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The Impact of Aquatic Salinization on Fish Habitats and Poor Communities in a Changing Climate: Evidence from Southwest Coastal Bangladesh☆,☆☆,☆☆☆

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ABSTRACT

Fisheries constitute an important source of livelihoods for tens of thousands of poor people in the southwest coastal region of Bangladesh, and they supply a significant portion of protein for millions. Among the various threats fisheries in the southwest coastal region will face because of climate change, adverse impacts from increased aquatic salinity caused by sea level rise will be one of the greatest challenges. This paper investigates possible impacts of climate change on aquatic salinity, fish species habitats, and poor communities using the salinity tolerance ranges of 83 fish species consumed in the region and aquatic salinity in 27 alternative scenarios of climate change in 2050. The results provide striking evidence that projected aquatic salinization may have an especially negative impact on poor households in the region. The estimates indicate that areas with poor populations that lose species are about six times more prevalent than areas gaining species.

1. Introduction

Nearly 43.2 million people or 30% of the population of Bangladesh live in poverty. This figure includes 24.4 million extremely poor people who are not even able to meet their basic needs food expenditure. In densely populated and land scarce Bangladesh, poor households are disadvantaged with regard to land access, and many end up settling in low-lying regions close to the coast. The poverty map developed by the Bangladesh Bureau of Statistics, World Food Program and World Bank identifies a high incidence of poverty near the coast, where 11.8 million poor people are located in 19 districts (World Bank, 2014a, 2014b).

The incidence of poverty is particularly severe in the southwest coastal region, where the area is prone to tidal surges and cyclones, soil and water are saline at certain times of the year, and living conditions are harsh. According to the climate projections of the Intergovernmental Panel on Climate Change and the World Meteorological Organization, the vulnerability of coastal regions to flooding, storm surges and salinity will further increase in this century. Therefore, climate change poses a serious threat to the livelihoods of the poor in the southwest coastal region, especially because they are held back by limited mobility due to their economic circumstances, disadvantages with land access, and near-total dependence on local ecosystems for their livelihood.

Fisheries make an important contribution to the economy of the southwest coastal region (Shah et al., 2010). Marine fisheries, inland open water or capture fisheries and closed water fisheries provide an important source of livelihood for tens of thousands of poor people and supply a significant portion of their protein intake (World Bank,

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2000; Alam and Thomson, 2001; Thilsted, 2010; Thilsted, 2012; Farnandes et al., 2015). Over the years, southwest coastal region inland open water fisheries have faced increasing threats from over-exploitation of resources; indiscriminate fishing with inappropriate fishing gear; destructive fishing practices, such as the use of poisons in closed creeks or canals; increased water pollution; reduction in the freshwater flow of the river system; and intrusion of salinity. While significant threats from human actions are likely to continue in the future, the stress on fisheries in the region may be further aggravated by climate change. Among climate-related threats fisheries in this region will face,[1] one of the greatest challenges will be increased aquatic salinity from sea level rise and climate-induced changes in temperature, rainfall and riverine flows from the Himalayas (Dasgupta et al., 2014; Gain et al., 2008). These changes will adversely affect many fish species, with significant impacts on their reproductive cycles, reproductive capacities, suitable spawning areas, feeding, breeding, and longitudinal migration. Consequent adverse impacts are anticipated for the incomes of coastal inhabitants dependent on capture fishery and dietary intake of animal protein.[2] Since fishing communities are among the poorest of the poor in Bangladesh, understanding these impacts is critical for ensuring the future sustainability of fishing-dependent households.

In 2008, Gain, Uddin and Sana studied the impact of river salinity on fish diversity in the southwest coastal region near the Sundarbans. Their research area included highly saline conditions in Paikgacha *upazila,* Khulna district, and moderately saline conditions in Rampal *upazila,* Bagerhat district. The researchers analyzed river salinity data monitored by the Bangladesh Water Development Board (BWDB) for the Sibsa river in Paikgacha and the Passur river in Rampal, and found a significant increase in salinity from 1975 to 2004. After surveying local fishermen, the researchers concluded that freshwater fish species declined by 59% in Paikgacha and 21% in Rampal, with little compensating increase in saline-tolerant fish. The study inferred that reduction in fish diversity is a serious threat to the local ecosystem and food supply.

In light of such evidence, the potential impacts of increasing salinity have become a major concern for the Government of Bangladesh and affiliated research institutions. Recently, the Bangladesh Climate Change Resilience Fund (BCCRF) Management Committee has highlighted salinity intrusion in coastal Bangladesh as a critical part of adaptation to climate change. Prior research on salinization has employed a variety of methods (see for example Nobi and Gupta, 1997; Aerts et al., 2000; IWM, 2003; CEGIS, 2006 and Bhuiyan and Dutta, 2011). Many of these studies have simulated salinity change in rivers and estuaries using hydraulic engineering models and then compared the results with monitored salinity data. In the most comprehensive study to date, Dasgupta et al. (2015a) have used 27 alternative climate change scenarios to project salinity trends in coastal rivers to 2050, with a model that links the spread and intensity of salinity to changes in the sea level, temperature, rainfall, and altered riverine flows from the Himalayas. The study provides new estimates of location-specific river salinity through 2050.

Resources will remain scarce, and mobilizing a cost-effective response will require an integrated spatial analysis of threats from salinity diffusion, their socioeconomic and ecological impacts, and the costs of adaptation. The temporal and geographic pattern of appropriate adaptation investments will depend critically on the ecological impacts of salinity diffusion in different locations. Understanding household choices will also be critical, since households may respond to localized threats of salinization by relocating some or all members to areas where expected earnings and survival probabilities are higher (Dasgupta et al., 2014).

[1] Other threats include increased water temperature, changes in cyclonic storm patterns, and changes in surge heights.

[2] Among the three distinct potential pathways between fish-related livelihoods and household nutritional security identified by Kawarazuka and Béné, 2010, direct nutritional contribution of fish consumption and purchasing power through sale of fish are critical for households in coastal Bangladesh.

This paper attempts to contribute by assessing the impact of aquatic salinization on the spatial distribution of fish species that are significant for the livelihoods of poor fishing communities in southwest coastal districts and the Sundarbans region.[3] In the absence of comprehensive data on the spatial distribution of fish abundance by species, the focus of our analysis is on expected impact of changing aquatic salinity on the extent of fish habitats. In particular, we have employed geographic information system (GIS) software to overlay fish habitats and poverty maps with projected river salinity for alternative scenarios of climate change, in order to project expected impacts of salinity on the prevalence of fish species and likely impacts on the poor habitants of the region by 2050. At the outset, the following should be noted about the scope of our analysis: (i) the focus of our paper is on progressive aquatic salinization with sea-level rise and our analysis does not address impacts of surface water salinization from cyclone-induced storm surges[4]; (ii) within the southwest coastal region, the Sundarbans[5] ecosystem provides a refuge for fish from predators and serves as a nursery for the larvae and juveniles of 90% of commercial fish and 35% of all fish in the Bay of Bengal (Shah et al., 2010). Although the importance of Sundarbans mangroves as fish habitats and nursery grounds is recognized in the literature, this paper does not consider the indirect impact that climate-induced changes in the location and composition of mangroves will have on fish species; (iii) our analysis does not address the contribution of fish-related activities to poverty reduction.

2. Data

The study area comprises 114 sub-districts (*upazilas*) in 4 regions of Bangladesh: Khulna (45 upazilas), Barisal (40), Dhaka (22) and Chittagong (7). See Appendix Fig. A1 for a map of the study region. We have used the best available, spatially disaggregated data from various public sources for our analysis. The data are described below:

2.1.1. Current and Future Aquatic Salinity in the Southwest Region

The analysis draws extensively on the River Salinity Information System[6] based on Dasgupta et al. (2015a, 2015b), which quantifies the prospective relationship between climate-induced changes in sea level, temperature, rainfall, and riverine flows from the Himalayas, and the spread and intensity of aquatic salinization in the coastal zone controlling for the projected land subsidence in the Ganges Delta, as well as alternative levels of upstream freshwater withdrawal. The system provides location-specific estimates of aquatic salinity during

[3] Examples of prior research on climate change and fisheries in coastal Bangladesh can be found in Ali (1999); World Bank (2000); Sarwar (2005); Hassan and Shah (2006); UK DEFR (2007); Chowdhury et al. (2010); World Bank (2011) and Nicholls et al. (2013). However, the bulk of this research makes inferences from descriptive statistics.

