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LETTER

Sea level rise and tigers: predicted impacts to Bangladesh's Sundarbans mangroves

A letter

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Abstract The Sundarbans mangrove ecosystem, shared by India and Bangladesh, is recognized as a global priority for biodiversity conservation. Sea level rise, due to climate change, threatens the long term persistence of the Sundarbans forests and its biodiversity. Among the forests' biota is the only tiger (*Panthera tigris*) population in the world adapted for life in mangrove forests. Prior predictions on the impacts of sea level rise on the Sundarbans have been hampered by coarse elevation data in this low-lying region, where every centimeter counts. Using high resolution elevation data, we estimate that with a 28 cm rise above 2000 sea levels, remaining

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tiger habitat in Bangladesh's Sundarbans would decline by 96% and the number of breeding individuals would be reduced to less than 20. Assuming current sea level rise predictions and local conditions do not change, a 28 cm sea level rise is likely to occur in the next 50–90 years. If actions to both limit green house gas emissions and increase resilience of the Sundarbans are not initiated soon, the tigers of the Sundarbans may join the Arctic's polar bears (*Ursus maritimus*) as early victims of climate change-induced habitat loss.

1 Introduction

Tigers occupy only 7% of their historic Asian range, and only about 4,000 are estimated to be living in the wild (Dinerstein et al. 2007). In Bangladesh, they are confined to the Sundarbans, a globally important mangroves ecosystem that extends into India and represents the last stronghold of tigers adapted to living in mangrove forests (Dinerstein et al. 2007; Gopal and Chauhan 2006; IUCN 2008; Sanderson et al. 2006). The mean elevation for most of the Sundarbans is less than one meter above sea level (Canonizado and Hossain 1998). Consequently, sea level rise (SLR) poses the single greatest climate change threat to the viability the Sundarbans forests (Field 1995).

Globally, sea level has increased by 1.8 ± 0.5 mm year^{-1} from 1961 to 2003, but 3.1 ± 0.7 mm year^{-1} from 1993 to 2003 (Bindoff et al. 2007). SLR is also related to a number of regional processes that may contribute to sea level changes different from the global average. These include geological processes (e.g., geological subsidence), drainage and withdrawal of water, oil and gas (Ko and Day 2004; Morton et al. 2002) and sedimentation (Broadus 1993). Using tidal gauge records, researchers at the SAARC Meteorology Research Centre (SMRC) in Dhaka, Bangladesh found an increasing east–west trend of 4 mm–7.8 mm year^{-1} rise in sea levelfor the Sundarbans from 1977 to 1998 (Alam 2003; SMRC 2003), which is greater than the average global SLR estimate during the same period.

Global and regional projections of the future rate of SLR also vary. Bindoff et al. (2007) predict that sea level will rise by 4 mm year^{-1}, with estimates of global SLR ranging between 0.22 and 0.42 ± 0.15 m by the mid 2090s. However, more recent global projections suggest that the rate of SLR is greater than previously thought and that sea levels are likely to rise in excess of one meter by 2100 (Hansen 2007; Pfeffer et al. 2008; Rahmstorf 2007). Regionally, estimates range from 0.3 to 0.5 m by 2050 (Government of Bangladesh 1993, 2005) and 0.3–1.0 m by 2100 (Agrawala et al. 2003; Government of Bangladesh 2005).

Most predictions on the impacts of sea level rise on the Sundarbans have used relatively coarse (>1 m vertical accuracy) elevation data (Dasgupta et al. 2007; Sarwar 2005; World Bank 2000). Using scale-appropriate elevation data, our study assesses the potential impact of SLR on Bangladesh's Sundarbans tiger population. We find that the Sundarbans, and its biodiversity, may be vulnerable to much lower increases in sea level than previously thought.

