

**Strategy for Adapting to Climate Change and Conserving Biodiversity in the  
Bangladesh Sundarbans**

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## **1. Introduction**

The Sundarbans region in Bangladesh and India is plagued with severe climate-related problems and doubts have been raised about the wisdom of pursuing a "business as usual" strategy for development. Data and analyses were needed to support identification of an improved strategy and to reduce the vulnerability of inhabitants and manage threats to biodiversity. Therefore a series of studies were conducted as part of an effort to answer the following question: what strategy could the Government of Bangladesh consider in order to enhance the security of inhabitants of the Bangladesh "Sundarbans Impact Zone" and conserve the biodiversity of the Sundarbans mangrove forest? This paper answers the question by laying out a strategy based on a synthesis of data and analyses from a team of social and natural scientists and engineers.

This section introduces the portion of the Sundarbans region that lies in Bangladesh, the area that is the subject of this paper. The next section frames the region's climate-related challenges by synthesizing relevant research concerning changes in sea level and biodiversity; commonly-made (but highly uncertain) assertions about increases in cyclonic storm intensity are mentioned for completeness. This is followed by a discussion of how a proposed strategy for responding to the challenges in the Sundarbans was created. Subsequent sections of the paper highlight elements of the strategy.

The Sundarbans region, which is formed by the Ganges, Brahmaputra and Meghna rivers, contains what is arguably the world's largest remaining mangrove forest and is known for its exceptional biodiversity. The Bangladesh Sundarbans was designated as a UNESCO World Heritage site in 1987. It is located entirely within Khulna, one of Bangladesh's seven divisions, and includes a complex network of waterways, mudflats and islands. The area consists of the Sundarbans Reserve Forest (SRF) and the Sundarbans Impact Zone (SIZ), defined as the region within 20 km of the SRF boundary (see Figure 1

[INSERT FIGURE 1 HERE] Sundarbans General Location Map).

The SIZ is characterized by its agricultural, fishing and aquaculture activities and it contains the major deep water port of Mongla.

The region landward of the SIZ was reclaimed from its original mangrove cover and is now a productive agricultural area with a high population density and several major towns, including Khulna (the largest). The SRF, the SIZ, and much of the area landwards of the SIZ lies below 2m MSL. This land is either actually or, if protected by embankments, potentially inundated by normal high tides. The region faces a number of pressing challenges linked to: rising sea level, reduced freshwater inflows, increased soil and water salinization, water logging, habitat loss, and embankment breaching and overtopping (Adri and Islam, 2012; Iftekhhar, 2006; Sarwar and Islam, 2013).

The Sundarbans contains a natural forest surrounded almost completely on the landward side by polders; i.e., enclosed areas of land reclaimed by constructing embankments. The tidal

range is about 4 m, and at highest tide the water levels are typically less than a meter from the tops of embankments. During periods of high waves or storm surges, embankments are regularly breached or overtopped and polders are flooded. Over 2.5 million people live in the SIZ and secure their livelihoods by relying mainly on subsistence agriculture, fishing, and some shrimp farming-related activities. Many residents face material poverty in multiple dimensions: poor health and education, limited employment opportunities, and economic gains threatened by cyclonic storms and associated floods.

For residents of the Bangladesh Sundarbans, the changes in global climate are felt most dramatically in the form of sea level rise, particularly the increased dangers of flooding linked to increases in high water maxima. For them, problems related to climate change are part of their day-to-day reality. When anthropogenic changes in biodiversity are added to challenges linked to sea level rise and flooding exacerbated by anthropogenic interventions, the situation of Sundarbans residents is dire by any measure.

## **2. Climate and Biodiversity Changes in the Sundarbans**

### ***2.1 Sea Level Rise***

The coastal zone containing the Bangladesh Sundarbans is increasingly at risk of flooding. The area's elevation has been reported to be from 0.27 to 0.64 meters above mean sea level (Iftekhar and Islam, 2004). Partly as a result of the region's low-lying terrain and the shallowness of the Bay of Bengal, the Sundarbans is very vulnerable to storm surges associated with tropical cyclones (Islam and Peterson, 2009).

Sea level rise (SLR) is making the potential for flooding worse. Pethick and Orford (2013) analyzed factors contributing to sea level rise at the location of three tide gauges in the Pussur Estuary in Southwest Bangladesh: Hiron Point, in the SRF at the mouth of the Pussur Estuary; Mongla, a port located between the SRF and the SIZ; and Khulna, which is within the heavily populated SIZ. As reported by Pethick and Orford (2013), most published sources put the rise in sea level for Bangladesh at between  $3 \text{ mm yr}^{-1}$  and  $6 \text{ mm yr}^{-1}$ . However, these figures do not reflect high water conditions. In terms of flood risk, the changes in high water levels, not average levels, are the ones that matter.

