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Hydrological Sensitivity of Commercial Fish Production Potentiality around Bangladesh

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Abstract: - Under future hydro-climatic changes and modifications of river discharge and water depth are expected to result in potential production shifts of riverine organisms, including commercial fin fish. Bangladesh is one of the world's leading fish producing countries with a total production of 4.3 million MT in FY 2017-18, in which river system contributes only about 7.5%. The fish production module underpins the estimation of riverine fish production of Bangladesh based on the discharge and water depth at different hydrological nodal points. We project changes for the highly valued commercial fish, the Hilsa Shad (*Tenualosa ilisha*), by applying a bio-hydrological model based on the Bayesian theorem considering 248 bio-hydrological variables, among which 170 variables linked with discharge and 78 with water depth. The hilsa production potentiality changes projected from the recent past (1985–2017) to two futures (2030 and 2050) were calculated for riverine waters around Bangladesh under four scenarios based on the climate change and economic condition. Our model projected that some districts, such as Gaibandha, Kurigram, Sirajganj, Pabna, Rajshahi, Faridpur, and Khulna, would highly be sensitized with the hydrological shifts under four scenarios. These changes might drive significant changes in hilsa production in future.

Keywords: Riverine Ecosystem, Hilsa Production Potentiality, Climate Change Scenarios, Bio-hydrological Modelling.

I. Introduction

Bangladesh is a riverine country, crisscrossed by 815 rivers, plays a crucial role primarily in the aquatic ecosystem and depended livelihoods. The mighty Ganges-Jamuna-Meghna River system forms the deltaic Bangladesh having tidal influence in the coast and support a wide range of biodiversity dominated by fisheries.

Hydro-climatic changes, leading to shifts in river discharge in terms of volume and timing significantly and water depth, have profound implications on the river ecosystem, its goods and services including fish populations. This can lead to a cascade of environmental, economic, and societal impacts, from flooding to water shortages and ecosystem disruption. Understanding and adapting to these changes is crucial for managing water resources, protecting infrastructure, and ensuring the sustainability of ecosystems in the face of a changing climate. The seasonally altered flow patterns and water availability further be influenced by climate variability, predicting and managing these changes is thus critical for countries like Bangladesh, where fish production is vital to the economy as well as food and nutritional security. Changes in water level and depth patterns with time affecting the connectivity of the habitats and bio-periods of the anadromous hilsa fish, might pose adverse impact on the productivity (1).

Bangladesh is one of the world's leading fish producing countries, significantly relying on riverine ecosystems for commercial fish production, particularly for valuable species like Hilsa Shad (*Tenualosa ilisha*) (2) (9). The riverine habitats contribute about 22.11% of country's total inland capture fishery production. On the contrary, the hilsa fishery contributes about 12% of the country total fish production and involves about 0.7 and 2.5 million of people directly and indirectly respectively, ushers in obtaining the title of Geographical Indication (GI) in 2017 (DoF 2023). However, changes in hydrological conditions have great impact over the river flows and riverine habitats, consequently affecting fisheries and the dependent communities (9) as hilsa is highly sensitive to the changed environment i.e., river discharge and depth. Additionally, anthropogenic activities such as deforestation, mining, urbanization, and various flood control measures have further degraded river ecosystems (9). Hilsa Shad is an anadromous fish that migrates from the sea to spawn in freshwater rivers, and this species constitutes an important fishery in Bangladesh (4). The river systems serve as critical habitats for fish breeding, migration, and overall health, making any hydrological shifts which is highly impactful (9). This sensitivity makes it an ideal candidate for studying the impacts of hydro-climatic changes on hilsa fish production. For instance, the alteration

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of hydrological regimes due to different water control activities significantly impacts river ecosystems, affecting factors like flow velocity, depth, and water temperature (10).

The bio-hydrological model used in this study integrates biological information (i.e., fish life cycles/bio-periods) with hydrological data (i.e., river discharge and water depth). By applying Bayesian inference, the model helps estimate the potential future changes in hilsa production under different hydro-climatic and economic scenarios, allowing for more accurate projections of production trends.

This model includes 248 bio-hydrological variables of which 170 are related to river discharge and 78 are associated with water depth. These variables are important because they shape the habitat conditions for hilsa, including spawning grounds and migration corridors. Predicting how the sustainability of fisheries will develop requires an understanding of how fish production responds to changes for these drivers.

The analysis compares historical data ranging from 1985–2017 to projections of expected occurrences at two time points i.e., 2030 and 2050. Four different climate and economic assumption scenarios have been considered for the projections, so that the study can analyze the possible extremes in either direction.

Recognizing the larger implications of hilsa as food and livelihood securities, this study will include results of hydrological sensitivity modelling of hilsa production in Bangladesh for the future climate change and economic scenarios. It utilizes a bio-hydrological model to forecast possible variations in hilsa production under changing river discharge and water depth scenarios, pinpointing the districts likely most vulnerable, for directing future fishery management and policy planning.

It is imperative to comprehend these movements for the long-lasting production of hilsa in the waters of Bangladesh as this fish species holds great importance for economy, culture and food security. The study informs policymakers and fishery managers regarding the foreseen changes in hilsa production to facilitate anticipation of necessary interventions, avoiding risks and enabling viable hilsa fishery in future.

