Policy Research Working Paper 11048

Fishing and Climate Change in Coastal Bangladesh

The Economic and Health Impacts of Increasing Salinity

Brian Blankespoor
Susmita Dasgupta
Mainul Huq
Zahirul Huque Khan
Md. Golam Mustafa
David Wheeler

WORLD BANK GROUP
Development Research Group
Development Data Group &
Environment Global Department
January 2025

Policy Research Working Paper 11048

Abstract

The composition of flora and fauna in low-lying coastal regions worldwide is being altered by sea-level rise in a changing climate, favoring saline-tolerant species. These shifts are projected to have significant implications for nature-based livelihoods, resource availability, market prices, and the food and nutrition security of coastal populations, particularly those with limited choices and affordability. The vulnerabilities arising from these changes underscore the critical need for adaptation planning to build resilience. In the southwest coastal region of Bangladesh, rising sea levels and upstream changes in freshwater flux are intensifying riverine salinity, with annual flux dynamics driving substantial salinity changes and providing insights into future trends as high-salinity water encroaches further inland. In this study, river salinity monitor data were combined with fish sales records from nearby wholesale markets to evaluate the magnitude, spatial distribution, and fishing impact of salinity changes throughout 2023. Significant impacts on fish quantities were observed, and analysis of associated child health data revealed that salinity-related health challenges persist despite steady poverty reduction. Econometric analysis of fish catch records demonstrated that salinity changes differentially affect the availability of fish species with varying salinity tolerances, reflecting the interplay of species-specific salinity aversion and fishers' adaptive strategies to optimize profitable catches. These findings highlight the importance of complementing technical assessments of species-specific salinity tolerances with empirical salinity and catch data to improve projections of salinity impacts on fish consumption in affected regions. The results provide actionable insights into the dynamic interactions between environmental change, ecological responses, and human adaptation in coastal settings.

This paper is a product of the Development Research Group and the Development Data Group, Development Economics and the Environment Global Department. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at http://www.worldbank.org/prwp. The authors may be contacted at sdasgupta@worldbank.org.

Fishing and Climate Change in Coastal Bangladesh:
The Economic and Health Impacts of Increasing Salinity

Brian Blankespoor
Senior Geographer, World Bank

Susmita Dasgupta
Lead Environmental Economist

Mainul Huq
Consultant, World Bank

Zahirul Huque Khan
Advisor, Coastal Zone and River Management, Institute of Water Modeling, Bangladesh

Md. Golam Mustafa
World Fish, Bangladesh

David Wheeler
Consultant, World Bank

Corresponding author: Susmita Dasgupta, Lead Environmental Economist, Development Economics Research Group, The World Bank, 1818 H Street, Washington, DC 20008, USA. Tel: 1-202-473-2679. Email: sdasgupta@worldbank.org

Funding: This research was funded by a grant from the Global Environment Facility to a World Bank program managed by Nagaraja Harshadeep Rao, Susmita Dasgupta and Brian Blankespoor.

Acknowledgments: We extend our gratitude to Ms. Ajanta Dey, Mr. Mohammed Nesaruddin, and Mr. Pritthijit (Raja) Kundu for providing the photos. Special thanks to Dr. Md. Istiak Sobhan for his assistance with logistics and to Mr. Pritthijit (Raja) Kundu for his contributions to the graphics.

Keywords: Climate change; River salinity; Fishing; Child health; Bangladesh

JEL Code: Q21; Q22; Q25; Q54; I14

1. Introduction

Climate change is impacting every region on Earth at an unprecedented scale, with overwhelming scientific evidence documenting its accelerating effects (IPCC, 2023). A key consequence of climate change is the rising sea level, which has increased substantially since 1900. NASA reports that the current rise in global sea levels surpasses historical rates over at least the past 3,000 years. In the past century alone, sea level rose by approximately 0.15 to 0.25 meters (6–10 inches), with nearly half of this increase occurring since 1993. The pace of this rise has also quickened: from 2006 to 2018, the rate reached 3.7 mm per year, compared to 1.9 mm per year between 1971 and 2006, and 1.3 mm per year from 1901 to 1971.[1] Even with stabilized greenhouse gas emissions, it is virtually certain that sea levels will continue to rise beyond 2100. Conservative projections suggest that sea levels could rise by 1 meter by the end of the century. Recent data on deglaciation rates in Greenland and Antarctica, coupled with uncertainties around the dynamics of outlet glaciers, indicate that rapid breakups of the Greenland and West Antarctic ice sheets could result in an even more dramatic rise, potentially reaching 3 to 5 meters.

Sea-level rise exerts multifaceted impacts on coastal regions, including permanent inundation, cyclone-induced flooding, accelerated erosion, wetland loss, and the salinization of soil and water resources. While extensive research has highlighted land loss due to permanent flooding as a key risk (for example, see Blankespoor, Dasgupta and Laplante 2014; Dasgupta et al. 2009), salinization remains an underexplored yet critical consequence of rising seas. Regions such as the Nile Delta, Mekong Delta, and Ganges-Brahmaputra Delta are already experiencing significant salinity intrusion. For instance, in the Arab Republic of Egypt, 30%–40% of soils in the Nile Delta are adversely affected by salt, while seawater intrusion in the Mekong Delta poses serious threats to agriculture. The rising salinity is driving shifts in the composition of flora and fauna, favoring saline-tolerant species in low-lying coastal areas worldwide. These ecological changes have far-reaching implications for resource availability, market prices, and the food and nutrition security of coastal populations, particularly for those with limited resources and adaptive capacity. Addressing these vulnerabilities necessitates proactive adaptation planning to foster resilience in these increasingly fragile ecosystems. This paper examines a critical aspect of this poverty-environment nexus by analyzing the impact of increased salinity on fishing in coastal waters, with a focus on the southwest coastal region of Bangladesh.

The southwest coastal region of Bangladesh was selected as the study area as this area is among the poorest regions in the country and faces compounding challenges from climate change, including increased flooding, storm surges, and rising salinity (Dasgupta et al., 2021a,b; 2018; 2017; 2016a,b; 2015a,b; 2014; Steele et al. 2017). Poor households in this region are particularly vulnerable due to their reliance on fragile local ecosystems for livelihoods and the constraints imposed by poverty on their mobility.