[4] Intrusion of saline water from the ocean can increase salinity in surface water significantly during cyclones (for example, see Mitra et al., 2011). Bangladesh is a global hotspot for tropical cyclones. On average, a severe cyclone hits Bangladesh every three years (Government of the People's Republic of Bangladesh [GOB], 2009). The low-lying coastal region of Bangladesh is protected by 123 polders, 49 of which are sea-facing, from the 1960s and 1970s. Salinization of surface water from storm surges during cyclones is usually temporary and lasts at most until the advent of the following rainy season, unless polders are overtopped or breached. Overtopping and breach of polders are not uncommon during severe cyclones; Cyclone Aila (May 2009) provides a recent example of devastating polder breach. When polders are breached, saline water gets trapped inside the polders and soil and surface water become saline. Scientific evidence indicates that increased sea surface temperature in a changing climate may intensify cyclone activity and heighten storm surges (Emanuel et al., 2008; International Workshop on Tropical Cyclones, 2006), Given the locational uncertainty of cyclone landfalls, severity and polder breaching, this paper does not consider the potential effects of climate change on cyclones and consequent impacts on surface water salinization and fish habitats.

[5] According to IUCN, water bodies in the Sundarbans (rivers, streams and canals) covering 1874 sq. km and marine zones covering 1603 sq. km support 27 families and 53 species of pelagic fish, 49 families and 124 species of dermal fish, 5 families and 24 species of shrimps, 3 families and 7 species of crabs, 2 species of gastropods, 6 species of pelecypods, and 8 species of locust lobsters. See Shah et al., 2010 for details.

[6] http://sdwebx.worldbank.org/climateportal/index.cfm?page=websalinity_dynamics&ThisRegion=Asia&ThisCcode=BGD Accessed March 2016.

December 2049 and six months in 2050: January–June. [7] The estimates are for 27 climate scenarios in 2050 that incorporate three global emissions scenarios (B1, A1B, A2)[8] from the IPCC's Fourth Assessment Report (AR4); two estimates of sea level rise by 2050 (27 cm for scenario B1, 32 cm for A1B and A2); three global circulation models (IPSL-CM4, MIROC3.2, ECHO-G)[9]; and three annual subsidence rates for land in the lower Ganges Delta (2, 5 and 9 mm/year).[10]

2.1.2. Salinity Tolerance of Fish Species Common in the Southwest Coastal Region

Our focus is on 83 fish species that are prevalent and typically consumed by households in the southwest coastal region (Saifuddin et al., 2010; World Fish-Bangladesh, 2013). Appendix 1 identifies these species. We compiled the salinity tolerance ranges of these fish species, drawing on secondary literature (for example, see Hussain et al., 2013; Rahman and Asaduzzaman, 2010; MoEF, 2010: Robin et al., 2010; Gain et al., 2008; Mustafa, 2003: Mustafa and Prava Dey, 1994; Kasim, 1979).[11] We define stable habitat as the area within which a species can survive year-round in any body of water that it inhabits. To illustrate, a species with a salinity tolerance range of 0–2 ppt has a stable habitat in an area whose annual salinity range is 0–1 ppt. In an area with salinity range 0–5 ppt, the species' habitat is limited to months with salinity in the range 0–2 ppt. Fig. 1 enumerates the species by salinity tolerance range.

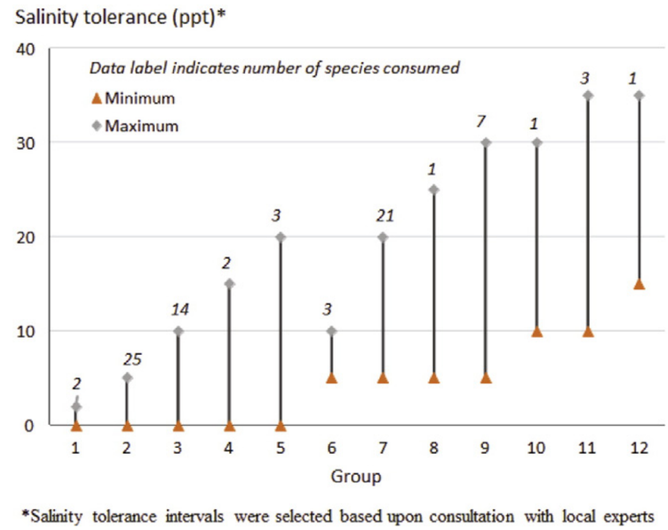

Fig. 1. Southwest coastal region: fish species consumed by households.

2.1.3. Incidence of Poverty

For understanding the incidence of poverty, we use the poverty maps developed by the Bangladesh Bureau of statistics, World Food Program and the World Bank. Total poverty populations for *upazila*s in 2011 are estimated by multiplying the 2010 poverty incidence estimates provided by the World Bank (2014b) and 2011 population estimates from the Bangladesh Bureau of Statistics. Following World Bank (2014a), we use two standards to determine poverty incidence: the upper poverty line, for households whose food expenditures are at or below the food poverty line established by the Bangladesh Bureau of Statistics[12]; and the lower poverty line, for extremely poor households whose total expenditures are at or below the food poverty line.

2.1.4. Administrative Boundaries of 114 Upazilas in the Southwest Coastal Region

Finally, *upazila* maps are constructed from an administrative shapefile provided by the Government of Bangladesh.

3. Methodology, Results and Discussion

We have conducted our analysis in two steps.

In step 1, GIS software is used to overlay fish habitats and maps with the projected river salinity for alternative scenarios of climate change to predict impacts of salinization on prevalence of fish species in the region by 2050.

In step 2, the analysis determines the exposure of the poor from GIS overlays of the expected change in fish habitats and the poverty map.

3.1. The Impact of Salinization on Fish Habitats

Fig. 2 displays the estimated spatial distribution and intensity of maximum aquatic salinity in 2012 and two projections for 2050[13]: least change (Scenario B1, GCM MIROC-3.2, SLR 27 cm, land subsidence 2 mm/year); and most change (Scenario A2, GCM IPSL-CM4, SLR 32 cm, land subsidence 9 mm/year) using data from the River Salinity Information System (Dasgupta et al., 2015a). In 2012 (Fig. 2(a)), most of the

[7] Average salinity concentrations of the rivers in the coastal area are higher in the dry season than in the monsoon because of lack of freshwater flow from upstream. Salinity generally increases almost linearly from October (post-monsoon) to late May (pre-monsoon) with the gradual reduction in freshwater flow. At the end of May, the salinity level drops sharply because of rainfall and upstream flow of freshwater through the river system and remains low until early October (Dasgupta et al., 2015a; Dasgupta et al., 2015b).

[8] Basic elements of the three scenarios are as follows:

B1: Rapid economic growth with convergence among regions; global population that peaks in mid-century and declines thereafter; rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies.

A1B: Rapid economic growth with convergence among regions; global population that peaks in mid-century and declines thereafter; rapid introduction of new and more efficient technologies; energy from mixed fossil and renewable sources.

A2: Non-convergent economic development; continuously increasing population; heterogeneous technologies and energy sources.

[9] Model implementing institutions are as follows:
IPSL-CM4: Institut Pierre Simon Laplace, France;
MIROC3.2: Center for Climate System Research, University of Tokyo,
National Institute for Environmental Studies, Japan,
Frontier Research Center for Global Change, Japan;
ECHO-G: Meteorological Institute of the University of Bonn, Germany,
Model and Data Group, Max Planck Institute for Meteorology, Hamburg, Germany,
Korea Meteorological Administration.

[10] The Ganges Delta in Bangladesh is still in an active, dynamic state. Therefore, it is critical to include projection of land subsidence of the lower Bengal delta (the Ganges Delta in Bangladesh) in simulating future climate scenarios. Physical impacts of relative mean sea-level rise are caused by a combination of sea-level rise scenarios associated with global warming and vertical land movement (subsidence or accretion). At present there is an intense controversy in Bangladesh regarding the estimates and projections of land subsidence in the coastal region (see Dasgupta et al., 2015a). In light of the widely varying estimates, the hydrological modeling for our analysis was run for three alternative scenarios of land subsidence: 2 mm per year, 5 mm per year, and 9 mm per year.

