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Impact of Climate Change and Aquatic Salinization on Fish Habitats and Poor Communities in Southwest Coastal Bangladesh and Bangladesh Sundarbans

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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 living near the UNESCO Heritage Sundarbans mangrove forest, and they supply a significant portion of protein for millions. Among the various threats fisheries in the southwest coastal region and Sundarbans mangrove forest will face because of climate change, adverse impacts from increased aquatic salinity caused by sea level rise have been identified as one of the greatest challenges. This paper focuses on 83 fish species consumed by poor households in the region. Using the salinity tolerance range for each species, 27 alternative scenarios of climate change in 2050 were investigated to assess the possible impacts of climate change and sea level rise on aquatic salinity, fish species habitats, and the poor communities that consume the affected fish species. 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.

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1. Introduction

Around 43.2 million people or 30 percent of the population of Bangladesh live in poverty. This figure includes 24.4 million extremely poor people who are not even able to afford their basic needs of 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, 2014).

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. The vulnerability of coastal regions to flooding, storm surges and salinity will further increase in this century, according to the climate projections of the Intergovernmental Panel on Climate Change and the World Meteorological Organization. Climate change thus poses a serious threat to the livelihoods of the poor in the southwest coastal region, especially because they are burdened 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 regional economy, especially in areas close to the Sundarbans mangrove forest (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 2000; Alam and Thomson 2001; Thilsted 2010; Thisted 2012; Fernandes 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. Significant threats from human actions are likely to continue in the future, and 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, Uddin and Sana, 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. Fishing communities are among the poorest of the poor in Bangladesh, so understanding these impacts is critical for ensuring the future sustainability of fishing-dependent households.

Within the southwest coastal region, Sundarbans ecosystem supports a wealth of fish diversity,[2] provides a refuge for fish from predators, and serves as a nursery for the larvae and juveniles of 90 percent of commercial fish and 35 percent of all fish in the Bay of Bengal (USAID 2010). 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

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

[2] According to IUCN, water bodies in the Sundarbans (ruvers, streams and canals) covering 1,874 sq. km and marine zones covering 1,603 sq. km upport 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 lobster. See Shah et al., 2010 for details.

local fishermen, the researchers concluded that freshwater fish species declined by 59 percent in Paikgacha and 21 percent 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 Das 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 actual measures. In the most comprehensive study to date, Dasgupta et al. (2015) have used 27~~twenty seven~~ 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).

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 absence of comprehensive data on 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. 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.

The remainder of the paper is organized as follows. Drawing on prior work by Dasgupta, et al. (2015), Section 2 develops high-resolution digital maps of aquatic salinity in the Sundarbans region for 2012, and salinity in 2050 projected for 27 combinations of IPCC climate change scenarios, global circulation models, and assumptions about rates of land subsidence in the Ganges Delta. In Section 3, we develop a database for 83 fish species that are important for the livelihoods of poor households in the Sundarbans region. Section 4 combines our salinity projections with information on fish species salinity tolerances to produce maps of projected changes in habitats and local species populations by 2050. In Section 5, we combine projected changes in species populations with *upazila*-level information on poverty to assess the potential impacts of aquatic salinization on poor households in the Sundarbans region. Section 6 summarizes and concludes the paper.

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[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.

2. Current and Future Aquatic Salinity in the Sundarbans Region

This paper draws extensively on the findings of Dasgupta, et al. (2015), who quantify 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. Their research takes account of projected land subsidence in the Ganges Delta, as well as alternative levels of upstream freshwater withdrawal. The research develops 27 aquatic salinity scenarios in 2050 that incorporate three global emissions scenarios (B1, A1B, A2)[4] 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);[5] and three annual subsidence rates for land in the lower Ganges Delta (2, 5 and 9 mm/year). Each of the 27 scenarios is used to produce high-resolution maps of projected maximum aquatic salinity during December 2049 and six months in 2050: January-June.[6]

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[4] 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.

[5] 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.

[6] 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, salinity level drops sharply because of rainfall and upstream flow of freshwater through the river system and remains low until early October.

Figure 1 displays the estimated spatial distribution and intensity of maximum aquatic salinity in 2012 and two projections for 2050:[7] 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). The figure is color-coded to highlight changes in relatively low-salinity areas.

In 2012 (Figure 1(a)), most of the core Sundarbans region (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 (Figure 1(c)). The eastern part of Figure 1 presents a strong contrast in 2012, with most of the area dominated by very low maximum salinity (0-2 ppt). The 2050 B1 scenario (Figure 1(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 (Figure 1(c) - most change), with area dominance shifting to the range 3-5 ppt and further expansion of 6-10 ppt.

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

Fig 1: Sundarbans region: estimated maximum aquatic salinity in 2012 and 2050

(a) 2012
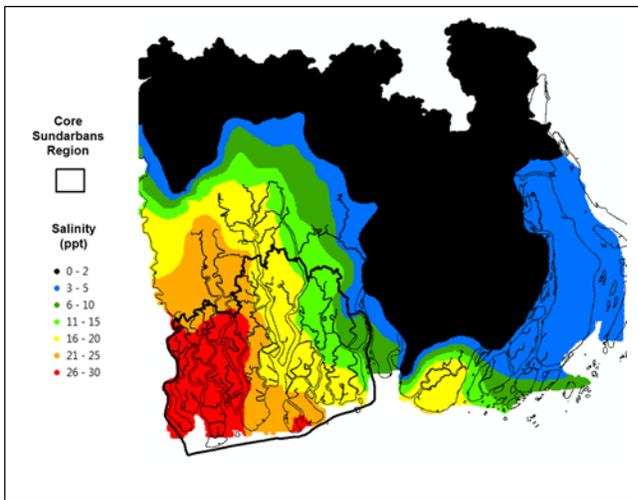
(b) 2050 (Least Change)
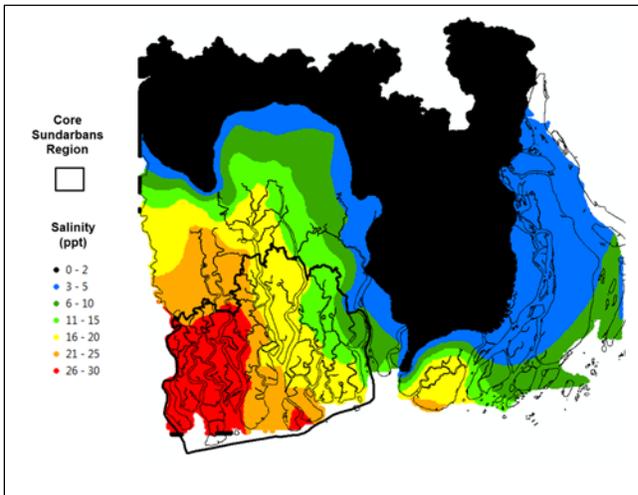
(c) 2050 (Most Change)
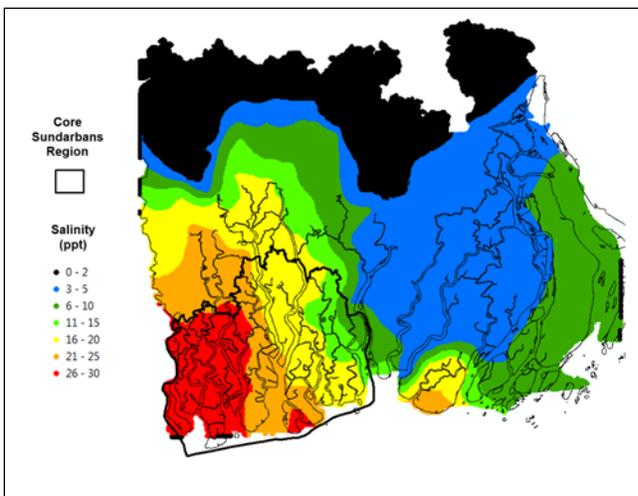
3. Fish Species in the Sundarbans Region