II. METHODOLOGY

2.1 Data Collection and Model Implementation for the Fisheries Module

The Fisheries Metamodel is a comprehensive and integrated framework designed to analyze the complex interconnections among hydrological factors influencing hilsa production potentiality in Bangladesh. This model provides critical insights for adaptive fisheries management in the face of climate variability and hydrodynamic changes (Figure 1).

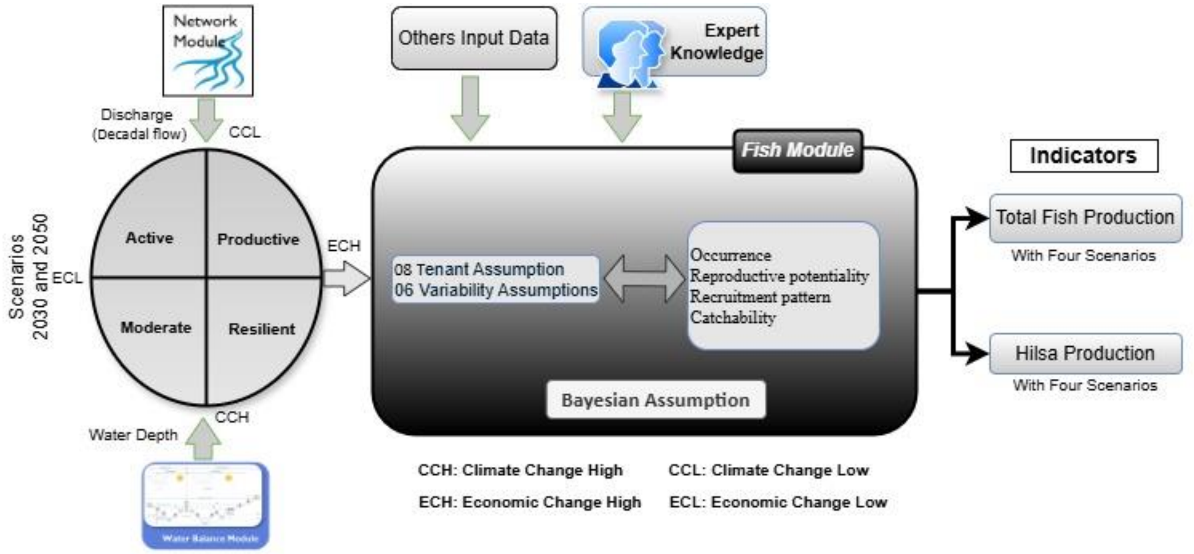

Figure 1. Development Approach

Key input data were sourced from various modules of the Bangladesh Metamodel. Discharge data, essential for analyzing river fish production, were collected on an Upazila (sub-district) basis from the Network Module. Water depth data, another critical input, were derived from the Water Balance Module. Together, these datasets were utilized within the Fisheries Module to simulate and predict fish production dynamics. We assumed that all the rivers connected to a nodal point have similar water depth.

To ensure the model's accuracy and robustness, the Fisheries Module incorporated 33 years of historical catch data (1985–2017) of the hilsa shad (*Tenualosa ilisha*). Additionally, the catch data, originally available at the district level from the Fisheries Resources Survey System (FRSS), were downscaled to the Upazila level by accounting for Upazila-specific fish habitat areas. This refined granularity enhances the model's precision and applicability.

Within the Fisheries Module, several key indicators were used to evaluate hilsa production potentiality:

- **Seasonal Breeding/Spawning Migratory Success in response to discharge and water depth:** Represents the annual variability from riverine ecosystems across Bangladesh.

- **Fishing Catchability sensitive to Hilsa Bio-period:** Focuses on Hilsa (*Tenualosa ilisha*), a fish of significant commercial and cultural importance in Bangladesh.

The model was applied to simulate fish production under four climatic scenarios across two different years, providing projections of fish yield under varying environmental and climatic conditions. These scenarios offer valuable insights into the potential impacts of climate variability on fish production.

Table 1: List of Scenarios

SL	Name	Short Description
1	Base 2020	Base Scenario
2	Resilient 2030	Resilient 2030 (Climate Change High and Economic Change High
3	Resilient 2050	Resilient 2050 (Climate Change High and Economic Change High)
4	Active 2030	Active 2030 (Climate Change High and Economic Change Low)
5	Active 2050	Active 2050 (Climate Change High and Economic Change Low)
6	Productive 2030	Productive 2030 (Climate Change Low and Economic Change High)
7	Productive 2050	Productive 2050 (Climate Change Low and Economic Change High
8	Moderate 2030	Moderate 2030 (Climate Change Low and Economic Change Low)
9	Moderate 2050	Moderate 2050 (Climate Change Low and Economic Change Low)

By integrating diverse environmental and socio-economic factors, the Fisheries Metamodel supports the development of evidence-based strategies for sustainable fisheries management in Bangladesh. The findings enable policymakers and stakeholders to design adaptive management strategies that address the challenges posed by climate change and ensure the long-term sustainability of fisheries resources.

