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ARTICLE

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PLANKTON DYNAMICS AND ITS INFLUENCE ON HILSA AVAILABILITY IN THE ESTUARINE REGION OF GANGA

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This study investigates seasonal variations in plankton composition and their impact on Hilsa shad (Tenualosa ilisha) availability in the Ganga River over four years. Significant fluctuations in water quality parameters, such as temperature (31.05 ± 4.37°C), salinity (up to 27.41 ppt), and dissolved oxygen (4.48 ± 1.08 mg/L), were observed. The research identified 56 plankton types, with diatoms dominating in Godakhali, and an abundance of cyanophytes in Fraserganj, indicating potential eutrophication. These findings highlight the critical relationship between plankton dynamics and Hilsa populations, emphasizing the need for targeted management strategies to sustain this vital fishery resource.

Keywords: *Seasonal variation, Water quality, Phytoplankton, Population dynamics*

Introduction

The Hilsa shad (*Tenualosa ilisha*), a significant migratory species found in various aquatic environments, including marine, estuarine, and riverine systems across the Indo-Pacific region, plays a significant role in the ecosystem and economy in the countries bordering Bay of Bengal, particularly India, Bangladesh, and Myanmar. Hilsa is distributed widely from Persian Gulf to the Bay of Bengal, inhabiting marine, estuarine, and the riverine environments. In India, Hilsa is primarily found in rivers such as the Bhagirathi, Ganga, Hooghly, Brahmaputra, Narmada and Godavari[1-5]. The Bhagirathi-Hooghly river system is a major habitat for Hilsa in India, contributing significantly to the fisheries[6]. This river system exhibited varying Hilsa landings over the years, with a significant increase post-Farakka barrage due to hydrological changes and increased fishing efforts[2,5]. In the Brahmaputra River, Hilsa landings have been modelled to predict future trends, indicating stagnation in abundance at around 3000 kg/year, highlighting the need for effective fishery management[7].

Hilsa are known for good nutritional value, cultural importance, and economic contributions. They migrate to the estuarine and riverine systems for spawning and the feeding. The Hooghly and Rupnarayan Rivers of India and the Meghna River of Bangladesh are the largest and most vital river systems, serving as a crucial spawning ground for Hilsa, providing the necessary conditions for their lifecycle, from hatching to juvenile growth. During its spawning cycle, Hilsa relies heavily on planktonic organisms, particularly phytoplankton, which serve as a primary food source and are rich in nutrients with essential omega-3 polyunsaturated fatty acids (PUFAs) necessary for its growth and survival[8,9].

Knowledge of seasonal plankton composition and fluctuations are a prerequisite for managing Hilsa stocks and sustaining fisheries. Abiotic components, such as salinity, water temperature, pH, and nutrients, influence plankton abundance and diversity in estuary. which vary seasonally with hydrological changes. Fluctuations affect plankton availability, impacting Hilsa feeding, growth, and reproduction. Seasonality affects key physicochemical

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parameters like salinity, temperature, and nutrient levels (nitrate, phosphate, and silicates), which in turn influence plankton diversity and abundance in estuarine ecosystems. Diatoms need silica for frustule formation and are common in areas with high silica availability. In contrast, green algae flourish in the environment with high nutrient content, especially in those with nitrogen and phosphorus. In these estuaries, the planktonic community, including phytoplankton (chlorophytes, cyanophytes, diatoms) and zooplankton (copepods, rotifers), plays a vital role in the nutrition of Hilsa, especially during critical spawning seasons. Water quality significantly influences plankton dynamics. Dissolved oxygen, turbidity, and pollution directly impact plankton survival and growth, affecting food availability for Hilsa. Anthropogenic activities like industrialisation, agricultural runoff, and habitat destruction threaten water quality in estuarine environments, disrupting plankton production and reducing Hilsa availability.

Availability of Hilsa has dropped due to overfishing, obstacles like dams and barrages and climate change. This situation highlights critical conservation requirements — safeguarding breeding grounds, promoting fishing bans during breeding seasons, and restoring ecosystems to be able to sustain Hilsa populations[4]. In eastern India, Hilsa is a lucrative fish that is essential to the socioeconomic structure of artisanal fishing. Since many fishermen rely on non-fishery activities or other species for their living, the economic viability of Hilsa fisheries is in jeopardy. The significant demand for Hilsa in India and Bangladesh underscores the necessity for efforts in conservation and management to sustain fishermen's livelihoods.