[11] It should be noted that it is difficult to pinpoint the salinity tolerance range of fish species at times. For example, (i) while Cardona (2000) reported that juvenile *Mugil cephalus* prefer low salinity areas and adults prefer polyhaline (18–30 ppt) areas, Chang et al. (2004) indicated individual differences in salinity preference of *Mugil cephalus*, as most of their specimens avoid freshwater throughout their lifecycle. (ii) Davenport and Wong (1987) reported that *Scylla serrata* can survive in 0–30 ppt salinity range. (iii) Mandal et al. (1987) reported that initial mortality is observed from 30.5 ppt from their direct release of *Liza parsia* to different levels of salinity. (iv) Haniza and Borhannuddin (2007) reported that the highest rates of survival and growth of *Lates calcarifer* are observed around 20 ppt salinity although it can survive 5–30 ppt salinity. (v) Chen et al. (2016) reported 10–35 ppt salinity as most suitable for the growth of *Penaeus monodon*. (vi) Ruby et al. (2010) reported that *Pangasius* grew well at salinity up to 13 ppt but could survive excursions up to 20 ppt. (vii) Kumlu and Jones (1995) reported that the best survival, growth and biomass of *Penaeus indicus* were observed in the 20–30 ppt salinity range. (viii) Arunachalam and Reddy (1979) reported that suitable salinity range for food intake, growth, food conversion and body composition of *Mystus vittatus* was 0–10 ppt. (ix) Chand et al. (2015) reported *Macrobrachium rosenbergii* grew and survived satisfactorily at 0–15 ppt salinity and exhibited highest final average weight at 10 ppt. The median lethal salinity of *M. rosenbergii* was estimated at 24.6 ppt. We are thankful to an anonymous reviewer for pointing out this intrinsic uncertainty.

[12] See report of the Household Income and Expenditure Survey/HIES 2010. Bangladesh Bureau of Statistics, Government of Bangladesh.

[13] The data are mean values for seven months (January–June, December).

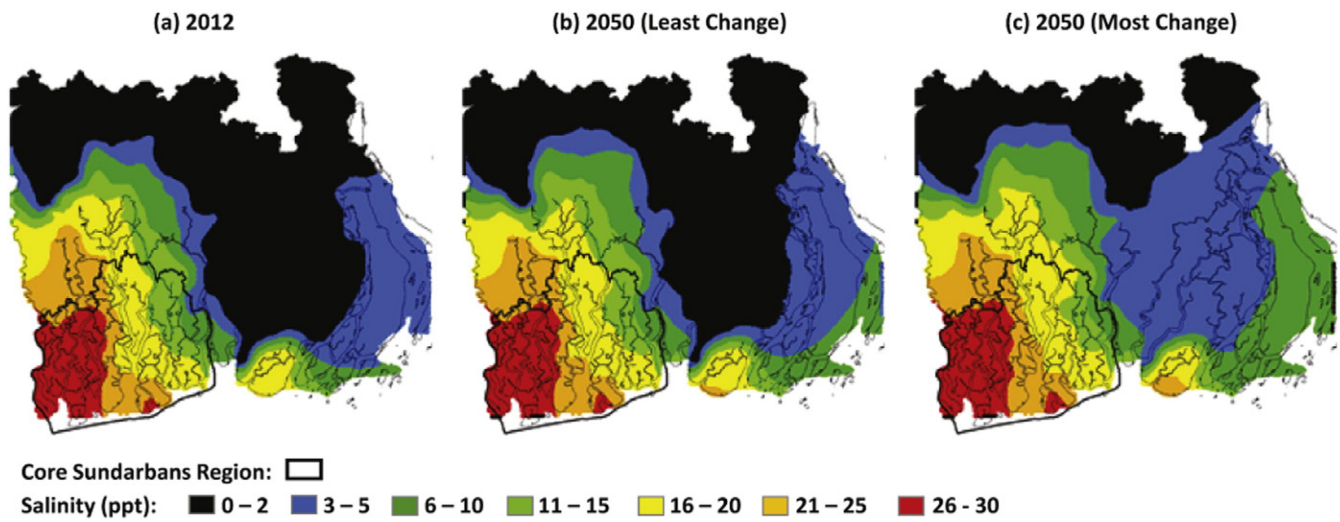

Fig. 2. Southwest coastal and Sundarbans region: actual and estimated maximum aquatic salinity in 2012 and 2050.

core Sundarbans region in the west (outlined in black) and its immediate neighborhood display north-south bands of maximum salinity that are highest (25 + ppt) in the west and decline eastward toward 10–15 ppt. Both 2050 scenarios exhibit expansion of these color bands, with somewhat greater change in the A2 case (Fig. 2(c)). The eastern part of the region as documented in Fig. 2 presents a strong contrast in 2012, with most of the area dominated by very low maximum salinity (0–2 ppt). The 2050 B1 scenario (Fig. 2(b) - least change) exhibits notable area reduction for 0–2 ppt, accompanied by expansion in the ranges 3–5 and 6–10 ppt. The shift is more pronounced for A2 (Fig. 2(c) - most change), with area dominance shifting to the range 3–5 ppt and further expansion of 6–10 ppt.

The salinity area changes in Fig. 2 have potential significance for the spatial distribution of fish species, since the stable habitat of each species is limited to areas whose salinity ranges fall within its salinity tolerance range. In this paper, expected change in the spatial distribution of fish species is calculated using the digital salinity maps provided by Dasgupta et al. (2015a, 2015b). For each of the 12 species salinity tolerance groups, we assign 1 to a geographical unit in the map for 2012 that satisfies the stable habitat criterion (salinity range of the geographical unit falls within the species tolerance range) and 0 otherwise. We add across 101,600 geographical units to determine total stable habitat by salinity tolerance group in 2012.[14] We perform the same operations for all 27 salinity scenarios in 2050; calculate percent changes from 2012 to 2050 for each scenario and salinity tolerance group; and tabulate the results in Tables 1 and 2.

Table 1 displays all the results, ordered by local subsidence level, IPCC AR4 scenario and global circulation model. We include summary information in Table 2 to aid interpretation. Panel a reports median change rates across IPCC scenarios and GCMs for different salinity tolerance groups and rates of local subsidence.

Panel a highlights three major features of the results in Table 1. The first is a clear division between fresh water tolerant species (minimum ppt 0) and species that require brackish water. The freshwater species (groups 1–5) all exhibit habitat loss with increased salinization, while the brackish water species all exhibit potential habitat gain. Habitat loss is particularly striking for groups 1 and 2 at subsidence rates of 5 and 9 mm/year. Among brackish water tolerant species, the greatest habitat gain (27–28%) is expected for group 6 (tolerance range 5–10 ppt). Groups 10 and 11 also have relatively large habitat growth.

The second feature highlighted by Panel a is an important asymmetry in habitat scale. The greatest habitat loss rates are for groups 1 and 2, which have large habitats in 2012 (46,982 and 63,692 geographical units or 15,363 and 20,827 sq. km respectively). Conversely, the greatest habitat increase rates are expected for groups 6, 10 and 11, which have much smaller habitats in 2012 (470, 12,534 and 12,534 geographical units or 154, 4099 and 4099 sq. km respectively). By implication, the scale of habitat losses for freshwater species is far greater than the scale of habitat gains for brackish water species. This difference is particularly striking for freshwater group 2, which comprises 25 species in a habitat of 63,392 geographical units (20,827 sq. km) in 2012, and brackish water group 7, which comprises 21 species with a habitat of 9855 geographical units (3223 sq. km).

The third striking feature of Panel a is the effect of the land subsidence rate on habitat loss in freshwater groups 1 and 2. For group 1, subsidence rates of 2, 5 and 9 mm/year are associated with habitat loss rates of 20.5%, 47.6% and 53.4%. In group 2, which has much greater species representation (25 vs. 2 in group 1), the equivalent loss rates are 8.7%, 13.6% and 21.7%.

It is more difficult to determine whether variations in IPCC climate scenarios and GCMs have significant impacts on the results in Table 1. To test these effects, we perform a regression analysis for the 324 change rates in Table 1 (27 scenarios, 12 salinity tolerance groups). We convert change rates to ranks in order to avoid scaling problems.[15] We regress the rank of the habitat change rate on dummy variables for salinity tolerance groups, local subsidence rates, IPCC scenarios and GCMs. We exclude one dummy variable from each category to make the regressions feasible.[16] Panel b of Table 2 reports results for climate scenarios and GCMs, after controlling for salinity groups and subsidence rates. We find no significance for the IPCC scenarios, but high significance for the GCMs.

It should be noted that expected loss in fresh water fish species is an issue of major concern, as fishery experts in Bangladesh indicate that despite the theoretical possibility of significant gain of brackish fish species in the study region, this is unlikely to occur in a changing climate by 2050. Salinity is only one of the multiple determinants of brackish fish behavior and habitats. Wild marine and brackish fish species prefer coastal ecosystems to river systems because of their feeding habits and biology; and are expected to move slowly over time to inland river

[14] We use geographical units for numerical convenience, although geographical unit numbers are readily translated to areas. In our mapping system, one geographical unit has an area of 0.327 sq. km. This is equivalent to a square cell with side length of 571.54 m.