Algorithm: Hydrological Condition Analysis and Fish Survival Estimation

Step 1: Calculate Prior Probability for Hydrological Conditions

1.1 Calculate Mean, Max, and Min flow values:

MAF_Qsec ← mean of Qsec

MAXF_Qsec ← max of Qsec

MINF_Qsec ← min of Qsec

1.2 Calculate Max and Min water depth (WD:

MAX_WD, MIN_WD ← max, min of WD

1.3 Calculate flow thresholds as percentages of MAF:

Define Qsec thresholds (e.g., 200%, 100%,60%,50%,40%,30%,25%, and 10%) by multiplying MAF_Qsec

1.4 Define a Critical Water Depth:

Critical_WD_m ← ((0.98 * 2.2) / 3.14) * 1.5

Step 2: Determine Occurrence of Different Hydrological Conditions

For each threshold condition:

If Qsec ⩾ threshold, set occurrence flag to 1, else to 0

For water depth thresholds (e.g., 10m, 5m,1m,0.5m, and 0.25m):

If WD ⩾ threshold, set occurrence flag to 1, else to 0

Step 3: Estimate Prior Probability of the Day

For each threshold:

Calculate conditional probability of each threshold occurrence

Step 4: Normalize Probability for Suitability of the Day

For each threshold:

Calculate normalized probability using conditional probability and overall occurrences

Step 5: Conditional Normalization of Qsec and WD

5.1 Normalize Qsec and WD to values between 0 and 1 based on min and max values

5.2 Calculate Habitat Normalization as the mean of Qsec and WD normalization

5.3 Calculate P_Suitability by multiplying Habitat Normalization with Conditional Sum

Step 6: Estimate Survival Likelihood for Fish Species

For each fish species:

Determine survival likelihood based on habitat suitability and fish-specific conditions

Step 7: Estimate Probabilistic Survival Score for Fish Species

For each fish species:

Calculate survival score using coefficients from nodeWiseFish_coef_intercept and fish-specific conditions

Step 8: Calculate Probability of Fish Survival

For each fish species:

Calculate survival probability using the survival score in a logistic model

Step 9: Estimate Posterior Probability (Likelihood) for Fish Species

Using historical fish production data:

Calculate the likelihood ratio of each fish species based on production data from specific areas

Step 10: Calculate Maximum Likelihood for Daily Suitability

For each fish species:

If production ratio is 0, set daily maximum likelihood to 0

Otherwise, calculate daily maximum likelihood using suitability probability and survival probability divided by production ratio

End Algorithm

III. RESULT

To achieve the objectives of the project, a field investigation is used, which allows the use of quality measurement and analysis instruments (network analyzer) in the transformers of the General Hospital of Latacunga, obtaining data on the behavior of the electrical system such as voltages, currents, powers, harmonics, among other disturbances; in order to determine anomalies in the system that are causing energy waste.

3.1 River Hydrology and Differential Hilsa Catches

The hilsa production is more aggregated under the hydrological condition driven by 70-140% of mean annual flow across the nodal points (Figure 1-A). Although, the production pattern of this fish shows more scattered under different water depths, particularly the two major dimensions, below and above 14m water depths (Figure 1-B). The principal component analysis also showed that maximum hilsa catch comes from the overlapping region of the below and above mean annual flow and also of 0-10 m, 10-20m, and 20-30m water depth conditions (Figure 1-C & -D). The findings indicate that a certain range of mean annual flow (70-140%) and water depth (4-14m) ensure a significant conditional space of fishing catchability and abundance of hilsa shad resulting in maximum hilsa catches.

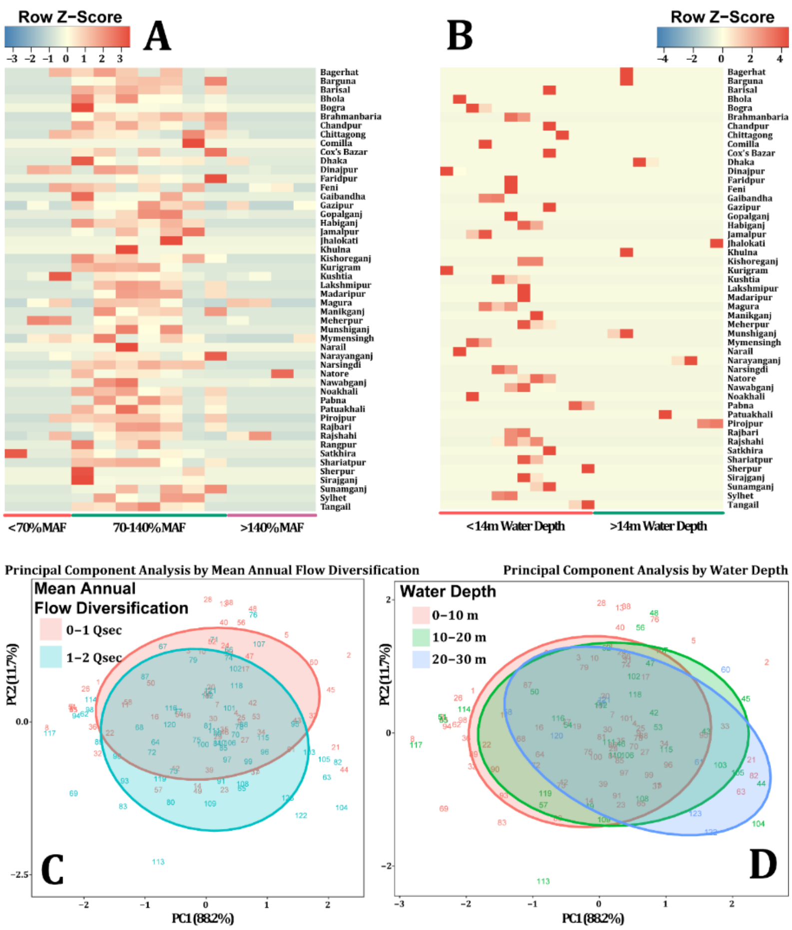

Figure 1. Differential analysis of annual hilsa catches under mean annual flow and mean annual water depth across the hydrological nodal points