The current study aims to examine the seasonal variations in plankton composition in the estuaries, focusing on how these changes influence the availability of Hilsa as a vital fishery resource. By examining the relationship between hydrological conditions, plankton dynamics, and Hilsa availability, this research seeks valuable insights into the management and conservation of Hilsa fisheries in India. Understanding how seasonal changes in plankton diversity and abundance correlate with the spawning success and nutritional status of Hilsa will help develop strategies for sustainable fisheries management, ensuring the long-term viability of this ecologically and economically important species.

Materials Methods

Study Area and Sampling Methodology: Godakhali (22.39614N, 88.13669E), Diamond Harbour (22.17988N, 88.1927E), and Fraserganj (21.5851°N, 88.2585°E.) were the three spots of the Ganga River which were selected for the sampling based on the Hilsa catch stations. This is a tide-dominated estuarine region where the tidal effect extends up to 300 km from the estuarine mouth, with amplitude variations between 3 to 5 m. Throughout the year, varying magnitudes of semi-diurnal tides affect the estuary by facilitating the exchange of freshwater and seawater, which makes this area suitable for Hilsa availability.

Seasonal sampling, specifically during March-May (pre-monsoon), July–September (monsoon), and October–February (post-monsoon), was conducted from February 2020 to December 2023, with per year three collections from each site, yielding plankton samples and water quality characteristics. Water samples were collected from the subsurface (0.5 m depth) from each designated sampling location using a conventional water sampler and immediately transferred to pre-rinsed HDPE sample bottles (1 L). Fifty litres of water samples were taken from each station to analyse the plankton community and were filtered using bolting silk plankton net with a mesh size of 20 μm. Samples were stored in 5% buffered formalin and collected in pre-rinsed HDPE bottles for subsequent analysis.

The physicochemical parameters of the water from sites, including pH, temperature, turbidity, dissolved oxygen, and specific conductivity, were assessed using pre-calibrated probe (AQUAPROBE AP-7000). Total hardness, total alkalinity, Ca_2^+, Mg_2^+, and nutrients (nitrate, phosphate-P, total nitrogen, silicate) as well as chlorophyll were quantified according to conventional methodologies[10].

Plankton Identification: Plankton species were classified to genus level utilising a binocular light microscope (Zeiss-Axioscope.A1) in accordance with identification characters by monograph[11,12,13] and AlgaeBase[14]. Plankton enumeration was conducted in a Sedgwick rafter counting chamber utilising 1 ml of conserved material. The chamber contains counting chambers with 20 rows and 50 columns, from which 10 rows were randomly chosen, and a total of 500 squares were examined for individual plankton presence. In the instance of colony-forming plankton, each individual was counted individually and included in the calculation.

Statistical Analysis: Descriptive statistics, including standard deviation and mean, were conducted using MS Excel 2010. Origin Pro 2024b was used to analyse the Pearson correlation and box plot preparation of water quality. Prior to conducting Canonical Correspondence Analysis (CCA) on the species-environment relationship, dominant plankton species (those over 1% abundance) were identified based on the relative contribution to the overall population. Canoco 4.5 was used to examine CCA