The area changes in Figure 1 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.[8] In this paper, we focus on 83 fish species that are consumed by households in the southwest coastal region as well as in the Sundarbans region. Appendix A1 identifies these species. We compiled salinity tolerance range 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 Dey 1994; Kasim 1979.) Table 1 enumerates the species by salinity tolerance range.

Table 1: Southwest coastal and Sundarbans regions: fish species consumed by households

	Salinity Tolerance (ppt)*		Number of Species
Group	Min	Max	Species
1	0	2	2
2	0	5	25
3	0	10	14
4	0	15	2
5	0	20	3
6	5	10	3
7	5	20	21
8	5	25	1
9	5	30	7
10	10	30	1
11	10	35	3
12	15	35	1
		Total	83

*Salinity tolerance intervals were selected based upon consultation with local experts.

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[8] 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.

Figures 1(a) and 1(c) strikingly illustrate the potential impact of climate change and sea level rise on species in salinity tolerance groups 1 and 2. For the two species in group 1 (tolerance range 0-2 ppt), stable habitat occupies a large swath of the eastern region (approximately 15,363 sq. km) in 2012 but practically disappears from that area by 2050 in the A2 (most change) scenario. The potential stakes are also high for the 25 species in group 2, which comprise 30% of all fish species consumed in the Sundarbans region. In 2012, almost the entire eastern part of the Sundarbans region is stable habitat for group 2. In the A2 scenario for 2050, however, maximum salinity has moved beyond the tolerance range of group 2 in broad north-south swaths at the eastern and western margins of the eastern part. By implication, poor communities in these swaths might face significant drops in fish supply by 2050.

4. The Impact of Salinization on Fish Habitats

We generalize the previous illustration using the digital salinity maps provided by Dasgupta, et al. (2015). For each of the 12 species salinity tolerance groups, we assign 1 to a pixel in the map for 2012 that satisfies the stable habitat criterion (pixel salinity range falls within the species tolerance range) and 0 otherwise. We add across 101,600 pixels to determine total stable habitat by salinity tolerance group in 2012.[9] 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 2 and 3.

Table 2 displays all the results, ordered by local subsidence level, IPCC AR4 scenario and global circulation model. We include summary information in Tables 3 and 4 to aid interpretation.

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

Table 3 reports median change rates across IPCC scenarios and GCMs for different salinity tolerance groups and rates of local subsidence.

Table 2: Stable habitat area change (%) 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 3: Median habitat change (%) by salinity tolerance and subsidence level

Group	Number of Species	Salinity Tolerance (ppt) Min	Salinity Tolerance (ppt) Max	Habitat Size in 2012 (Pixels)	Habitat size in 2012 (sq. km)	Local Subsidence (mm/year) 2	Local Subsidence (mm/year) 5	Local Subsidence (mm/year) 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	9,855	3,222.585	11.4	12.0	13.2
8	1	5	25	16,690	5,457.63	7.6	9.2	10.7
9	7	5	30	22,254	7,277.058	7.4	8.9	10.6
10	1	10	30	12,534	4,098.618	11.9	14.0	16.4
11	3	10	35	12,534	4,098.618	11.9	14.0	16.4
12	1	15	35	5,507	1,800.789	7.2	9.7	12.7

Table 3 highlights three major features of the results in Table 2. 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 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%) occurs for group 6 (tolerance range 5-10 ppt). Groups 10 and 11 also have relatively large habitat growth.

The second feature highlighted by Table 3 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 pixels or 15,363 and 20,827 sq. km respectively). Conversely, the greatest habitat increase rates are for groups 6, 10 and 11, which have much smaller habitats in 2012 (470, 12,534 and 12,534 pixels or 154, 4,099 and 4,099 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 pixels (20,827 sq. km) in 2012, and brackish water group 7, which comprises 21 species with a habitat of 9,855 pixels (3,223 sq. km).

The third striking feature of Table 3 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 2. To test these effects, we perform a regression analysis for the 324 change rates in Table 2 (27 scenarios, 12 salinity tolerance groups). We convert change rates to ranks in order to avoid scaling problems.[10] 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 regression feasible.[11] Table 4 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.

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

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

Table 4: Selected rank regression results for habitat change rates

Dependent variable: Rank of habitat change rate
(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%

5. The Potential Impact of Salinization on Poor Households

Figure 1 and Tables 2-4 reveal a spatially-uneven pattern of salinization and fish habitat change with continued climate change, sea level rise and land subsidence in the Sundarbans region. 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).[12] The potential impact on poor households will depend on their

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[12] 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).

vulnerability to changes in fish species in areas where salinization will significantly alter habitats.[13]

Vulnerability will in turn depend on the relative abundance, average size, 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 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). In addition, we have only spotty information about the relative abundance, commercial value and dietary status of the 83 fish species consumed by the poor in the Sundarbans 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.[14]

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[13] 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 percent of daily fish sales. Using the IPCC A1B emissions scenario, Farnandes et al. (2015) have predicted a 35 percent reduction in production of this species in Banglades's exclusive economic zone.