3.2 Discharge and water depth interaction is a conditional space for sustainable hilsa catch

The study identified some nodal points, located in Rangpur, Rajshahi, Dhaka, Khulna, and Barishal, where the discharge has a significant effect on the water depth. Moreover, the effect size (beta estimate in Figure 2-A-E) shows significant seasonal variation in these nodal points. It has, for example, been identified that water discharge effect on the water depth become higher gradually from April up to December at N185 Point, located in Ghoraghat Upazila under Dinajpur District on the Jamuna River, whereas at N70 Point (Fulchhari Upazila of Gaibandha District) an unpredictable effect size was estimated during the month of June, although from July the effect size has gradually been increased and drastically fall down during the month of November. The effect coefficient values at these two nodal points indicate that the sufficient water depth for the seasonal diadromous fishes is highly dependent on the discharge variability. However, discharge at N70 Point in Char Rajibpur Upazila under Kurigram District has significant steady seasonal effect on the water depth changes, although lower effect size than above two hydrological nodes (Figure 2-A). We observed the similar findings for all the significant nodal points of hilsa producing major river systems in Bangladesh (Figure 2-B-E). It is, therefore, suggested that the influence variability of discharge on water depth critically depends on the existing water depth condition at a particular river point. On the other hand, the districts of such nodal points having a significant and constant seasonal discharge-water depth conditional space are documented to contribute higher hilsa production to the country (Figure 2-F). It is, thus, hypothesized that the hilsa production might be the aggregated function of water discharge and water depth. Moreover, when a riverine habitat has no sufficient water depth that is highly fluctuated by the water discharge of seasonal variability, it might not function as the usable area by the hilsa shad.