Given that increases in relative mean sea level are not the key to analyzing flood hazard, Pethick and Orford (2013) introduce a parameter, Effective Sea Level Rise (ESLR), which reflects changes in high water maxima. They used the region's limited available tide data to measure the contributions of four component causes of ESLR in the Bangladesh Sundarbans: eustatic (or global) sea-level rise; land subsidence; reductions in fresh water flow; and changes in tidal range (i.e., the vertical difference in height between consecutive high and low tides). Pethick and Orford assumed provisionally (pending the collection of additional field data on subsidence rates) that "contribution made to tidal range amplification by changes in high water level is approximately the same as those made by changes in low water level and can be simulated using the tidal amplitude" (p. 243).

Pethick and Orford use available data to estimate each of the four components of ESLR [e.g., they use data from Cazenave, Lombard and Llovel (2008) to estimate eustatic sea level rise as  $2.0 \text{ mm yr}^{-1}$ ]. Of the four components, changes in tidal amplitude account for approximately 57% (on average) of the ESLR in the Pussur Estuary. Pethick and Orford argue that the probable

causes of amplification of the tidal range include construction of embankments, which constrict tidal channels, and dredging, which deepen tidal channels.

Based on data from the three gauging stations, Pethick and Orford estimated that high water levels (as measured by ESLR) are rising at an average rate of  $14.1 \text{ mm yr}^{-1}$  across the three gauges. The highest ESLR value,  $17.2 \text{ mm yr}^{-1}$ , occurs at Khulna, which is troublesome given that Khulna is within the densely populated SIZ. Thus the estimate of  $17.2 \text{ mm yr}^{-1}$  of rise in high tide is the important value to consider in terms of flood risk.

To put this  $17.2 \text{ mm yr}^{-1}$  of ESLR in perspective, consider projections in the report of Working Group I for the 5th Assessment Report of the UN Intergovernmental Panel on Climate Change (Church et al., 2013). Depending on the scenario selected, the ranges for the period from 2081 to 2100 presented by the IPCC for global SLR go as high as  $8$  to  $16 \text{ mm yr}^{-1}$  (Church et al., 2013, p. 1140). Thus, effective sea level rise in the Sundarbans is *already* rising at a faster rate ( $17.2 \text{ mm yr}^{-1}$ ) than the maximum global SLR predicted by IPCC 5th Assessment for 2100. The global component is *additive* with changes caused by local factors -- land subsidence, reductions in fresh water flows, and changes in tidal amplitude. Considering both global and local factors, the resulting ESLR values (which provide estimates of high water levels) provide alarming threats to both the integrity of embankments and the safety of the SIZ population. These findings are based on tide-gauge records that are the only ones available for the entire Sundarbans. However, the records “are far from ideal, lacking overall consistency and, in the case of Mongla, of short duration” (Pethick and Orford, 2013, p. 238). Given these circumstances, the findings should be verified and further examined as additional and more reliable data becomes available.

## 2.2 *Cyclonic Storms*

Research to establish relationships between climate change and the frequency and intensity of tropical cyclones has been conducted, but many uncertainties exist and results have not been definitive. We recognize the absence of confidence in the projections, but to give a sense of claims made by others we include a few of them below.

A review by Knutson et al. (2010, 157) summarized the situation:

“[F]uture projections based on theory and high-resolution dynamical models consistently indicate that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms, with intensity increases of 2–11% by 2100. [They also add a caveat:] For all cyclone parameters, projected changes for individual basins show large variations between different modelling studies.”

According to Webster et al. (2005), Elsner, Kossin and Jagger (2008) and Webster (2014), the Sundarbans mangrove forest and the SIZ are susceptible to potential increases in the intensity of tropical cyclones in the North Indian Ocean. Dasgupta et al. (2010) argued that projections show storm surges associated with cyclones in Bangladesh that will reach further inland and be more damaging than those in the past. Moreover, according to an analysis of trends in storm surge heights in Bangladesh, Rana et al. (2011, 23) claim “[it can be] averred that with the increasing trend of intensity of the cyclones in a future warmer climate, higher storm surges can be expected.” That analysis cautioned that “super cyclones” will be more common in Bangladesh and the associated propensity of surge heights will be “higher and fiercer with the increase in intensity of the cyclones” (25).

Notwithstanding the above-mentioned claims, major uncertainties exist regarding the likelihood of increased frequency and/or intensity of cyclones in Bangladesh. Significantly, the IPCC 5th Assessment report (Church et al., 2013, p. 1140) indicated “*low confidence* in region-specific projections of storminess and associated storm surges.”