[14] This is an issue of major concern as fishery experts in Bangladesh indicated that significant gain of brackish fish species in the study region 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 systems, if at all. On the contrary, many freshwater fish species have low swimming speed, prefer local habitats and will cease to survive with increase 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 indicated that with change in aquatic salinity, a

5.1 Fish Species Change Scenarios for *Upazila*s in the Sundarbans Region

For each of the 83 species identified in Appendix Table A1, we build a digital map for 2012 that assigns 1 to pixels that satisfy the species' stable habitat criterion (pixel salinity range falls within the species' tolerance range) and 0 otherwise. We add across the 83 maps to determine total species with stable habitat in each of 101,600 pixels. Then we perform the same operations for all 27 salinity scenarios in 2050 and calculate percent changes (2012-2050) in total species for each pixel. Overlaying an administrative map shapefile provided by the Government of Bangladesh, we compute mean percent changes in the 27 scenarios for 110 *upazila*s in the Sundarbans region.

5.2 Poverty Incidence in the Sundarbans Region

We assess collective risk using estimated total poverty populations for *upazila*s in 2011. These are the product of 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;[15] and the lower poverty line, for extremely poor households whose total expenditures are at or below the food poverty line.

5.3 Risk Assessment for *Upazila*s in the Sundarbans Region

To illustrate the range of results produced by this exercise, we employ the two bounding scenarios for 2050 that are mapped at the pixel level in Figure 1: least change (Scenario B1, GCM MIROC-3.2, SLR 27 cm, land subsidence 2 mm/year); and most change (Scenario A2, GCM

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few coastal fish species may emerge gradually in inland water but their harvesting technology is costly and not affordable to the poor.

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

IPSL-CM4, SLR 32 cm, land subsidence 9 mm/year). We map the results for 110 *upazilas* in Figures 2 and 3. The maps illustrate two critical dimensions for priority-setting: percent change in species counts, and poverty populations identified using lower and upper poverty lines.

Figure 2 overlays color-coded changes in fish species with black circles scaled by lower poverty line populations. Figure 2(a) displays the scenario with least change (B1), while 2(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 2(b). Second, the two scenarios exhibit widespread species decrease in both scenarios, and strikingly higher decrease rates in 2(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.

Risk assessment 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 Figure 2(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 of Figure 3, because poverty populations are less skew-distributed when we employ the upper poverty line.

Fig 2: *Upazila* change scenarios, lower poverty line populations
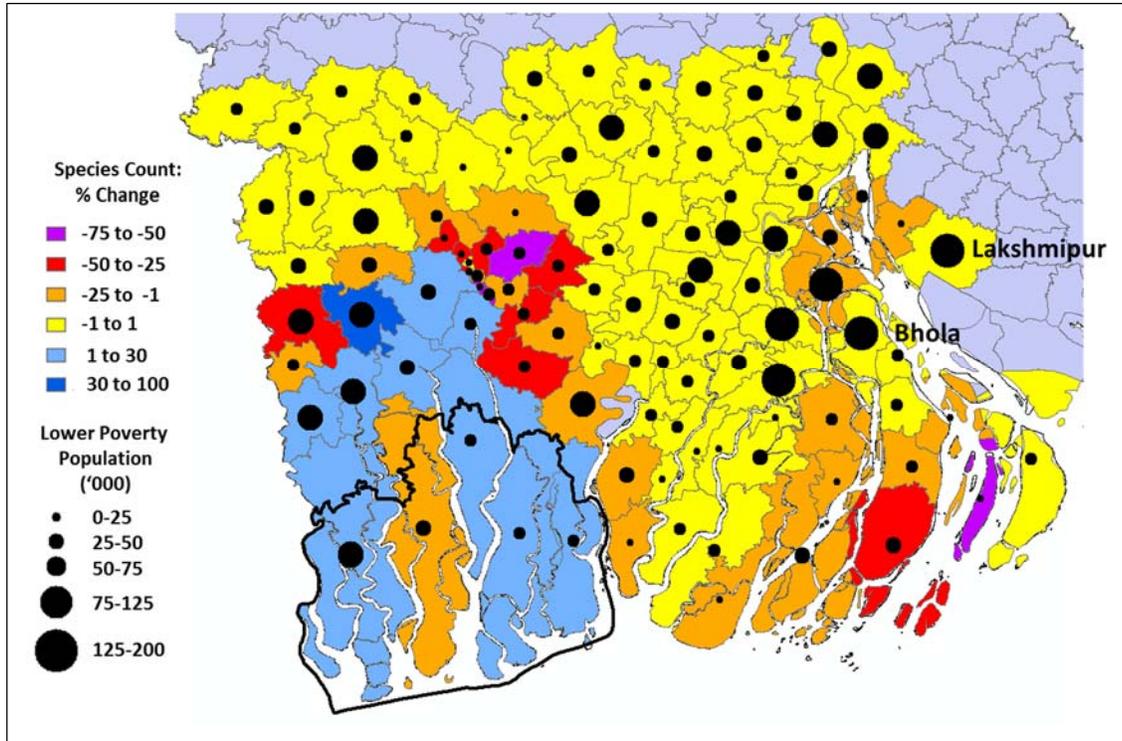
(a) Least Change

