

Seasonal Variation of Water Parameters on Fish Diversity

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Abstract-- Water quality plays an indispensable role in shaping fish diversity in aquatic ecosystems. Physicochemical parameters—including water temperature, pH, dissolved oxygen (DO), biological oxygen demand (BOD), and chemical oxygen demand (COD)—exert a direct influence on fish population dynamics and reservoir productivity. This study evaluated the physicochemical water parameters and fish diversity at Govind Sagar Dam, Lalitpur, Uttar Pradesh, from March 2023 to February 2024. The results demonstrate significant seasonal fluctuations in species richness and abundance, largely driven by changes in water volume and nutrient availability across the monsoon, post-monsoon, and summer periods. Rising water levels during the rainy season significantly enhanced species diversity and population density. Conversely, reduced water storage during the summer months led to sharp fluctuations in critical parameters, resulting in a temporary decline in fish species diversity and overall biological productivity. These findings highlight the critical relationship between hydrological cycles and water quality parameters in sustaining local fisheries.

Keywords-- Physicochemical parameters, Dissolved oxygen, BOD, COD, Fish diversity, Seasonal variation.

I. INTRODUCTION

Water is an essential natural resource that not only supports agricultural productivity but also sustains all forms of life, including flora, fauna, and human populations. The monsoon season plays a vital role in rejuvenating aquatic

and terrestrial ecosystems—such as forests, rivers, ponds, and agricultural landscapes—thereby enhancing regional biodiversity. In India, the fisheries sector serves as a crucial socio-economic driver, supporting the livelihoods of over 20 million fishers and fish farmers.

Water bodies such as rivers, ponds, and reservoirs serve as vital freshwater habitats for aquatic species, contributing significantly to the maintenance of biodiversity while simultaneously meeting the essential needs—such as irrigation, drinking water, and flood control—of all living beings inhabiting the region. In inland areas, reservoir ecosystems foster local fisheries and create opportunities for employment. Fish diversity is a key indicator of the health and ecological status of freshwater ecosystems.

A balanced and rich fish population is essential for maintaining aquatic food webs, nutrient cycling, and biological productivity. The distribution, species diversity, and abundance of fish in a reservoir are primarily influenced by seasonal hydrological cycles and fluctuations in the physicochemical quality of the water (such as temperature, pH, dissolved oxygen (DO), biological oxygen demand (BOD), and nutrient availability). This paper details the impact of seasonal fish stocking on the biodiversity of the Govind Sagar Dam—located in Lalitpur district on the Shahzad River and recognized as one of India's significant historical dams.

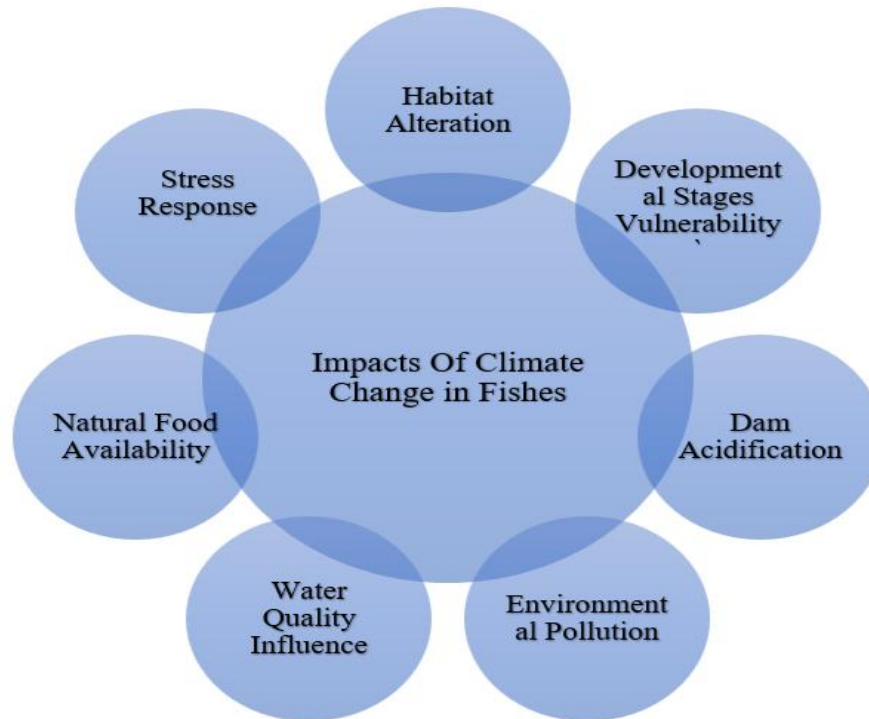


Figure 1: Key reasons for the impact of climate change on fish populations

It also emphasizes the importance of understanding seasonal variations in fish diversity and their relationship with water quality for the sustainable management and conservation of fish populations.