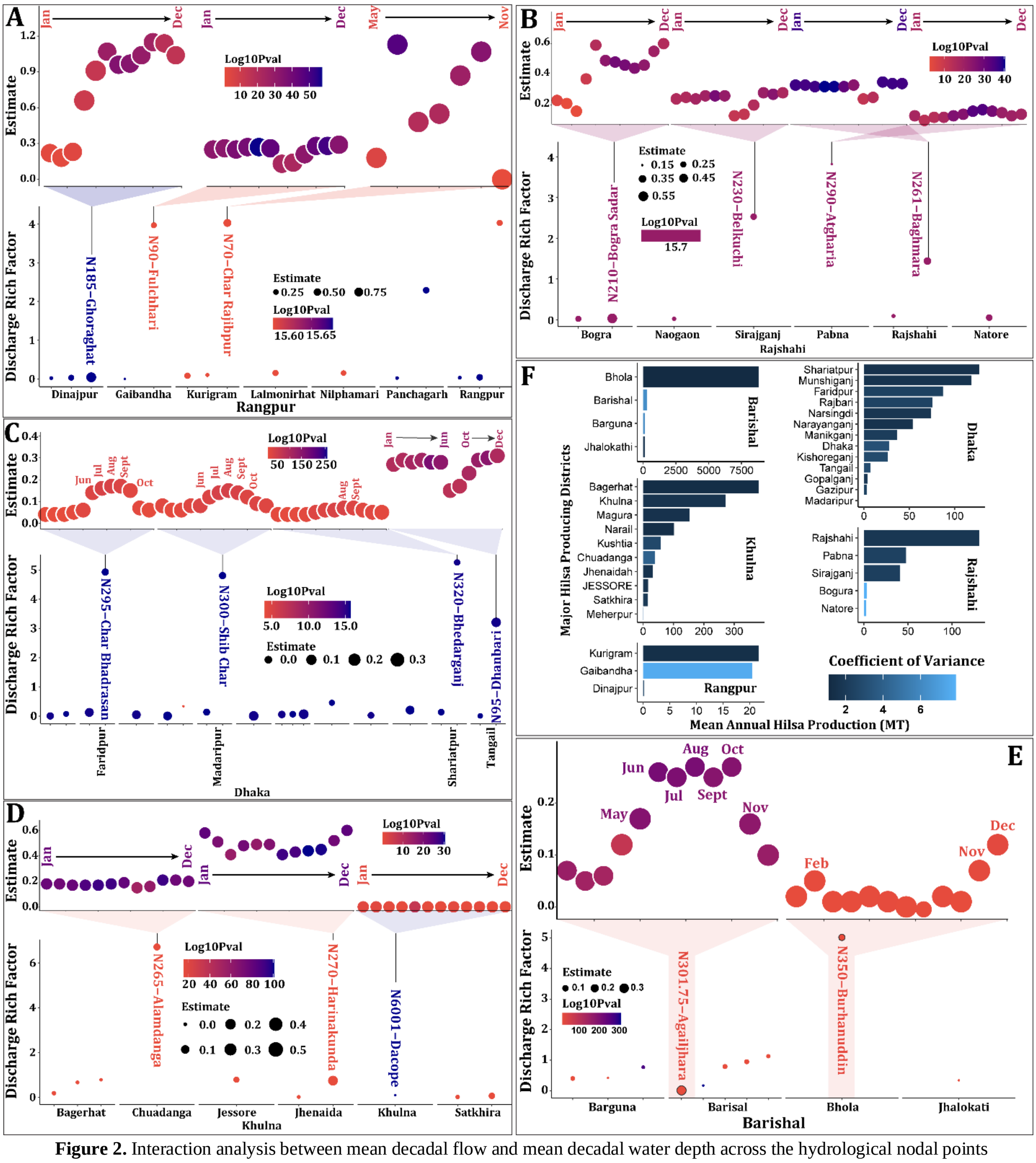

Figure 2. Interaction analysis between mean decadal flow and mean decadal water depth across the hydrological nodal points

3.3 Water Depth might be a mediator

The proposed model identified that water depth has significant mediation effect on the production potentiality of the hilsa shad particularly at such nodes where water discharge plays a crucial role in changing the water depth (Figure 3). The interaction analysis identified the five nodal points at which mean monthly flow (MMF) and water depth can significantly but variably explain the variability of production potentiality of the hilsa shad. It has been found that the significant causal effect of the MMF depends on the below and above mean annual flow (MAF) of a particular node. MMF and mean monthly water depth (MMWD) above MAF was regarded as treated and below MAF as the control for the mediation analysis. In case of N90 Point, the MMF has a significant causal effect on the production potentiality of the hilsa shad through mediating MMWD at both the treated and control flow dimensions. However, both the causal and mediation effect at N230 Point becomes significant at the treated condition (above MAF) inferring that the MMF can be a significant cause through mediating MMWD for impacting production potentiality of the hilsa shad when it is above the MAF level. In case of N290 and N295 nodal points, the average causal mediation effect (ACME) in the direction of MMF-MMWD-Production Potentiality of hilsa shad has a significant positive effect at both the treated and control conditions, but only the direct effect (ADE) of MMF above MAF level has a significant negative effect on the hilsa shad production potentiality. The findings indicate that the MMF above MAF might have influence on the out-migration behavior of the hilsa shad resulting in reducing the fishing catchability at these points. In contrast, ADE of MMF has been identified to be positively noticeable at N261 Point indicating a critical influence on the in-migration behavior of the diadromous fishes and/or increasing fishing catchability. Therefore, different percentage of MAF (according to the Tenant's E-flow requirement method) might define the net migration behavior and resulting catchability of the hilsa shad-like diadromous fish.

3.4 Changes in Production Potentialities

Our model predicted the probable changes of the production potentiality of hilsa shad of the four scenarios based on the climate change and national economic growth driving factors for the 2018-2050 future period (Figure 4). It has been predicted that the production potentiality would be significantly upregulated in all the future scenarios for N230 and N261 but downregulated for N290 and N295 nodes relative to the base scenario (1985-2017) (Figure 4-A). In contrast, the production potentiality would not be significantly changed in case of N90 nodal point. However, the aggregated log-fold changes have been predicted for all the subjected nodal points (Figure 4-B).

