

4.5.4. Rhesus monkey (*Macaca mulatta*)

Rhesus macaque is one of the principal prey species of the tiger in both India and Bangladesh. Foraging on the banks of smaller or narrower channels close to the thickets was not usually observed because they are prone to sudden tiger predation there. Rhesus macaque was captured more or less throughout the Indian Sundarbans landscape with highest concentration of photo-captures in Sajnekhali beat of Sajnekhali WLS. Its sign and sighting encounter rate were higher in the East range of the Sundarbans NP as well as in the buffer zone of the Basirhat range. Reza[25] recorded a total of 37 groups in Katka-Kachikhali, the largest group size was 41 and the smallest one only three, mean group size 11.92 individuals/group, and biomass of the animals was 126.7 kg/km^2 and 2903.2 kg/km^2. Dey[26] recorded 51,000 rhesus monkeys in the Bangladesh Sundarbans. Hasan et al.[27] recorded a total population of 966 individuals distributed in 41 groups (mean size 23.6 ± 5.2; range 14–31; adult male-female ratio 1:2.84 and adult-immature ratio 1:1.64 including sub-adult male, sub-adult female, juvenile and infant) in the Sundarbans (southwestern).

The capture hotspot in this beat coincides with the location of the beat and range offices where there is maximum instantaneous human presence inside the tiger reserve on any given day as these offices issue tourist and fishing permits.

Mallick[28] recorded the rhesus density in STR as 1.2/km^2. The Rhesus population densities (extrapolated) in six selected sites in the Bangladesh Sundarbans[29] are given below (**Table 13**).

Table 13. Rhesus population densities in Bangladesh Sundarbans.

Location	Relative density	Absolute density
Katka-Kochikhali	2.42 (±0.77)	6.5
Hironpoint	2.36 (±0.81)	6.3
Mandarbaria	2.40 (±0.69)	6.4
Harintana	1.18 (±0.59)	3.2
Burigoalini	0.85 (±0.47)	2.3
Chandpai	0.83 (±0.45)	2.2

Mallick[29] also recorded the highest concentration (based on personal observations) in the western Sundarbans, particularly in the protected areas and surrounding reserve forests of Sajnekhali WLS (362.40 km^2) between the rivers Peechkhali and Gomdi, Halliday (5.95 km^2) on the river Matla and Lothian Islands (38 km^2) at the confluence of the river Saptamukhi and the Bay of Bengal. Troops were sighted at the popular tourist spots-cum-supplementary feeding sites with well maintained sweet water ponds, e.g., Sajnekhali, Sudhanyakhali, Choragazi, Dobanki and Netidhopani (STR).

A small troop was camera-trapped in south 24-Parganas Division[5]. The monkeys also inhabit the northern anthropogenic (civil) areas (e.g., Gosaba). Mallick[30] also referred to the earlier records of *M. mulatta* in the eastern Sundarbans. Sightings were more common in the east Sanctuary (312.26 km^2) than the west (715.02 km^2) and south (369.70 km^2) WLSs as well as ten individuals camera-trapped in the east WLS during 6 September–4 December 2006[31].

The estimated rhesus population in STR was about 38,000 in the 1990s[27]. No such estimate for the south 24-Parganas Forest Division is available, but the population appears to be comparatively low (about 10,000) on the basis of counting the population at Bakkhali in January 2001 and then extrapolating the figure for the entire division[29]. The Bangladesh population was between 40,000 and 68,200 against the higher estimate of 88,000 to 126,220, but the current estimate is 40,000 to 50,000[29]. Due to shrinkage of habitat, the population has declined over the last two decades.

Density of the Rhesus population in various mangrove vegetation types in the Sundarbans was studied during 2011–2012[28]. The results are shown below (**Table 14**).

Table 14. Rhesus density in STR.

Major pure and mixed genera (Number of species)	Forest zone	Area (in km^2)	Population density (%)
Sonneratia-Excoecaria-Oryza (5)	River flat	82.86	60
Ceriops-Excoecaria-Sonneratia (6)		648.07	15
Excoecaria-Heritiera (2)	River flat-Ridge forest	1816.76	6
Excoecaria-Ceriops-Xylocarpus (5)		346.04	5
Xylocarpus-Bruguiera- Avicennia (9)	Ridge forest-River flat slope-River flat	40.30	5
Pure *Excoecaria* (1)	River flat	215.20	4
Heritiera-Xylocarpus-Bruguiera (7)	Ridge forest-River flat slope	95.56	4
Pure *Heritiera* (1)	Ridge forest	749.92	1
Total		3994.71	100

4.5.5. Monitor lizard [*Varanus* spp. (Reptilia: Varanidae)]

Sundarbans is considered as the most potential habitat for the Asian water monitor (*Varanus salvator*). The capture hotspots of the monitor lizards in STR were in the Sajnekhali WLS, the buffer zone of Basirhat range and the core area of the NP West range. Monitor lizard sign and sighting encounter rate was highest in the Chandpai-Sarankhola range of Bangladesh, while its presence was not recorded in many areas.