2 Materials and methods

We use a new sub-meter digital elevation model (DEM), with eight estimates of SLR to predict effects on tiger habitat and population size. To create our continuous

DEM we imported 80,584 GPS elevation points—measured in mm above sea level—into a GIS. The point data was initially collected by FINNMAP, a Finnish consulting firm, in 1991 for the Government of Bangladesh. We used a radial basis interpolation function which forces the elevation surface to go through each input elevation point. We used 4 mm year^{-1} as a conservative estimate of annual SLR upon which to predict potential impacts to tiger habitat and assumed 10 km^2 as the minimum habitat patch size and 5 km as the maximum dispersal distance. For each of the eight SLR time steps we identified year 2000 land area that would fall below the rising elevation of the sea. To assess the potential range of tiger population for each time step, we combined three classes of relative tiger abundance (Barlow et al. 2008) with two sets of three potential female tiger home range sizes, based on local telemetry of females ($n = 2$) and a literature review of home range sizes in other habitats. We derived two estimates of total breeding female population, which we merged with two estimates of male:female sex ratios to derive four estimates of total adult tiger populations at each SLR time step (see Supplementary Information for additional details on methods).

3 Results

Both tiger habitat (Table 1, Fig. 1) and tiger populations (Fig. 2) in the Bangladeshi Sundarbans will likely reach a critical threshold at SLR between 24 and 28 cm above the year 2000 baseline; beyond 28 cm Sundarbans tiger populations are unlikely to remain viable. Prior research on tiger population viability has shown that the ability of a population to persist as the number of breeding individuals goes from 50 to 25 declines in a non-linear manner, given stochastic, demographic, genetic, and environmental events (Chapron et al. 2008; Kenny et al. 1995). At a 28 cm rise in sea level, total estimated remaining habitat is 3.8% of the baseline, fragmented into five patches, and all models estimate total adult tiger populations at less than 20 (range = 5–19; Fig. 2b). Furthermore, the current protected area system—encompassing approximately 900 km^2 (22%) of the year 2000 land area

Table 1 Remaining tiger habitat associated with increasing sea levels

Sea level rise (cm) (baseline is year 2000)	High tiger abundance habitat (km^2)	Medium tiger abundance habitat (km^2)	Low tiger abundance habitat (km^2)	Total tiger habitat (km^2)
0	574	1,445	2,155	4,175
4	574	1,442	2,153	4,169
8	551	1,352	2,117	4,021
12	527	1,229	1,941	3,697
16	458	1,011	1,477	2,946
20	309	622	840	1,771
24	142	236	296	674
28	37	74	48	159

Total tiger habitat is separated into high, medium and low relative tiger abundance categories (Barlow et al. 2008)