[15] Change rates are ranked from the greatest decrease (−54.4%, assigned rank 1) to the greatest increase (+35.5%, rank 324).

[16] Inclusion of all dummy variables produces total collinearity of regression variables and failure of the regression algorithm.

Table 1
Stable habitat area change (percent) by species salinity tolerance range, 2012–2050.

Local Subsidence (mm/year)	SLR by 2050 (cm)	IPCC AR4 scenario	Global circulation model	Salinity Tolerance Range (ppt)											
				1 0–2	2 0–5	3 0–10	4 0–15	5 0–20	6 5–10	7 5–20	8 5–25	9 5–30	10 10–30	11 10–35	12 15–35
2	27	B1	ECHO-G	−13.8	−8.0	−1.3	−0.3	−0.3	21.5	13.2	7.8	7.4	11.2	11.2	6.4
2	27	B1	IPSL-CM4	−14.4	−8.8	−2.1	−1.4	−0.5	21.7	10.6	7.5	7.4	11.2	11.2	6.4
2	27	B1	MIROC3.2	−13.7	−7.8	−1.2	−0.1	−0.2	21.3	13.7	7.8	7.3	11.2	11.2	6.4
2	32	A1B	ECHO-G	−20.7	−8.7	−1.3	−0.5	−0.4	21.9	11.4	7.6	7.4	11.9	11.9	7.2
2	32	A1B	IPSL-CM4	−21.3	−9.6	−2.1	−1.8	−0.8	22.6	8.6	7.3	7.4	12.0	12.0	7.2
2	32	A1B	MIROC3.2	−20.5	−8.4	−1.1	−0.2	−0.4	22.3	12.1	7.7	7.4	11.9	11.9	7.2
2	32	A2	ECHO-G	−20.8	−8.7	−1.3	−0.5	−0.5	21.9	11.2	7.6	7.4	11.9	11.9	7.2
2	32	A2	IPSL-CM4	−21.2	−9.3	−1.8	−1.4	−0.7	22.3	9.4	7.4	7.4	12.0	12.0	7.2
2	32	A2	MIROC3.2	−20.2	−8.1	−1.0	0.0	−0.4	22.1	12.1	7.7	7.3	11.9	11.9	7.2
5	27	B1	ECHO-G	−45.5	−12.8	−2.0	−1.1	−0.7	28.1	12.5	9.4	9.0	13.3	13.3	8.3
5	27	B1	IPSL-CM4	−46.0	−13.6	−2.9	−2.2	−1.0	27.4	10.2	9.2	9.0	13.4	13.4	8.3
5	27	B1	MIROC3.2	−45.3	−12.6	−1.9	−0.8	−0.8	28.1	12.0	9.5	9.0	13.3	13.3	8.3
5	32	A1B	ECHO-G	−47.6	−5.4	−1.1	−0.5	−0.4	35.5	14.7	10.2	8.9	14.0	14.0	9.7
5	32	A1B	IPSL-CM4	−48.5	−14.7	−2.7	−2.5	−1.2	27.0	8.2	8.8	8.9	14.0	14.0	9.6
5	32	A1B	MIROC3.2	−47.7	−13.9	−1.7	−0.9	−0.7	26.8	12.5	9.2	8.9	13.9	13.9	9.7
5	32	A2	ECHO-G	−47.9	−14.1	−1.9	−1.2	−0.8	26.8	11.4	9.0	8.9	14.0	14.0	9.7
5	32	A2	IPSL-CM4	−48.4	−14.7	−2.4	−2.1	−1.0	26.6	9.6	8.8	8.9	14.0	14.0	9.7
5	32	A2	MIROC3.2	−47.4	−13.5	−1.6	−0.6	−0.7	27.2	12.4	9.2	8.9	14.0	14.0	9.7
9	27	B1	ECHO-G	−52.4	−19.3	−3.0	−2.1	−1.0	32.3	14.3	11.3	11.0	16.1	16.1	11.5
9	27	B1	IPSL-CM4	−53.0	−20.0	−3.9	−3.2	−1.4	31.7	11.2	11.1	11.0	16.1	16.1	11.5
9	27	B1	MIROC3.2	−52.3	−19.2	−2.9	−1.8	−0.9	32.3	15.1	11.4	11.0	16.1	16.1	11.5
9	32	A1B	ECHO-G	−53.7	−22.0	−2.8	−2.1	−1.0	27.9	13.2	10.6	10.6	16.4	16.4	12.7
9	32	A1B	IPSL-CM4	−54.4	−22.6	−3.7	−3.5	−1.8	26.6	6.5	10.2	10.5	16.4	16.4	12.6
9	32	A1B	MIROC3.2	−53.4	−21.7	−2.7	−1.8	−1.0	28.1	13.9	10.8	10.6	16.4	16.4	12.7
9	32	A2	ECHO-G	−53.7	−22.0	−2.9	−2.1	−1.1	28.1	12.8	10.6	10.6	16.4	16.4	12.7
9	32	A2	IPSL-CM4	−54.2	−22.5	−3.4	−3.0	−1.4	27.4	10.1	10.3	10.6	16.4	16.4	12.7
9	32	A2	MIROC3.2	−53.2	−21.4	−2.6	−1.5	−1.0	28.1	13.9	10.7	10.6	16.4	16.4	12.7

Table 2
Impact of salinization on fish habitats.

Panel a: Median habitat change (percent) by salinity tolerance and subsidence level

Group	Number of species	Salinity tolerance (ppt)		Habitat size in 2012 (geographical units)	Habitat size in 2012 (sq. km)	Local subsidence (mm/year)		
		Min	Max			2	5	9
1	2	0	2	46,982	15,363.11	−20.5	−47.6	−53.4
2	25	0	5	63,692	20,827.28	−8.7	−13.6	−21.7
3	14	0	10	70,964	23,205.23	−1.3	−1.9	−2.9
4	2	0	15	77,826	25,449.1	−0.5	−1.1	−2.1
5	3	0	20	88,906	29,072.26	−0.4	−0.8	−1.0
6	3	5	10	470	153.69	21.9	27.2	28.1
7	21	5	20	9855	3222.585	11.4	12.0	13.2
8	1	5	25	16,690	5457.63	7.6	9.2	10.7
9	7	5	30	22,254	7277.058	7.4	8.9	10.6
10	1	10	30	12,534	4098.618	11.9	14.0	16.4
11	3	10	35	12,534	4098.618	11.9	14.0	16.4
12	1	15	35	5507	1800.789	7.2	9.7	12.7

Panel b: Selected rank regression results for habitat change rates

Dependent variable: Rank of habitat change rat (smallest = 1)

Full regression dummy variable set: Salinity tolerance group, subsidence rate, IPCC scenario, GCM

IPCC scenario	
A1B	−0.204
	(0.07)
A2	−0.046
	(0.01)
GCM	
ECHO	10.926
	(3.54)**
MIROC	12.56
	(4.07)**

Observations 324; R-squared 0.94 absolute value of t statistics in parentheses.