4.6. Man-animal interaction[22]

Records of man-tiger conflict are available since 1670. A very limited number of the tiger is man-eater in the Sundarbans and they are officially hunted by proclamation. Besides the permit holders, a large number of non-permit holders also enter into the forests and die due to tiger attack and these go unrecorded because they could not claim compensation from the Government because of their illegal entries.

The number of man-tiger conflict is mostly reported from the western Sundarbans because the populations of the spotted deer and the wild boar are not so abundant here compared to the eastern Sundarbans. Retaliatory killings of the tiger (i.e., driven by a desire for retribution following livestock depredation or attacks on humans by tigers as well as socio-psychological factors) were also on record.

427 human killings were recorded during 1912–1921 as against 452 tigers. A toll of about 1000 human beings was recorded during next 50 years. 401 human casualty and 41 tiger poaching cases were reported during 1984–2000 in Bangladesh. In Indian Sundarban, between 1985 and 2009, 789 persons were attacked by tigers out of which 666 succumbed to their injuries with an average of 27.75 events per year. Most of the (humans entering with permit or illegally) killings takes place in the forest involving fishermen (44%), woodcutters (36%) and honey collectors (18%). Current levels of human and tiger deaths in the Sundarbans are relatively low compared to mean levels recorded in the last 140 years.

Furthermore, the 2–3 tigers killed each year in the Sundarbans in addition to an unknown number poached, could threaten the long-term viability of the tiger population. Reducing both tiger and human deaths is, therefore, needed to improve conservation prospects for tigers in the Sundarbans.

The man-eating nature of the tigers was studied many times. 392 casualties were reported between 1956 and 1970, out of which 365 were known by place of incidence with 198 (54.2%) occurring in Satkhira range. The possible reason behind such occurrences, among other factors, was the saline estuarine water. Subsequent data (2002, 2003 and 2007) prove that the portion of casualties in the Satkhira range has always been high and has increased slowly. During the period 1974–1983, the differences in casualties between the low and high salinity zones became insignificant and the casualties in the medium salinity zone were significantly higher than those of the other two zones. This trend does not justify the hypothesis that the salinity of the water causes tigers to develop man-eating behaviour.

Reasons for the man-tiger conflict

The identified reasons for the man-tiger conflict in the Sundarbans are discussed below:

(i) Scarcity of prey animals;
(ii) Difficulty in hunting;
(iii) Proximity of reclaimed human settlement to the tiger habitat;
(iv) Tigers do not stray in the village to kill easy prey like humans;
(v) Embankment protection mangrove strips of the villages are confused by the tigers as their own habitat;
(vi) Littering female strays in the paddy field to protect her cubs;
(vii) Paddy fields confused with *Porteresia coarctata;*
(viii) Generally old tigers stray for easy prey;
(ix) Straying due to washing out of pheromone by tidal waves;
(x) The male tiger losing domain to the aggressive male tiger may stray;
(xi) Fog factor;
(xii) Adventure;
(xiii) Impact of environmental change.

4.7. Conservation challenges

The Bengal tiger is a conservation-dependent species that needs good quality habitat with sufficient prey-base and undisturbed breeding grounds. Tigers today face incredible challenges as their numbers shrink in the wild due to poaching, encroaching human population, and loss of habitat as well as traditional prey. Saving the Bengal tigers is critical for the Sundarbans and without tigers, the entire ecosystem would collapse. Therefore, habitat management using scientific-based ecological data and protection of tigers and

their prey from poaching are the prime prerequisites of tiger conservation in the Sundarbans.

4.8. Conservation priorities

While setting priorities for the global tiger conservation (2005–2015), the Sundarban mangrove landscape was provisionally considered a class III (low priority) tiger conservation landscape (TCL) with insufficient habitat, high threat level, low tiger population, too diminished prey bases to recover within a decade, and lack of commitment to tiger conservation by local people and government in the TCL. However, after a decade of successful conservation efforts, the Sundarban mangrove landscape was promoted to the class I (highest) TCL of global priority to represent mangrove habitat over 5304 km^2 or 51.6% of total terrestrial and aquatic mangrove habitat in the region for long-term conservation.