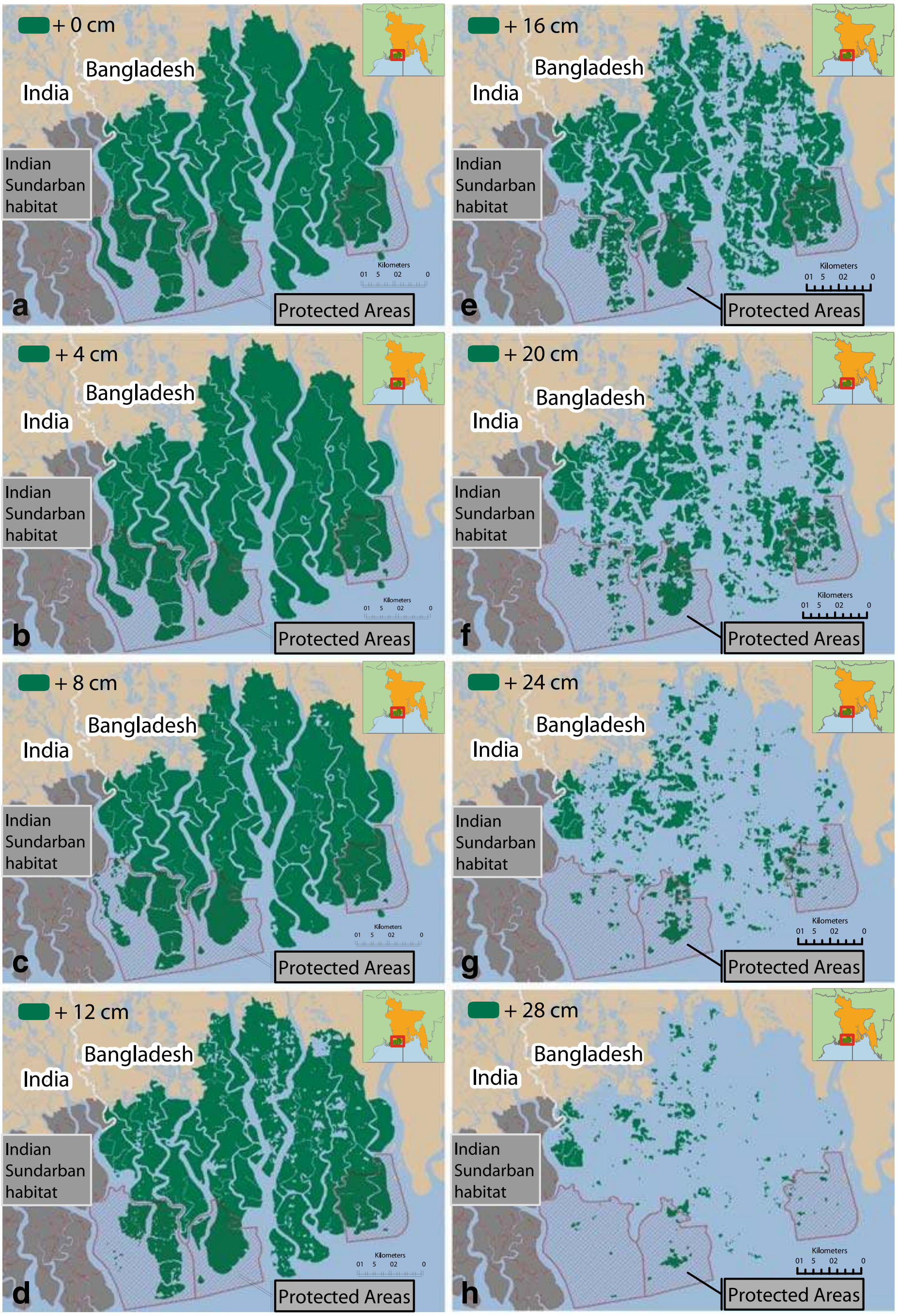

Fig. 1 Predicted tiger habitat loss in the Bangladeshi Sundarbans under increasing sea levels. Sea level is shown for eight elevations (year 2000 is baseline). The land area that lies above the predicted sea level is shown in *green*. SLR impacts are only shown for the Sundarbans, and not the surrounding land area

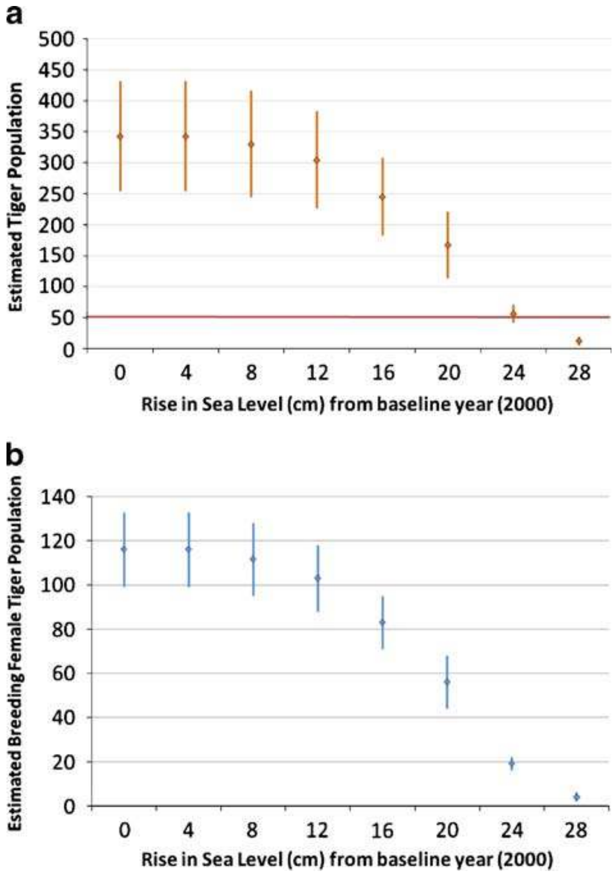

Fig. 2 Adult tiger population estimates with associated increasing sea levels. **a** Female breeding tiger population, showing mean, minimum and maximum estimates; **b** Total adult resident tiger population showing mean, minimum and maximum estimates. *Red line* indicates level at which the ability of a population to persist declines in a non-linear manner (Kenny et al. 1995)

and classified as a UNESCO World Heritage Site—is rendered largely ineffective in protecting tiger habitat at sea levels greater than 28 cm (Fig. 1).

