東京湾の底層におけるマイクロプラスチックの分布と動態に関する研究

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[課程博士・論文博士共通]

博士学位論文要約

Summary of Dissertation

専　攻 Major	Applied Marine Environmental Studies	氏　名 Name	Hashim Said Mohamed
論文題目 Title	Studies on the distribution and dynamics of microplastics in the benthic zone: A case study of Tokyo Bay		

Chapter 1: Introduction

In recent years, plastics' production, use, and subsequent pollution have increased substantially. Most of the plastics are produced and utilized in terrestrial environments, however, due to inadequate disposal and treatment, these plastics become pollutants in natural environments including the ocean. With time, floating microplastics are deposited in the benthic zone which is believed to be the final sink for microplastics. Despite the importance of the benthic zone in marine health, there are limited studies that analyze the level of plastic pollution in the seabed, and even fewer that study benthic macrofauna (0.5-2mm size). This study aimed to understand the dynamics of microplastics in the benthic ecosystem by analyzing near-bottom water, sediments, and macrofauna. Further analysis was conducted to understand the depositional history of microplastics and their level of degradation across the various compartments in the benthic zone.

Chapter 2: Interaction of microplastics and organisms in the benthic zone

The concentration and characteristics of microplastics (MPs) in the benthic environment, (near-bottom water, sediments, and macrofauna) from four stations in Tokyo Bay were analyzed. Samples were collected using a mud collector attached to a winch on board R/V Seiyo Maru and analyzed for MPs using a micro-Fourier Transform InfraRed Spectrometer (µFTIR).

Results

Total Organic Matter (TOM) was highest in the headward station and reduced towards the mouth of the bay. The sediment particle sizes were smaller in the inner station compared to the outer station. An average of 221±189 pcs L^{-1} were recorded from near-bottom water, with the highest concentrations recorded from Station 3 (344±252.7 pcs L^{-1}), followed by Station 6 (329.3±216.4 pcs L^{-1}), Station 2 (149.3±33.3 pcs L^{-1}), while station 4 had the lowest concentration of microplastics (63.1±20.5 pcs L^{-1}). In the sediment, an average of 16.6±8.0 pcs g^{-1} D.W was recorded where Station 2 had 21.1±5.9 pcs g^{-1} D.W while Station 6 and Station 3 had 17.3±14.0 and 16.4±8.3 pcs g^{-1} D.W respectively. Station 4 recorded 11.5±4.0 pcs g^{-1} D.W. There was a high similarity between the polymers recorded in the water and the sediments as PE and copolymer dominated, however a higher abundance of denser polymers were observed in the sediments compared to the water above, PA also had a higher abundance in sediments compared to water.

A total of 98 organisms were recorded but only 90% were recorded to have ingested MPs. MPs in the macrobenthos were further analyzed based on their feeding modes. Deposit feeders ingested 6.7±7.2 pcs ind^{-1} , predators ingested 4.2±4.1 pcs ind^{-1},and filter feeders 3.3±4.1 pcs ind^{-1}. PE and PA dominated and showed the influence of sediments on MPs ingestion by organisms. The lower ingestion rate of predators compared to deposit feeders indicates that there is no bioaccumulation of MPs in the benthic food chain of Tokyo Bay. The sizes of MPs particles ingested were small sized.

Discussion and Conclusion

Results show significantly higher MPs concentrations in near-bottom water compared to surface water, attributed to factors such as semi-closed topography and plastic contaminants from major rivers. The study identifies bottom-water resuspension, river inputs, and density gradients as contributors to elevated MPs levels. Analysis of sediment data reveals predominant polymer types and smaller-sized particles, suggesting terrestrial sources and fragmentation. MPs ingestion by macrofauna, particularly crustaceans, is observed, with MPs in sediment influencing ingestion rates. The study contributes to understanding MPs distribution, sources, and interactions with benthic fauna in Tokyo Bay, enhancing knowledge of marine plastic pollution dynamics.