4.9. Conservation actions[1,22,28,32]

To preserve the Bengal tiger population in the region, the establishment of STR stands out as a crucial initiative in 1973 followed by creation of six tiger-bearing PAs in the region.

Thereafter, a series of preventive measures have been taken against the man-tiger conflict in the Indian Sundarbans. These are enlisted below:

(a) Digging of freshwater ponds began in 1975.
(b) Issuance of permit for collection of *Phoenix* and *Nypa* was discontinued in 1980.
(c) Electrified dummies and human face masks made of rubber were introduced in 1983 and 1987 respectively, but discontinued in 1990.
(d) Fiberglass headgear was introduced with reintroduction of dummies and face masks in 1994.
(e) Clay models of the fishermen, woodcutters and honey-collectors were set up at Netidhopani, Pirkhali, Panchamukhani and Jhilla forest blocks, which were wrapped with energisers, charged to 230 volts by a 12 volt battery source.
(f) Tiger guards were given to the field staff.

4.10. Compensation

An *ex gratia* compensation is paid by the government for every family, a member of which entered the forest in the buffer zone with a valid permit and attacked by a tiger; but for death in the prohibited core area no compensation is paid. In 2016, it appeared that out of 100 fishermen killed due to tiger attacks in the past six years, only five families applied for compensation, of which only three actually received it. The COVID-19 pandemic and disruptions of other livelihood options led the desperate fringe people to enter the core area, often illegally. As other avenues of income dwindled between 2020 and 2022, over 30 people were reportedly attacked by tigers and most of them were located in the core areas.

4.11. Anti-poaching measures

Now, the authorities have implemented a range of measures, including anti-poaching patrols, Tiger Response Teams, satellite installation and monitoring of tigers to know their roaming areas, resolve the human-tiger conflict by constructing nylon fencing, habitat management, and community engagement, aimed at safeguarding the tiger population. Some of the important actions are detailed below.

(1) Land-based and floating protection camps

In STR, there are 21 land-based anti-poaching and five floating camps, where all members of the camp stay in a boat and use another boat for patrolling through narrow creeks within the islands. There are limitations of shortage of staff. In Bangladesh Sundarbans too, there are a total of 17 stations and 61 running patrolling camps across the four ranges: Sarankhola, Chandpai, Khulna and Satkhira. As the patrolling camps

are run by two to three staff each, it is becoming tougher for the Forest Department to guard the entire area regularly and protect forest resources. For acute manpower shortage, the rackets of smugglers and poachers are easily carrying out their crimes. As the forest guards play the key role to protect the Sundarbans' resources, the manpower must be increased to make it sufficient.

(2) Use of specially designed application for patrolling

Different field camps are involved in electronic data collection related to the following on a day-to-day basis:

(i) Tiger sighting and direct and indirect evidence.
(ii) Other wildlife sightings and indirect evidence.
(iii) Protection related data.
(iv) In 2015 E-patrol/Smart patrolling was introduced in STR and SRF. In this new system, every camp has been given a cell phone having an android operating system with a compatible mobile application installed in it for monitoring and patrolling purposes. With the help of this application, the frontline staff are recording every possible activity like patrolling, monitoring the condition of fences, night patrolling, offence detections, and wildlife sightings.

(3) Use of unmanned aerial vehicle (UAV)

UAV or drone outfitted with a camera has been introduced as a part of the Smart Patrolling initiative in the Sundarbans. With the help of drones or unmanned aerial vehicle (UAV) outfitted with GPS device and hi-resolution cameras, sitting at one point, scanning a forest area of 15–20 km^2 is done along with tracking the movements of animals or entry of poachers, timber mafias or illegal fishers with limited staff. These have proven a remarkably useful tool in patrolling those areas in STR which are otherwise inaccessible. This tool has also proven useful in case of locating a stray animal in a locality, especially a tiger. UAV are also being used to monitor a post-released animal in the wild up to considerable distance inside the forest.

4.12. Radio telemetry

4.12.1. Indian Sundarbans

The details of radio-collaring are given below (**Table 15**).

Table 15. Records of radio-collaring in STR.