Table 1 Plankton distribution in three sampling estuarine sites of river Ganga

	Class	Family	*Genus*	Godakhali	Diamond Harbour	Fraserganj
Phytoplankton	Bacillariophyceae	Tabellariaceae	*Asterionella* sp.	+	-	+
		Pseudonitzschiaceae	*Pseudonitzschia* sp.	-	+	+
		Naviculaceae	*Gyrosigma* sp.	+	+	+
		Naviculaceae	*Navicula* sp.	-	+	+
		Diploneidaceae	*Diploneis* sp.	-	-	+
		Surirellaceae	*Surirella* sp.	+	-	+
		Bacillariaceae	*Bacillaria* sp.	+	-	+
		Pinnulariaceae	*Pinnularia* sp.	-	+	-
		Fragilariaceae	*Fragilaria* sp.	+	+	-
		Fragilariaceae	*Synedra* sp.	+	+	+
		Bacillariaceae	*Entomoneis* sp.	+	+	+
	Coscinodiscophyceae	Coscinodiscaceae	*Coscinodiscus* sp.	+	+	+
		Melosiraceae	*Melosira* sp.	+	-	-
		Melosiraceae	*Aulacoseira* sp.	+	+	-
		Stephanodiscaceae	*Cyclotella* sp.	-	+	+
		Chaetocerotaceae	*Chaetoceros* sp.	+	+	+
		Lithodesmiaceae	*Ditylum* sp.	-	-	+
		Triceratiaceae	*Odontella* sp.	+	-	+
	Dinophyceae	Cerataceae	*Ceratium* sp.	-	-	+
		Centriscaceae	*Centritractus* sp.	-	-	+
	Zygnematophyceae	Zygnemataceae	*Spirogyra* sp.	-	+	-
		Desmidiaceae	*Staurastrum* sp.	+	-	+
	Euglenophyceae	Euglenaceae	*Phacus* sp.	-	+	+
	Chlorophyceae	Hydrodictyaceae	*Pediastrum* sp.	+	+	-
		Oocystaceae	*Oocystis* sp.	+	+	-
		Coelastraceae	*Coelastrum* sp.	+	-	-
		Selenastraceae	*Selenastrum* sp.	+	-	+
		Sphaeropleaceae	*Ankistrodesmu* sp.	+	-	-
		Protococcaceae	*Protococcus* sp.	+	-	-
		Microsporaceae	*Microspora* sp.	+	-	+
		Dictyosphaeriaceae	*Dictyosphaerium* sp.	+	-	-
		Actinastraceae	*Actinastrum* sp.	+	+	-
		Scenedesmaceae	*Scenedesmus* sp.	+	+	-
		Chlorococcaceae	*Gloeocystis* sp.	+	-	-
	Cyanophyceae	Chroococcaceae	*Gloeocapsa* sp.	+	-	-
		Oscillatoriaceae	*Phormidium* sp.	+	+	+
		Microcystaceae	*Microcystis* sp.	+	+	-
		Aphanizomenonaceae	*Aphanizomenon* sp.	+	-	+

	Class	Family	*Genus*	Godakhali	Diamond Harbour	Fraserganj
		Oscillatoriaceae	*Pseudanabaena* sp.	+	-	-
		Oscillatoriaceae	*Oscillatoria* sp.	-	+	-
Zooplankton	Rotifera	Lecanidae	*Lecane* sp.	-	+	-
		Asplanchnidae	*Asplanchna* sp.	+	+	+
		Brachionidae	*Brachionus* sp.	+	+	+
		Brachionidae	*Keratella* sp.	-	-	+
	Copepoda	Cyclopidae	*Testudinella* sp.	+	+	-
		Diaptomidae	*Cyclopoid copepods*	-	+	-
	Testacea	Trichoceridae	*Frontonia* sp.	-	-	-
	Monogononta	Chydoridae	*Trichocera* sp.	-	-	-
	Ciliophora	Favellidae	*Favella* sp.	-	+	-
		Naupliidae	*Diaptomus* sp.	+	+	+
		Daphniidae	*Monostyla* sp.	-	-	-
	Crustacea	Bosminidae	*Daphnia* sp.	+	-	-
		Favellidae	*Bosmina* sp.	-	-	-
	Branchiopoda	Ciliophora	*Tintinids* sp.	+	+	-
		Arcellidae	*Leydigia* sp.	-	+	-
		Monostylidae	*Arcella* sp.	+	-	+

for the relationship between water quality and the predominant plankton species across three different sampling sites. A dataset comprising water quality variables, including water temperature (WT), pH(ph), transparency (TRN), dissolved oxygen (DO), total alkalinity (TA), specific conductivity (CON), turbidity (TUR), silicate (SI), total nitrate (TN), total hardness (TH), total phosphate (TP) and salinity (SAL) was analysed using Canonical Correspondence Analysis (CCA).