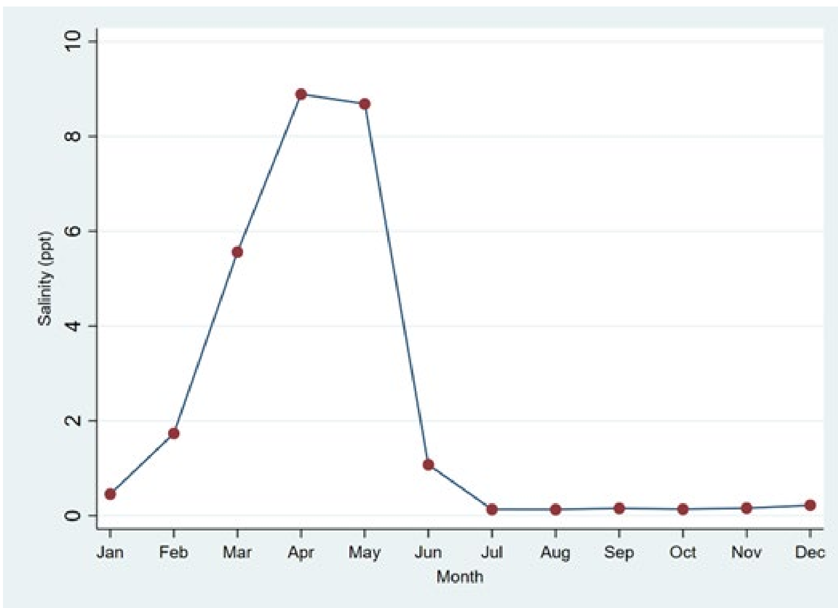
Extensive research has documented that coastal fisheries play a vital role in sustaining the livelihoods and nutritional needs of the region's poor households (World Bank, 2000; Alam and Thomson, 2001; Thilsted, 2010; Fernandes et al., 2015). However, these fisheries are increasingly threatened by climate-induced salinity changes resulting from sea-level rise and altered riverine flows (Dasgupta et al., 2016a; Gain, Uddin, and Sana, 2008). Local fish species, which vary in salinity tolerance, are adapting their ranges in response to shifting salinity patterns (Dasgupta et al., 2017). Such changes in the spatial and temporal

[1] https://sealevel.nasa.gov/understanding-sea-level/by-the-numbers/

distribution of fish have significant implications for fishing households and protein access for the broader poor population.

The study area also offers a valuable context for analyzing these dynamics, as seasonal freshwater fluxes from upstream drive marked variations in coastal salinity. During spring, when freshwater inflows diminish, marine salinity moves upstream, resulting in a surge in riverine salinity. Later, as freshwater inflows increase, salinity declines, stabilizing at low levels for the remainder of the year. These seasonal shifts provide a natural framework for investigating the ecological and socioeconomic impacts of salinity changes on coastal fisheries and dependent livelihoods. For example, Figure 1 illustrates this fluctuation with monthly mean salinity readings for (2020 – 2022) from a monitoring station on the Rupsha River in Khulna District. Over the annual cycle, river salinity varies from 0.13 ppt in August to 8.89 ppt in April, more than a 68-fold difference.

Figure 1: Monthly mean salinity – Rupsha River, Khulna



Source: The Institute of Water Modeling, Bangladesh

Riverine salinity fluctuations of this magnitude provide an excellent template for studying the impacts of salinity change on local fish supplies, prices and household welfare. This paper quantifies those impacts for many fish species, using a panel dataset that tracks monthly riverine salinities, catch quantities and prices at wholesale markets spread across the region.

The remainder of the paper is organized as follows. Section 2 introduces the salinity monitoring stations, the neighboring wholesale fish markets, the food fish species used for the analysis, and the survey exercise that has produced the panel dataset. In Section 3, we quantify the effects of salinity changes on species catch quantities in the river areas near the wholesale markets. Section 4 investigates the price responses to supply fluctuations created by varying salinity. In Section 5 we combine our results with Demographic and Health Survey (DHS) data from southwest coastal Bangladesh to assess the health impacts of salinity fluctuations. Section 6 summarizes and concludes the paper.

2. Data

2.1 River Salinity

Our salinity data are drawn from river monitoring stations spread across the southwest coastal region in five areas (Figure 2a): Khulna (Rupsha River), Mongla (Passur), Sarankhola (Boleshor), Amtali (Paira) and Galachipa (Ramnabad). Figure 3 displays monthly mean salinity readings for [2020 – 2022], which display the same peak salinity in the spring. However, Figure 3 and the table in Figure 2b also show that typical annual readings vary greatly from west to east because varying flux conditions create different mixing ratios for fresh and salt water. Each location has minimum salinity below 0.25 ppt, but maximum salinity varies from 0.23 ppt (Amtali) to 12.75 ppt (Mongla).

Figure 2: River monitoring stations

(2a) Station locations

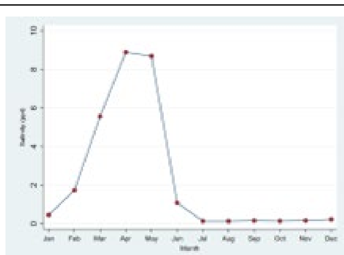
Source: The Institute of Water Modeling, Bangladesh

(2b) Salinity readings

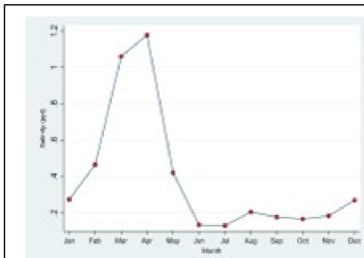
Station	Salinity (ppt) Min	Max
Khulna	0.13	8.89
Mongla	0.21	12.75
Sarankhola	0.13	1.18
Amtali	0.06	0.23
Galachipa	0.07	0.58

Figure 3: Monthly salinity readings

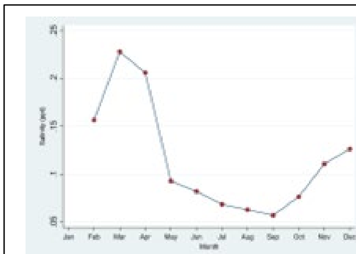
(3a) Khulna [Min 0.13; Max 8.89]



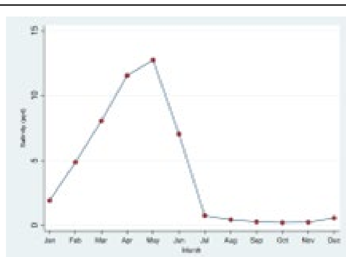
(3c) Sarankhola [Min 0.13; Max 1.18]



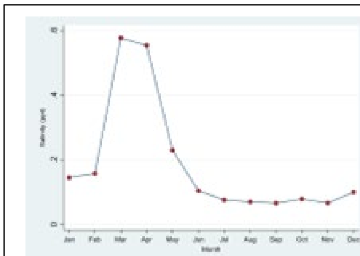
(3d) Amtali [Min 0.06; Max 0.23]



(3b) Mongla [Min 021; Max 12.75]



(3e) Galachipa [Min 0.07 Max 0.58]



2.2 Surveyed Fish Species

The 29 fish species included in this study have been drawn from Dasgupta et al. (2024), who use recent advances in machine-based pattern recognition to estimate occurrence maps for over 600,000 species reported by the Global Biodiversity Information Facility. During the period August – September 2024, the study team surveyed catch and price records for these species in five wholesale markets located near our salinity monitoring sites. Figure 4 identifies the locations of the markets, where the surveyors transcribed 832 records of daily catch quantities and prices for the 29 species during the months of March, May, July and October 2023. Table 1 displays the species' scientific names, along with their common names, mean prices and total catch volumes during the recorded period, and maximum water salinity tolerances. The table is sorted from lowest to highest price.