(b) Most Change
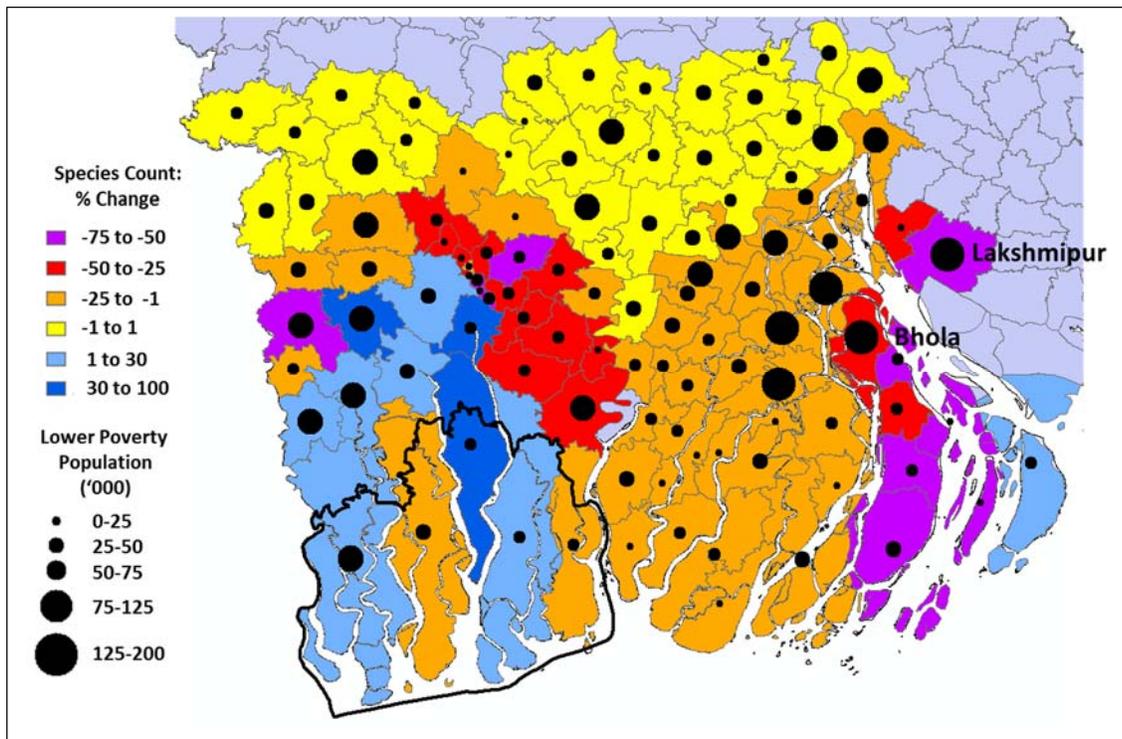
Fig 3: *Upazila* **change scenarios, upper poverty line populations**

(a) Least Change

Least Change Scenario, Upper Poverty Population

Species Count: % Change
- -75 to -50
- -50 to -25
- -25 to -1
- -1 to 1
- 1 to 30
- 30 to 100

Upper Poverty Population ('000)
- 0-40
- 40-80
- 80-120
- 120-180
- 180-320

(b) Most Change

Species Count: % Change
- -75 to -50
- -50 to -25
- -25 to -1
- -1 to 1
- 1 to 30
- 30 to 100

Upper Poverty Population ('000)
- 0-40
- 40-80
- 80-120
- 120-180
- 180-320
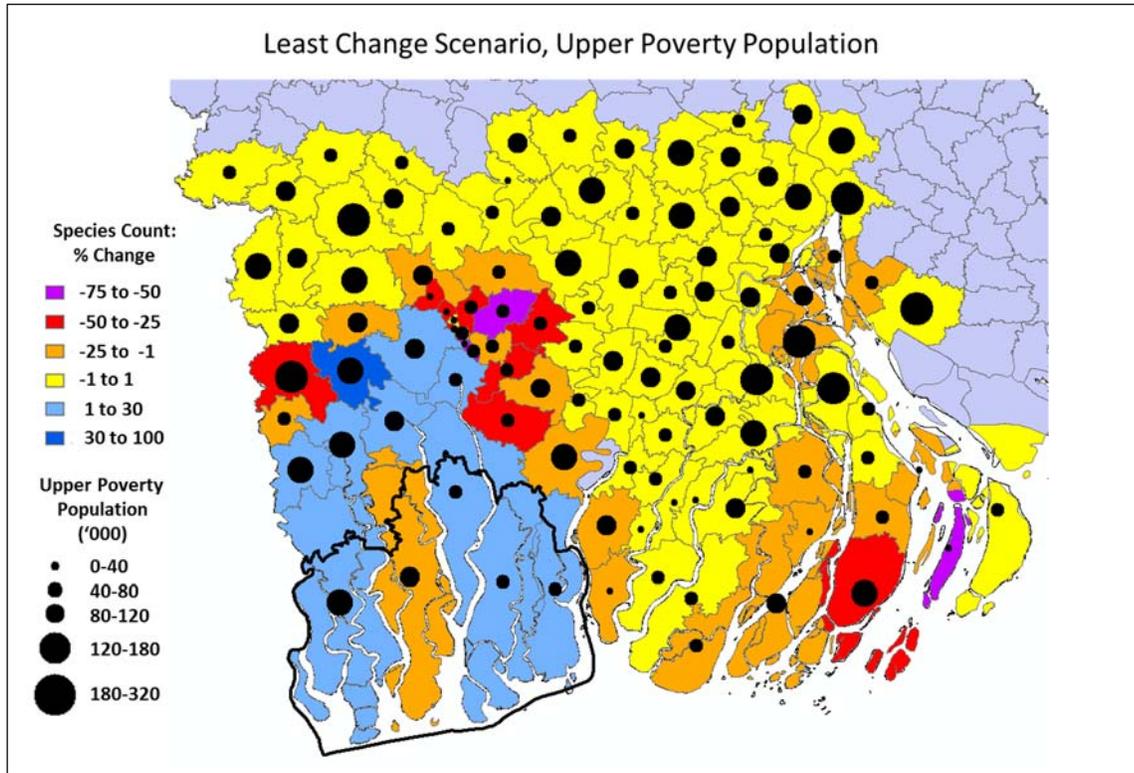
To provide a clearer basis for identifying priority cases, we construct more general risk indicators for all 27 scenarios and 2 poverty definitions. First, we multiply the species change rate in each *upazila* by its share of the region's poverty population to create a poverty-weighted species change 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.[16] Table 5 presents summary statistics for the three correlation exercises.

Table 5: Summary statistics: rank correlation coefficients for species change indices

*Upazila*s: 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

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 .89; the first- and third-quartile correlations are .84 and .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. We provide complete tabulations of our results in Tables A2 (76 *upazila*s that lose species), A3 (11 *upazila*s that gain species), and A4 (23 *upazila*s with no change). Figures 4 and 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,

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

Mollahat, Morrelganj, Rampal,[17] 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).