** Significant at 1%.

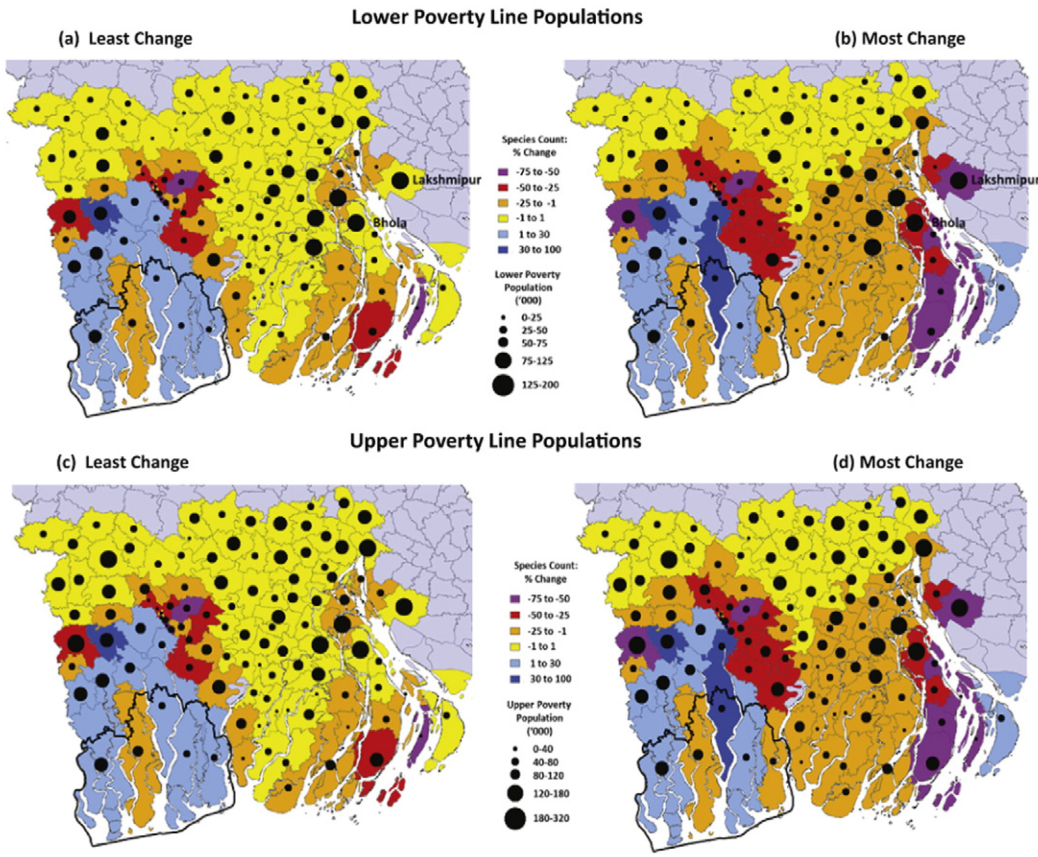

Fig. 3. *Upazila* change scenarios, lower and upper poverty line populations.

systems, if at all. On the contrary, many freshwater fish species have low swimming speed, prefer local habitats and will cease to survive with increases in salinity (Robin et al., 2010). Gain et al., 2008 also reported significant decline in fish diversity with increase in salinity in *Sibsa* River near *Paikgacha*. In 1975, fresh water fish species near Paikgacha were abundant, but in 2005 the field sampling could not locate 17 fresh water species, including *Labeo rohita, Catla catla, Anabas testudineus* and *Clarius batrachus.* Experts also indicate that with change in aquatic salinity, a few coastal fish species may emerge gradually in inland water but their harvesting technology is costly and not affordable in Bangladesh.

3.2. The Potential Impact of Salinization on Poor Households

Fig. 2 and Tables 1-2 reveal a spatially-uneven pattern of salinization and fish habitat change with continued climate change, sea level rise and land subsidence in southwest coastal Bangladesh. Data from rural areas in Bangladesh suggest that small low-value wild freshwater species are the most common fish consumed and the most important source of dietary protein for the poor (Belton et al., 2011; Thilsted, 2010, 2012).[17] The potential impact on poor households will depend on their vulnerability to changes in fish species in areas where salinization will significantly alter habitats.[18] Vulnerability will in turn depend on the relative abundance, average size, preference for, commercial value and dietary status of local fresh- and brackish-water fish species. If the aquatic intensity (yield per unit volume) of fish biomass, commercial value, taste preference, and dietary status were always identical for fresh- and brackish-water species groups, then salinization would have no impact on the welfare of poor households. Tropical field research on habitat salinity and fish biomass has revealed diverse patterns in different regions and ecosystems, but no clear, robust relationship between biomass yields in fresh and brackish water bodies (see for example Welcomme et al., 2010; Nixon, 1988; Marten and Polovina, 1982). Information about the relative abundance, commercial value and dietary status of the 83 fish species consumed by the poor in the southwest region can at best be described as spotty. In addition, we have only anecdotal evidence on relative preference for freshwater and brackish-water fish in coastal Bangladesh. Further research is warranted on the feasibility of substitution of freshwater fish by brackish-water fish in the study region.

Given the lack of robust research results and species-specific data, we cannot project the ultimate impact of salinization on fish consumption by poor households with any confidence. However, it does seem reasonable to assert that transitional risks for poor households will be higher in areas where the greatest changes in fish species will occur. And collective risks will be greater in areas where the settlement density of poor households is also high.

In view of the above, our analysis follows several steps to assess the exposure of the poor to fish species change scenarios. The details of the procedure are outlined below.

(i) We build a digital map for 2012 that assigns 1 to geographical units that satisfy the species' stable habitat criterion (salinity range of the geographical unit falls within the species' tolerance range) and 0 otherwise, for each of the 83 species identified in Appendix Table A1.

[17] The nutritional contribution of small fish species is generally high. As many small fish species are consumed whole, they provide a significant percentage of recommended intakes of calcium, vitamin A, iron, and some minerals (Thilsted, 2010, 2012).

[18] An example is provided by Bombay duck (*Harpadon nehereus*), a low price fish that is still caught in abundance and preferred by poor and middle class consumers all along the Bangladesh coast. On average, Bombay Duck accounts for 14% of daily fish sales. Using the IPCC A1B emissions scenario, Farnandes et al. (2015) have predicted a 35% reduction in production of this species in the exclusive economic zone of Bangladesh.

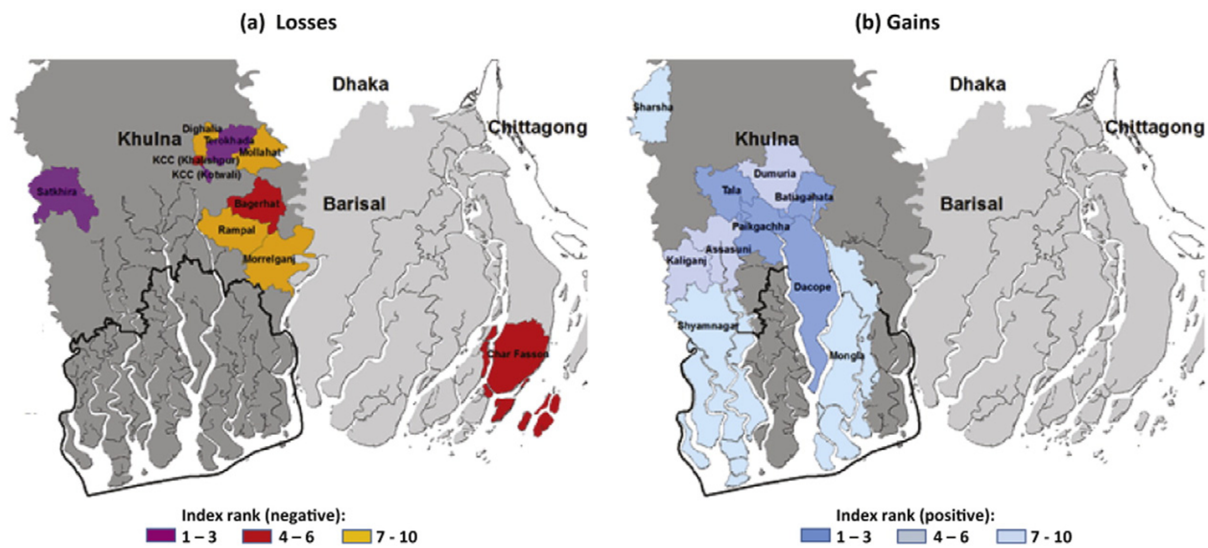

Fig. 4. *Upazilas* with species losses and gains: top ten index values.

(ii) We add across the 83 maps to determine total species with stable habitat in each of 101,600 geographical units.

(iii) We perform the same operations for all 27 salinity scenarios in 2050 and calculate percent changes (2012–2050) in total species for each geographical unit.

(iv) We overlay an *upazila*-level administrative map shapefile and compute mean percent changes in the 27 scenarios for 110 *upazila*s to approximate *upazila*-level fish species changes by 2050.

(v) We calculate exposure of the poor and extremely poor population to fish species changes by overlaying *upazila*-specific fish species changes with the appropriate count of total poor and extremely poor population computed from the location-specific upper and lower poverty incidence estimates (World Bank, 2014b) and 2011 population estimates from the Bangladesh Bureau of Statistics.

To illustrate the range of results produced by this exercise, we employ the two bounding scenarios for 2050 that are mapped at the geographical unit level in Fig. 2: least change (Scenario B1, GCM MIROC-3.2, SLR 27 cm, land subsidence 2 mm/year); and most change (Scenario A2, GCM IPSL-CM4, SLR 32 cm, land subsidence 9 mm/year). We map the results for 110 *upazilas* in Figs. 3 and 4. The maps illustrate two critical dimensions for priority-setting: percent change in species counts, and poverty populations identified using lower and upper poverty lines.