Figure 4: Locations of surveyed wholesale markets

Table 1: Surveyed fish species

Species	Common Name	Mean Wholesale Price (taka/kg)	Total Catch Quantity (kg)	Maximum Salinity (ppt)
Coilia dussumieri	Goldspotted anchovy	102	1844	20
Thunnus obesus	Bigeye tuna	122	549	30
Johnius coitor	Coitor croaker	139	551	30
Ilisha elongata	Herring	155	1936	20
Escualosa thoracata	White sardine	170	4183	30
Setipinna phasa	Gangetic hairfin anchovy	181	2087	20
Setipinna taty	Scaly hairfin anchovy	205	369	20
Euthynnus affinis	Kawakawa	215	1047	30
Labeo bata	Bata labeo	233	245	20
Sillaginopsis panijus	Flathead silago	279	2608	20
Pseudapocryptes elongatus	Pointed-tail goby	299	2470	10
Platycephalus indicus	Bartail flathead	318	171	30
Scomberomorus guttatus	King mackerel	323	1509	30
Pomadasys maculatus	Blotched grunter	325	310	30
Mystus gulio	Gulio catfish	341	3146	20
Stigmatogobius sadanundio	Knight goby	351	665	10
Otolithoides pama	Pama croaker	393	9917	30
Scomberomorus commerson	Spanish mackerel	397	1176	30
Lobotes surinamensis	Tripletail	398	1016	20
Rastrelliger kanagurta	Indian mackerel	426	841	30
Parastromateus niger	Black pomfret	457	723	30
Otolithes ruber	Tigertooth croaker	481	906	30
Plotosus canius	Eeltail catfish	576	577	20
Polynemus paradiseus	Paradise threadfin	583	5845	20
Pangasius pangasius	Fatty catfish	727	3817	20
Pampus argenteus	Silver pomfret	747	3946	30
Lates calcarifer	Lates perch	769	5594	30
Tenualosa ilisha	Hilsa shad	812	41826	30
Arius arius	Catfish	891	105	20

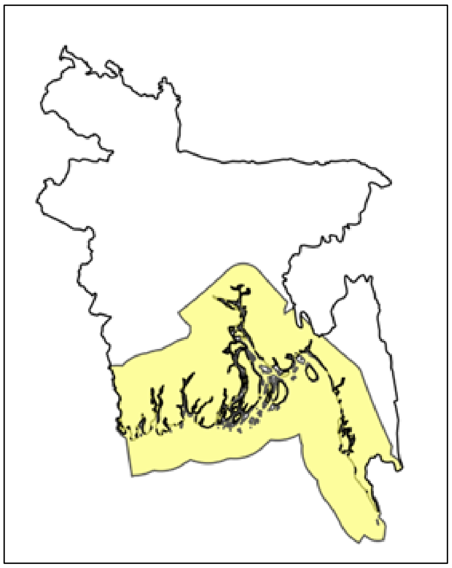
We illustrate using three species with widely varying prices and relatively large catch quantities.

Low-price species: Coilia dussumieri (Goldspotted Anchovy)

Figure 5 displays an image for *Coilia dussumieri* (Goldspotted anchovy), along with the GBIF occurrence map for Bangladesh and its Extended Economic Zone (Figure 5a). The survey records a total catch of 1,844 kg for this species, which is among the lowest-priced of those surveyed (102 taka/kg). As an affordable species for poor households, *Coilia dissumieri* is joined by *Thunnus obesus* (Bigeye Tuna), *Johnius coitor* (Coitor croaker), *Ilisha elongata* (Herring) and *Escualosa thoracata* (White sardine).

Figure 5: *Coilia dussumieri* (Goldspotted Anchovy)

(5a) GBIF occurrence map



(5b) Image

Source: https://commons.wikimedia.org/wiki/File:Coilia_dussumieri.jpg

Medium-price species: Mystus gulio (Gulio catfish)

Figure 6 displays an image for *Mystus gulio* (Gulio catfish), along with the GBIF occurrence map for Bangladesh and its Extended Economic Zone (Figure 6a). The survey records catch of 3,146 kg for *Mystus gulio*, which has a midrange price among the surveyed species (341 taka/kg).

Figure 6: *Mystus gulio* (Gulio catfish)

(6a) GBIF occurrence map

(6b) Image

Source: https://commons.wikimedia.org/wiki/File:Mystus_gulio.jpg

High-price species: Lates calcarifer

Figure 7 displays an image for *Lates calcarifer* (Lates perch), along with the GBIF occurrence map for Bangladesh and its Extended Economic Zone (Figure 7a). The survey records a relatively large catch (5,594 kg) and a high price (769 taka/kg) among the surveyed species.

Figure 7: *Lates calcarifer* (Lates perch)

(7a) GBIF occurrence map

(7b) Image

Source: https://commons.wikimedia.org/wiki/File:Lates_calcarifer%2C_2014-09-19a.jpg

3. Measuring Salinity Response

3.1 Catch Dynamics

The 29 species in Table 1 all have ranges that include riverine areas in southwest coastal Bangladesh, and they all have rated maximum salinity tolerances of at least 10 ppt. As Figures 2 and 3 show, the occurrence of salinity values greater than 10 ppt is rare in the study area. However, maximum salinity tolerances are more akin to survival values than environmental comfort indicators for fish. Different species with the same maximum saline tolerance ratings may well exhibit different propensities to leave an area of a river as its salinity rises, and return as salinity falls. By implication, salinity changes in part of a river may induce complex relocation patterns for food fish in the area. Local fishers will quickly perceive changes in catch size and species composition, and they will search for new areas where fishing will yield higher expected returns.

In summary, a change in salinity may prompt both fish and fishers to relocate, leading to complex changes in the stocks of fish that are sold in riverine wholesale markets. Even if all fish tend to relocate as salinity rises, leading to some decline in all local stocks, fishers' evaluation of catch probabilities and expected economic returns may prompt a shift of focus that increases the marketed quantities for some fish. By implication, food fish species may exhibit both positive and negative market supply responses to increased salinity. For this study, we employ our wholesale market survey data to quantify the comparative supply responses of 29 species as salinity changes. Figure 8 illustrates riverine fishing activities in coastal Bangladesh, showing float fishing in the Baleswar River Channel (Figure 8a) and cast net fishing (Figure 8b). Figure 8c depicts a typical fish market in Shyamnagar.

Figure 8: Riverine fishing activity in coastal Bangladesh

(8a) Float fishing, Baleswar River Channel

Photo credit: Mohmmed Nesaruddin

(8b) Shore fishing, Sundarban

Photo Credit: Ajanta Dey

(8c) Fish market, Shyamnagar

Source: Mohmmed Nesaruddin

(8d) Fish vendor, Dhaka

Photo Credit: Pritthijit (Raja) Kundu

3.2 Illustrative Cases

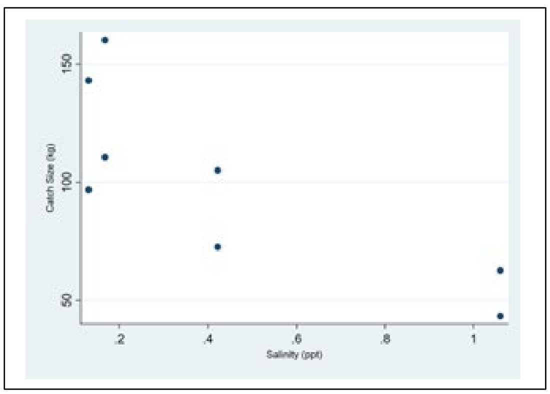
We select two species, *Scomberomorus guttatus* (King mackerel) and *Scomberomorus commerson* (Spanish mackerel) to illustrate the variability of catch dynamics. Both King and Spanish mackerels are medium-price species in regional wholesale markets (323 and 397 taka/kg, respectively), both have medium-scale total catch quantities (1,509 and 1,176 kg) and both have a maximum salinity tolerance rating of 30 ppt. Nevertheless, the market data show that their catch quantities respond very differently to changing salinity. Their responses show that variable catch dynamics can generate both negative and positive salinity responses for different species.