### 2.3 *Biodiversity*

A characteristic feature of the Sundarbans is the effect of current and tidal action in eroding edges of tidal creeks in some places and depositing sediments in others to form mudflats. The mudflats are held together by roots of trees that grow out of the water to form the mangrove forest. The flora of the Sundarbans is rich, containing about 44 percent of global mangrove species (Spalding, Kainuma and Collins, 2010). Among the fauna, the Royal Bengal tiger (*Panthera tigris*) is at the top of the ecological pyramid (Khan, 2011).

The Sundarbans has experienced notable declines in biodiversity and habitat for tigers and other wildlife as a result of: conversion of forest to other uses (historically paddy fields and more recently shrimp farms); unsustainable exploitation of timber resources and fauna (particularly shrimp fry collection to supply shrimp farms); alterations of the hydrological regime through polder construction and interventions that cut freshwater flows (e.g., the Farakka Barrage in India); and changes in the salinity regime, with saline waters moving further inland (Iftekhar, 2006; Giri, Pengra, Zhu, Singh and Tieszen, 2007; Islam and Gnauck, 2011a and 2011b). Discharges of domestic and industrial wastewater into surface waters have also been damaging (Ahmad et al., 2010). (Figure 2

[INSERT FIGURE 2 HERE] Sundarbans Landsat 8 Image from March 2014).



The Landsat image in Figure 2 shows the encroachment by land conversions (pink areas) on the Sundarbans mangrove forest in both India and Bangladesh.

Sea level rise poses a significant threat to habitat in the Sundarbans, as does the salinity increase that has accompanied both SLR and the diminution of freshwater flows into the delta. Salinity is a key factor affecting the mangrove ecosystem, and the Sundarbans has already experienced significant replacement of dominant mangrove species with species that can better tolerate saline conditions (Islam, 2008; Islam and Gnauck, 2011a).

Loss of mangrove has affected the Royal Bengal tiger. Habitat loss for the tiger, together with prey depletion, has led to an increase in dangerous, and often fatal, human-tiger interactions. Tiger populations are declining because of poaching as well as retribution killings following attacks on humans and livestock (Barlow, 2009).

Some argue that shrimp farming has been the most damaging contributor to mangrove destruction in the Bangladesh Sundarbans and that it has also led to losses of other biological resources, including the wild shrimp fishery (Islam and Haque, 2004). Although increased shrimp farming has provided opportunities for local residents to earn income by collecting wild shrimp larvae, the rise in collection has led to significant biodiversity loss. The stock of shrimp in the deep sea depends on the survival of juveniles who spend time in the mangrove nursery grounds. Indiscriminate collection of wild shrimp larvae has also been accompanied by high levels of by-catch of juvenile fish and crustaceans. A Government of Bangladesh (GoB) ban on wild shrimp larvae collection exists, but it has not been well enforced (Ahmed and Troell, 2010).

A practical reason for maintaining the integrity of the Sundarbans mangrove forest relates to the services it provides. Uddin (2011) estimated the economic value of those services to be almost \$43 million/year, with the vast majority (\$42 million) of economic benefits attributed to “regulatory services,” such as coastal protection. Other sources of value include approximately \$744,000 for “provisioning services” (e.g., timber, fish, thatching materials, fuel wood, crab, honey and wax), and about \$42,000 for “cultural services” in the form of tourism opportunities. The \$43 million/year figure is an underestimate because it excludes values resulting from carbon retention and sequestration, which, based on a meta-analysis by Salem and Mercer (2012), has been estimated to have annual values ranging between \$40 and \$4250 per hectare.

### **3. Rationale for the Proposed Strategy**

The remainder of the paper concerns results of a study to create a strategy for reducing risks faced by Sundarbans residents and conserving biodiversity. From 2009 to 2012, a team consisting of more than two dozen social and natural scientists and engineers gathered data and conducted analyses across a broad range of subjects (see Acknowledgements). A number of studies examined the state of particular sectors and activities: livelihoods (including aquaculture and agriculture); education; health; water and sanitation; energy; transportation; and household air pollution (from use of solid fuels). Also, a survey of 2144 households in the Sundarbans was conducted to provide a demographic and economic profile of households and information on patterns of migration in response to extreme-weather events (Ortolano, et al., 2016). Two studies dealing with weather-related hazards were conducted: one on cyclonic storm trends and another on changes in erosion and accretion in tidal channels and consequent effects on the integrity of

embankments. In addition, assessments were made of the effectiveness of existing disaster risk management systems and government subsidies for Sundarbans' residents.

