Evaluating Microplastic Pollution in Coastal Waters and Its Impact on Aquatic Food Webs

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Abstract: The objective was to delineate a methodology to investigate the correlation between spatio-temporal variations in habitat usage, feeding ecosystems, and microplastics (MPs) contamination throughout various ontogenetic stages of fish from various trophic stages inhabiting the aquatic food web. The sedimentary layer of the river was analyzed for the annual and regional fluctuation of MPs and their relationship to the pollution of zooplankton and demersal varieties of fish, according to the same sample methodology. The concentration of MPs in the water column influences their bioavailability. Attention is being paid to research on the geographic distribution of MPs and the geographical and temporal variations in ecological factors and fauna, which is rising in both number and quality. Should the environmental methods delineated in this research be repeated in other estuaries, comparative analyses might elucidate the functioning of communities. Established techniques for sampling, removal, counting, and categorizing MPs and other pollutants consumed by fish are being established and described below to facilitate comparability. Standardized and consistent sample designs and lab procedures are essential for developing and disseminating management solutions across several locations and for temporal comparisons within the same ecosystem.

Keywords – Microplastic; Coastal; Aquatic Food Web; Pollution.

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I. Introduction

Plastics comprise a diverse array of polymer forms, such as polypropylenes, polyethylenes, polystyrenes, polyvinyl chlorides, polyethylene terephthalates, and polyamides, primarily derived from energy sources like petroleum, natural gas, or fossil fuels, and engineered to fulfill the varied requirements of final goods. Due to its flexibility, durability, and affordability, plastics have been instrumental in several important areas, including packaging, building, transportation, electronic devices, agriculture, healthcare, and athletics Verma, Prasad & Katiyar (2024). The widespread use of plastics accelerates global manufacturing of plastics, which has shown a consistent increase over the last few years, culminating in an output of 345 million tons in 2018. The predominant use of plastics is for packaging, which often becomes garbage after a bit of use. The extensive use of plastic items, insufficient elimination of plastic trash, and the persistent nature of plastic materials result in the unregulated accumulation of plastic debris in land and marine environments. A minimum of 8 million tons of plastic garbage is anticipated to enter the world's seas annually Chowdhury, Chowdhury & Sait (2021). By 2050, the mass of ocean plastic is projected to surpass that of fish. The rapid proliferation of plastic debris in the natural world has generated escalating worldwide concern.

Released plastics often undergo gradual fragmentation due to the combined effects of ambient physico-chemical and biotic variables, including mechanical scratches, UV radiation, and microbial deterioration. The disintegration of bigger plastic waste produces many additional microplastics (MP) Yang et al. (2024) (less than 5mm), which are the primary source of MPs in aquatic ecosystems. Plastics are initially made at a tiny scale, such as the prominent MPs, which are often used as exfoliants in some cosmetics or as particles of resin in plastic manufacturing. Principal MPs enter aquatic environments through surface runoff and effluent from treating wastewater facilities or home and commercial waterways. Multiple monitoring projects have shown the widespread occurrence of these MP particles in diverse aquatic habitats worldwide Ahmed et al. (2021).

Upon entering aquatic environments, MPs can extensively disperse across various environments (surface water, water column, and benthic sand) due to differences in shapes and polymer concentrations, potentially influencing their accessibility to aquatic biota inhabiting different environments or trophic levels. MP consumption has been documented in diverse marine wildlife, from minute crustaceans to giant predatory animals. The ingestion of these minuscule plastic fragments can negatively affect the living things that consume them, leading to mechanical damage and allergic reactions, while also serving as a conduit for the infiltration of dangerous chemicals, such as intrinsic plastic ingredients, environmental pollutants, and pathogenic microbes into the water-based food web. The prevalent absorption of MPs by consumable aquatic organisms presents a possible threat to the security of food and the wellness of humans Al Mamun et al. (2023).