Strongly negative catch response: Scomberomorus guttatus (King mackerel)

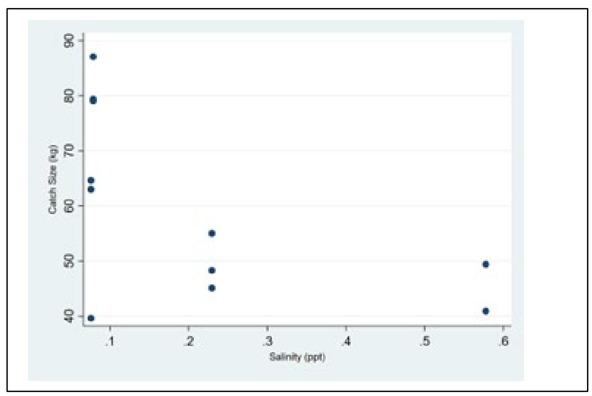
King mackerel catches are reported for Sarankhola and Galachipa (Figure 9). In Sarankhola, as salinity rises from about 0.15 to 1.1 ppt, the typical catch declines from around 125 kg to around 55 kg. In Galachipa, as salinity rises from around 0.1 to 0.6 ppt, the typical catch falls from around 70 kg to around 45 kg.

Figure 9: *Scomberomorus guttatus* (King mackerel): catch quantity vs. salinity

9(a) Sarankhola Upazila



9(b) Galachipa Upazila

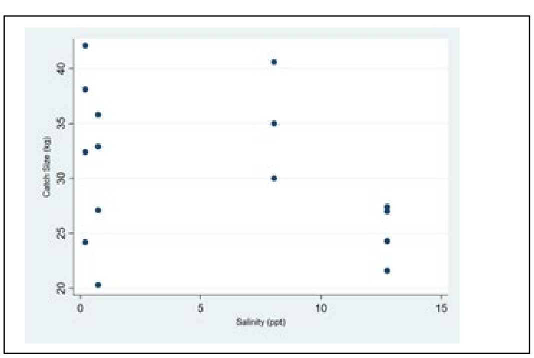


Neutral to positive catch response: Scomberomorus commerson (Spanish mackerel)

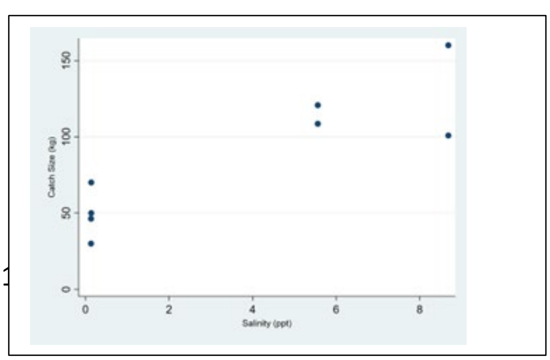
Figure 10 displays fish catch data for *Scomberomorus commerson*. In Mongla, as salinity rises from about 0.20 to 12.8 ppt, the typical catch for the Spanish mackerel has no apparent trend. In Khulna, as salinity rises from around 0.13 to 8.7 ppt, the typical catch rises from around 50 kg to around 130 kg.

Figure 10: Scomberomorus *commerson (Spanish mackerel)*: catch quantity vs. salinity

10(a) Mongla Upazila



10(b) Khulna



3.3 Econometric Measurement of Catch Quantity Response

We use econometric estimation to generate species-level measures of salinity response elasticity: the percent change in catch quantity associated with a 1 percent change in riverine salinity. Our econometric model captures interactions between local riverine salinity and species identity. We estimate the model in logarithm form because the estimated salinity parameters can be interpreted as elasticity measures.

$$(1)\quad \ln(Q_i) = \beta_{0+} \sum_i \beta_i D_{Ui} + \sum_j \gamma_j D_{Fj} + \epsilon_0 \ln(S_i) + \sum_j \epsilon_j D_{Fj} \ln(S_i) + \varepsilon_i$$

where Q_i = Catch quantity at market location (upazila) i

D_{Ui} = Dummy variable for upazila i (1 if upazila i; 0 otherwise)

D_{Fj} = Dummy variable for fish species j (1 if fish species j; 0 otherwise)

S_i = River salinity near upazila i

In model (1), the log of a catch quantity recorded at the market in upazila i is a function of upazila-specific factors ($\beta_i D_{Ui}$), the species caught ($\gamma_j D_{Fj}$), the log of riverine salinity near the market (S_i), and the interaction of salinity with species factors ($D_{Fj} \ln(S_i)$). For each species (j), the salinity response elasticity is given by:

$$(2)\quad \epsilon_{Fj} = \epsilon_0 + \epsilon_j$$

We have estimated the model with 832 observations; full results are presented in Appendix Table A1. The model fit is robust, with an adjusted R^2 of 0.55 and high significance for many parameter estimates. The results have been combined with equation (2) to produce the species salinity response elasticities in Table 2. These vary from -.49 for *Labeo bata* (0.49% *decline* in catch size for each 1% increase in salinity) to 0.20 for *Platycephalus indicus* (0.20% *increase* in catch size for each 1% increase in salinity). For our two illustrative examples, Table 2 shows that *Scomberomorus guttatus* (King mackerel) has an overall saline response elasticity of -.08. For *Scomberomorus commerson* (Spanish mackerel), the elasticity is +0.07.