In addition, workshops and consultations were held with representatives of: GoB ministries, boards and authorities (e.g., Ministry of Environment and Forests, Ministry of Water Resources, and Bangladesh Forest Department); local researchers (e.g., Institute of Water Modelling, and the Center for Environmental and Geographical Information Services, Khulna University); NGOs such as IUCN Bangladesh, Wild Team, and Shushilan; and other stakeholders. The interactions with stakeholders were used to identify issues to be addressed in individual studies and to discuss findings from the studies as they emerged. These interactions also informed creation of the proposed strategy.

The motivation for developing the proposed strategy for risk reduction and biodiversity conservation can be summarized as follows. For the more than 2.5 million people who live in the SIZ, the region has become increasingly hazardous, and high levels of material poverty have been evident for generations. By any measure, the quality of life for residents is marginal. What was a 16,700 km<sup>2</sup> forest in the 1800s has dwindled to a forest of only about 6,000 km.<sup>2</sup> For centuries, large parts of the forest have been extensively exploited for timber, fish, prawns and fodder, or converted for paddy and aquaculture. Upstream water diversions and other anthropogenic changes have adversely impacted the safety of embankments used to create polders. Although the population level has stabilized over the past decade, the region's natural resource base has faced historical pressure from population growth. This growth has been accompanied by degradation of the mangrove forest, unsustainable extraction of natural

resources, accelerating levels of pollution and the exposure of large numbers of people to significant and recurring flood risks. Agriculture is being imperiled as a result of increased salinity and water logging, and shrimp farming practices have made aquaculture unsustainable. In addition, because of reductions in animal habitat, the frequency of human-animal conflicts (particularly those involving tigers) has increased. The absence of adequate physical infrastructure (e.g., electric power and water supply) in the region also contributes to the low standards of living.

Any strategy for the Bangladesh Sundarbans must strike a balance between investing heavily in a region in which hazardous conditions are likely to worsen and respecting the freedom of Bangladeshis to choose where they live. A conventional rural development approach based on major investments to improve infrastructure and expand livelihood opportunities would likely attract migrants to the SIZ, an outcome that would expose more people to high disaster risks and inhospitable living conditions. Indeed, people living in the Sundarbans will continue to face multiple stresses, such as increasing salinity and embankment overtopping, and existing livelihood options may not be sustainable. Moreover, significant investments in transport networks and electric power in the SIZ would be economically inefficient because projected SLR is likely to make parts of the region uninhabitable in the coming decades. For these reasons, we did not consider a conventional rural development approach. We also considered but rejected a policy of relocation over a short time period. This approach was dropped because it would lead to major social disruption. A “business as usual” strategy would not address the region’s challenges and thus it was also omitted from consideration.

The strategy summarized herein rests on measures to build the economic, human and social capital of residents to migrate to relatively safe areas outside the SIZ that provide improved options for health care, education and employment. Such options exist in urban areas outside the region, but most residents have been unable to pursue them because they lack the capacity for successful out-migration. In order to buy time while the needed economic, human and social capital is being built, the study team proposed a program to improve the integrity of the embankment system and the effectiveness of the disaster risk reduction system. These measures would also reduce the risks of embankment failure and storm-related threats to human life and livestock for those who choose to remain in the SIZ.

The proposed strategy includes four elements:

- Modify embankment system and reduce disaster risk
- Incentivize out-migration and enhance capacity of SIZ residents to leave
- Conserve biodiversity
- Strengthen institutions

The first element recognizes that, while it is infeasible to eliminate exposure to hazards for SIZ residents, risks can be reduced by improving disaster risk management programs and making significant changes in the system of embankments. The second element centers on interventions to enhance the capacity of residents to migrate out of the SIZ successfully. The third element employs biological conservation as a strategy for reducing *both* hazard exposure (via ecosystem service provision) and vulnerability (by creating new revenue streams that

support building the capacity of local residents to seek improved opportunities outside the region). The final element involves reform of government agencies operating in the SRF and SIZ so that other elements of the strategy can be implemented effectively. Key components of the proposed strategy are discussed below.

#### **4. Reducing Exposure to Climate-related Hazards**

The first component of the proposed development plan emphasizes two main types of intervention to deal with climate-related disasters: short-term measures that extend Bangladesh's disaster management efforts; and a long-term program of large-scale embankment realignment.

The short-term measures are a response to problems associated with the existing disaster management system. Proposed actions include improved cyclone and flood warning systems, additional emergency shelters and a more highly coordinated decision-making scheme for emergency management.