A comprehensive knowledge of the biological effects of MPs aids in accurately evaluating the environmental hazards posed by this growing pollutant. Current studies on MPs primarily focus on compiling their sources, occurrences, abundances, and analysis methods across different environments Allen et al. (2022). While several studies have addressed the toxicological impacts of MPs on aquatic animals, most concentrate on marine wildlife. A significant deficiency exists in understanding the trophic transfer mechanisms of MPs and their related pollutants from aquatic food chains to humans, along with the consequent consequences for human wellness Nair & Perumal (2022). This study consolidates the ecotoxicological impacts of MPs and their associated chemicals on aquatic life, including freshwater and marine animals, from the leading suppliers to diverse aquatic animals Vo & Pham (2021).

II. Methods

- Research area

The river watershed has an overall drainage surface of 2800 km². A system of tiny channels functions as a receptor for home and commercial wastewater and waste throughout its brief and low-volume movement. The basin provides water to around 650000 people. The mean flow rate of water is around 12 m^3/s, ranging from 0.5 to 22 m^3/s. The last 18 km of its trajectory is affected by tidal cycles, defining the estuary.

- Sampling methodologies

To elucidate the relationship among wildlife and the yearly and spatial fluctuations of the surrounding conditions (salinity slope, oxygen concentration, and water temperatures), the water section of River was scrutinized for the intermittent and geographic shift in MPs (MPs < 5 mm) and their quantification in connection with seston (e.g., MPs and marine organisms) and the pollution of demersal varieties of fish, following a targeted sampling strategy to test the theory regarding the seasonality of harmful substances (metals, persistent organic pollutants, and MPs) in sediments and water.

  - The seasonal structures of estuarine utilization by various ontogenetic stages (larvae, youngsters, subadults, and adolescents) of faunal groups or organisms.
  - The seasonal structures of faunal pollution (organs or gut contents) throughout the main channels of the estuary (the top, center, and lower regions).

The data generated from these sample design procedures will examine the species within every level of trophic structure, accounting for every ontogenetic stage (larvae, young, sub-adult, and adults). Every ontogenetic stage requires a habitat over a specific seasonal period, allowing for a precise analysis of individual contamination histories about temporal and spatial variables. Disparities between rivers and other regions are identified with enhanced accuracy. This research delineates the analytical approach used for each river ecosystem, including the central canal, external elements, seston, demersal aquatic life, and its pollution via predation. The innovation of this suggested technique is correlating MP pollution with the seasons, fish developmental stages, and the specific areas of the estuarine environment necessary to complete their life cycles.

- Ecological factors

Precipitation was recorded by an automated meteorological sensor near the river's southern entrance. Water temperatures (°C) and saltiness were measured at the surface and bottom before collecting aquatic life and seston specimens. This ecological information was combined with biological and MP concentrations to characterize the changing seasons and geographic river circumstances over the sapling phase.

- Seston collection

The specimens collected to analyze the seston consisted of three surface (0 - 2 m) and three bottom (3 - 7 m) water specimens, obtained monthly over twelve months in each estuarine location. This was achieved by dragging a conical plankton netting (320 µm; 0.7 m; 3 m long) for 10 minutes at a mean velocity of 2.8 knots. The amount of water purified per tow was determined with a flowmeter.

- Laboratory protocols for seston testing

Collections were partitioned into smaller portions (120 mL) to enable the segregation of plankton and plastic detritus from organic substances, using a stereomicroscope. Upon entering the testing facility, fish pupae, eggs of fish, and MPs were completely segregated from the bulk samples, and their quantities per unit were standardized to 120 m^3. The taxonomy classification of ichthyoplankton was derived from an evolutionary sequence, tracing back from young and adolescents collected in a single area, using traits shared across progressively earlier ontogenetic stages. The total length was determined to determine the developmental stage lengths of the principal fish larval species. To enumerate the zooplankton, triple sub-samples of 12 mL were extracted from a reduced 750 mL specimen for each stream, using a Stempel pipette, followed by repositioning. The average number was calculated by independently counting each zooplankton species from each portion. Mean counts were then extended to 750 ml and, for ichthyoplankton and MPs, adjusted to a standard quantity of 120 m^3.