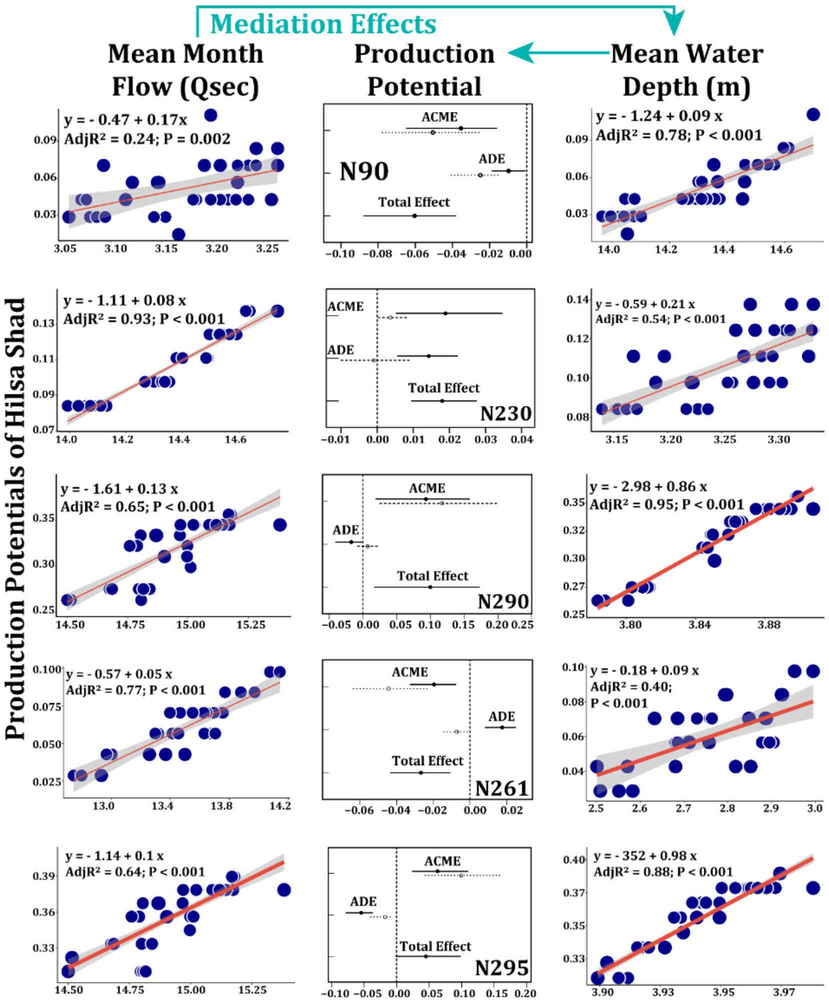

Figure 3. Mediation analysis among mean month flow, mean month water depth, and production potentiality of the hilsa shad

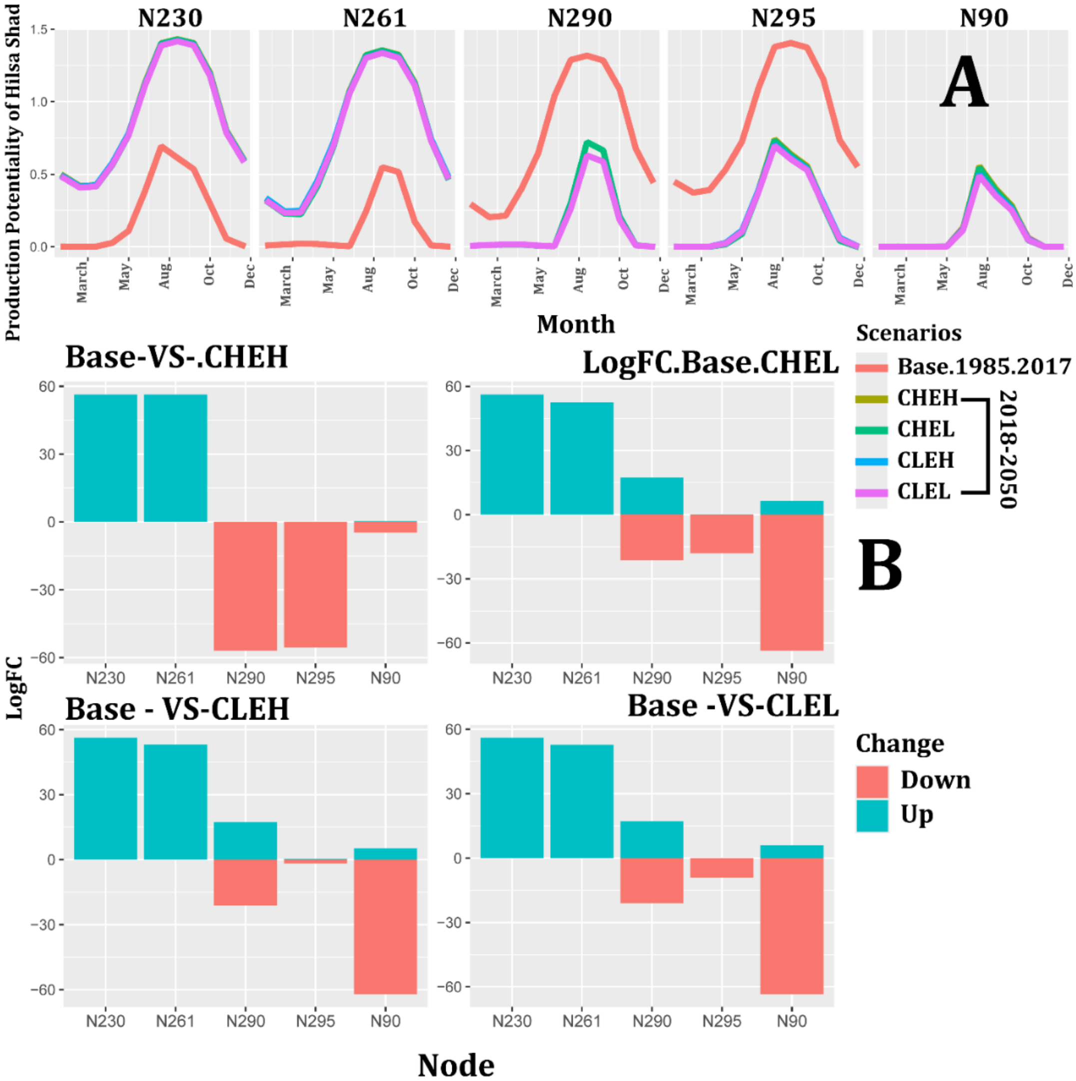

Figure 4. The model predicts the log-fold change of production potentiality of the hilsa shad for the significant nodal points from 2018 to 2050 under CHEH (High Climate and High Economic Growth Scenario, Resilient), CLEH (Moderate Climate and High Economic Growth Scenario, Productive), CLEL (Moderate Climate and Moderate Economic Growth Scenario, Moderate), CHEL (High Climate and Moderate Economic Growth Scenario, Active).