Results

Analysis of Environmental Parameters: This study represents a comparative analysis of water quality parameters for three sites, Godakhali, Diamond Harbour, and Fraserganj, over four years (2020–2023), incorporating calculated standard deviations to assess variability. Water temperature showed significant fluctuations, with the highest standard deviation observed in Fraserganj (31.05 ± 4.37), indicating notable variability. Transparency was the most variable in Fraserganj (22 ± 7.39), with Godakhali showing consistent low values. Turbidity revealed distinct site-specific trends, with Diamond Harbour exhibiting the highest variation (91.9 ± 22.36). Conductivity varied widely, particularly in Fraserganj (37.6 ± 14.47), attributed to site-specific environmental factors. The pH levels were relatively stable, with minimal deviation across all sites (7.65 ± 0.23), maintaining neutral to slightly alkaline conditions. Dissolved oxygen (DO) levels decreased across the years, with Fraserganj experiencing the lowest variability (4.48 ± 1.08), while Godakhali exhibited the most decline. Total alkalinity and hardness displayed significant differences, with Fraserganj consistently showing the highest values and variability in hardness (3600 ± 14.9). Nutrients such as total nitrogen and total phosphate were more stable in Godakhali, while Diamond Harbour showed higher variability (total nitrogen: 0.44 ± 0.52, total phosphate: 0.15 ± 0.20). Silicate levels (5.62 ± 3.90) exhibited fluctuations, particularly in Fraserganj, reflecting diverse ecological conditions. Over four years, salinity varies across Godakhali, Diamond Harbour, and Fraserganj. Godakhali (0.10–5.27 ppt) and Diamond Harbour (0.40–2.81 ppt) show lower salinity due to freshwater influx and tidal dynamics, while coastal Fraserganj consistently records the highest salinity (23.13–27.41 ppt). Godakhali and Diamond Harbour are affected by freshwater influx, seasonal variation, and tidal dynamics, whereas Fraserganj has significant salinity due to its coastal closeness. Fraserganj demonstrated the greatest variability across most parameters, suggesting dynamic environmental conditions, while Godakhali maintained a more stable water quality. This analysis underscores the need for tailored conservation strategies addressing site-specific ecological challenges. Figure 1 presents the box plot of several water quality characteristics across these three sites. The Pearson correlation analysis revealed significant relationships between various water parameters. This study indicated multiple significant correlations. Positive correlations, including transparency and conductivity (0.702), total hardness and salinity (0.970), and silicate and nitrogen (0.896), suggest that clearer water generally possesses elevated mineral content, saline waters exhibit increased hardness due to dissolved ions, and silicate concentrations frequently increase alongside nitrogen, likely from nutrient-dense sources. Negative correlations, such as between transparency and turbidity (-0.629), phosphate and pH (-0.472), and dissolved oxygen and phosphate (-0.411), indicate that turbidity diminishes water clarity, phosphate levels decline in more alkaline environments, and elevated phosphate concentrations may result in oxygen depletion, presumably due to eutrophication. The modest correlation of 0.085 between DO and pH indicates a negligible impact of pH on oxygen levels. These findings highlight the interaction of physical and chemical elements, illustrating both natural processes and human influences, offering essential insights for water quality management in tackling issues such as fertiliser loading, salinity regulation, and pollution reduction.