Fig. 3 overlays color-coded changes in fish species with black circles scaled by lower and upper poverty line populations. For the lower poverty line population, Fig. 3(a) displays the scenario with least change (B1), while 3(b) displays the scenario with most change (A2). Although the maps present a wealth of information, three patterns are immediately clear. First, the two scenarios exhibit a very similar pattern of species increase (colored blue) in the southwest, with growth somewhat more pronounced in 3(b). Second, the two scenarios exhibit widespread species decrease in both scenarios, and strikingly higher decrease rates in 3(b). Third, the distribution of the lower level poverty population is strikingly non-uniform across *upazila*s, with the largest concentrations in the center of the eastern region.

Exposure assessment of the poor to fish species change should incorporate both species change and poverty population size, focusing particularly on *upazila*s which have high species loss rates and large poverty populations. Visual inspection reveals two obvious priority candidates in Fig. 3(b): Lakshmipur in Chittagong Division, and Bhola in Barisal. Both have large extreme poverty populations (defined by the lower poverty line) and species loss rates greater than 50%. Elsewhere, the diversity of change rates and poverty populations makes it more difficult to identify clear patterns. This is also true for Fig. 3(c) and (d), because poverty populations are less skew-distributed when we employ the upper poverty line.

To provide a clearer basis for identifying priority cases, we construct more general risk indicators for all 27 scenarios and 2 poverty definitions. To start with, we multiply the species change rate in each *upazila* by its share of the region's poverty population to create a poverty-weighted species change index. To check for robustness, we generate index values for 110 *upazila*s in all 54 cases (27 scenarios, 2 poverty definitions) and calculate rank correlation coefficients within and across the two poverty groups.[19] Summary statistics for the three correlation exercises are presented in Panel a of Table 3.

These results suggest that our methodology is robust to changes in scenarios and poverty definitions. In all three exercises, the median and mean correlation coefficients are around 0.89; the first- and third-quartile correlations are 0.84 and 0.95, respectively; and the minimum correlation never falls below 0.74.

Given these results, we believe that a summary index can provide useful information for identifying priority cases. Accordingly, we compute mean ranks for the 110 *upazila*s across all 54 cases and use the results to rank *upazila*s in three classes: species losses, species gains and no change.[20] Fig. 5 display *upazila*s with the top-ten index values for species losses and gains. Among the *upazila*s with top-ten species loss indicators, nine are in Khulna (Bagerhat, Dighalia, Khalishpur, Kotwali, Mollahat, Morrelganj, Rampal,[21] Satkhira, Terokhada) and one is in Barisal (Char Fasson). All ten *upazila*s with top-ten species gain indicators are in Khulna (Tala, Assasuni, Batiagahata, Dacope, Dumuria, Kaliganj, Mongla, Paikgachha, Sharsha, Shyamnagar).

Since 76 *upazila*s have projected species losses and only 11 have projected gains, it seems likely that the majority of poor households are in areas with projected losses. Table 3 (Panel b) confirms this difference, which turns out to be very large. Poverty populations in *upazila*s with losses are 4.0 and 6.6 million for lower and upper poverty lines, respectively. The comparative populations for *upazila*s with species gains

[19] We use rank correlations to eliminate potential outlier effects, and because rankings are the core identifier for priority assessment in any case.

[20] Dasgupta et al., 2016 provides complete tabulations of the results in Tables A2 (76 *upazilas* that lose species), A3 (11 *upazila*s that gain species), and A4 (23 *upazila*s with no change).

[21] Our findings for Rampal are in line with the reduction in fish diversity noted by Gain et al. (2008).

Table 3
Poverty population and fish species change.

Panel a: Summary statistics: rank correlation coefficients for species change indices

Upazilas: 110
Scenarios: 27

Poverty line	Min	P10	P25	Median	Mean	P75	P90	Max
Lower	0.744	0.816	0.835	0.886	0.892	0.948	0.985	0.999
Upper	0.757	0.822	0.838	0.892	0.895	0.947	0.986	0.999
Lower vs. upper	0.744	0.820	0.839	0.892	0.896	0.954	0.991	0.999

Panel b: Poverty populations by species change

	Poverty population	
Species change	Lower line	Upper line
Loss	3,993,190	6,578,473
Gain	692,757	1,167,131
None	1,165,526	2,130,843

are 0.7 million and 1.2 million, respectively. For both poverty lines, the ratio of populations with losses to those with gains is about 6:1.

To provide more concrete illustrations, Fig. 5 below shows the minimum and maximum variants from our 27 salinity change scenarios to portray projected range changes for a variety of species that are important for fish consumption by poor households.

Any significant compensating change from commercial aquaculture is also not anticipated, as historically the coastal population in Bangladesh, especially the habitants of the flood and saline prone study region of this paper, have depended mostly on capture fishery for their livelihood as well as for their dietary intake.[22] Furthermore, the contribution of aquaculture to the 83 fish species identified for this study is negligible. Aquaculture in Bangladesh is dominated by commercial polyculture of major species of carp, catfish, climbing perch and prawn[23]; and aquaculture of fish is more prevalent in the northern, eastern and central part of Bangladesh. Relatively high cost of transportation has so far prevented transfer of low-cost cultured fish to the southwest coastal region of Bangladesh and the situation is unlikely to change in the near future. It is also unlikely that the poor and the extremely poor with their total and food expenditure below the food poverty line established by the Bangladesh Bureau of Statistics will be able to afford to consume alternative sources of animal protein, such as beef, lamb or poultry on a regular basis. Therefore, the probable decline in the biodiversity of freshwater, low-value, wild fish species with increased river salinity may have significant implications for the nutrition of the rural poor.

4. Summary and Conclusions

Data on water quality indicates river salinity has increased significantly in the southwest coastal region of Bangladesh over time (IWM, 2003; Dasgupta et al., 2015a). Scientists and hydrologists unanimously agree that river salinity in the Sundarbans will increase due to sea level rise in a changing climate. In this paper we have used a detailed scenario analysis for the Sundarbans region to assess possible impacts of climate change and aquatic salinity on fish species habitats, and the poor communities that consume the affected fish species. Drawing on Dasgupta et al. (2015a), we use a digital map of aquatic salinity for 2012 and 27 digital maps for 2050, projected from combinations of three IPCC climate change scenarios (B1, A1B, A2), three global circulation models (IPSL-CM4, MIROC3.2, ECHO-G) and three assumptions about the rate of subsidence in the Ganges Delta (2, 5 and 9 mm/year). Our exercise uses 101,600 geographical units, at a resolution of 0.327 sq. km per geographical unit.

We focus on 83 fish species that are found and consumed by households in the region. Using the salinity tolerance range for each species, we construct digital maps of its stable (12-month) habitats for 2012 and 27 scenarios in 2050. We add across maps to generate species counts for each geographical unit and compute percent changes for 2012–2050. Our results indicate two broad patterns of change, with brackish water expanding moderately into fresh water habitat in the western part of the region and more broadly in the eastern part. Increase in salinity is expected to have adverse impacts on the reproductive cycle, reproductive capacity, extent of suitable spawning area, and feeding/ breeding/ longitudinal migration of fish species.

To assess the consequences for poor households, we overlay our results with an administrative map of Bangladesh and compute mean percent changes in fish species for 110 *upazilas* that lie within the region. We construct an impact indicator that weights these results by *upazila* poverty populations identified using two bounds: an upper poverty line, for households whose food expenditures are at or below the food poverty line established by the Bangladesh Bureau of Statistics; and the lower poverty line, for extremely poor households whose total expenditures are at or below the food poverty line. Our calculations encompass 54 cases (27 scenarios, 2 poverty definitions). We find that potential impact rankings are highly correlated, so we use the mean rank across 54 cases as a robust general impact indicator. This enables us to produce rank-orderings for 76 *upazilas* that lose fish species and 11 *upazilas* that gain species (23 *upazilas* exhibit no change). Among the 20 *upazilas* with top-ten loss and gain indices, 19 are in Khulna and one (a species loss case) is in Barisal.

Our summary results provide striking evidence that projected aquatic salinization may have a strongly regressive impact on poor households in the Sundarbans region. For both poverty definitions, we find that poverty populations in *upazilas* that lose and gain species have a ratio of approximately 6:1. Adverse impacts are anticipated for net loss of fish species on purchasing power through sale of fish for households dependent on capture fishery and on direct nutritional contribution of fish consumption. In Bangladesh, small fish are generally sold in rural markets and can be purchased in affordable quantities by the rural poor and shared more equitably among household members, including women and children (Roos et al., 2007). Most of the rural poor cannot afford to purchase alternative sources of animal protein,

[22] Toufique and Belton (2014) reported increased supply of fish from commercial aquaculture in Bangladesh from 2000 to 2010. However, they also noted that total fish consumption by extremely poor and poor households remained more or less constant, around only 9 kg and 13 kg per capita respectively from 2000 to 2005; and total fish consumption of extremely poor and poor households increased only by 0.7 kg and 0.5 kg during 2005 to 2010, The low increase in consumption of fish by the poor during high growth of production of aquaculture indicates the reliance of the poor on capture fishery.