III. Discussions

Wo-way Analysis of Variance (ANOVA) was applied to ascertain whether significant fish volume, biomass, and variety count variations occurred across spatial and temporal dimensions. ANOVA was used to examine variations in community features across different locations (the top, center, and lower river) and periods. All information underwent $\log10(x + 1)$ transformation to enhance distribution normalcy. Levene's test was employed to assess the uniformity of variations. When significant variations were identified, the Bonferroni Test was applied a posteriori.

Canonical Communication Assessment (CCA) was employed to assess the relationships between ecological information and the color of MPs, as well as the categories of food consumed by fish predators, with the dependent factors represented by the Index of Relative Importance (Ip), consumed prey, and MPs. Significant variations were acknowledged when $p < 0.05$. CCA is a direct gradient assessment in which the composition and geographic distribution of animals, victims, and MPs are directly correlated with external elements. CCA was executed by multiple least-squares regression analyses, utilizing site scores (obtained from the weighted mean of animals' ontogenetic stages) as the variables in dependence and surroundings as independent factors. The density information for specific target fish species was analyzed by direct gradient assessment to identify fluctuation patterns in connection with external variables. Species comprising less than 2% of the overall density and biomass were omitted from the analysis. The investigations concentrated on asymmetric and biplot diagram scaling, with the ecological and biological information subjected to $\log10(x + 1)$ transformation. A Monte-Carlo randomization test was employed to identify the environmental factors that significantly influenced the variability of the variable being studied. A ceremony illustration was generated (triplot: incorporating ecological factors), wherein the abundance of organisms (predators and prey) and MPs (or alternative contaminants) were depicted by rectangles, sites for every season by rectangles, and ecological factors (saltiness, water temperature, oxygen concentration,

and Secchi length) by arrows. The graphic illustrates how the primary pattern of variance in the makeup of communities is affected by external variables, as well as the ranges of animals (predators and victims) and pollution from MP across each ecological factor.

IV. Recommendations

To enhance comprehension of the ecological hazards posed by MPs to aquatic creatures and people, the following research goals are proposed:

- Utilize ecologically appropriate doses in MPs exposure research.
- Conduct more research to elucidate the impacts of MPs on aquatic primary producers and the variables that influence these effects.
- Increase focus on the ecotoxicological impacts of MPs on apex predators and freshwater species.
- Conduct a thorough assessment of the synthetic impacts of MPs and ecological pollutants and ascertain the function of MPs in the trophic transmission of pollutants to the environment.
- Conduct more research on the determinants influencing the sensitivity of aquatic creatures to MPs and the toxicity and fate of swallowed MPs inside these animals.
- Implement comprehensive surveillance initiatives to assess the prevalence of MPs in aquatic goods intended for human intake and quantify the MPs ingested by people via these products.
- Conduct more in vitro research to elucidate the destiny and actions of MPs and their related pollutants inside the human digestive system.
- Concentrate on the prevalence and cytotoxicity of nanoplastics in aquatic creatures and assess the consequences for human well-being.
- Conduct more research to elucidate the function of MPs as carriers for infectious microorganisms and their possible environmental implications.

V. Conclusion

Standardized sampling techniques for collecting data on estuarine ecosystems and food web pollution (MPs, metals, and other contaminants) are essential for conducting analyses across and within estuarine environments to identify alterations. While several studies have examined the contamination of fish by plastic waste, few efforts have been directed towards understanding the temporal and spatial variations of MP accessibility and consumption. The distribution habits of fish and the accessibility of MPs fluctuate with the geographical and temporal shifts of the characteristics of tropical and subtropical rivers. Any inquiry seeking to ascertain the effects of MPs (and/or other contaminants) on aquatic habitats must include the influence of the estuary ecocline on fish behavioral ecology and the likelihood of contact with MPs. This methodology is crucial for identifying ecological variables correlated with trends in MP exposure and consumption throughout the life cycle of certain kinds of fish. Alterations in the behavioral habits of fish and other animals inside the watershed will be more accurately identified.

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