Table 2: Species salinity response elasticities

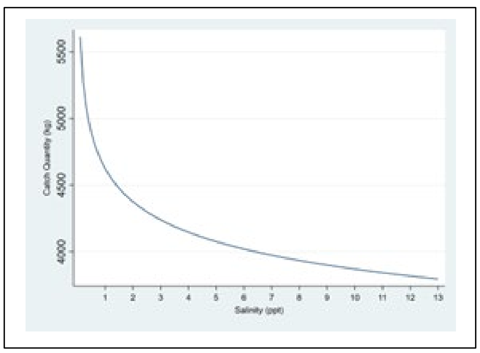
Species	Common Name	ε_0	ε_j	ε_{Fj}
Labeo bata	Bata labeo	-0.26	-0.22	-0.49
Arius arius	Catfish	-0.26	-0.14	-0.40
Sillaginopsis panijus	Flathead silago	-0.26	-0.09	-0.35
Otolithoides pama	Pama croaker	-0.26	-0.08	-0.35
Euthynnus affinis	Kawakawa	-0.26	-0.05	-0.31
Tenualosa ilisha	Hilsa shad	-0.26	0.00	-0.26
Setipinna phasa	Gangetic hairfin anchovy	-0.26	0.05	-0.21
Pangasius pangasius	Fatty catfish	-0.26	0.06	-0.20
Pampus argenteus	Silver pomfret	-0.26	0.13	-0.14
Johnius coitor	Coitor croaker	-0.26	0.13	-0.13
Pomadasys maculatus	Blotched grunter	-0.26	0.14	-0.12
Polynemus paradiseus	Paradise threadfin	-0.26	0.15	-0.11
Coilia dussumieri	Golds potted anchovy	-0.26	0.15	-0.11
Scomberomorus guttatus	King mackerel	-0.26	0.18	-0.08
Pseudapocryptes elongatus	Pointed-tail goby	-0.26	0.19	-0.07
Escualosa thoracata	White sardine	-0.26	0.20	-0.06
Rastrelliger kanagurta	Indian mackerel	-0.26	0.22	-0.05
Ilisha elongata	Herring	-0.26	0.23	-0.04
Thunnus obesus	Bigeye tuna	-0.26	0.23	-0.03
Lobotes surinamensis	Tripletail	-0.26	0.23	-0.03
Plotosus canius	Eeltail catfish	-0.26	0.24	-0.02
Setipinna taty	Scaly hairfin anchovy	-0.26	0.25	-0.01
Stigmatogobius sadanundio	Knight goby	-0.26	0.28	0.01
Mystus gulio	Gulio catfish	-0.26	0.29	0.03
Otolithes ruber	Tigertooth croaker	-0.26	0.31	0.05
Parastromateus niger	Black pomfret	-0.26	0.33	0.06
Scomberomorus commerson	Spanish mackerel	-0.26	0.33	0.07
Lates calcarifer	Lates perches	-0.26	0.33	0.07
Platycephalus indicus	Bartail flathead	-0.26	0.46	0.20

3.4 Predicted Catch Quantity Responses to Salinity Changes

All five wholesale markets are located within the boundaries of GBIF-determined occurrence maps for all 29 surveyed species. To assess the full implications of our results, we construct a prediction dataset that includes all 2,900 combinations for 5 upazila locations, 20 observed salinities, and 29 species. Using the econometric results, we predict the catch quantity for each species at each location and salinity. For this exercise, we divide the fish species into three groups (see Table 1): low-price [100 – 200 taka/kg], medium-price [201 – 500 taka/kg] and high-price [>500 taka/kg]. We are particularly interested in the low-cost species which are more important for poor households. Our results show a differentiated response across groups, but one that is more favorable to poor households. For the low-price species, increasing salinity from 0.1 to 13 ppt reduces the total catch by 32.4%, from 5,612 to 3,796 kg. The medium-price species catch declines by 35.5%, from 7,600 to 4,900 kg, while the high-price catch declines by 52.8%, from 3,147 to 1,484 kg.

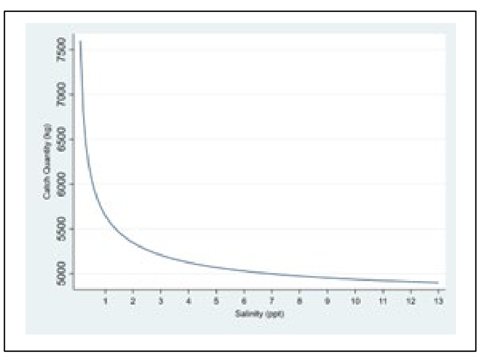
Figure 11: Total catch response to salinity change

11(a) Low-price species



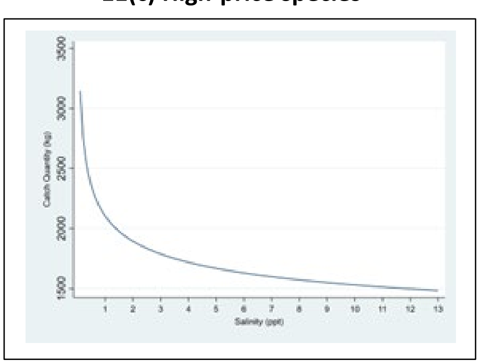
Min Catch	Max Catch	% Change
3,796	5,612	-32.4

11(b) Medium-price species



Min Catch	Max Catch	% Change
4,900	7,600	-35.5

11(c) High-price species



Min Catch	Max Catch	% Change
1,484	3,147	-52.8

4 Econometric Measurement of Fish Price Response

We also test the impact of changing salinity on fish prices, taking account of price differentials across species and upazila locations. As we have seen, increasing salinity induces a significant decline in the fish catch and marketed quantity in local wholesale markets. Given the magnitude of the induced change, it would be plausible to expect the market response to include increased prices. We estimate model (3) separately for fish in the low-, medium- and high-price groups. Our estimation exercise includes testing for a lagged effect of salinity on price, and we find the best fit for a two-month lag. Full results are reported in Appendix Table A2. We find no significant price responsiveness to salinity change in the low- and medium-price groups. However, price does respond significantly to salinity change for high-price fish. We use the high-price regression results to predict the effect of increasing salinity on the mean unit price across species and upazilas. Figure 12 displays the result – a "mirror image" of the quantity effect for high-price fish in Figure 11(c). A sharp quantity decline as salinity increases from 0.1 to 4.0 ppt induces a corresponding increase in fish prices. Both effects diminish as salinity continues to increase. Overall, we find a modest price/salinity response: increasing salinity from 0.1 to 13 ppt increases the mean unit price by only 12.6%.

We find these results to be somewhat surprising, given the large quantity changes induced by changing salinity. Our results suggest that local wholesalers show great restraint in raising prices as available quantities fall, opting instead for some form of stock rationing. This topic may well warrant further research.

(3) $\ln(P_i) = \beta_{0+} \sum_i \beta_i D_{Ui} + \sum_j \gamma_j D_{Fj} + \epsilon \ln(S_i) + \varepsilon_i$

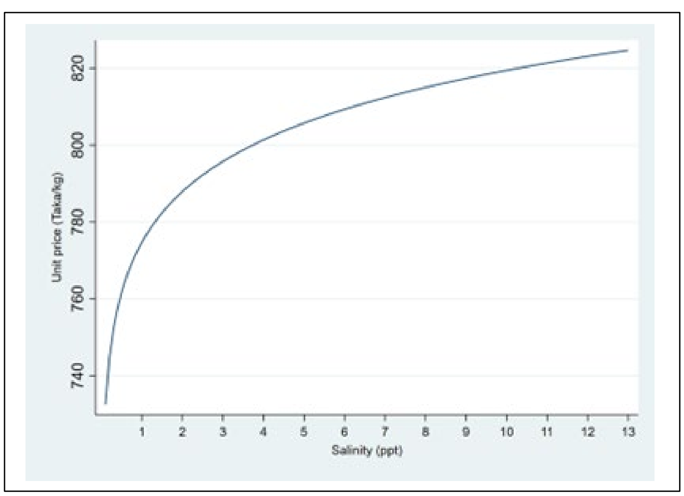
where P_i = Catch unit price (taka/kg) at market location (upazila) i

D_{Ui} = Dummy variable for upazila i (1 if upazila i; 0 otherwise)

D_{Fj} = Dummy variable for fish species j (1 if fish species j; 0 otherwise)

S_i = River salinity near upazila i

Figure 12: Price impact of salinity change – high-price fish species



5 Potential Health Impacts

The results in Section 3 show a large decline in the food-fish catch as riverine salinity moves from its minimum to maximum level during the year. A decline of this magnitude has potentially serious health implications for the region, since ample previous research has documented the role of fish protein intake in promoting mother/child health in Bangladesh (Rifata et al. 2023; Andrews et al. 2022; Dasgupta et al. 2021; Dasgupta and Wheeler 2019; Ferdous et al. 2015; Bogard et al. 2015). As Figure 3 and our econometric results show, the decline of food fish supplies is concentrated during the period of rapid riverine salinity increase in the spring. The magnitude of the associated health impacts depends upon whether mothers have the resources to compensate for declining fish supplies by increasing consumption of other protein sources. In this context, Bangladesh's recent progress in reducing poverty is notable. According to the World Bank's World Development Indicators, the country's multidimensional poverty headcount ratio was 31.3% in 2010, 20.5% in 2016 and 6.6% in 2022. While the southwest coastal area remains relatively poor when compared with other regions, it has undoubtedly benefited from this trend.