Fig 4: *Upazila*s with species losses: top ten index values
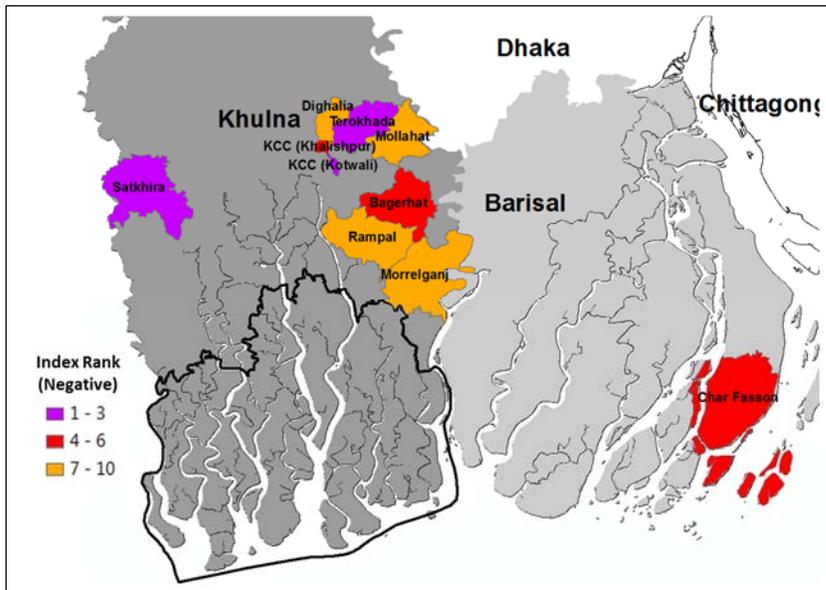
Fig 5 *Upazila*s with species gains: top ten index values

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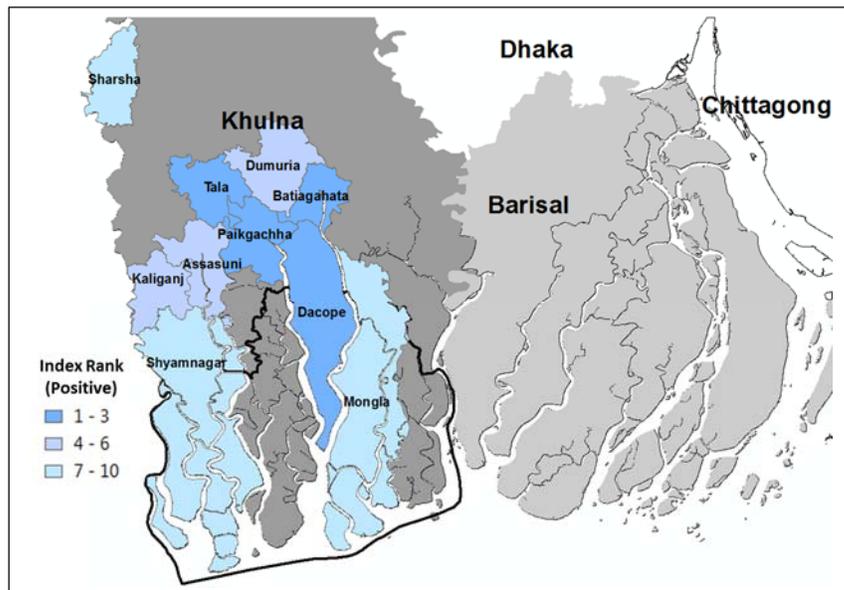
[17] Our findings for Rampal are in line with the reduction in fish diversity noted by Gain et al. (2008).

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 6 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 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.

Table 6: 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

To provide more concrete illustrations, the figures 6 and 7 below show the minimum and maximum variants from our twenty seven salinity change scenarios to portray projected range changes for a variety of species that are important for fish consumption by poor households.

Fig 6: Range Changes for Illustrative Fish Species (0-5ppt) typically consumed by the poor
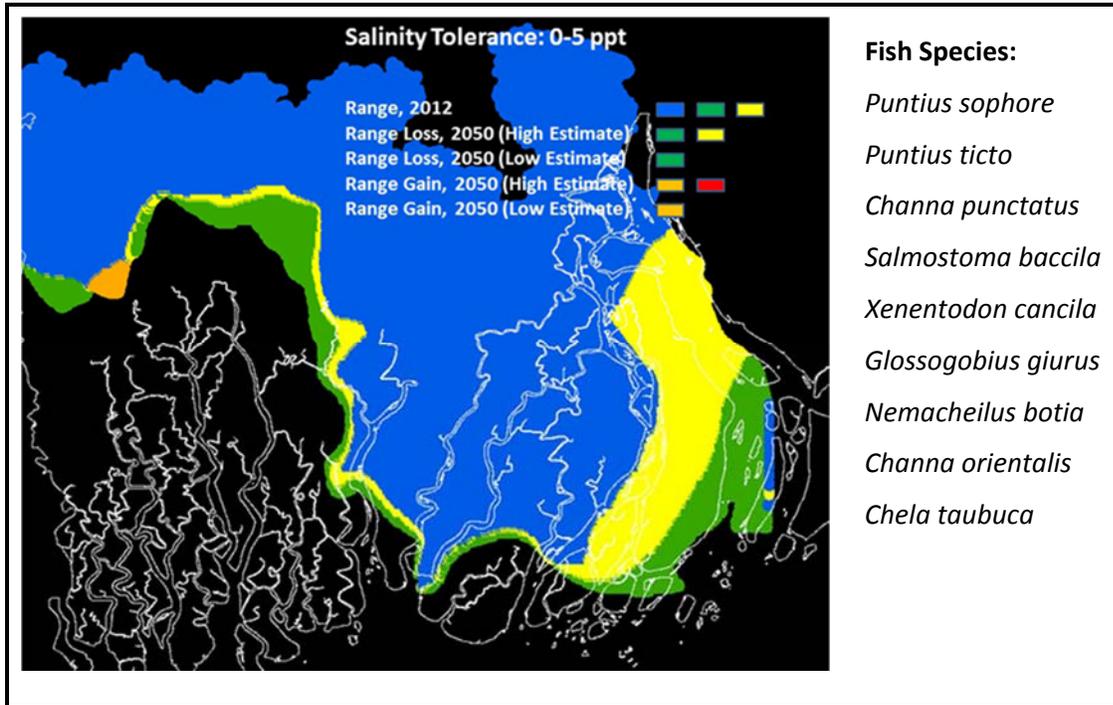
High estimate: Scenario: A2, GCM: IPSL-CM4, SLR: 32 cm, land subsidence: 9mm/year
Low estimate: Scenario: B1, GCM: MIROC 3.2, SLR: 27 cm, land subsidence: 2mm/year