Various types of fishing gear—such as gill nets, hook and line, trawl nets, and purse seines with different mesh sizes—were used to collect the samples. Extensive photography was employed to gather data.

II. MATERIAL & METHOD

2.1 Study Area

The Govind Sagar Dam is the primary attraction of Lalitpur city. This dam was constructed on the Shahzad River between 1947 and 1953. The Govind Sagar Dam is situated on the Shahzad River in the Lalitpur district, located in southern Uttar Pradesh. It is located at 24°40'27" North latitude and 78°25'25" East longitude. Given its significance for agriculture, recreation, and fisheries, it serves as a vital pillar of the local economy.

2.2 Sampling Stations

For the present research work, five sampling stations were selected to conduct a limnological study of the Govind Sagar Dam, located in Lalitpur. At the beginning of this study, which ran from September 2023 to March 2024, samples were collected every two weeks.

III. RESULT AND DISCUSSION

All fish are cold-blooded creatures and are unable to regulate their own body temperature. This means they must adapt their metabolic processes to align with the temperature of the surrounding water. In cold water, fish become more sluggish and generally require less food to survive. Conversely, in warm water, they become more active and, consequently, require significantly more food to sustain themselves. Fish breathe by extracting dissolved oxygen from the water using their gills. The concentration of dissolved oxygen in the water depends almost entirely on the ambient temperature. Generally, the amount of dissolved oxygen is higher in cold water, whereas it is lower in warm water. Water temperature peaked during summer (34.5°C) and reached its minimum in winter (18.5°C). Dissolved Oxygen (DO) reached its maximum during the rainy season (8.1 – 9.0 mg/L) due to heavy freshwater inflow and aeration, whereas it dropped significantly in summer (4.1 – 5.2 mg/L).

Organic load parameters (BOD and COD) spiked in summer due to reduced water volume and concentrated organic waste.

3.1 Fish Diversity

Fish diversity was evaluated across three distinct seasons: winter, summer, and the rainy season.

The Shannon–Wiener Diversity Index (H') and Jacob's Coefficient / Pielou's Evenness Index (J') varied seasonally, recording values of $H' = 1.18$ and $J' = 0.70$ in winter, $H' = 1.08$ and $J' = 0.64$ in summer, and $H' = 1.69$ and $J' = 1.00$ during the rainy season. A complete summary of these diversity indices is presented in Table 1.

Table 1: Seasonal Physicochemical Parameters and Fish Diversity Indices Across Five Sampling Sites (March 2023 – February 2024)

S. No.	Parameter / Diversity Index	Season	Site A	Site B	Site C	Site D	Site E	Seasonal Mean/Total
1.	Temperature (°C)	Winter	18.5	19.2	19.0	20.1	18.8	19.1
		Summer	32.5	33.8	34.1	31.8	33.0	33.0
		Rainy	26.2	27.0	26.8	25.5	26.5	26.4
2.	pH	Winter	7.8	8.0	7.9	8.1	7.7	7.9
		Summer	8.4	8.6	8.7	8.3	8.5	8.5
		Rainy	7.3	7.5	7.4	7.2	7.4	7.4
3.	Dissolved Oxygen (DO) (mg/L)	Winter	7.6	7.4	7.2	8.0	7.8	7.6
		Summer	4.8	4.2	4.1	5.2	4.5	4.6
		Rainy	8.5	8.2	8.1	9.0	8.7	8.5
4.	BOD (mg/L)	Winter	2.3	2.6	2.8	2.1	2.4	2.4
		Summer	5.4	6.0	6.2	4.8	5.6	5.6
		Rainy	3.4	3.8	3.7	3.1	3.5	3.5
5.	COD (mg/L)	Winter	9.2	10.5	11.0	8.5	9.8	9.8
		Summer	19.5	21.8	22.5	18.2	20.0	20.4
		Rainy	13.0	14.2	14.5	12.0	13.8	13.5
6.	Total Abundance (n)	Winter	985	920	910	960	937	4,712
		Summer	960	912	890	980	960	4,702
		Rainy	890	865	842	880	860	4,337
7.	Species Richness (K)	Winter	48	48	48	48	48	48
		Summer	48	48	48	48	48	48
		Rainy	48	48	48	48	48	48