[23] Carp (*Labeo rohita, Catla catla, Cirrhinus mrigala*), exotic carps (silver carp - *Hypophthalmus molitrix*, Grass carp- *Ctenopharyngodon idella*, Common carp - *Cyprinus carpio*), catfish (*Pangasius hypophthalmus*), Nile tilapia and Java berb (*Barbonymus gonionotus*), other small catfish (*Heteropneustes fossilis, Clarias batrachus, Ompok pabda, Mystus tengara*), climbing perch (*Anabas testudineus*) and prawn (*Macrobrachium rosenbergii*).

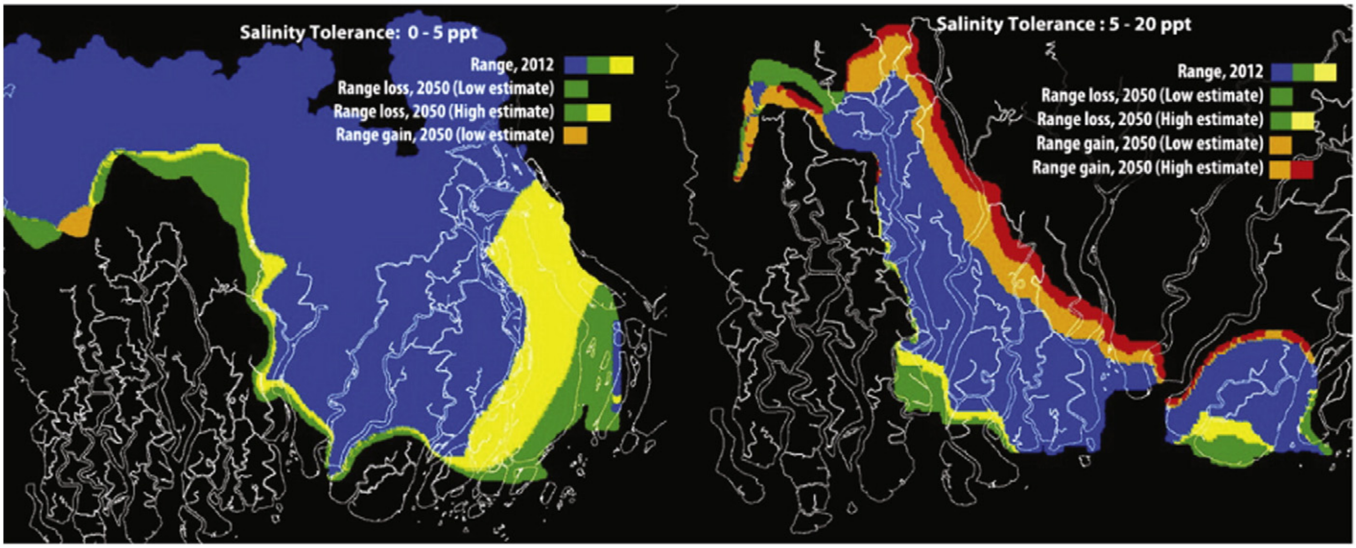

Fig. 5. Range changes for illustrative fish species (0–5 ppt and 5–20 ppt) typically consumed by poor households. High estimate: Scenario: A2, GCM: IPSL-CM4, SLR: 32 cm, Land subsidence: 9 mm/year. Low estimate: Scenario: B1, GCM: MIROC3.2, SLR: 27 cm, Land subsidence: 2 mm/year. Note: In this figure, color-coded sections identify fish habitat ranges in 2012 for two different salinity scenarios. The blue/green/yellow colored sections show fish habitat areas in 2012; the green section reflects range loss in 2050 "low" estimate scenario, the yellow reflecting additional loss in a 2050 "high" estimate scenario. Additional red/orange color sections show 2050 range gain: orange for "low" estimate scenario, and the addition of the red section in a "high" estimate scenario.

such as beef, lamb, poultry and eggs. Given that fish is the main source of animal protein in the diet of 43.2 million poor people, and that chronic as well as acute malnutrition levels, as indicated by statistics on wasting and stunting of children in Bangladesh, are higher than the WHO's thresholds for public health emergencies,[24] our finding is serious and emphasizes the importance of mainstreaming climate change in relevant policies, action plans and programs in the country.

As we note in the paper, we must attach one strong caveat to our results. Our measure of potential risk is simply the change in species count because we do not have good evidence on other important factors: species-specific fishing yields, commercial values, preference for freshwater and brackish-water fish and dietary status of the poor. It is possible that these factors would reinforce our results, but it is also possible that they could be countervailing, perhaps strongly so. Inclusion of these factors and especially the feasibility of substitution of freshwater fish by brackish-water fish should be a high priority for future research on aquatic salinization, fish habitat changes, and poverty impacts in the Sundarbans region. Our research also highlights the importance of systematic data collection for monitoring impacts of climate change on fish and other aquatic species.

Nevertheless, to the best of our knowledge, this paper presents the first thorough analysis of expected impacts of climate change and river salinity on the habitats of 83 fish species. It is expected that this analysis will serve as a foundation for further analyses of climate change and fisheries in Bangladesh. The paper will contribute to multiple ongoing and future action plans and programs under the Environment Policy 1992,[25] National Fisheries Policy 1998,[26] the Coastal Zone Policy 2005,[27] the Climate Change Action Plan 2009[28] and Strategic Plan for Health Population and Nutrition Sector Development Program 2011–2016 of Government of Bangladesh.[29]

It should also be noted that the Government of Bangladesh has already adopted the Ocean/Blue Economy initiative to promote sustainable and inclusive growth and employment opportunities in maritime economic activities, highlighting its important role in poverty alleviation, ensuring food and nutrition security and sharing prosperity in the short, medium and long time frames.[30] In this context, priorities have been assigned to increasing sustainable fishing capacity, promoting sustainable management of small-scale fisheries, supporting artisanal communities' access to information, technology, finance, regulation and governance processes to ensure their year-round employment, and increasing the share of capture fisheries in fish production through protection and restoration of critical habitats (see Alam, 2015 for details). It is well recognized that addressing climate change impacts on fisheries is critical for protection and restoration of critical habitats and increasing sustainable fishing capacity, as well as promoting sustainable management of fisheries. Our paper with the baseline of fish habitats in 2012 and the detailed scenario analysis of possible impacts of climate change and aquatic salinity on fish species habitats for the Sundarbans region will provide a science-based approach essential for mainstreaming climate change in adaptive management and decision-making essential for developing the Blue Economy. In light of our findings, introduction of coastal and/or sea fish breeding programs and sea ranching to enhance diversity of key species, establishment of conservation measures to protect fish breeding areas and nurseries, establishment of protected areas and marine reserves are expected to produce beneficial outcomes.

[24] Government of Bangladesh: Strategic Plan for Health Population and Nutrition Sector Development Program (HPNSDP) 2011–2016, http://www.bma.org.bd/pdf/strategic_Plan_HPNSDP_2011-16.pdf.

[25] Bangladesh Environmental Policy 1992: Conservation of habitats for fish (Stated Objective 3.8.1).

[26] Bangladesh National Fisheries Policy 1998, Page 2: Stated objectives are enhancement of fisheries production, poverty alleviation through creating self-employment and improvement of socioeconomic conditions of the fisheries, fulfillment of the demand for animal protein, achievement of economic growth through earning foreign currency by exporting fish and fish and fisheries, maintenance of ecological products' balance and conservation of biodiversity. http://faolex.fao.org/docs/pdf/bgd149571.pdf.

[27] Bangladesh Coastal Zone Policy 2005: Provision of basic needs and opportunities for livelihoods (Framework 4.2a), Sustainable management of natural resources (framework 4.4c), http://lib.pmo.gov.bd/legalms/pdf/Costal-Zone-Policy-2005.pdf.

[28] Bangladesh Climate Change Strategy and Action Plan 2009: Research and knowledge management of impacts of climate change on ecosystems and biodiversity (Pillar 4.3), linkages between climate change, poverty and vulnerability (Pillar 4.5a), linkages between climate change, poverty and health to identify interventions to increase the resilience of the poor and vulnerable households to climate change (Pillar 4.5b). http://www.climatechangecell.org.bd/Documents/climate_change_strategy2009.pdf.