Fig 7: Range Changes for Illustrative Fish Species (5-20ppt) typically consumed by the poor
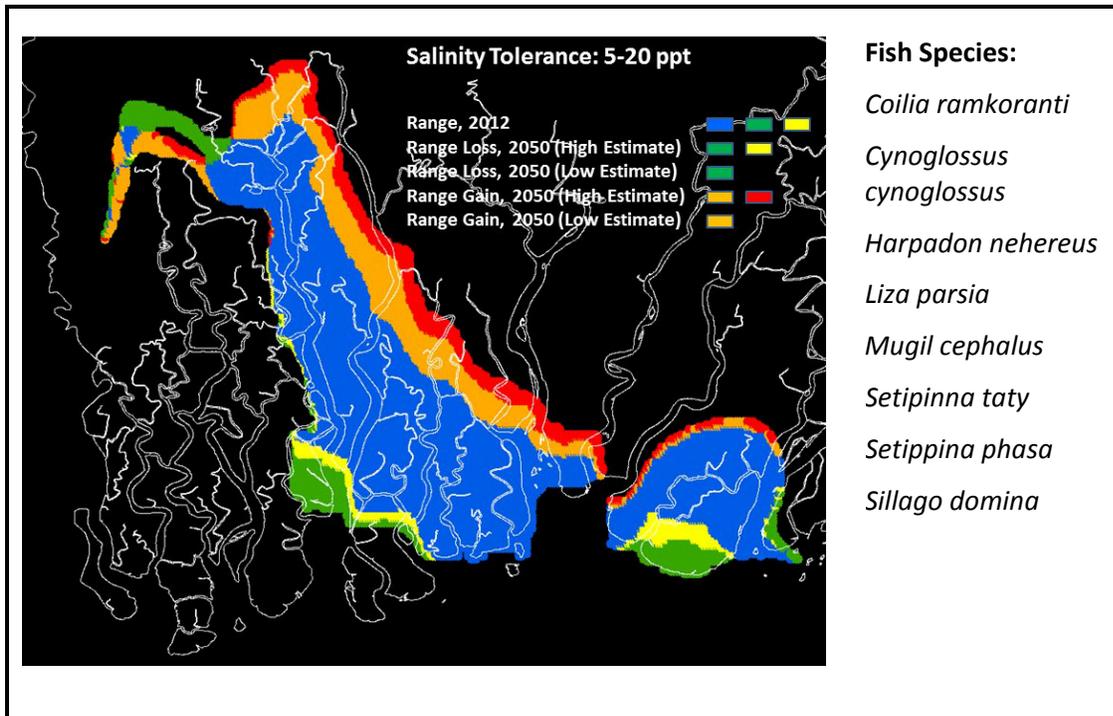
High estimate: Scenario: A2, GCM: IPSL-CM4, SLR: 32 cm, land subsidence: 9mm/year
Low estimate: Scenario: B1, GCM: MIROC 3.2, SLR: 27 cm, land subsidence: 2mm/year

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6. Summary and Conclusions

Data on water quality indicates river salinity increased significantly in southwest coastal region of Bangladesh over time (IWM 2003; Dasgupta et al. 2015). Scientists and hydrologists unanimously agree that river salinity in Sundarbans will increase due to sea level rise in a changing climate. In the absence of agreement among scientists about the time and spatial profile of climate change, 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. (2015), 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 pixels, at a resolution of 0.327 sq. km per pixel.

We focus on 83 fish species that are 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 pixel 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 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 *upazila*s 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 *upazila*s that lose fish species and 11 *upazila*s that gain species (23 *upazila*s exhibit no change). Among the 20 *upazila*s 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 *upazila*s that lose and gain species have a ratio of approximately 6:1. Given that fish is the main source of protein in the diet of 43.2 million poor people, and the 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,[18] 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

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[18] 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

important factors: species-specific fishing yields, commercial values 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 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 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,[19] National Fisheries Policy 1998,[20] the Coastal Zone Policy 2005,[21] the Climate Change Action Plan 2009[22] and Strategic Plan for Health Population and Nutrition Sector Development Program 2011-2016 of Government of Bangladesh.[23]

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 the maritime economic activities, and highlighted its important role in poverty

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

[20] Bangladesh National Fisheries Policy 1998, Page 2: Stated objectives ae enhancement of the 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 frowth 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

[21] 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

[22] 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

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

alleviation, ensuring food and nutrition security and sharing prosperity in the short, medium and long time frames.[24] 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, 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 result in rewarding outcomes.

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[24] Alam 2014.

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Table A1: Salinity tolerance ranges:
Fish species found and consumed in southwest coastal region and Sundarbans

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
Mystus vittatus	Tengra	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
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
Nematopalaernon tenuipes	Gura icha	Spider prawn	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
Scylla serrata	Kakra	Mud crab	0	20
Thryssa dussumieri	Phasa	Dussumiers thryssa	0	20

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
Lates calcarifer	Bhetki, koral	Seabass, barramundi	5	20
Liza parsia	Pashia,bata	Gold spot mullet	5	20
Liza spp	Bata	Mullet	5	20
Mugil cephalus	khorul bata	Flathoad grey 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
Penaeus Indicus	Chaga chingri	Indian white shrimp'	10	30
Metapenaeus lysianassa	Hanny	Brown shri mp	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

Sources: Hussain et al. 2013; Rahman and Asaduzzaman 2010; MoEF 2010: Robin et al. 2010; Gain et al. 2008; Mustafa 2003: Mustafa and Dey 1994; Kasim 1979.