Particular challenges exist with the emergency cyclone shelters. Notwithstanding that Bangladesh's Disaster Management Bureau estimates that 80% of residents are adequately served either through shelters or equivalent safe buildings, field visits conducted by study team members found that accessible and suitable shelters are available for far fewer than 80% of residents. Moreover, studies cited by Paul (2009) show that unless a cyclone shelter is within 1.6 km of coastal residences, it may be too far to reach during an emergency. In many circumstances, roads and tracks follow embankments in the Sundarbans, and therefore access could be blocked if embankments are destroyed or polders are flooded. In addition, the

aforementioned field visits determined that the quality of shelters is mixed, with some not meeting basic needs of women, the sick, the elderly, or those with livestock. Moreover, many structures designed to withstand only flood conditions had been damaged by wind or falling debris.

The shortfalls in the shelter system found during field visits are consistent with results of the aforementioned household survey (Ortolano, et al., 2016). About 98% of the 2144 household survey respondents indicated that they had experienced damage to their dwelling or interference with livelihood activities between 2006 and 2011 because of a cyclone, and 58.6% evacuated their homes during the event. Of those who evacuated, 25.8% went to shelters and 10.1% evacuated to schools, but 22.9% of them went to the nearest embankments or elevated roads, which are among the most exposed places during cyclonic storms. Many residents (38.4% of the surveyed households who left their homes) simply evacuated “elsewhere,” which could mean a public building, a mosque, a house of a neighbor, an open field, or a boat. Such locations are unlikely to provide safe refuge under cyclonic-storm conditions and might pose a greater hazard than the dwellings of those seeking safe shelter. Based on estimates of shelter usage from the household survey, the study team recommended constructing at least 1000 additional shelters in order to adequately serve the existing population.

The other major approach to reducing hazard exposure in the Bangladesh Sundarbans involves longer-term protection measures using embankments and other land-form changes. However, the embankment approaches currently in use are not working as planned. For example, during Cyclone Aila, Polder 15 was almost completely flooded. Moreover, as reported by

Auerbach, et al. (2015), there were several breaches in the embankment at Polder 32, and they appear to have resulted from undercutting caused by erosion. The effect of embankment construction was to cause the land elevation inside Polder 32 to be more than a meter below the elevation of adjacent land outside the polder. This difference in elevation exacerbated the devastation caused by the embankment breaches.

The work of the study team included geomorphological modeling that, while preliminary and based on the limited existing tide-gauge records, suggests that human interventions in the Sundarbans -- embankment construction, channel dredging and changes in freshwater flows -- have interrupted the natural cycle of sediment flows and channel morphology in ways that adversely impact the safety of embankments. For example, the construction of polders severed smaller creeks from tidal influence, thereby reducing flows in the larger channels. In some cases, reductions in flow due to polder construction caused rapid siltation in the larger channels, notably near Mongla Port; that has led to dredging and other attempts to remove sediments. The significance of embankment construction in disrupting the flows of sediments in the Sundarbans is also highlighted by Auerbach et al. (2015), who documented significant land elevation losses in the poldered zone since the embankment construction of the 1960s.

Projections based on models of estuary dynamics indicate that during the next half century, many tidal channels in the Bangladesh Sundarbans will widen as a result of erosion and the area will become poor in sediments (Pethick and Orford, 2013). Changes in channel shape will vary both between and within estuaries. A number of tidal channels will be deeper and many will widen to the point of undercutting existing embankments.



The results of estuary modeling conducted by study team members have implications for managing flood risks in the future. The proposed response to predicted channel widening due to erosion is a program of managed embankment realignment so that the widening channels do not cause embankment failures. In some cases, e.g., the Pussur channel, the channel widths are expected to increase by approximately 180 m on average by sometime near the end of the century, and embankments will need to be retreated by an average of 90 m on either side of the channel. Modelling outputs provide more location-specific results. In the case of estuaries where no erosion is predicted (e.g., the Sibsa), existing embankments need not be realigned. In addition, the heights of embankments will need to be raised to keep pace with changes in ESLR resulting from increased tidal amplitude and provide increased protection against frequent storm surges. Some embankment heights need to be increased in the short term, but much of the heightening can be carried out gradually as sea level rises.

The proposed strategy also includes allowance for mangrove regeneration in a 50 m wide area between existing embankments and the (new) realigned embankments. Regenerated mangrove can add to the ability of the existing mangrove forest to provide a bioshield to attenuate wind energy during cyclonic storms and thus reduce the wind-related damage to downwind land areas.

The Bangladesh Sundarbans is now sediment rich and the sediments can be used to increase embankment heights and raise the height of mudflats, among other things. But beginning sometime near the middle of the century, a shift is predicted to occur and the region will begin to experience sediment loss due to channel erosion. Under the circumstances, the

study team proposes a program to husband sediments in the near term while opportunities still exist. Techniques to husband sediments include use of tidal sedimentation ponds, rainbow pumping and trickle filtering. In addition, polders can be flooded periodically to allow sediments to deposit and raise land levels. [Information on these sediment husbandry methods is given by Colenutt (1999) and Harun and Paul (2014).] Allowing mangrove to regenerate in areas between existing and realigned embankments would also increase the trapping of suspended sediment in the intertidal zone. Landscape changes associated with sediment capture and embankment realignment will not eliminate exposure to hazards, but they can provide some breathing room while programs are put in place to provide residents with the economic, human and social capital needed to be successful by out-migrating voluntarily.