SN	Date	Sex	Trapped at	Released at	Collar	Territory	Remarks
1	5 December 2007	♀	Panchamukhani-3	Panchamukhani 3	GPS	35–42 km^2	Functional four months 8 April
2	24 February 2010	♀	Pirkhali-2 to Sonagaon	Netidhopani-2, 65 km away	Satellite	80 km linear distance	Functional 1.5 months 9 April
3	28 February 2010	♀	Pirkhali-5	Pirkhali-7	Satellite	5 km^2	Functional 11 days 1–10 March 2010
4	20 March 2010	♂	Netidhopani-1	Pirkhali-7	Satellite	30 km^2	Functional 21 March–6 April 2010
5	22 May 2010	♂	Jhilla-3 to Kalidaspur	Khatuajhuri-1	Satellite	70 km linear distance	Functional 2.5 months at Talpatti, Bangladesh
6	22 May 2010	♂	Netidhopani-1	Netidhopani-1	Satellite	30 km^2	>4 months till 2 October 2010
7	30 September 2010	♀	Netidhopani-1	Netidhopani-1	GPS	Same tiger at 6 above	>2 months till 15 December 2010
8	15 August 2014	♀	Pirkhali-1	Netidhopani-1	GPS+ Satellite	100 km linear distance	-
9	29 January 2016	♀	Bali Khal; Tridibnagar	Chora Mayadwip Khal, Gosaba-3	GPS+ Satellite	-	-
10	25 January 2017	♀	Kishorimohan-pur	Ajmalmari near Boni camp	GPS-Satellite	-	-

The tigers often prowl on either side of the Raimangal river. A male tiger, radio-collared in end December 2020, travelled from STR all the way to the Bangladesh part of the mangroves, a journey of about 100 km in over four months. In the course of its long journey, the big cat even crossed a few rivers, some of them wider than a kilometre. It was captured from Haribhanga forest, just opposite the Harikhali camp under Basirhat range, and later released with the satellite collar on 27 December 2020. After initial movements for a few days on the Indian side, it started venturing into the Talpatti island in Bangladesh Sundarbans and crossed rivers such as Choto Harikhali, Boro Harikhali and even the Raimangal. In over four months from 27 Decamber 2020 to 11 May 2021, when the radio collar stopped giving signals, the tiger moved across three islands: Haribhanga and Khatuajhuri in the Indian Sundarbans, and Talpatti island in the Bangladesh Sundarbans, and mostly stayed in the Bangladesh Sundarbans, and did not even come close to human habitats. The last recorded location of the tiger on 11 May was at Talpatti island in Bangladesh.

In January 2017, a tigress was radio-collared and released in the south 24-Parganas division, the buffer area of the forest. This tiger, too, travelled a linear distance of over 100 km in four months to reach the tip of the Bay of Bengal before finally settling in its territory. Before that, five other tigers, one of which had also ventured into Bangladesh's Talpatti island, were also radio-collared in the Indian Sundarbans. The gadget also had a mortality sensor, which gives signals in case of the tiger's death. But neither that signal nor any static signal from the collar was received, which points that the tiger is safe. In all probability, the collar has slipped off its neck. In the Sundarbans, salinity in the water can also damage radio collars.

4.12.2. Bangladesh Sundarbans

As pointed out by Barlow[33], in the Bangladesh Sundarbans, a female tiger, occupying a home range of 10–14 km^2, moves on average 1.65–1.72 km/day with a maximum of 10–11.3 km/day. Distances moved include traversing both terrestrial habitat and waterways; a SRF female tiger crossed a *khal* 10–15 times/month (equivalent to one crossing every two to three days). This frequent rate of waterway crossing suggests that a monitoring survey, based on track counts along creek banks, would have a high chance of detecting tiger presence.

4.13. Electronic microchip

Electronic microchip was introduced to track tigers that repeatedly stray into human settlements. Since July 2009, some of the strayed tigers in STR were ear-tagged with microchips. In the first case, a pregnant tigress, who was unable to catch prey in the forests, had entered Adivasipara on Kumirmari Island and, opportunistically, killed some livestock. It was caught, examined and tagged with a microchip placed at the base of her tail before release. Her microchip code was 001 and she returned. Then she was captured for the second time and then released. Her first straying took place in July and barely two months later, she returned. After killing a cow and a pig over a week she walked into a trap in Rajat Jubilee village on Satjelia Island. To ensure that she didn't stage a repeat comeback, she was released in Kalash Island in Dhulibhasani at the estuary of the river Matla, about 74.08 km away from where she had been trapped. But hunger might have driven her back to human habitation again, as did a tiger a few years ago, three times over, before he was permanently placed behind the bars in the Alipore Zoo, Kolkata.