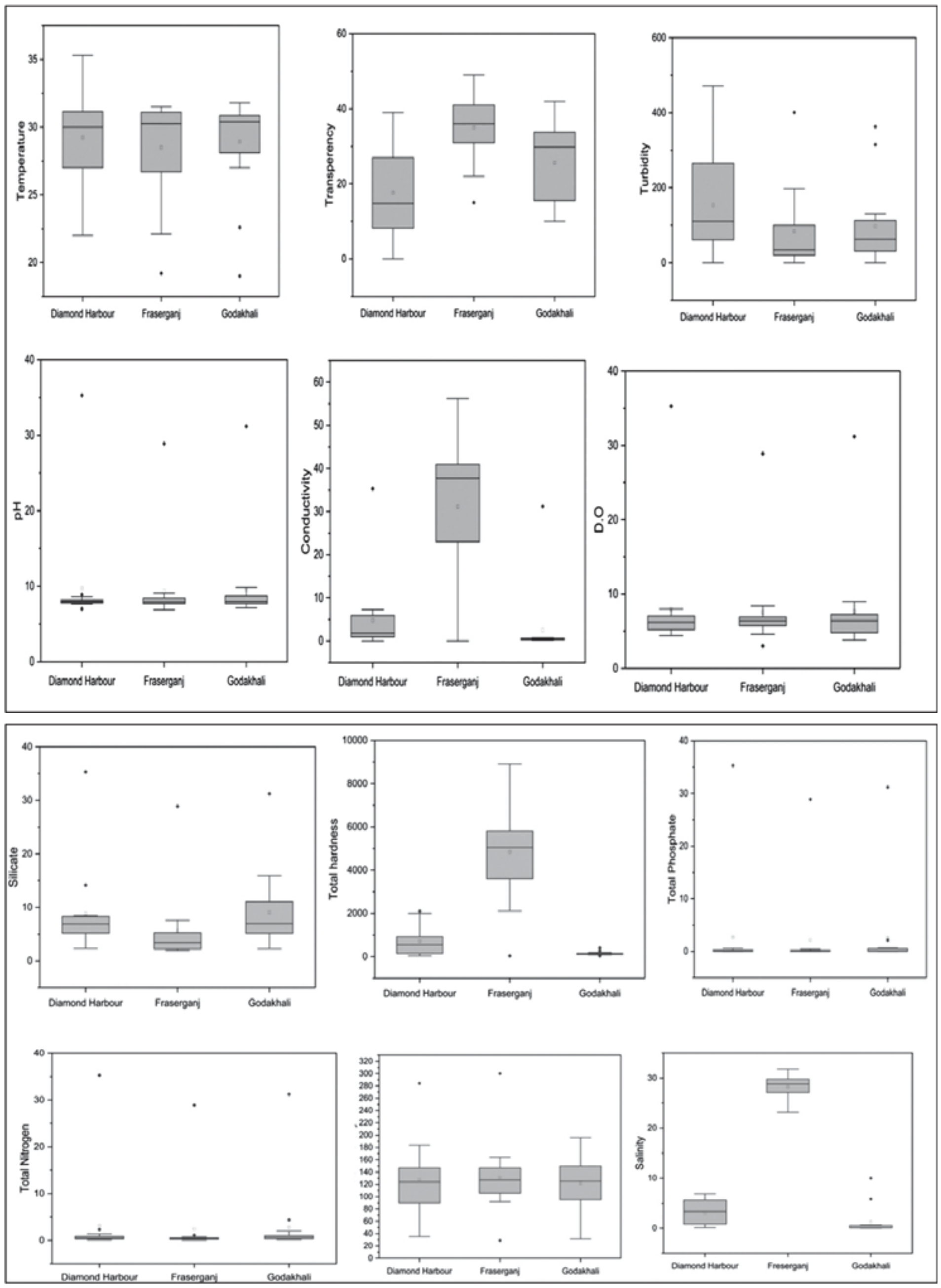

Fig. 1 a & b: Box plotting of various water quality parameters of three different sites.

Plankton Diversity and Abundance: Over four years (2020–2023), plankton diversity in the three sites-Godakhali, Diamond Harbour, and Fraserganj exhibited significant temporal and spatial variations, reflecting the influence of environmental factors and water quality changes. A total of 56 types of plankton were observed in these areas over the time period. 40 genera of phytoplankton and 16 genera of zooplankton contributed to the planktonic diversity throughout those years. In an aspect of total plankton load, Godakhali was the highest, followed by Diamond Harbour and Fresarganj. Interestingly, it was observed that there was a regular increase in plankton load in four consecutive years. Plankton availability was observed to

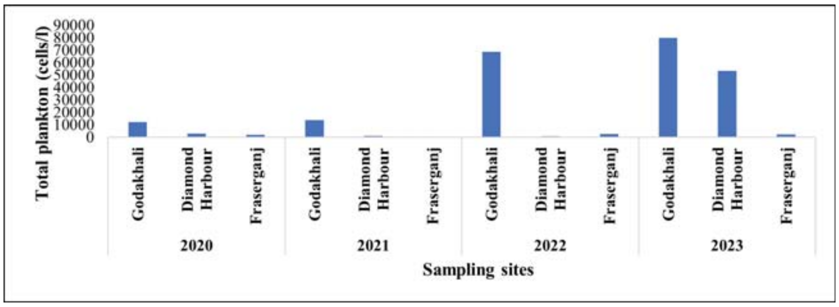

Fig. 2a. Total plankton load

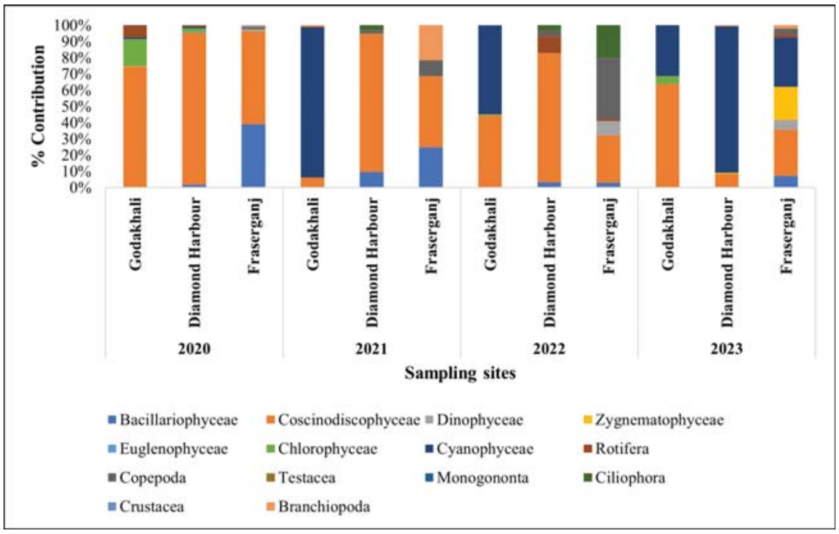

Fig. 2b. Percentage contribution of different plankton groups in three different sites