- *A: Log-fold changes of seasonal potentiality among the scenarios; B: Aggregated log-fold change of potentiality per nodal point.*

IV. Discussion

The fate of the production potentiality of the hilsa shad is highly dependent on its migration probability, which is crucially regulated by the hydrodynamic changes driven by the climatic variability, especially by precipitation. In Bangladesh, Hilsa (*Tenualosa ilisha*) migration normally begins in early September with a peak between October and early November. It is often characterized by increased rainfall, leading to elevated river discharge, which creates optimal spawning conditions. This study highlights the intricate relationship between river hydrology and differential hilsa catches in Bangladesh's river systems. Our findings demonstrate that mean annual flow (MAF) within the range of 70-140% and water depths between 4-14 meters create an optimal conditional space for hilsa shad catchability and abundance. Specifically, overlapping hydrological conditions, encompassing different water depth strata (0-10 m, 10-20 m, and 20-30 m), are crucial for maximizing production.

Migration is closely linked to sexual maturity and the volume of freshwater input from river discharge and runoff during and onwards the monsoon season (June-September). Major spawning is held during the full moon and new moon with high river flows at the peak of the spawning period in September and October (7). It indicates that higher river flows during these lunar phases facilitate the migration of Hilsa into shallow waters for spawning. The Hilsa needs specific depth of water for optimal breeding. For spawning, it usually chooses shallower areas such as rivers and estuaries. During spawning migration, it prefers water depth between one and twenty meters. If the water is too deep, it may affect spawning behavior (5). Since Hilsa migrates from the sea upstream into rivers, water flow dynamics play a critical role (6). We also found that fluctuations in freshwater discharge from rivers into estuaries have a significant role in salinity and nutrient levels, which are more vital for Hilsa spawning and growth (8). The identified nodal points—such as Rangpur, Rajshahi, Dhaka, Khulna, and Barishal exhibit significant interactions between water discharge and depth, with distinct seasonal variations in effect size. For example, discharge effects at N185 in Ghoraghat Upazila peak from April to December, while N70 in Fulchhari Upazila shows erratic patterns during June, stabilizing later.

This indicates that seasonal variability in discharge critically influences water depth, which, in turn, affects hilsa production potential. Water depth mediates the relationship between mean monthly flow (MMF) and production potentiality, as seen in nodes like N90 and N230. The mediation effect depends on whether the flow is above or below MAF, with significant implications for migration behaviors. At nodes like N290 and N295, MMF above MAF negatively impacts production, likely due to out-migration, while at N261, positive direct effects suggest enhanced in-migration and catchability. These variations underscore the need for site-specific flow management strategies (Figure 5).

Future projections (2018-2050) indicate diverse impacts: production potential is expected to increase at nodes N230 and N261 but decrease at N290 and N295, highlighting the complex interplay of climate change and economic growth. These insights emphasize the necessity of adaptive hydrological management to sustain hilsa fisheries, particularly focusing on maintaining optimal discharge and depth conditions across critical nodal points.