4.14. Nylon-net fencing

Nylon net fences have been raised in all the tiger straying sensitive areas of Indian Sundarban. A stretch of 96 km was covered in STR-21 km in NP (west), 35 km in Sajnekhali WLS and 40 km in Basirhat ranges. Now this fencing has been extended by 10 km. The 24-Parganas (south) FD currently manages a 65 km area where a nylon net fence has been erected. It is found to play an important role in preventing the straying out of tigers into village's areas from forest. However, due to tidal rhythm and creeks, the maintenance of nylon

net fences is difficult. Tiger, an intelligent predator, is also adapting fast to overcome the barriers. Cases of chewing of nylon-net fences by tigers to create holes, jumping and swimming over the fences during high tides in creeks have been recorded.

A protocol for maintenance of the nylon-net fencing has been designed with an aim of carrying out thorough checking and proper maintenance. The protocol includes involvement of local stakeholders in FPC/EDC members also along with forest staff. In addition, the primary response team (PRT) members are also voluntarily involved with the local Forest Department staff for fence-patrolling and maintenance on a regular basis.

Now Bangladesh plans to fence 60 km of Sundarbans as human-tiger conflicts surge during 2023–2024.

4.15. Provision for sweet water

For the wild animals 43 sweet water ponds have been dug in STR near the camps and many other areas away from the camp. However, it appeared that the poachers used these remote areas for hunting. So, to prevent this, a conscious decision was made by the management to close the water holes which were away from the camps.

The tiger has adapted to drinking waters of the saline creeks, yet the sweet water is an attraction and preferred to the saline water as evident from the pugmarks found near the water holes dug artificially all over the forests

4.16. Community-based voluntary village tiger response teams (VTRTs)

An initiative was taken to build a VTR team, who will instantly respond to any kind of human-tiger conflict incidents inside the village and keep the role as primary manager. The first team was established in 2007 in the Chandpai range of Bangladesh Sundarbans. At that time only two such teams were formed in that area because of the high frequency of tiger straying incidents. Those two teams immediately got accepted by the local people by showing their capability of handling conflict incidents in their area. The success story of the two groups was used to motivate people in other villages to establish other such groups. By 2010, 29 teams were established in the villages adjacent to Sundarbans area, and by the end of 2012 a total of 49 teams were established covering 80% of the border villages in four ranges of Sundarbans. Currently, VTRTs have 340 members including 20 women.

From 2007 to 2018, VTRTs successfully facilitated to rescue and set free three tigers, and more than 349 other wild animals (deer, wild boar, fishing cat, python, crocodiles, turtle, otter, bird, monkey, Bengal monitor, water monitor, wild fox etc.). They effectively managed 30 tiger straying incidents and sent them back to the forest, conducted 140 patrolling inside villages, and recovered 27 dead bodies of tiger victims. They also provided emergency first-aid to seven people injured for tiger attacks, and conducted a total of 2949 village meetings to raise awareness for conflict management. Apart from that, VTRTs helped the Forest Department and firefighters to manage 12 fire incidents in the Bangladesh Sundarbans. India's rapid response team (RRT) assisted the FD to rescue an adult male tiger strayed into Kultali village near Garankanthi forests of western Sundarbans on 23 December 2021. The tiger was tranquilized and translocated to the Bonnie Forest camp using the RRT's boat and after a day's monitoring, it was finally released in Dhulibhasani block of Ramganga range.

4.17. Protection of aquatic corridors

The constant movement of boats acts as a potential barrier to the isolated tiger's dispersal between the islands within Sundarban. The cargo movement through the mangrove forests of Sundarbans has been

stopped on the Indian side since 2011. Now, the ships and barges take alternate water routes, avoiding the Indian Sundarbans, to reach Bangladesh. But such a movement continues in the Bangladesh part.

The Wildlife Institute of India (WII) in a study report (2018) recommended that India and Bangladesh should carefully use the water-channels in the Sundarbans in a bid not to disturb the free movement of tigers between the two countries, which may ultimately affect their gene flow.

Despite efforts by Forest Departments of both the countries, joint patrolling and joint management activities remain a non-starter. Boat traffic during the active phase of the tiger's aquatic movement needs to be controlled.