fluctuate in Diamond Harbour, but in 2023, it was observed to be highest in comparison to other years. In Fresarganj it plankton load was low (Fig. 2a & b). Among the plankton, it was observed that phytoplankton, members of Bacillariophyceae, such as *Navicula*, *Coscinodiscus*, and *Cyclotella*, were dominant in all sites, particularly in Godakhali, where diatoms thrived due to relatively stable nutrient conditions. Chlorophyceae, represented by genera such as *Pediastrum* and *Scenedesmus*, showed an increasing presence in Diamond Harbour, while Cyanophyceae, including *Microcystis* and *Oscillatoria*, became more prevalent in Fraserganj, signalling possible eutrophication. This shift towards cyanophyte dominance in Fraserganj suggests higher nutrient loads and declining water quality in the area. Zooplankton diversity followed similar site-specific trends, with Rotifera, such as *Brachionus* and *Keratella*, being abundant in Godakhali and Fraserganj, and copepods, such as *Cyclopoid copepods* and *Diaptomus*, showing a notable rise in Diamond Harbour by 2023. Cladocera, including *Daphnia* and *Bosmina*, were also observed across the sites, responding dynamically to the changing phytoplankton composition. The dominance of cyanophytes in Fraserganj and the prevalence of diatoms in Godakhali highlight the contrasting ecological conditions driven by nutrient availability and environmental factors. Key indicator species, such as *Microcystis* in Fraserganj and *Keratella* in Godakhali, underline shifts in ecological health and water quality across the sites, reflecting the impacts of anthropogenic and natural factors on plankton communities.

CCA Analysis: CCA is used to identify the pattern in the distribution of biological taxa with regard to the environmental variables in aquatic ecosystems (Fig. 3). The specific set of scalars indicated a correlation of 0.516 and 40.7% on axis 1, and 0.327 and 25.7% on axis 2, among the three sampling sites concerning water quality parameters and