[29] Bangladesh HPNSDSP 2011–2016: Action plans for mainstreaming nutrition services of the Directorate General of Health Policy (DGHS).

[30] Alam, 2015.

Appendix 1

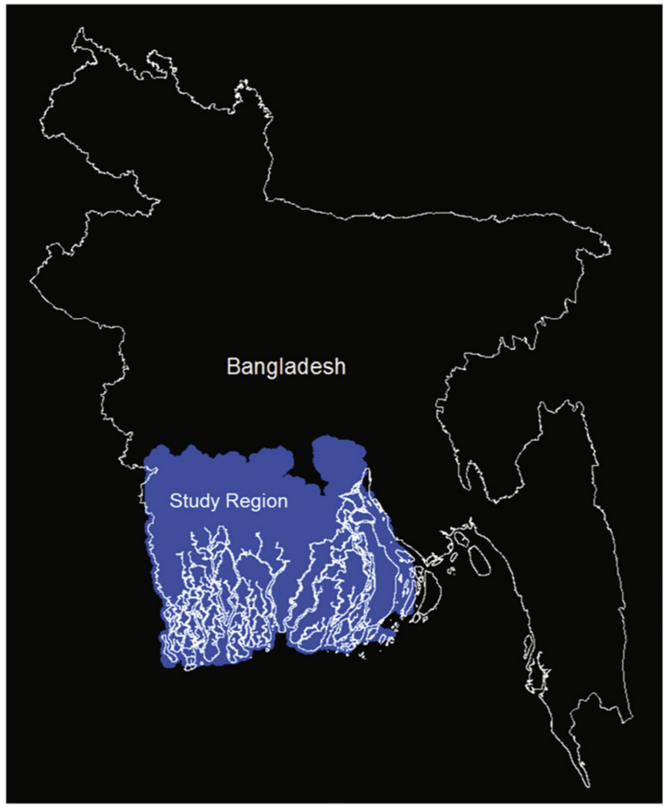

Fig. A1. Geographical area of the study.

Table A1
Salinity tolerance ranges: Fish species found and consumed in southwest coastal region and Sundarbans.
Sources: Hussain et al., 2013; Rahman and Asaduzzaman, 2010; MoEF, 2010: Robin et al., 2010; Gain et al., 2008; Mustafa, 2003: Mustafa and Prava Dey, 1994; Kasim, 1979.

Fresh water tolerant species				
Scientific Name	Bangladesh Name	English Name	Salinity tolerance (ppt)	
			Min	Max
Clarias batrachus	Magur	Walking catfish	0	2
Heteropneustes fossilis	Shing	Stinging catfish	0	2
Anabas testudineus	Koi	Climbing perch	0	5
Catla catla	Catla	Carp	0	5
Channa orientalis	Gachua	Snakehead	0	5
Channa punctatus	Taki	Spotted snakehead	0	5
Channa striatus	Shol	Snakehead murrel	0	5
Chela laubuca	Kash khaira	Indian grass barb	0	5
Cirrhinus reba	Bata	Reba carp	0	5
Clupisoma garua	Ghaura	River catfish	0	5
Dermogenys pussilus	Ekthota	Wrestling halfbeak	0	5
Eutropiichthys vacha	Bacha	River catfish	0	5
Gagata cenia	Kauwa	River catfish	0	5
Labeo calbasu	Kalibaus	Carp	0	5
Labeo gonius	Goinna	Carp	0	5
Mystus tengara	Bajari tengra	Long bled catfish	0	5
Nandus nandus	Meni	Perch	0	5
Nemacheilus botia	Loach	Zipper loach	0	5
Notopterus notopterus	Foli	Bronze featherback	0	5
Ompak bimaculatus	Kani pabda	Butter catfish	0	5
Ompok pabda	Pabda	Butter catfish	0	5
Puntius sophore	Jatputi	Pool barb	0	5
Puntius ticto	Tit puti	Ticto barb	0	5
Salmostoma bacaila	Katari	Minnow	0	5
Wallago attu	Boal	Freshwater shark	0	5
Xenentodon cancila	Kakila	Garfish	0	5
Aorichthys aor	Ayre	Long barb catfish	0	10
Gagata gagata	Gang tengra	Catfish	0	10
Glossogobius giurus	Baila	Tankqoby	0	10

(continued on next page)

Table A1 (*continued*)

Fresh water tolerant species

Scientific Name	Bangladesh Name	English Name	Salinity tolerance (ppt) Min	Max
Macrobrachium birmanicus	Nazari icha, shul icha	Freshwater prawn	0	10
Macrobrachium dolichodactylus	Icha	Freshwater prawn	0	10
Macrobrachium lamarrei	Thenga icha	Freshwater prawn	0	10
Macrobrachium malcolmsonii	Boro icha	Indian freshwater prawn	0	10
Macrobrachium villosimanus	Dimua icha	Dimua river prawn	0	10
Macrobrachiurn rudis	Kucha chingri	Hairy river prawn	0	10
Monopterus cuchia	Kuicha baim	Mud eel	0	10
Mystus bleekeri	Golsha tengra	Long bled catfish	0	10
Mystus tengara	Tengra	Catfish	0	10
Mystus vittatus	Tengra	Catfish	0	10
Pseudambassis ranga	Lal chanda	Indian glassy perchlet	0	10
Himantura fluviatilis	Saplapata	Gangetic stingray	0	15
Pellona ditchela	Choikka	Indian pillona	0	15
Palaemon styliferus	Gura icha	Freshwater prawn	0	20
Thryssa dussumieri	Phasa	Dussumiers thryssa	0	20
Scylla serrata	Kakra	Mud crab	0	30

Saline water tolerant species

Scientific name	Bangladesh name	English name	Salinity tolerance (ppt) Min	Max
Apocryptes bato	Chiring	Goby	5	10
Odontamblyopus rubicandas	Lal chewa	Irubicundus ee!goby	5	10
Parapocryptes batoides	Chewa, chirin	Goby	5	10
Plotosus Canius	Kaim Magur	Canine ell tail fish	5	20
Arius caelatus	Mad, kata	Engraved cat fish	5	20
Arius gagora	Mad, kata	Gagor cat fish	5	20
Arius thalassinus	Mad, kata	Giant sea cat fish	5	20
Coilia ramkoranti	Olua	Tepertail anchovy	5	20
Cynoalossus lingua	kukurjib	Long tonguesole	5	20
Cynoglossus cynoglossus	Kukurjib	Gangetic tonguesole	5	20
Eleuthronema tetradactylum	Thailla	Fourfingor throadfin	5	20
Harpadon nehereus	Loytta	Bombay duck	5	20
Liza spp	Bata	Mullet	5	20
Mystus gulio	Guilla,nuna tengra	Long-whiskered catfish	5	20
Pangasius pangasius	Pangas	Fatty cat fish	5	20
Polynemus indicus	Lakhua	Indian threadfin	5	20
Rhinomugil corsula	Kholla,bata	Yellow tail mullet	5	20
Scatophagus argus	Bishtara	Spotted scat	5	20
Setipinna taty	Tailla phasa	Scally hair fin anchovy	5	20
Setippina phasa	Phasa	Gangetic hairfin anchovy	5	20
Sillago domina	Hundra, tolar dandi	Ladyfish	5	20
Macrobrachiurn rosenbergii	Golda chingri	Giant freshwater prawn	5	25
Lepturacanthus savala	Chhuri	Ribbonfish	5	30
Panna microdon	Poa	Panna croker	5	30
Pomadasys maculatus	Guti datina	Blotched grunt	5	30
Tenualosa ilisha	Ilish	Hilsa shad	5	30
Therapon jarbua	Barguni	Therapon porch	5	30
Trichiurus leopturus	Buri	Ribbon fish	5	30
Johnius sp	Poa mach	Jew fish	5	30
Lates calcarifer	Bhetki, koral	Seabass, barramundi	5	30
Mugil cephalus	khorul bata	Flathoad grey mullet	5	30
Liza parsia	Pashia,bata	Gold spot mullet	10	20
Penaeus indicus	Chaga chingri	Indian white shrimp	10	30
Metapenaeus lysianassa	Hanny	Brown shrimp	10	35
Metapenaeus monoceros	Horina chingri	Brown shrimp	10	35
Penaeus monodon	Bagda chingri	Tiger shrimp	10	35
Parapenaeopsis uncta	Kddi chingri	Uncta shrimp	15	35

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