4.18. Joint forest management (JFM)

Whereas up to 1998, 10 forest protection committees (FPCs) and 12 eco-development committees (EDCs) consisting of 10,000 families have been formed in STR and 21 FPCs consisting of 8300 families in undivided 24-Parganas Forest Division. At present, 51 FPCs and 14 EDCs have been registered in SBR. It appears that in STR, 8548 families of 14 EDCs and 11 FPCs protect about 252 km^2 of forests, falling under WLS and RFs (buffer area). In 24-Parganas (South) Division, 40 FPCs composed of 26,519 families protect about 390 km^2 of forests.

Prior to the 1990s and in the 1990s due to the frequent problem of tiger straying into the villages adjacent to TR, and the problem of cattle-lifting by the strayed tigers, many tigers were killed by the villagers. After implementation of JFM in Sundarban, human-wildlife (mainly tiger) conflicts have been reduced considerably in the villages. Formation of FPCs and EDCs as well as women self-help groups definitely helped curb the retaliatory killings of tigers by the fringe villagers and it also helped spread awareness among the people regarding the conservation of tigers. Rather than killing the straying tiger, villagers are driving it back into the forest by brandishing flaming torches and setting off firecrackers. If this fails, they call the nearest forest office to get a swat team on the ground with a tranquilliser to sedate the tiger so that it can be released back to the forest. FPCs and EDCs not only helped save the straying tigers, capture and release them in the wild, but also many other straying animals, even during the flash floods due to cyclones.

EDCs around TR are also eligible for 25% of the total revenues earned from tourism, which is then used for development works in the villages. The participants derive direct benefits from sustainable use of forest resources. Numerous eco-development works like construction of jetties, brick paths, solar lighting, providing alternative livelihood support, skill development, plantation etc. has been benefitting the communities in great ways. But it has been alleged that manipulation, corruption, etc. by the village elites and politicization of JFM benefits are depriving the real needy and deserving villagers from enjoying the usufructs.

4.19. Border security force (BSF)

BSF guards the nearly 300 km riverine border with Bangladesh in Sundarbans. It patrols amid the dense mangrove forests or where the rivers meet the Bay of Bengal. Border guards on a fast patrol boat in the estuarine areas. A floating BOP (Border Outpost) stands guard past the last land BOP in Shamshernagar, North 24-Parganas. BSF has three floating BOPs deployed along the border with Bangladesh in the Sundarbans.

5. Conclusion

Though the mangrove forest of the Sundarbans is considered as vulnerable to endangered under Red List of Ecosystems driven by historical clearing and diminishing wildlife populations, there is cause for 'cautious future optimism' since:

(i) the trend of historically high rates of mangrove clearing and degradation has since slowed down; and,

(ii) tiger population in the Sundarban mangroves has slightly increased and is stable. Of late, tigers have been spotted at certain locations where they were not seen before. The increase in density and abundance of tigers can be attributed to some positive improvements of tiger habitat management. Specially, SMART patrol has restrained some illegal resource collectors and poachers leading to the improvements of tiger's status.

There lies the necessity of increasing the notified core areas to prevent man-animal conflict. In order to intensify tiger management in the mangrove landscape, STR is likely to be expanded by about 1000 km^2, as proposed by the Forest Department, by merging three more forest ranges, namely Matla, Raidighi, and Ramganga under 24-Parganas (South) Division to STR, provided formal clearance from NTCA is received. According to All India Tiger Estimation 2022, this proposed extended area comprises roughly 30 tigers. Once STR gets expanded from 2585 km^2 to about 3600 km^2, the habitat would become the largest one in India.

Further increase of tiger population in the greater Sundarbans may not be impossible in future if the habitats are adequately protected by filling up of the vacant posts because in Bangladesh Sundarbans protection and preservation was being hampered due to the Forest Department's shortage of manpower and logistics with 344 out 1172 posts lying vacant in 2018. As a result, there was only one guard for every nine km^2 of the forest. Thus, the Forest Department's activities in the Sundarbans, including averting smuggling of forest resources and poaching, are being severely hindered. Even sometimes the boatmen have to play the role of forest guards. The vacancies are being increased with the retirement of the existing staff. In Indian Sundarbans, about 50% of posts are lying vacant.

It is important that the trans-boundary tiger population is managed as a single population through joint patrolling. To evaluate the situation in its entirety, extensive monitoring on spatial as well as temporal scale is needed. To preserve the ecological integrity of the area, cross-border collaboration and knowledge exchange between India and Bangladesh are imperative.

To UNESCO, the future of the Sundarbans lies in "biodiversity, aesthetic values and integrity" and management of ecological balances challenged by development works and anthropogenic activities.

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Conflict of interest

The author declares no conflict of interest.

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