Under current conditions, are the resources of poor households adequate to compensate for the sharp salinity-induced swings in riverine fish supplies in the southwest coastal region? To address this question, we have extracted the relevant individual and household data from the two most recent Bangladesh Demographic and Health Surveys (DHS): 2022 and 2018. We have limited our sample to household clusters in the six southwest coastal districts that are most strongly impacted by salinity-driven fluctuation in fish supplies. The two most recent DHS surveys do not include survey information for the peak salinity months, so we cannot draw direct inferences from the data. However, they do include information about the birth months of surveyed children. This permits investigation of differences in child morbidity and mortality measures for children born during the three peak salinity months (March, April, May) when food fish stocks are sharply lower.

Table 3 reports our results for DHS sampling clusters in southwest coastal Bangladesh during the survey years 2018 and 2022. Sample sizes for the two years are 1,271 and 1,344 individuals. The table reports means and percent differences for probabilities of mortality, diarrhea and stunting for children born in peak salinity months and off-peak months.[2]

Table 3: Southwest coastal Bangladesh – peak salinity at birth and child morbidity/mortality[3]

N	Year	Peak Salinity Birth Month	Prob. Death	% Difference	Prob. Diarrhea	% Difference	Prob. Stunted	% Difference
1,271	2018	0	0.039		0.037		0.258	
	2018	1	0.048	25.187	0.062	69.896	0.280	8.787
1,344	2022	0	0.025		0.048		0.100	
	2022	1	0.028	13.333	0.040	-16.478	0.127	26.543

[2] We use the conventional definition of moderate to severe stunting, which corresponds to a height-for-age z-score below -2.0.

[3] The probability of death in Table 3 is the incidence of children reported dead for whom birth months are provided.

These results provide evidence that, despite recent poverty reduction in Bangladesh, children born in the southwest coastal region during peak salinity months have suffered from higher morbidity and mortality rates. For children born in peak salinity months, death probabilities in the 2018 and 2022 surveys are 25.2% and 13.3% higher, respectively. The evidence for diarrhea is mixed, with a probability 69.9% higher in 2018 but 16.5% lower in 2022. For stunting, children born in the peak salinity months have probabilities 8.8% higher in 2018 and 26.5% higher in 2022.

6 Summary and Conclusions

Rising sea levels and upstream changes in fresh water flux are combining to increase riverine salinity in the southwest coastal region of Bangladesh. At the same time, annual flux dynamics propel salinity changes so large that they can provide insights into future changes as high-salinity water moves steadily inland. This paper combines measures from river salinity monitors with fish sales records from neighboring wholesale markets to assess the magnitude, spatial distribution and fishing impact of salinity changes over the annual cycle in 2023. In traditional analyses, measured changes in river salinity are combined with species-level saline tolerance parameters to project changes in the spatial distribution of fish stocks. In this analysis, we incorporate two additional factors: differential responses to salinity change by fish species with similar survival limits for salinity exposure; and fishers' search for more profitable fishing grounds as the fish respond to changing salinity. Together, these two factors determine fluctuations in fish catches as salinity changes.

Our econometric analysis shows that the complex interplay of species-specific relocation behavior and fishers' search can generate very different catch patterns for fish that have similar or identical salinity tolerance ranges. For some species increasing salinity induces a sharp decline in the catch, while for others the interplay of relocation and fishers' profit-motivated search can induce an increase in the catch. The strength of our results suggests that technically determined saline tolerance parameters have limited utility as predictors of the magnitude and spatial distribution of fish catch quantities as salinity changes. Since fish catch records of the type we have surveyed are commonly available, we believe that future analyses could profit from the evidence they provide.

To assess the implications for households at different income levels, we have performed separate econometric analysis for low-, medium, and high-price fish. We find great responsiveness to salinity change in all groups, but the response of the fish catch to salinity change is greatest in the high-price group. In a parallel exercise, we have performed an econometric analysis of the fish price response as varying salinity changes the typical catch size. We find a statistically significant but relatively modest price response for high-price fish, perhaps reflecting a greater quantity response for luxury commodities. However, for low- and medium-price fish we find no significant price response to salinity change. This somewhat surprising result may warrant further research, since it suggests that fish sellers in southwest coastal Bangladesh choose to keep prices relatively stable for fish that are marketed to households of more modest means. By implication, reduced stocks in high-salinity periods are rationed by non-price methods.

Sudden drops in low-price fish supply during high-salinity periods may have significant consequences for protein consumption in low-income households, with associated impacts on maternal/child nutrition and health. The magnitude of the impact will depend on whether poor consumers' resources enable them to substitute other protein sources. Poverty has fallen significantly in Bangladesh during the past two decades, although the southwest coastal region has remained relatively poor by national standards. To test whether recent income growth has increased household resilience in this context, we analyze over

2,500 case records from DHS survey clusters for the southwest coastal region in 2018 and 2022. Our analysis asks whether three standard measures of child health – mortality, diarrhea incidence and stunting – are worse for children born during the annual peak salinity months. We find substantially higher mortality and stunting rates for children born during those months, while the results for diarrhea are mixed.

In summary, our research suggests two basic conclusions about salinity responses in southwest coastal Bangladesh. First, the results show that salinity change in riverine Bangladesh has very large consequences for fish protein availability, and the available evidence suggests that this remains a significant child health problem despite the continuing fall in the national poverty rate. The second conclusion relates to methodology. Traditionally, projections of salinity impacts on the size and spatial distribution of fish stocks have relied on technically determined salinity tolerance parameters. However, the results of our econometric analysis suggest that these parameters have limited utility for projecting the impact of salinity changes on actual fish catches. Future projection exercises might well benefit from using more empirical evidence on the timing and magnitude of fish catches as salinity changes.

With the near certainty that sea-level rise will persist beyond 2100, even with immediate stabilization of greenhouse gas emissions, coastal regions like Bangladesh are at the forefront of climate change impacts. Our research highlights how coastal communities adapt to increasing river water salinization by modifying their behaviors. These adaptive strategies provide valuable insights into the potential responses of millions of households worldwide who will confront similar challenges by the end of the century.

References

Alam, M. F., & Thomson, K. J. (2001). Current constraints and future possibilities for Bangladesh fisheries. *Food policy*, *26*(3), 297-313.