The temporary or permanent displacement of some inhabitants will be necessary to accomplish the above embankment realignment measures. In addition, embankment realignment will also involve loss of a modest fraction of the total agricultural land, and plans must be made to provide livelihood options for those displaced. This will be socially disruptive, but it is an unavoidable cost of eliminating a scenario characterized by continued breaching and overtopping of embankments. Strengthening existing embankments (e.g., using concrete facings or core construction) is not a relevant approach when embankments are undercut by eroding estuarine channels. A strategy based on realigning embankments, raising crest heights of the realigned embankments and husbanding sediments is essential for managing the impacts of sea level rise predicted by geomorphologic modeling studies.

## **5. Reducing Risk Exposure by Incentivizing Out-Migration**

As discussed in the previous section, the proposed strategy for diminishing exposure to risk relies on putting systems in place to reduce damages: improving the disaster response system, realigning embankments and regenerating mangrove. However, these measures cannot succeed by themselves and increasing numbers of SIZ residents may view permanent migration out of the SIZ as a desirable option.

We consider out-migration as an important element of a strategy to reduce the vulnerability of SIZ residents to projected hazards, but permanent out-migration from the Sundarbans is not common and therefore represents a potentially controversial strategy element. The survey of 2144 SIZ households conducted as part of the study determined that nearly 19% of surveyed households had one or more members migrate to other places following recent cyclones and/or floods, but most did so temporarily to find employment. (This finding regarding temporary migration is consistent with results reported by Gray and Mueller (2012) and Penning-Rowsell, Sultana and Thompson (2013).) Permanent out-migration is uncommon in part because SIZ residents generally lack the education and social capital to obtain attractive employment elsewhere, and they are aware of the challenges of life in urban slums (Mallick and Vogt, 2013).

Under the circumstances, what would encourage those living in the SIZ to migrate? Using the push-pull terminology of Dorigo and Tobler (1983), “push factors” relate to characteristics of one’s current location that lead to dissatisfaction. In the context of the Sundarbans, push factors include the hazardous conditions that exist now and are expected to worsen as a result of changes in climate and coastal geomorphology.

To help inform residents of the increasingly hazardous conditions in the zone, we propose use of information campaigns. In addition to describing the commonly experienced hazards (e.g., cyclones, floods and embankment failures), the information would characterize expected reductions in livelihood options: shrimp farming will be unsustainable as a result of competitive pressures and damage to aquatic systems associated with current environmentally damaging approaches to obtaining shrimp larvae; agriculture will be increasingly infeasible because of soil salinization and water logging; and tourism-related employment will be limited because the area is too fragile to sustain mass tourism. In addition, shrinking tiger habitat will lead to more frequent human-tiger incidents, which are sometimes fatal. This information can be transmitted using multiple information campaigns, including those operated through schools (Habiba, Abedin and Shaw, 2013).

We also propose a re-examination of incentives that encourage residents to remain in the SIZ even in the face of significant danger. These take the form of the government assistance and international aid agency programs that encourage Sundarbans' residents to remain in the area following major weather-related disasters. Based on a study of why so few Bangladeshis failed to migrate following severe tornados, Paul (2005) found that government provision of monetary compensation for damage caused by disasters affected decisions not to leave permanently.

“Pull factors” are attributes of other places that make them particularly appealing, such as the attractiveness of urban centers with solid prospects for employment. To take advantage of such pull factors, we propose a campaign to disseminate information on how residents could improve their options for employment, health and education by migrating to cities outside of the SIZ. This

information would highlight research showing positive effects of rural-urban migration on income in comparison to rural incomes (e.g., Young, 2013). We also propose using small subsidies to encourage out-migration by reducing financial risks associated with moving to an unknown place on a journey with uncertain outcomes. This approach has been shown to play an important role in reducing risks for poor Bangladeshis migrating to cities (Bryan, Chowdhury and Mobarak, 2013).

Recognizing the significance of building human capital, we also propose use of conditional cash transfers in the form of health and education vouchers that could be employed in cities in Bangladesh outside the SIZ. Some of the study team's household survey results suggest that this approach could be successful: 87.6% of 2144 surveyed households indicated a willingness to send all their children to Dhaka or other areas within Bangladesh for better educational opportunities in secondary schools if the government paid all expenses including fees, accommodation and food. An additional 9.9% said they would do so, but only for male children.