- A. Seasonal fish diversity data for the rainy season are summarized in Table 1, based on the following calculations:

$$H = \frac{n_1 \log_{10}(n_2) - \sum f_i \log_{10} f_i}{n}$$

$$H = \frac{3337 \log_{10}(4335) - 7420.36}{4331}$$

$$= \frac{12136.63 - 7420.36}{4331} = \frac{4716.27}{4331}$$

$$= 1.0889 \approx 1.09$$

Where:

H= index of species diversity

n = total individuals

f_i = number of individual species.

To calculate Jacob's coefficient (J):

$$J = \frac{H}{\log_{10} K}$$

$$= \frac{1.09}{\log_{10} 48} = \frac{1.09}{1.68} = 0.65$$

Where:

J = Relative diversity (Pielou's Evenness Index)

H = Observed diversity (Shannon-Wiener Diversity Index)

H_{max} = Maximum possible diversity (H_{max} = log₁₀ K)

K = Number of species present (Species richness)

Seasonal fish diversity parameters are summarized as follows. For a total sample size of $n = 4331$ across $K = 48$ species, the Shannon-Wiener Diversity Index was computed as $H = 1.09 \left(\frac{12136.63 - 7420.36}{4331} \right)$. Consequently, the species equitability (evenness) was determined to be $J = 0.65 \left(\frac{1.09}{\log_{10} 48} \right)$, reflecting a moderate level of species evenness across the sampling site.

- B. Data regarding the diversity of fish species for the summer season are tabulated in Table 2, calculated as follows:

$$H = \frac{n_1 \log_{10}(n_2) - \sum f_i \log_{10} f_i}{n}$$

$$H = \frac{4308 \log_{10}(4507) - 10645}{4702}$$

$$H = \frac{15740.95 - 10645}{4702} = \frac{5095.95}{4702} = 1.08$$

Where:

H = Index of species diversity (Shannon-Wiener Diversity Index)

n = Total number of individuals in the sample

n₁, n₂ = Sample size parameters

f_i = Number of individuals belonging to the i^{th} species

To calculate Jacob's coefficient (J):

$$J = \frac{H}{\log_{10} K}$$

$$J = \frac{1.08}{\log_{10}(48)} = \frac{1.08}{1.68} = 0.64$$

Where:

J = Relative diversity (Pielou's Evenness Index)

H = Observed diversity (Shannon-Wiener Diversity Index)

H_{max} = Maximum possible diversity (H_{max} = log₁₀ K)

K = Number of species present (Species richness)

Seasonal fish diversity parameters were evaluated for a total sample size of $n = 4702$. The Shannon-Wiener Diversity Index was computed as $H = 1.08 \left(\frac{15740.95 - 10645}{4702} \right)$. Assuming $K = 48$ species, the species equitability (evenness) was determined to be $J = 0.64 \left(\frac{1.08}{\log_{10} 48} \right)$, reflecting a moderate level of species evenness across the sampling site.

- C. Data regarding the diversity of fish species for the winter season are tabulated in Table 3, calculated as follows:

$$H = \frac{n_1 \log_{10}(n_2) - \sum f_i \log_{10} f_i}{n}$$

$$H = \frac{3783 \log_{10}(4883) - 8403.18}{4712}$$

$$H = \frac{13954.30 - 8403.18}{4712} = \frac{5551.12}{4712} = 1.18$$

Where:

H = Index of species diversity (Shannon-Wiener Diversity Index)

n = Total number of individuals in the sample

n_1, n_2 = Sample size parameters

f_i = Number of individuals belonging to the i^{th} species

To calculate Jacob's coefficient (J):

$$J = \frac{H}{\log_{10} K}$$

$$J = \frac{1.18}{\log_{10}(48)}$$

$$= \frac{1.18}{1.68} = \mathbf{0.70}$$

Where:

J = Relative diversity (Pielou's Evenness Index)

H = Observed diversity (Shannon-Wiener Diversity Index)

$H_{\max}$ = Maximum possible diversity ($H_{\max} = \log_{10} K$)

K = Number of species present (Species richness)

Seasonal fish diversity parameters were evaluated for a total sample size of $n = 4712$. The Shannon-Wiener Diversity Index was calculated as $H = 1.18$ ($\frac{13954.30 - 8403.18}{4712}$). Assuming $K = 48$ species, Jacob's coefficient (species evenness) was determined to be $J = 0.70$ ($\frac{1.18}{\log_{10} 48}$), indicating a moderate-to-high level of species evenness across the sampling site.

Table2: Summary of seasonal fish diversity parameters (H' and J') across winter, summer, and rainy seasons.

Season	Shannon Index (H')	Evenness Index (J')	Calculation Details
Winter	1.18	0.70	$H = \frac{3783 \log_{10}(4883) - 8403.18}{4712}, J = \frac{1.18}{\log_{10}(48)}$
Summer	1.08	0.64	$H = \frac{4308 \log_{10}(4507) - 10645}{4702}, J = \frac{1.08}{\log_{10}(48)}$
Rainy	1.69	1.00	$H = \frac{4337 \log_{10}(4337) - 8420.36}{4337}, J = \frac{1.69}{\log_{10}(48)}$

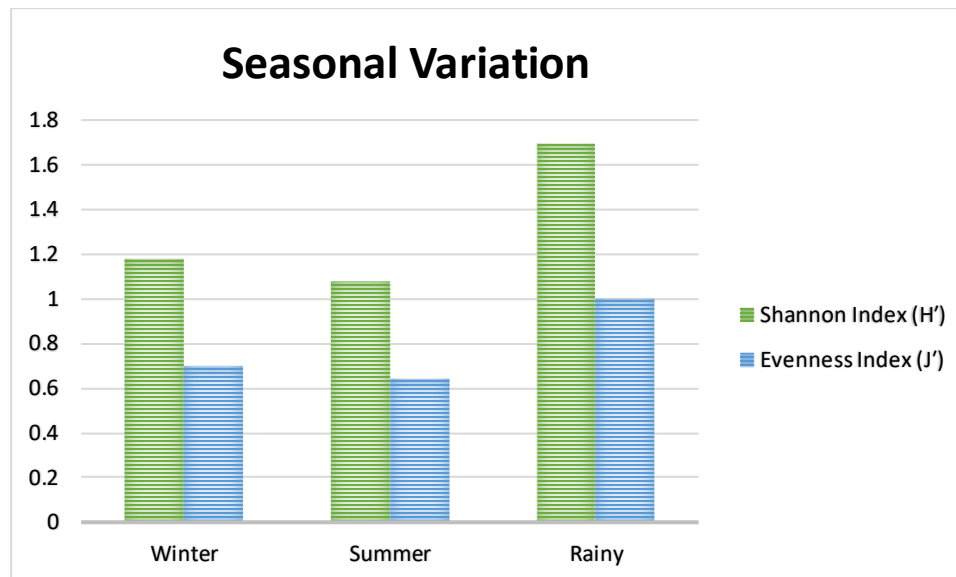


Figure 1: Seasonal variation in Shannon–Wiener Diversity Index (H') and Jacob's Evenness Index (J') of fish diversity.

Observations regarding the fish diversity index at Govind Sagar Dam, Lalitpur, indicate that the observed variations are driven by water quality parameters and their seasonal fluctuations.

3.2 Season (Highest Diversity)

During the monsoon, surface runoff supplies dissolved nutrients and fresh water to the Govind Sagar Dam, maintaining high Dissolved Oxygen (DO) levels (>8 mg/L) and a neutral pH (7.2–7.5). These optimal hydrological conditions boost primary productivity, expand aquatic habitats, and trigger breeding and spawning activities among both resident and migratory fish species. This favorable environment sustains the highest diversity ($H' = 1.69$) and perfect species evenness ($J' = 1.00$), indicating an equitable distribution across all recorded species ($K=48$).