Table A2: Impact indicator ranks for *upazila*s with fish species losses

Rank	Division	District	Upazila	Geocode	Percent Species Loss (27 Scenarios)				Poverty Population	
					Mean	Median	Max	Min	Lower Line	Upper Line
1	Khulna	Satkhira	Satkhira	48782	-47.99	-47.66	-53.06	-43.50	119,832	198,644
2	Khulna	Khulna	KCC (Kotwali)	44751	-72.82	-73.68	-73.68	-63.64	42,195	79,678
3	Khulna	Khulna	Terokhada	44794	-51.13	-51.05	-52.21	-51.05	35,013	57,888
4	Khulna	Bagerhat	Bagerhat	40108	-31.08	-31.26	-42.26	-16.82	49,548	95,634
5	Barisal	Bhola	Char Fasson	10925	-41.17	-51.00	-55.63	0.64	68,009	128,715
6	Khulna	Khulna	KCC (Khalishpur)	44745	-43.03	-42.11	-73.68	-15.79	38,845	67,938
7	Khulna	Bagerhat	Rampal	40173	-37.58	-38.91	-49.41	-29.04	34,867	63,691
8	Khulna	Bagerhat	Morrelganj	40160	-16.75	-16.45	-25.03	-9.52	79,536	136,978
9	Khulna	Bagerhat	Mollahat	40156	-31.39	-31.64	-37.29	-23.83	34,944	60,335
10	Khulna	Khulna	Dighalia	44740	-40.30	-40.36	-42.58	-38.11	25,313	45,425
11	Khulna	Bagerhat	Fakirhat	40134	-37.63	-36.87	-45.18	-30.81	26,455	50,155
12	Barisal	Bhola	Lalmohan	10954	-32.16	-38.15	-56.32	0.00	43,151	78,921
13	Khulna	Khulna	KCC (Sonadanga)	44785	-73.68	-73.68	-73.68	-73.68	12,245	32,374
14	Barisal	Bhola	Manpura	10965	-52.01	-52.33	-56.82	-44.86	14,857	25,119
15	Khulna	Jessore	Abhaynagar	44104	-17.56	-17.04	-28.02	-9.86	41,727	94,476
16	Khulna	Khulna	Rupsa	44775	-18.55	-16.91	-33.76	-8.58	36,263	66,243
17	Khulna	Khulna	Phultala	44769	-41.36	-41.82	-45.12	-32.17	14,260	28,268
18	Barisal	Bhola	Tazumuddin	10991	-42.89	-56.03	-56.82	-3.56	14,344	28,308
19	Barisal	Pirojpur	Mothbaria	17958	-7.75	-8.08	-10.81	-4.03	67,287	99,880
20	Khulna	Khulna	Koyra	44753	-9.51	-8.58	-17.56	-3.72	56,434	95,220
21	Barisal	Barisal	Barisal	10651	-3.39	-4.35	-4.35	-0.23	163,375	262,982
22	Barisal	Barisal	Mehendiganj	10662	-3.35	-2.82	-6.05	-1.37	150,523	193,874
23	Barisal	Patuakhali	Galachipa	17857	-11.58	-9.12	-20.59	2.16	52,059	93,995
24	Khulna	Satkhira	Debhata	48725	-13.06	-13.03	-13.13	-12.93	34,473	54,029
25	Barisal	Barisal	Bakerganj	10607	-3.32	-4.33	-4.33	-0.23	132,443	173,870
26	Barisal	Patuakhali	Kalapara	17866	-17.65	-19.15	-22.98	-8.39	23,070	48,280

					Percent Species Loss (27 Scenarios)				Poverty Population	
Rank	Division	District	Upazila	Geocode	Mean	Median	Max	Min	Lower Line	Upper Line
27	Khulna	Khulna	Khan Jahan Ali	44748	-28.27	-27.38	-35.82	-24.21	13,661	25,939
28	Khulna	Narail	Kalia	46528	-16.48	-16.44	-24.69	-7.67	21,360	51,307
29	Barisal	Bhola	Burhanuddin	10921	-18.21	-12.53	-49.48	-0.24	38,119	66,182
30	Khulna	Jessore	Keshabpur	44138	-6.59	-6.61	-11.87	-2.16	51,671	106,382
31	Barisal	Barisal	Hizla	10636	-4.07	-4.35	-4.35	-1.90	72,308	91,006
32	Khulna	Bagerhat	Kuchua	40138	-11.05	-8.99	-26.11	-0.46	22,895	41,230
33	Chittagong	Chandpur	Haimchar	21347	-4.35	-4.35	-4.35	-4.35	44,926	67,169
34	Barisal	Bhola	Bhola	10918	-10.05	-0.10	-43.01	-0.10	153,696	211,816
35	Barisal	Barisal	Muladi	10669	-3.06	-4.02	-4.18	0.00	77,076	101,719
36	Chittagong	Lakshmipur	Roypur	25158	-10.39	-4.35	-31.52	-4.35	23,939	45,952
37	Khulna	Jessore	Manirampur	44161	-2.15	-1.89	-5.05	-0.50	80,980	167,803
38	Barisal	Patuakhali	Bauphal	17838	-3.90	-4.19	-4.39	-2.76	42,295	73,028
39	Dhaka	Shariatpur	Gosairhat	38636	-2.17	-2.45	-3.44	-0.17	64,170	91,919
40	Barisal	Bhola	Daulatkhan	10929	-20.05	-5.14	-56.82	0.00	30,342	51,076
41	Barisal	Pirojpur	Pirojpur	17980	-2.26	-1.69	-5.35	-0.63	46,916	69,802
42	Barisal	Patuakhali	Patuakhali	17895	-2.90	-4.35	-4.35	0.00	73,736	116,774
43	Barisal	Patuakhali	Dashmina	17852	-6.28	-3.54	-13.59	-3.29	13,943	26,899
44	Barisal	Barguna	Barguan	10428	-3.26	-4.37	-5.10	-0.45	25,873	50,178
45	Barisal	Jhalokati	Nalchity	14273	-2.90	-4.35	-4.35	0.00	62,906	90,004
46	Barisal	Barguna	Amtali	10409	-2.09	-2.37	-4.04	-0.03	32,496	61,743
47	Barisal	Pirojpur	Bandaria	17914	-2.27	-2.85	-4.35	0.00	44,300	62,227
48	Barisal	Barisal	Babuganj	10603	-2.90	-4.35	-4.35	0.00	51,653	68,356
49	Barisal	Barisal	Wazirpur	10694	-1.60	-2.01	-3.09	0.00	88,815	122,414
50	Barisal	Jhalokati	Jhalokati	14240	-2.89	-4.35	-4.35	0.00	48,246	81,563
51	Khulna	Bagerhat	Chitalmari	40114	-1.22	-1.01	-2.53	-0.57	41,643	69,405
52	Chittagong	Chandpur	Chandpur	21322	-1.61	-2.90	-2.90	0.00	120,673	211,993
53	Barisal	Barguna	Patharghata	10485	-3.86	-3.61	-4.76	-2.81	10,000	21,147