We do not suggest having a formal development ceiling within the SIZ. However, an implicit cap will exist in that proposed changes in livelihood options for those who remain would be limited to putting existing options on a more sustainable basis when possible. For example, aquaculture could be made more viable by improving shrimp larvae collection procedures. Moreover, development of major infrastructure would be limited to embankment realignment. Only small scale infrastructure improvement measures would be made, such as installing passive solar systems to treat drinking water for clusters of households.

The suggested proposals to encourage voluntary out-migration raise questions about where migrants might go. We anticipate that migrants would go to cities outside the SIZ that offer good opportunities for employment as well as improved healthcare for household members and educational opportunities for their children. Megacities such as Dhaka would not be the preferred option since recent research based on cross-country panel data found that migration out of agriculture into secondary cities or rural non-farm activities led to faster reductions in material poverty than migration to megacities (Christiansen and Todo, 2014). Possible destinations for SIZ migrants include secondary cities, such as Khulna. We do not recommend particular cities for migration because the development of opportunities for increased employment in urban areas will unfold over time as structural economic changes take place. GoB is pursuing an economic transformation from the primary sector (e.g., agriculture and forestry) to the manufacturing and services sectors because it sees an opportunity to establish itself as a competitive international center for manufacturing (GoB, 2012).

GoB and city governments could prepare for the anticipated increase in rural-to-urban migration by promoting rational urban land-use development as well as the needed infrastructure (particularly in transport and energy) to accommodate economic activity in the manufacturing and services sectors. Governments could also redouble their efforts to deal with the air and water pollution problems that plague many Bangladeshi cities and make improvements in delivering education and other urban services. In addition, local governments could create job training

centers as well as social networks and support systems to help integrate migrants into urban labor markets.

The proposed approaches to encouraging out-migration cannot work if in-migration increases. In-migration cannot be stopped by government edict, but it can be discouraged by disseminating information to potential migrants using the aforementioned mass education program regarding dangers associated with life in the SIZ. Potential in-migrants could be reached by information dissemination programs in locations known (via the study's household survey) to be common departure points for in-migrants.

A related dimension of the proposed strategy involves purchase of land voluntarily put up for sale by out-migrants. This land could be purchased by GoB so that it can revert to forest and be protected, either in the SRF or (depending on the location) using another designation for the conservation of forest lands. GoB could also consider gradually phasing out protection of specific polders that are in high-risk areas close to the SRF (e.g., Polder 15) since these are difficult to safeguard with embankments. Those areas could then be used to hold sediment and eventually revert to mangrove.

Complete explanations for decisions to migrate have not yet been developed by social scientists (Bryan, Chowdhury and Mobarak, 2014). Thus implementation of elements of the migration approach we suggest can be viewed as a sequence of small-scale policy experiments that will need to be designed with explicit data gathering programs to determine effectiveness. Results can be used to modify subsequent programs to influence migration decisions.

In summary, we propose incentivizing out-migration because, notwithstanding the measures to realign and raise embankments, weather-related disasters, including the overtopping of embankments, will continue to occur. Moreover, the resource base to support livelihoods is continuing to degrade as a result of salinity and waterlogging, unsustainable shrimp aquaculture practices, and reductions in tiger habitat. Thus, some residents may come to realize that the area is no longer habitable. The approach we encourage involves taking steps to make successful, voluntary out-migration a viable option.

## 6. Conserving Biodiversity

The GoB strategy for forest conservation within the Sundarbans has been to set aside three wildlife sanctuaries and instituting a temporary moratorium on commercial timber extraction from the SRF. However, this approach does not effectively reduce the incentives of residents near the SRF borders to exploit forest resources unsustainably. Moreover, the GoB strategy does not address the uncertainties associated with climate change.

Additional actions could be taken to conserve biodiversity of the SRF, and three are mentioned here as examples. The first example involves assigning property rights on forest assets and granting those rights to local communities. For instance, incentives to conserve forest resources could be established by having GoB develop unambiguous property rights on forest resources in ways that yield funds for programs (such as education vouchers) benefiting individuals living near the SRF. In addition, property rights could be associated with non-extractive use functions, such as tiger viewing by tourists and carbon sequestration, both of



which could generate revenue that could be shared with local communities. As shown by experiences in several countries (Alden Wily and Dewees, 2001; Katila, 2008), innovative schemes for forest management involving local communities can give residents of those communities incentives to become custodians of the forest.