Andrews, C., Shrestha, R., Ghosh, S., Appel, K., Gurung, S., Ausman, L. M., ... & Webb, P. (2022). Consumption of animal source foods, especially fish, is associated with better nutritional status among women of reproductive age in rural Bangladesh. *Maternal & Child Nutrition*, *18*(1), e13287.

Bandyopadhyay, S., Dasgupta, S., Khan, Z. H., & Wheeler, D. (2021). Spatiotemporal analysis of tropical cyclone landfalls in Northern Bay of Bengal, India and Bangladesh. *Asia-Pacific Journal of Atmospheric Sciences*, 1-17.

Blankespoor, B., Dasgupta, S., & Laplante, B. (2014). Sea-level rise and coastal wetlands. *Ambio*, *43*, 996-1005.

Bogard, J. R., Hother, A. L., Saha, M., Bose, S., Kabir, H., Marks, G. C., & Thilsted, S. H. (2015). Inclusion of small indigenous fish improves nutritional quality during the first 1000 days. *Food and nutrition bulletin*, *36*(3), 276-289.

Dasgupta, S., Blankespoor, B., & Wheeler, D. J. (2024). *Revisiting Global Biodiversity: A Spatial Analysis of Species Occurrence Data from the Global Biodiversity Information Facility* (No. 10821). The World Bank.

Dasgupta, S., Wheeler, D., Bandyopadhyay, S., Ghosh, S., & Roy, U. (2022). Coastal dilemma: climate change, public assistance and population displacement. *World Development*, *150*, 105707.

Dasgupta, S., Mustafa, G., Paul, T., & Wheeler, D. (2021). The socioeconomics of fish consumption and child health: An observational cohort study from Bangladesh. *World Development*, *137*, 105201.

Dasgupta, S., & Wheeler, D. (2019). Accounting for Regional Differences in Mother and Child Health: Bangladesh, West Bengal, Bihar, and Jharkhand. *World Bank Policy Research Working Paper*, (8798).

Dasgupta, S., Hossain, M. M., Huq, M., & Wheeler, D. (2018). Climate change, salinization and high-yield rice production in coastal Bangladesh. *Agricultural and Resource Economics Review*, *47*(1), 66-89.

Dasgupta, S., Huq, M., Mustafa, M. G., Sobhan, M. I., & Wheeler, D. (2017). The impact of aquatic salinization on fish habitats and poor communities in a changing climate: evidence from southwest coastal Bangladesh. *Ecological Economics*, *139*, 128-139.

Dasgupta, S., Moqbul Hossain, M. D., Huq, M., & Wheeler, D. (2016a). Facing the hungry tide: Climate change, livelihood threats, and household responses in coastal Bangladesh. *Climate Change Economics*, *7*(03), 1650007.

Dasgupta, S., Huq, M., & Wheeler, D. (2016b). Drinking water salinity and infant mortality in coastal Bangladesh. *Water Economics and Policy*, *2*(01), 1650003.

Dasgupta, S., Hossain, M. M., Huq, M., & Wheeler, D. (2014). Climate change, groundwater salinization and road maintenance costs in coastal Bangladesh. World Bank Policy Research Working Paper, (7147).

Dasgupta, S., Kamal, F.A., Khan, Z.H., Choudhury, S., Nishat, A. (2015). *River Salinity and Climate Change: Evidence from Coastal Bangladesh*, in Asia and the World Economy - Actions on Climate Change by Asian Countries, 2015 (eds. John Whalley and Jiahua Pan). World Scientific Press, 205-242.

Dasgupta, S., Hossain, M. M., Huq, M., & Wheeler, D. (2015). Climate change and soil salinity: The case of coastal Bangladesh. *Ambio*, *44*, 815-826.

Dasgupta, S., Akhter Kamal, F. A. R. H. A. N. A., HUQUE KHAN, Z. A. H. I. R. U. L., Choudhury, S., & Nishat, A. (2015). River salinity and climate change: evidence from coastal Bangladesh. In *World scientific reference on Asia and the world economy* (pp. 205-242).

Dasgupta, S., Huq, M., Khan, Z. H., Ahmed, M. M. Z., Mukherjee, N., Khan, M. F., & Pandey, K. (2014). Cyclones in a changing climate: the case of Bangladesh. *Climate and Development*, *6*(2), 96-110.

Dasgupta, S., Laplante, B., Meisner, C., Wheeler, D., & Yan, J. (2009). The impact of sea level rise on developing countries: a comparative analysis. *Climatic change*, *93*(3), 379-388.

Ferdous, M. J., Sumon, M. A. A., Mahamud, A. N., Ara, M. G., Fatema, J., & Fatema, M. K. (2015). A comparative study on fish intake and nutritional status of children in different areas of Sylhet district, Bangladesh. *Int J Nat Soc*, *2*(4), 113-117.

Fernandes, J. A., Kay, S., Hossain, M. A., Ahmed, M., Cheung, W. W., Lazar, A. N., & Barange, M. (2016). Projecting marine fish production and catch potential in Bangladesh in the 21st century under long-term environmental change and management scenarios. *ICES Journal of Marine Science*, *73*(5), 1357-1369.

Gain, A. K., Uddin, M. N., & Sana, P. (2008). Impact of river salinity on fish diversity in the south-west coastal region of Bangladesh. *Int. J. Ecol. Environ. Sci*, *34*(1), 49-54.

Rifat, M. A., Wahab, M. A., Rahman, M. A., Nahiduzzaman, M., & Mamun, A. A. (2023). Nutritional value of the marine fish in Bangladesh and their potential to address malnutrition: A review. *Heliyon*, *9*(2).

Steele, J. E., Sundsøy, P. R., Pezzulo, C., Alegana, V. A., Bird, T. J., Blumenstock, J., ... & Bengtsson, L. (2017). Mapping poverty using mobile phone and satellite data. *Journal of The Royal Society Interface*, *14*(127), 20160690.

Thilsted, S. H. (2012). Improved management, increased culture and consumption of small fish species can improve diets of the rural poor. ." In Sustainable Diets and Biodiversity: Directions and Solutions for Policy, Research and Action Farming the Waters for People and Food. Edited by B. Burlingame and S. Dernini. Proceedings of the International Scientific Symposium on Biodiversity and Sustainable Diets United against Hunger, FAO Headquarters, Rome. November 3–5. Pages 176–81.

Thilsted, S. H. (2012). The potential of nutrient-rich small fish species in aquaculture to improve human nutrition and health. In Farming the Waters for People and Food. Edited by R.P. Subasinghe, J.R. Arthur, D.M. Bartley, S.S. De Silva, M. Halwart, N. Hishamunda, C.V. Mohan, and P. Sorgeloos. Proceedings of the Global Conference on Aquaculture 2010, Phuket, Thailand. September 22–25. Pages 57–73.

World Bank. 2000. Bangladesh: Climate Change and Sustainable Development. Report No. 21104-BD. Rural Development Unit, South Asia Region. December.