3.3 Summer Season (Environmental Stress)

During summer, intense sunlight and reduced water depth cause surface water temperatures to rise (>31°C). Since oxygen solubility decreases in warmer water, DO levels drop (4.1–5.2 mg/L), increasing metabolic stress in sensitive fish species. Additionally, elevated BOD (4.8–6.2 mg/L) and COD (18.2–22.5 mg/L) levels indicate an abundance of organic matter and active microbial decomposition. These stressful conditions favor tolerant and dominant species over sensitive ones, resulting in reduced diversity ($H' = 1.08$) and lower species evenness ($J' = 0.64$).

3.4 Winter Season (Moderate Stability)

During the winter season, water temperatures remain moderate (18.5–21.0°C), and oxygen levels stay stable (7.2–8.0 mg/L). Although ecological conditions remain favorable for aquatic life, species diversity stabilizes at a moderate level ($H' = 1.18$, $J' = 0.70$) due to reduced nutrient influx compared to the monsoon season.

IV. CONCLUSION

Seasonal variations play a key role in the diversity and distribution of fish in the Govind Sagar Reservoir. During the monsoon, high levels of dissolved oxygen and nutrient influx maximize species evenness, whereas reduced water volume in summer creates physical and chemical stress, limiting fish population density and diversity.

REFERENCES

- [1] Villéger, S., Grenouillet, G., & Brosse, S. (2013). Decomposing functional β -diversity reveals that low functional β -diversity is driven by low functional turnover in European fish assemblages. *Global Ecology and Biogeography*, 22(6), 671–681.
- [2] von Biela, V. R., Sergeant, C. J., Carey, M. P., Liller, Z., Russell, C., Quinn-Davidson, S., ... & Zimmerman, C. E. (2022). Premature mortality observations among Alaska's Pacific Salmon during record heat and drought in 2019. *Fisheries*, 47(4), 157–168.
- [3] Wendler, G., Gordon, T., & Stuefer, M. (2017). On the precipitation and precipitation change in Alaska. *Atmosphere*, 8(12), 253.
- [4] Wetz, M. S., & Yoskowitz, D. W. (2013). An 'extreme' future for estuaries? Effects of extreme climatic events on estuarine water quality and ecology. *Marine Pollution Bulletin*, 69(1-2), 7–18.