Rank	Division	District	Upazila	Geocode	Percent Species Loss (27 Scenarios)				Poverty Population	
					Mean	Median	Max	Min	Lower Line	Upper Line
54	Barisal	Pirojpur	Nazirpur	17976	-0.51	-0.45	-0.84	-0.26	66,029	92,910
55	Barisal	Jhalokati	Rajapur	14284	-2.66	-3.89	-4.35	0.00	44,251	62,367
56	Barisal	Pirojpur	Nesarabad	17987	-1.69	-1.73	-3.80	0.00	63,521	91,377
57	Barisal	Barisal	Banaripara	10610	-1.83	-2.16	-3.69	0.00	56,460	77,354
58	Barisal	Barisal	Gaurnadi	10632	-1.31	-1.79	-2.35	0.00	75,246	104,665
59	Barisal	Barguna	Bamna	10419	-2.95	-4.35	-4.35	-0.05	7,081	13,605
60	Barisal	Jhalokati	Kanthalia	14243	-2.88	-4.35	-4.35	0.00	26,594	42,501
61	Khulna	Narail	Narail	46576	-0.87	-0.82	-1.29	-0.64	16,645	47,207
62	Chittagong	Lakshmipur	Lakshmipur	25143	-12.63	0.00	-56.82	0.00	197,114	312,098
63	Khulna	Narail	Lohagara	46552	-0.17	-0.12	-0.39	-0.04	17,373	45,490
64	Barisal	Barguna	Betagi	10447	-2.90	-4.35	-4.35	0.00	12,066	22,960
65	Barisal	Patuakhali	Mirzapur	17876	-2.90	-4.35	-4.35	0.00	11,685	21,665
66	Barisal	Pirojpur	Kawkhali	17947	-1.67	-0.97	-4.35	0.00	27,771	36,608
67	Barisal	Patuakhali	Dumki	17855	-2.90	-4.35	-4.35	0.00	9,256	15,544
68	Dhaka	Shariatpur	Bhedarganj	38614	-0.19	-0.06	-0.62	0.00	96,989	142,571
69	Khulna	Jessore	Jessore	44147	-0.02	-0.01	-0.15	0.00	121,835	262,243
70	Chittagong	Noakhali	Hatiya	27536	-9.18	0.00	-56.82	4.55	26,695	72,394
71	Dhaka	Gopalganj	Gopalganj	33532	0.00	0.00	-0.02	0.00	86,690	141,387
72	Barisal	Barisal	Agailjhara	10602	-0.06	0.00	-0.22	0.00	57,092	76,372
73	Dhaka	Shariatpur	Damudya	38625	-0.09	0.00	-0.38	0.00	32,047	52,212
74	Khulna	Khulna	KCC (Daulatpur)	44721	-0.66	0.00	-8.93	0.00	19,565	38,792
75	Dhaka	Madaripur	Kalkini	35440	-0.05	0.00	-0.23	0.00	43,175	90,722
76	Khulna	Satkhira	Kalaroa	48743	-0.10	-0.09	-0.97	0.58	68,304	109,476

Table A3: Impact indicator ranks for *upazila*s with fish species gains

Rank	Division	District	*Upazila*	Geocode	Percent Species Gain (27 Scenarios)				Poverty Population	
					Mean	Median	Min	Max	Lower Line	Upper Line
1	Khulna	Satkhira	Tala	48790	75.73	83.01	38.79	100.77	86,648	135,519
2	Khulna	Khulna	Dacope	44717	29.82	29.96	25.48	32.77	37,927	67,781
3	Khulna	Khulna	Batiagahata	44712	27.35	27.91	15.85	36.67	38,974	69,535
4	Khulna	Khulna	Paikgachha	44764	18.37	18.97	15.70	20.66	57,780	105,145
5	Khulna	Khulna	Dumuria	44730	16.45	17.84	2.23	30.50	59,912	113,711
6	Khulna	Satkhira	Assasuni	48704	10.48	12.62	2.21	16.95	86,001	130,077
7	Khulna	Satkhira	Kaliganj	48747	5.09	5.44	3.13	6.56	87,140	131,947
8	Khulna	Bagerhat	Mongla	40158	11.03	10.65	8.94	14.52	31,005	57,230
9	Khulna	Satkhira	Shyamnagar	48786	1.88	1.96	1.33	2.36	107,570	159,764
10	Khulna	Jessore	Sharsha	44190	0.39	0.40	0.34	0.43	66,218	139,262
11	Khulna	Bagerhat	Sarankhola	40177	1.27	1.79	-1.39	3.17	33,582	57,160

Table A4: *Upazila*s with no change in fish species

Division	District	Upazila	Geocode	Percent Species Change (27 Scenarios)				Poverty Population	
				Mean	Median	Min	Max	Lower Line	Upper Line
Dhaka	Faridpur	Nagarkandi	32962	0	0	0	0	37,996	71,045
Dhaka	Munshiganj	Lahajang	35944	0	0	0	0	32,008	53,505
Dhaka	Faridpur	Bhanga	32910	0	0	0	0	44,035	86,776
Chittagong	Chandpur	Uttar Matlab	21379	0	0	0	0	83,528	145,736
Khulna	Jessore	Chaugachha	44111	0	0	0	0	47,894	99,026
Khulna	Jhenaidah	Kaliganj	44433	0	0	0	0	27,107	67,768
Dhaka	Gopalganj	Muksudpur	33558	0	0	0	0	86,532	134,574
Khulna	Jessore	Jhikargachha	44123	0	0	0	0	53,505	116,275
Dhaka	Munshiganj	Munshiganj	35956	0	0	0	0	57,873	118,045
Dhaka	Gopalganj	Kashiani	33543	0	0	0	0	51,073	81,177
Dhaka	Gopalganj	Tungipara	33591	0	0	0	0	26,333	42,980
Dhaka	Madaripur	Rajoir	35480	0	0	0	0	35,221	71,815
Khulna	Jhenaidah	Maheshpur	44471	0	0	0	0	31,256	78,473
Dhaka	Shariatpur	Naria	38665	0	0	0	0	70,651	111,421
Khulna	Jessore	Bagher para	44109	0	0	0	0	45,331	92,181
Dhaka	Madaripur	Shib Char	35487	0	0	0	0	64,280	123,469
Dhaka	Faridpur	Boalmari	32918	0	0	0	0	55,181	100,867
Dhaka	Faridpur	Alfadanga	32903	0	0	0	0	16,787	32,382
Dhaka	Madaripur	Madaripur	35454	0	0	0	0	60,509	121,017
Dhaka	Gopalganj	Kotalipara	33551	0	0	0	0	63,847	100,495
Khulna	Magura	Shalikha	45585	0	0	0	0	40,424	72,337
Dhaka	Shariatpur	Zanjira	38694	0	0	0	0	67,713	104,770
Dhaka	Shariatpur	Palong	38669	0	0	0	0	66,442	104,709