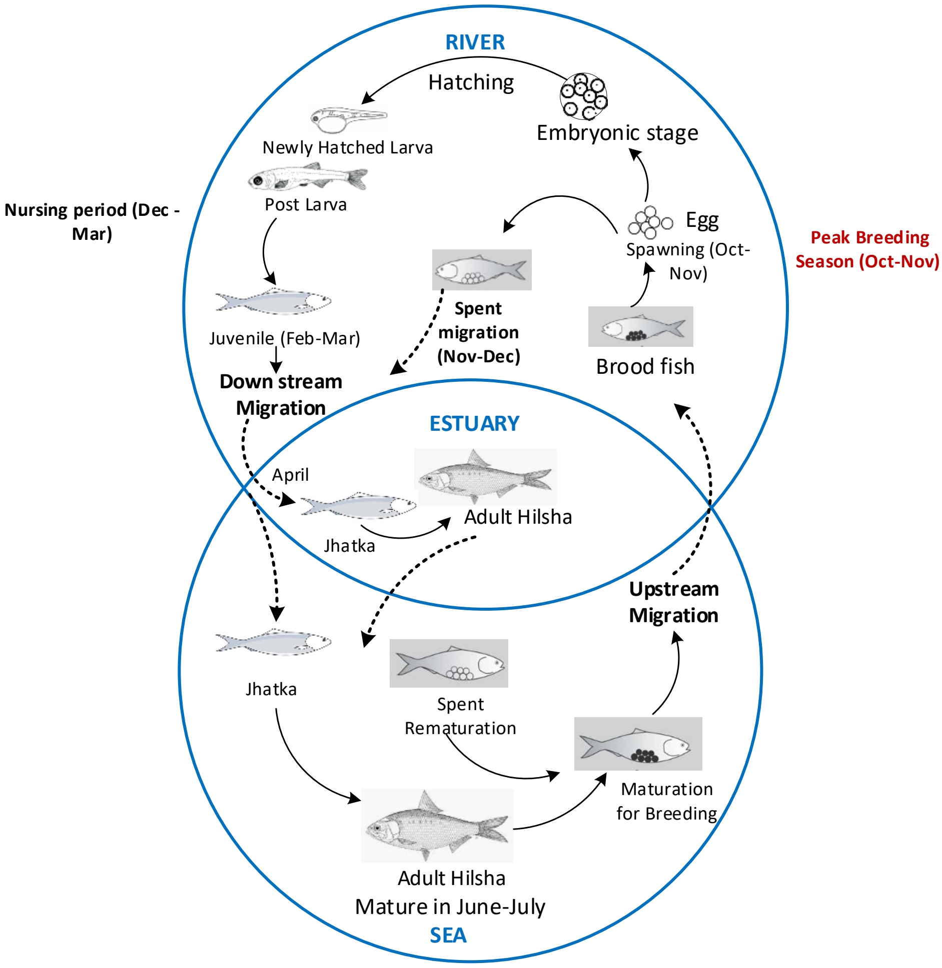

Figure 5. Bio-period of the Hilsa Shad

V. Conclusion

In conclusion, the study suggests that sustainable hilsa production relies heavily on maintaining dynamic yet balanced hydrological conditions. Effective management of river discharge and water depth, considering seasonal and spatial variability, is essential for enhancing hilsa catchability and ensuring long-term fisheries sustainability. However, the fisheries module only integrated the outputs from the water balance and river network modules. The fisheries module has several limitations that affect its overall effectiveness. First, it does not fully incorporate critical socioeconomic factors such as local livelihoods, market dynamics, and community-based management practices, which are vital for achieving sustainable fisheries management. The module also focuses primarily on river fish production, neglecting other important fisheries sectors. Furthermore, the model may oversimplify the complexities of aquatic ecosystems, failing to capture dynamic changes in biodiversity, water quality, and the broader environmental impacts, including climate change. Another key limitation is the reliance on limited, outdated, or incomplete fisheries data, which diminishes the model's accuracy and predictive reliability. Additionally, the module does not account for important environmental variables like temperature and salinity, which significantly influence fish populations and ecosystem health. Incorporating these factors would improve the model's realism, providing more comprehensive and reliable insights for decision-makers managing Bangladesh’s fisheries sector.

Biography:

Author Name	Research Interest	Contribution
Mohammed Mukteruzzaman	Conservation and Management of Fisheries	First author to design the study, integrating hydrological and biological information, interpretation of data, and preparation of the article
Moshiur Rahman Rimu	AI-driven solutions for water resource management, sustainable fisheries, and enhancing food security through environmental data analytics	First author having similar contribution to the research
Md. Ashraful Alom	Aquaculture and Fisheries Resources	Resource management
Md. Atikul Islam	Aquatic Habitat Quality and Coastal Aquaculture	Resource management
Sharmin Akhter	Genetic Variation and Adaptation, Microbiomes	Resource management
Roland Nathan Mandal	Genetics and Genomics, Fish Breeding, Fish Biology, and Fisheries Resources	Corresponding author

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REFERENCES

[1] "Bangladesh Water Development Board: On Going Project". www.Bwdb.Gov.Bd. Retrieved 22 December 2021.

[2] Asadujjaman, M., Rahman, M.A., Mojumdar, S., Yeasmine, S., Hasan, M.B. And Marimuthu, K., 2022. Present Status, Prospects and Conservation of Hilsa, Tenualosa ilisha (Clupeiformes: Clupeidae) Fishery in Bangladesh. Uttar Pradesh Journal of Zoology, 43(21), Pp.74-83.

[3] Hanna, J.E. And Michalski, M.F., 1982. Fisheries Productivity and Water Level Fluctuations in Lac Seul, Northwestern Ontario. Canadian Water Resources Journal, 7(2), Pp.365-388.

[4] Hossain, M.S., Sharifuzzaman, S.M., Rouf, M.A., Pomeroy, R.S., Hossain, M.D., Chowdhury, S.R. And Aftabuddin, S., 2019. Tropical Hilsa Shad (Tenualosa Ilisha): Biology, Fishery and Management. Fish and Fisheries, 20(1), Pp.44-65.

[5] Hussain, M. G., et al. (2015). Ecology and Assessment of Hilsa (Tenualosa ilisha) Fishery in Bangladesh. Journal of Marine Biology.

[6] Khan, M. R., et al. (2019). Migration and Spawning Behavior of Hilsa Shad (Tenualosa ilisha) in the River Meghna, Bangladesh. Fishery Bulletin.

[7] Miah, M. A. M., et al. (1997). "Breeding Biology of the Indian Shad (Tenualosa ilisha) in the Bangladesh Coast." Journal of Fisheries Research.

[8] Shahadat, M., et al. (2020). Influence of River Discharge on the Abundance and Distribution of Hilsa Shad in Bangladesh. Aquatic Ecosystem Health & Management.

[9] Vass, K., Das, M., Tyagi, R., Katiha, P., Samanta, S., Srivastava, N., Bhattacharjya, B., Suresh, V., Pathak, V., Chandra, G. And Debnath, D., 2011. Strategies For Sustainable Fisheries in The Indian Part of The Ganga-Brahmaputra River Basins. International Journal of Ecology and Environmental Sciences, 37(4), Pp.157-218.

[10] Zhang, W., Di, Z., Yao, W.W. And Li, L., 2016. Optimizing the Operation of a Hydraulic Dam for Ecological Flow Requirements of The You-Shui River Due to A Hydropower Station Construction. Lake and Reservoir Management, 32(1), Pp.1-12.