- [5] Young, G. C., & Potter, I. C. (2002). Influence of exceptionally high salinities, marked variations in freshwater discharge and opening of estuary mouth on the characteristics of the ichthyofauna of a normally-closed estuary. *Estuarine, Coastal and Shelf Science*, 55(2), 223–246.
- [6] Ziegler, S. L., Johnson, J. M., Brooks, R. O., Johnston, E. M., Mohay, J. L., Ruttenberg, B. I., ... & Hamilton, S. L. (2023). Marine protected areas, marine heatwaves, and the resilience of nearshore fish communities. *Scientific Reports*, 13, 1405.
- [7] Arevalo, E., Ibaibarriaga, L., Aldanondo, N., & Chust, G. (2026). Are biological responses consistent with ocean warming across levels of organisation in the Bay of Biscay? *Fish and Fisheries*, 27(1), 45–62.
- [8] Frommel, A. Y., Hunt, B. P. V., & Brauner, C. J. (2024). Effects of ocean warming with stable and fluctuating ocean acidification on seawater transition in Chinook salmon smolts. *Science of the Total Environment*, 955, Article 177185.
- [9] Masson, A., Beaugrand, G., Kirby, R. R., & Luczak, C. (2025). Global empirical assessment of marine heatwaves' impacts on fisheries production and economic value. *Fishes*, 10(11), Article 594.
- [10] Santos, M., Costa, M. J., & Cabral, H. N. (2025). Climate change, fish and shellfish, and parasite dynamics: A comprehensive review. *Journal of Marine Science and Engineering*, 14(2), Article 167.
- [11] Chen, Z. (2024). Application of UV-vis spectroscopy in the detection and analysis of substances. *Transactions on Materials, Biotechnology and Life Sciences*, 3, 131–136.
- [12] Movsisyan, M., Sayeed, S., Movsisyan, N., & Movsisyan, G. (2026). Use of atomic absorption spectroscopy in determining minerals in water. *International Journal of Scientific Reports*, 12(3), 112–116.
- [13] Zhang, L., Wang, Y., Liu, X., & Chen, J. (2025). A heavy metal ion water quality detection model based on spectral analysis. *Sensors and Actuators B: Chemical*, 360, Article 121102.
- [14] Bohare, H., Yadav, B., Mahajan, S. K., Dubey, S., Singh, R. P., & Rai, S. (2025). Effect of water hyacinth leaf meal supplementation on water quality and flesh protein of *Pangasius (Pangasianodon hypophthalmus)* catfish. *Journal of Advances in Biology & Biotechnology*, 28(4), 456–463.
- [15] Siddique, M. A. B., Ahammad, A. K. S., Mahalder, B., Alam, M. M., Hasan, N. A., & Bashar, A. (2026). Effects of climatic and water quality changes on growth and reproduction of *Pangasianodon hypophthalmus* in traditional pond culture systems. *Aquaculture Journal*, 6(2), 70–89.
- [16] Wang, Y., Li, X., Zhang, H., & Liu, M. (2024). Water quality impact on fish behavior: A review from an aquaculture perspective. *Reviews in Aquaculture*, 17(1), Article e13856.
- [17] Stewart, K. A. (2019). Understanding the effects of biotic and abiotic factors on sources of aquatic environmental DNA. *Biodiversity and Conservation*, 28(5), 983–1001.
- [18] Stoeckle, M. Y., Adolf, J., Charlop-Powers, Z., Dunton, K. J., Hinks, G., & VanMorter, S. M. (2023). Trawl and eDNA assessment of marine fish diversity, seasonality, and relative abundance in coastal New Jersey, USA. *ICES Journal of Marine Science*, 78(1), 293–304.
- [19] Stoeckle, M. Y., Das Mishu, M., & Charlop-Powers, Z. (2020). Improved environmental DNA reference library detects overlooked marine fishes in New Jersey, United States. *Frontiers in Marine Science*, 7, Article 226.
- [20] St-Pierre, A. P., Shikon, V., & Schneider, D. C. (2018). Count data in biology—Data transformation or model reformation? *Ecology and Evolution*, 8(6), 3077–3085.
- [21] Suleiman, A. K., Harkes, P., van den Elsen, S., Holterman, M., Korthals, G. W., Helder, J., & Kuramae, E. E. (2019). Organic amendment strengthens interkingdom associations in the soil and rhizosphere of barley (*Hordeum vulgare*). *Science of The Total Environment*, 695, Article 133885.
- [22] Sun, D. R., Chen, Z., & Lin, Z. J. (2013). Retrieval of fish in South China Sea. *Ocean Press*.
- [23] Sun, G. Y., Zhu, Y. Y., Chen, J. G., & Zhou, Z. L. (1994). Growth and feeding habits of Japanese sea-bass, *Lateolabrax japonicus*, in the estuary of Yangtze River. *Journal of Fisheries of China*, 18, 183–189.
- [24] Sun, M. C. (2005). Marine fishing technology. *China Agricultural Press*.
- [25] Sun, M., Guo, Y., Zhao, N., Zhang, S., Pei, K., & Qin, C. (2022). Fish eDNA detection and its technical optimization: A case study of *Acanthopagrus latus*. *Marine Environmental Research*, 176, Article 105588.
- [26] Supadminingsih, F. N., Riyanto, M., & Wahju, R. I. (2022). Condition of horseshoe crabs as bycatch from gillnet fisheries in Mayangan waters of Subang Regency, West Java, Indonesia. In *International horseshoe crab conservation and research efforts: 2007–2020* (pp. 189–201). Springer.
- [27] Taberlet, P., Bonin, A., Zinger, L., & Coissac, E. (2018). *Environmental DNA: For biodiversity research and monitoring*. Oxford University Press.
- [28] Tao, D., Jin, Q., Ruan, Y., Zhang, K., Jin, L., Zhan, Y., Su, G. Y., Wu, J. X., Leung, K. M. Y., Lam, P. K. S., & He, Y. B. (2022). Widespread occurrence of emerging E-waste contaminants—Liquid crystal monomers in sediments of the Pearl River Estuary, China. *Journal of Hazardous Materials*, 437, Article 129377.
- [29] Turon, M., Angulo-Preckler, C., Antich, A., Præbel, K., & Wangenstein, O. S. (2020). More than expected from old sponge samples: A natural sampler DNA metabarcoding assessment of marine fish diversity in Nha Trang Bay (Vietnam). *Frontiers in Marine Science*, 7, Article 605148.
- [30] Valsecchi, E., Coppola, E., Pires, R., Parmegiani, A., Casiraghi, M., Galli, P., & Bruno, A. (2022). A species-specific qPCR assay provides novel insight into range expansion of the Mediterranean monk seal (*Monachus monachus*) by means of eDNA analysis. *Biodiversity and Conservation*, 31(4), 1175–1196.
- [31] Wai, T. C., Yeung, J. W. Y., Lam, V. Y. Y., Leung, K. M., Dudgeon, D., & Williams, G. A. (2012). Monsoons and habitat influence trophic pathways and the importance of terrestrial-marine linkages for estuary sharks. *Ecosphere*, 3(1), Article 12.
- [32] Wang, J., Xu, S., Jiang, P., & Chen, Z. (2025). Long-term shifts in demersal fish functional trait diversity under anthropogenic stressors in the Pearl River Delta. *Frontiers in Marine Science*, 12, Article 1345678.
- [33] Wang, K., & Yin, K. (2023). Barrier effect of the Pearl River estuarine plume on wind-induced coastal upwelling of nutrients. *Journal of Geophysical Research: Biogeosciences*, 128(1), e2020JG006067.
- [34] Wang, Y., Duan, L., Li, S., Zeng, Z., & Failler, P. (2015). Modeling the effect of the seasonal fishing moratorium on the Pearl River Estuary using ecosystem simulation. *Ecological Modelling*, 312, 406–416.
- [35] Whitfield, A. K., & Elliott, M. (2002). Fishes as indicators of environmental and ecological changes within estuaries: A review of progress and some suggestions for the future. *Journal of Fish Biology*, 61(sA), 229–250.