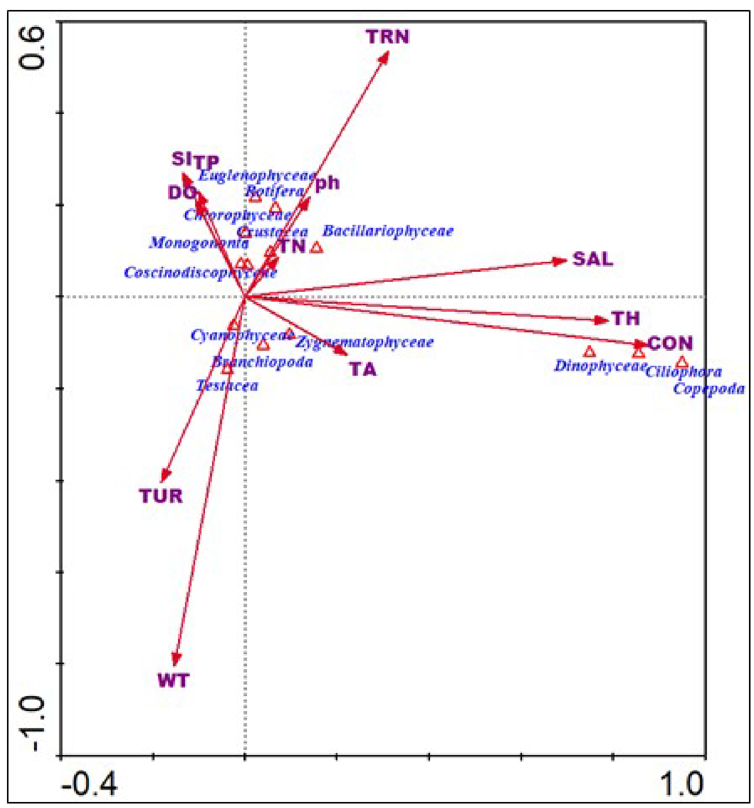

Fig. 3. CCA plot depicting plankton class and environmental variable

plankton groups. Thus, it was discovered that the WT and TUR are in well agreement with the increased development of taxa like Cyanophyceae and Testaceae, consequently, their enhanced abundance in warmer and highly turbid waters, which can be attributed to nutrient loadings or low water clarity. On the other hand, Rotifera and Euglenophyceae have preferred the optimal pH indicating that they are sensitive to light and water chemical conditions. Specific conductivity (CON) and total hardness (TH) are positively correlated with Dinophyceae and Ciliophora pH is high in nutrient-enriched or anthropogenically influenced situations such as urban runoff or agricultural contributions. Bacillariophyceae showed a positive effect on salinity. The water alkalinity (TA) favours taxa such as Zygnematophyceae and Branchiopoda, which are related to the balanced water conditions. High values of nitrate (TN) and phosphate (TP); such conditions normally represent eutrophication and lead to the possible dominance of plankton groups under such conditions.

Discussion

Plankton Distribution in Hilsa Dominant Sites of Estuarine Zone of Ganga: This study seeks to elucidate the diversity and distribution of plankton across three distinct locations in the Hooghly River estuary, where Hilsa catch is more abundant (Table 1). Studies have been conducted on arrays of phytoplankton and zooplankton in diverse estuarine ecosystems of India. Numerous studies have been undertaken regarding the spread of the phytoplankton community in the Hooghly-Matlah estuary by different researchers[15-18]. This study depicted the plankton community structure in relation to Hilsa availability in the tropical Gangetic estuary of India's east coast. Variations in plankton diversity and abundance across locations and time periods significantly impact Hilsa shad populations in rivers of India and Bangladesh. Hilsa shad (*Tenualosa ilisha*) exhibits complex feeding habits influenced by age and environment. Juveniles primarily consume zooplankton (copepods) and diatoms (*Coscinodiscus, Synedra, Rhizosolenia*), while adults shift towards diatoms (*Coscinodiscus, Nitzschia*) due to developed gill rakers, crucial for filtering planktonic food[19,20]. This dietary shift supports growth and migration. Feeding intensity and composition vary seasonally and regionally, correlating with chlorophyll-A and salinity[21-23]. Young Hilsa also engages in epibenthic feeding, consuming tychoplanktonic diatoms and copepods, evidenced by sand grains in their guts in areas like the Meghna estuary[24].

Diatoms such as *Navicula*, *Coscinodiscus*, and *Cyclotella* dominate in Godakhali, where nutrient conditions are stable, matching the preference of Hilsa for diatoms as a primary food source[25,26]. Godakhali may offer good feeding grounds for Hilsa, possibly leading to larger populations or quicker growth rates. The rising Chlorophyceae in Diamond Harbour and the shift to Cyanophyceae dominance in Fraserganj are raising concerns about possible eutrophication and its effects on Hilsa. Some studies indicate that Hilsa can consume various phytoplankton, such as green algae and cyanobacteria, but the nutritional value and potential toxicity of certain cyanobacteria species need more research. Analysing the plankton in Hilsa's gut against the surrounding environment reveals their feeding preferences and how food availability may affect their distribution and numbers. The gut contents of Hilsa in the northern Bay of Bengal and Meghna River basin, were also analysed showing a diet mainly consisting of phytoplankton, including diatoms, green algae, and cyanobacteria in varying amounts[25]. The emphasise the connections among plankton abundance, eco-climatic factors and Hilsa maturation, indicating that plankton availability is vital for Hilsa's reproductive success[26]. This also examines fish composition and biodiversity in Bangladesh's riverine fish sanctuaries, emphasising the need to preserve healthy plankton communities for Hilsa conservation. Knowing the plankton needs of Hilsa at various life stages is essential for effective management strategies. Broodstock development and captive maturation of Hilsa, highlights the necessity of suitable food sources for effective reproduction[21,9]. Salinity affects Hilsa shad migration and spawning in estuaries. Importance of salinity gradients for Hilsa mobility and warn that freshwater flow alterations may harm changed salinity regimes. The appropriateness of Bay of Bengal locations for Hilsa shad depends on salinity and other physicochemical parameters, according to authors[26].