4 Discussion

How much time do these tigers have? Using a conservative rate of 4 cm per decade increase, which is consistent with the 4th IPCC report on sea level rise (Bindoff et al. 2007) and local tidal gauge records (SMRC 2003), we predict the Sundarbans will realize a 28 cm increase in sea level around 2070. Using high and low SLR estimates from IPCC model projections bounds this prediction to between 2060 and 2100 (Bindoff et al. 2007). The protected area system, which is located on the seaward side of the Sundarbans, loses habitat at generally the same rate as the rest of the Sundarbans (Fig. 1). While there is wide variation in predictions of sea level rise, we structured our analysis to focus on the height in which a rise in sea level would greatly reduce tiger persistence beyond 50 years, not the year in which it is likely to happen.

The benefit of this approach is that our findings can be revised if sea level rises faster or slower than predicted.

Like any prediction of the future, ours must be interpreted with caution. We did not assess the Indian portion of the Sundarbans because of data limitations. It may be possible that together the Indian and Bangladesh portions of the Sundarbans could continue to act as a single meta-population, increasing the number of total breeding individuals and extending the viability of the populations beyond the predictions presented here. Furthermore, we did not incorporate potential effects of geological processes, drainage, withdrawal of water, and sedimentation; factors which may reduce or increase the level of permanent inundation. There is also some evidence to suggest that the Bangladesh coast, including the Sundarbans, is currently growing in land mass through sediment accretion (Inman 2009). We were unable to ascertain whether the mangroves would be able to adapt to the pace of changing bio-physical conditions, including rising seas. Lastly, our study assumes that once the sea level rises above the land in the Sundarbans that this will no longer be potential habitat. There may likely be a time lag from inundation to non-use of the area by tigers or their prey.

The Sundarbans and its biodiversity is critical to the survival of millions of Bangladeshis (and Indians) who share the coast and benefit from the ecosystem services (e.g. protection from cyclones, food and building supplies, fisheries, and carbon cycling) (Alley et al. 2007; Biswas et al. 2008; Iftekhar and Islam 2004) the Sundarbans provide (Agrawala et al. 2003; Islam and Haque 2004). As such, strategies to conserve the Sundarbans must begin as soon as possible (Government of Bangladesh 2008). Potential adaptation activities to conserve tigers need to focus on conserving both their mangrove refuge and the prey on which they depend. Globally, action should include limits on carbon emissions to slow climatic change. Regionally, potential adaptation activities should focus on better coordination among neighboring countries to identify mechanisms that would increase sediment delivery and freshwater flows to the coastal region to support agriculture and replenishment of land (Agrawala et al. 2003; Government of Bangladesh 2008). Locally, management activities that conserve habitat or limit threats include building dykes, developing and planting mangroves that can adapt to the rising seas and changing salinity, and limiting poaching or retaliatory killing of tigers and their prey.

Mangrove ecosystems have a natural resiliency that enables them to succeed in the dynamic interface between land and sea (McLeod and Salm 2006). However, due to a number of natural and anthropogenic factors, the Sundarbans may not be able to keep up with the current rate of sea level rise, which is predicted to increase (Rahmstorf 2007). While tigers are a highly adaptable species, thriving in the snows of Russia to the tropical forests of Indonesia, the Sundarbans ecosystem has become an isolated refuge, boxed in by humans and the sea. Although there is considerable uncertainty regarding the degree of future habitat loss due to SLR, it is still imperative to act now to mitigate the potential habitat loss. If we fail to act globally, regionally, and locally to conserve the Sundarbans, our collective inaction may result in the tiger joining the polar bear (*Ursus maritimus*) as early victims of climate-change induced habitat loss.

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