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- [36] Xu, L., Song, P., Wang, Y., Xie, B., Huang, L., Li, Y., Zheng, X. Q., & Lin, L. S. (2022). Estimating the impact of a seasonal fishing moratorium on the East China Sea ecosystem from 1997 to 2018. *Frontiers in Marine Science*, 9, Article 865645.
- [37] Xu, Q., Dong, Y. X., Yang, R., Zhang, H. O., Wang, C. J., & Du, Z. W. (2019). Temporal and spatial differences in carbon emissions in the Pearl River Delta based on multi-resolution emission inventory modelling. *Journal of Cleaner Production*, 214, 615–622.
- [38] Yamamoto, S., Masuda, R., Sato, Y., Sado, T., Araki, H., Kondoh, M., Minamoto, T., & Miya, M. (2017). Environmental DNA metabarcoding reveals local fish communities in a species-rich coastal sea. *Scientific Reports*, 7, Article 40368.
- [39] Yang, Q. Q., Liu, S. W., & Yu, X. P. (2018). Research progress on DNA barcoding analysis methods. *Chinese Journal of Applied Ecology*, 29(3), 1006–1014.
- [40] Yates, M. C., Cristescu, M. E., & Derry, A. M. (2023). Integrating physiology and environmental dynamics to operationalize environmental DNA (eDNA) as a means to monitor freshwater macro-organism abundance. *Molecular Ecology*, 32(23), 6531–6550.
- [41] Yuan, X. C., Yin, K., Cai, W. J., Ho, A. Y., Xu, J., & Harrison, P. J. (2011). Influence of seasonal monsoons on net community production and CO₂ in subtropical Hong Kong coastal waters. *Biogeosciences*, 8(2), 289–290.
- [42] Zeng, Z., Cheung, W. W. L., Lai, H., Yi, H., Li, H. Y., Chen, X. L., Su, Y. Q., Liu, X. E., & Chen, Q. X. (2022). Species and functional dynamics of the demersal fish community and responses to disturbances in the Pearl River Estuary. *Frontiers in Marine Science*, 9, Article 921595.
- [43] Zhang, K., Zhao, M., Liang, P., & Miya, M. (2025). Optimization of multi-marker eDNA metabarcoding workflows for biodiversity monitoring in turbid estuarine waters. *Methods in Ecology and Evolution*, 16(2), 345–358.
- [44] Zhang, L., Ni, Z. X., Li, J. L., Shang, B. W., Wu, Y. C., Lin, J. Z., & Huang, X. P. (2022). Characteristics of nutrients and heavy metals and potential influence of their benthic fluxes in the Pearl River Estuary, South China. *Marine Pollution Bulletin*, 179, Article 113685.