Water Quality in Estuarine Zone of Ganga and Hilsa Shad Availability: Estuarine region of Ganga is vital for the life cycle of the Hilsa shad (*Tenualosa ilisha*). Water quality in this estuarine system critically influences Hilsa shad populations, impacting their migration, spawning, and survival. Key water quality parameters influence Hilsa shad. Salinity is key in estuarine environments, significantly influencing Hilsa shad migration and spawning. It emphasises the significance of salinity gradients for Hilsa movement and points out the possible adverse effects of modified salinity regimes from changes in freshwater flow[37]. Salinity importance has also highlighted the importance of salinity and other physicochemical factors in assessing the suitability of various regions in the Bay of Bengal for Hilsa shad[37]. Dissolved oxygen is a crucial factor for the survival of all aquatic organisms, including Hilsa shad. Higher DO was observed in Godakhali, where the maximum Hilsa catch was observed. Pollution and other factors influence DO levels in the Ganga River system, highlighting the risk of hypoxic conditions harming Hilsa shad populations. Dissolved Oxygen acts as a crucial factor in evaluating the potential of various regions for Hilsa shad[37]. Temperature significantly influences Hilsa shad biology. Specific temperature requirements for Hilsa shad in the estuarine zone of Ganga vary by life stage. Temperature fluctuations are crucial for predicting Hilsa shad movements and spawning patterns. High turbidity reduces light penetration, affecting primary productivity and food sources for Hilsa shad. Nutrient levels like nitrates and phosphates are crucial for primary productivity, the foundation of the food web that supports Hilsa shad. Fertiliser and agrochemical use affects nutrient levels in the Ganga River system. Nutrient cycling dynamics and their impact on plankton communities are essential for assessing Hilsa shad food availability. The studies provide insights into water quality and Hilsa shad biology. Biology of Hilsa in the Hooghly River, a Ganga tributary, offers essential life history information on the species. Plankton diversity and abundance in Bangladesh's Hilsa shad migratory rivers, offers insights into the food web that supports Hilsa shad.

Effects of Physicochemical Parameters on Plankton: Phytoplankton composition in estuaries is influenced by various factors, including ecological, hydrological, climatic, and anthropogenic factors. Physiochemical characteristics such as water temperature, alkalinity, and other nutrients can affect phytoplankton species diversity[27-29]. In this present study, water temperature in these areas changes from post-monsoon to monsoon. The study indicated that Bacillariophyceae were more prevalent during monsoon and post-monsoon times, aligning with several studies of similar peak periods[30,17]. Among zooplankton, Branchiopoda and Testaceae were observed to be more positively correlated with the temperature. On the other hand, Rotifera and Cilophora were positively correlated with dissolved oxygen. This kind of similar type of observation is documented by many researchers[31-33]. Silicates significantly influence the distribution of the class Bacillariophyceae. In our investigation, Bacillariophyceans, specifically *Tabellaria* sp., *Cymbella* sp., *Nitzschia* sp., *Surirella* sp., *Bacillaria* sp., and *Pinnularia* sp., exhibited a positive connection[28,34]. A favourable correlation between *Navicula* sp. and *Coscinodiscus* sp. and turbidity was discovered in the freshwater region of the estuary. The estuarine environment exhibited a consistently moderate alkaline character throughout the study period. Salinity plays a key role in nutrient distribution, plankton composition, primary production, and the diversity of phytoplankton under varying regimes. Species like *Nitzschia,, Cyclotella, Surirella, Tabellaria, Navicula, Skeletonema, Pinnularia,,* and *Coscinodiscus* showed a positive correlation with salinity gradients[35,36,17].

Conclusion

The study on Hilsa shad (*Tenualosa ilisha*) emphasizes the critical relationship between seasonal plankton dynamics and water quality parameters in the estuarine zone of Ganga, which significantly influences Hilsa availability. Hilsa, a vital species for the economies of countries bordering the Bay of Bengal, relies heavily on plankton, particularly phytoplankton, during its spawning cycle. The research highlights how fluctuations in water temperature, salinity, dissolved oxygen, and nutrient levels affect plankton composition and abundance, which in turn impacts Hilsa feeding, growth, and reproduction. Seasonal variations in physicochemical parameters, driven by hydrological changes, play a crucial role in shaping the planktonic ecosystem, with diatoms thriving in stable nutrient conditions and green algae flourishing in nutrient-rich environments. The findings indicate that anthropogenic activities, such as pollution and habitat destruction, threaten water quality and plankton production, leading to a decline in Hilsa availability. Effective management strategies, including habitat protection and regulation of fishing during critical breeding seasons, are essential for sustaining Hilsa populations. By understanding the dynamics of plankton availability and its correlation with Hilsa's reproductive success, the study provides valuable insights for the conservation and sustainable management of Hilsa fisheries, ensuring the long-term viability of this ecologically and economically important species.

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