A second illustrative intervention involves scaling up an existing co-management program: the “Integrated Protected Area Co-Management” (IPAC) approach for natural resources management and restoration in protected areas launched in Bangladesh by the USAID Office of Inspector General (2011). Community-based co-management could eventually be expanded to cover the entire SIZ and include incentives and regulations to make logging and degradation of the environment illegal. Examples of community-based natural resources management include: eco-restoration of degraded and barren mangrove areas through the planting of mangroves; and, designation of newly reclaimed areas as community reserves with well-defined benefit sharing arrangements for sustainable harvests of timber, fisheries and other resources.

A final illustration of an intervention to enhance biodiversity involves the capture of carbon values using carbon financing programs, such as the UN-REDD and voluntary carbon markets. Sustainable forestry practices provide a basis for accessing carbon financing because of their ability to prevent deforestation, thereby retaining forests for sequestering atmospheric carbon. The resulting revenues can assist in funding programs that enable Sundarbans’ residents to find more robust livelihood opportunities by migrating outside the region.

More generally, we recommend building on the recent Memorandum of Understanding between India and Bangladesh on Conservation of Sundarbans (Governments of Bangladesh and India, 2011). This agreement recognizes the Sundarbans in India and Bangladesh as a single ecosystem and provides a basis for achieving mutual gains by more extensive cooperation in a number of areas (e.g., controlling wildlife poaching, monitoring human casualties from tiger attacks and sharing forest management experience). Progress during the first few years following the agreement has been slow. A more robust implementation of the agreement could help preserve the biodiversity of the Sundarbans in both India and Bangladesh.

## **7. Strengthening Institutions**

Many agencies have responsibilities for implementing programs in the SIZ. Notwithstanding that they sometimes have overlapping responsibilities, collaboration and resource sharing has been minimal, and the performance of some agencies has been sharply criticized. For example, in halting the Sundarbans Biodiversity Conservation Project well before it was completed, the Asian Development Bank (2008) noted that “[t]he implementing agencies were either unwilling and/or unable to coordinate among themselves, resulting in poor integration of project activities.” Successful implementation of interventions noted in the previous sections can be facilitated by enhancing agency performance.

One way to motivate improved agency performance is to tie budgets to success in meeting performance targets. Under this approach, GoB agencies operating in the Sundarbans could adopt annual goals based on priorities, such as reducing vulnerability to cyclones, or enhancing the human capital of the region’s population. Progress in meeting annual goals could

be assessed and reported to GoB. Funding during the next budget cycle could then be increased for agencies achieving solid results and decreased for agencies performing poorly.

New regulatory instruments could also be introduced. For example, GoB could increase the portions of the SIZ subject to legal protection using the Coastal Zone Policy 2005. Using this Policy, GoB could create coastal zone regulations to preserve biodiversity of the Sundarbans as well as programs to promote sustainable aquaculture practices and mangrove planting in the Sundarbans.

## 8. Conclusions

The view that sea level rise resulting from future global climate change represents *the* major threat to low lying coastal areas such as the Bangladesh Sundarbans is an oversimplification. Residents of the SIZ face major challenges now, and those challenges have multiple causes, not just climate change. Examples include increased salinization and water logging, land subsidence, habitat loss, cyclonic storms and embankment overtopping. These problems occur in the context of grinding levels of material poverty and the challenges associated with global climate change.

Any strategy for the Bangladesh Sundarbans must strike a balance between investing heavily in a region in which hazardous conditions are likely to worsen and respecting the freedom of Bangladeshis to choose where they want to live. A conventional rural development approach based on major investments to improve infrastructure and expand livelihood opportunities would strike the wrong balance because it would likely attract migrants to the SIZ, an outcome that would expose more people to high disaster risks and inhospitable living

conditions. A policy involving short term relocation would be unacceptable because of violations of individual freedom. A “business as usual” approach would not address the region’s challenges.

The strategy summarized herein strikes a balance between offering incentives for voluntary out-migration and providing risk reduction measures for SIZ residents who choose to remain in the SIZ. Incentives include job training and subsidy programs (e.g., using conditional cash transfers for education and health care provided outside the SIZ) that can help build the economic, human and social capital that migrants will need to be successful. In addition, GoB and local governments can take steps to prepare for the arrival of large numbers of new migrants. In order to buy time while the needed economic, human and social capital is being built and cities prepare for an influx of SIZ migrants, the integrity of the embankment system and the effectiveness of the disaster risk reduction system could be improved. These measures would also reduce the risks of embankment failure and storm-related threats to human life and livestock for those who choose to remain in the SIZ.

Other suggested actions involve protecting (and increasing) the areal extent of the mangrove forest in order to conserve biodiversity while simultaneously providing a natural windbreak that reduces damages from cyclones. Consideration could also be given to phasing out protection for polders that are close to the SRF in locations that cannot be easily defended by embankments; those areas could be allowed to become part of the protected forest area and revert back to mangrove.

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