Appendix Table A1: Econometric results for model (1)

Dependent Variable: Log Catch Quantity (kg)

Variable		Parameter	t-Statistic
Upazila or District Location (Sarankhola excl.)			
Amtali		0.545***	(6.77)
Galachipa		0.188**	(2.64)
Khulna		0.429***	(3.41)
Mongla		-0.344***	(-3.78)
Species[a]	Common Name		
Pampus argenteus	Silver pomfret	-0.200	(-1.21)
Parastromateus niger	Black pomfret	-0.701***	(-3.50)
Scomberomorus commerson	Spanish mackerel	-0.797***	(-5.31)
Rastrelliger kanagurta	Indian mackerel	-0.220	(-0.52)
Scomberomorus guttatus	King mackerel	-0.566	(-1.93)
Polynemus paradiseus	Paradise threadfin	-0.876***	(-7.64)
Lates calcarifer	Lates perches	-0.802***	(-8.44)
Lobotes surinamensis	Tripletail	-0.744***	(-5.45)
Sillaginopsis panijus	Flathead silago	-0.584***	(-3.61)
Otolithes ruber	Tigertooth croaker	-0.209	(-0.50)
Otolithoides pama	Pama croaker	-0.638***	(-3.69)
Thunnus obesus	Bigeye tuna	0.00541	(0.02)
Ilisha elongata	Herring	0.444*	(2.35)
Setipinna phasa	Gangetic hairfin anchovy	-0.238	(-0.80)
Setipinna taty	Scaly hairfin anchovy	-0.0506	(-0.10)
Coilia dussumieri	Golds potted anchovy	-0.534***	(-3.54)
Pomadasys maculatus	Blotched grunter	-0.942*	(-2.48)
Mystus gulio	Gulio catfish	-0.426***	(-3.42)
Pangasius pangasius	Fatty catfish	-1.229***	(-7.63)
Plotosus canius	Eeltail catfish	-1.065*	(-2.34)
Arius arius	Catfish	-1.401**	(-2.60)
Labeo bata	Bata labeo	-0.659	(-1.22)
Euthynnus affinis	Kawakawa	-0.258	(-0.17)
Escualosa thoracata	White sardine	1.104***	(5.51)
Johnius coitor	Coitor croaker	-0.117	(-0.36)
Pseudapocryptes elongatus	Pointed-tail goby	-0.262	(-0.67)
Stigmatogobius sadanundio	Knight goby	-1.060***	(-7.05)
Platycephalus indicus	Bartail flathead	-0.707	(-0.99)

[a] The dummy variable for *Tenualosa Ilisha* has been excluded to prevent total collinearity.

Variable		Parameter	t-Statistic
Log Salinity (ppt)		-0.264***	(-7.49)
<u>Log Salinity x Species</u>	Common Name		
Pampus argenteus	Silver pomfret	0.126	(1.59)
Parastromateus niger	Black pomfret	0.326***	(3.33)
Scomberomorus commerson	Spanish mackerel	0.332***	(4.34)
Rastrelliger kanagurta	Indian mackerel	0.218	(0.90)
Scomberomorus guttatus	King mackerel	0.181	(1.15)
Polynemus paradiseus	Paradise threadfin	0.150*	(2.58)
Lates calcarifer	Lates perches	0.334***	(6.81)
Lobotes surinamensis	Tripletail	0.235**	(3.15)
Sillaginopsis panijus	Flathead silago	-0.0903	(-1.11)
Otolithes ruber	Tigertooth croaker	0.315	(1.29)
Otolithoides pama	Pama croaker	-0.0824	(-0.89)
Thunnus obesus	Bigeye tuna	0.234	(1.78)
Ilisha elongata	Herring	0.226*	(2.15)
Setipinna phasa	Gangetic hairfin anchovy	0.0498	(0.28)
Setipinna taty	Scaly hairfin anchovy	0.251	(0.68)
Coilia dussumieri	Golds potted anchovy	0.152*	(1.98)
Pomadasys maculatus	Blotched grunter	0.145	(0.51)
Mystus gulio	Gulio catfish	0.290***	(4.68)
Pangasius pangasius	Fatty catfish	0.0612	(0.79)
Plotosus canius	Eeltail catfish	0.242	(1.10)
Arius arius	Catfish	-0.138	(-0.30)
Labeo bata	Bata labeo	-0.222	(-0.48)
Euthynnus affinis	Kawakawa	-0.0476	(-0.07)
Escualosa thoracata	White sardine	0.202*	(2.06)
Johnius coitor	Coitor croaker	0.129	(0.82)
Pseudapocryptes elongatus	Pointed-tail goby	0.192	(1.05)
Stigmatogobius sadanundio	Knight goby	0.279***	(3.55)
Platycephalus indicus	Bartail flathead	0.460	(1.27)
Constant		4.558***	(58.30)
Observations	832		
Adj. R^2	0.55		

Significance:

*	**	***
$p<0.05$	$p<0.01$	$p<0.001$

Appendix Table A2: Econometric results for model (3)[a,b,c]

Dependent Variable: Log Price (taka/kg)

(a) Low-price fish

Amtali	1.237***	(9.47)
Mongla	-0.0475	(-0.90)
Sarankhola	0.486***	(6.52)
Coilia dussumieri	-0.313***	(-4.32)
Escualosa thoracata	0.310***	(3.88)
Ilisha elongata	0.0604	(0.75)
Johnius coitor	0.0974	(0.89)
Setipinna phasa	-0.358**	(-3.42)
log Salinity (ppt)[d]	0.0165	(1.22)
Constant	4.826***	(63.44)
Observations	73	
Adj. R2	0.78	

(b) Medium-price fish

Amtali	0.577***	(3.61)
Galachipa	0.938***	(5.78)
Mongla	0.439***	(4.01)
Sarankhola	1.130***	(7.47)
Euthynnus affinis	0.513	(1.42)
Lobotes surinamensis	1.060***	(3.85)
Mystus gulio	0.831**	(3.12)
Otolithes ruber	0.827**	(2.87)
Otolithoides pama	0.613*	(2.42)
Parastromateus niger	1.484***	(4.92)
Platycephalus indicus	0.513	(1.54)
Pomadasys maculatus	0.329	(1.13)
Pseudapocryptes elongatus	0.504	(1.84)
Rastrelliger kanagurta	0.523	(1.81)
Scomberomorus commerson	1.343***	(4.72)
Scomberomorus guttatus	0.444	(1.67)
Setipinna taty	-0.125	(-0.39)
Sillaginopsis panijus	0.839**	(3.00)
Stigmatogobius sadanundio	0.679*	(2.39)
log Salinity (ppt)[d]	0.0128	(0.53)
Constant	4.330***	(15.19)
Observations	274	
Adj. R2	0.28	

(c) High-price fish

Amtali	-0.0117	(-0.16)
Galachipa	-0.0597	(-0.88)
Mongla	-0.341***	(-5.38)
Sarankhola	0.0479	(0.71)
Lates calcarifer	-0.00951	(-0.09)
Pampus argenteus	-0.0495	(-0.40)
Pangasius pangasius	-0.0871	(-0.78)
Plotosus canius	-0.405**	(-3.26)
Polynemus paradiseus	-0.300**	(-2.73)
Tenualosa ilisha	0.0180	(0.17)
log Salinity (ppt)[d]	0.0243*	(2.50)
Constant	6.754***	(53.94)
Observations	443	
Adj. R2	0.43	

[a] Table columns are variable, parameter, t-statistic

[b] Non-collinear species included

[c] Significance: * p<0.05 ** p<0.01 *** p<0.001

[d] Salinity two months prior to the price observation