Chapter 3: Vertical distribution of microplastics in the benthic zone

Triplicate sediment cores having depths of 35 cm were collected on board *RV* Seiyo Maru to understand the trends in MPs pollution. The core was sectioned into 5 cm sections resulting in 7 segments each analyzed for MPs. The sediment age was determined using ^{210}Pb and ^{137}Cs and the ^{137}Cs indicated 2 peaks marking the 2011 Great Japan earthquake and Chernobyl accident.

Results

Based on these two peaks the sedimentation rate was estimated at 0.8±0.2 cm y^{-1}, the lowest core dated post-1976, indicating the expected accumulation of plastic particles. MPs analysis indicated an increase in MPs deposition in the upper depths. The highest MPs in the sediment were found in the topmost layer (25.9±3.0 pcs g^{-1} D.W) and were the lowest at the deepest sections 8.4±7.9 pcs g^{-1} D.W. Polymer was dominated by PE in all depth zones, followed by copolymer and PP. The particle sizes in all depths had a peak at 40-60 µm. In terms of polymer sizes, PET recorded larger particle sizes and aspect ratios in all depth sizes where it was present, while polyethylene had the smallest particle size. The increase of MPs in the ocean corresponds with the annual increase in the production of plastic.

Discussion and Conclusion

Microplastic (MPs) concentrations increased with depth, paralleling global plastic production trends and associated pollution. Predominant polymers included polyethylene (PE) and polypropylene (PP), consistent with high production volumes and single-use packaging. Despite being an early plastic, polyvinyl chloride (PVC) was only present in the top layer, reflecting its longer lifespan and lower pollution levels.

MPs sizes peaked at 30-60 µm across depths, suggesting mechanical degradation in sediments. PET particles were larger due to their density, while PE and PP exhibited smaller sizes, indicating fragmentation. Recycling efforts were reflected in decreased PET abundance, highlighting the role of recycling in reducing plastic pollution.

The study underscores the need for strategies to reduce plastic production and promote recycling to mitigate ocean pollution. Longer product lifespans, like those of PVC, could further minimize pollution. Overall, the findings provide valuable insights into plastic pollution dynamics and inform environmental management efforts.

Chapter 4: Degradation degree of microplastics in the benthic zone

The degradation levels of PE and PP particles recorded in Chapters 3 and 4 were analyzed using the Carbonyl Index (CI) by utilizing the SAUB technique. A total of 748 spectra were analyzed.

Results

Generally, the CI values were relatively high with the sediments CI was slightly higher than in water. Station-wise analysis of PE for CI indicated higher values in station 2 with 3.2±0.8 in sediments and 3.1±0.7 in near-bottom water. PP on the other hand was highest in station 4 for sediments with 2.9±0.8 while PP's CI value in water was highest in station 2 with 3.0±0.5. Both Macrofaunal CI indices for PE and PP seemed to be influenced more by sediment as their high CI value stations corresponded with high CI values. The depth analysis showed a negative correlation with depth, where the deeper layer had lesser CI values compared to the surface sediments.

Discussion and Conclusion

Comparisons with previous studies revealed slightly higher CI values in the near-bottom water, indicating prolonged residence time and degradation processes before settling undergoing photodegradation, biotic degradation, and mechanical weathering, ultimately altering their physiochemical properties.

Macrofauna exhibited higher CI values than sediments and near-bottom water, suggesting significant biotic degradation of ingested MPs. Spatial variations in CI values among sampling stations were observed, influenced by local environmental conditions such as hydrodynamics, organic matter content, and microbial activity.

Depth-wise analysis indicated a negative correlation between CI values and depth, with a more pronounced reduction observed in PE-related CI values compared to PP. Shallower sediments exhibited higher oxidative degradation due to exposure to microbial activity, redox potential, and organic matter content. While deeper particles undergo physical degradation exposing areas with lower CI values.

The study underscores the importance of understanding microplastic behavior in aquatic ecosystems, particularly in terms of polymer type, location, depth, and particle characteristics. Continued research and monitoring are essential to mitigate the environmental impacts of microplastics.

Chapter 5: Conclusion

A higher concentration of MPs near river sources and an abundance of package-derived single-use polymers (PE, PP, and Copolymers) suggests terrestrial inputs of MPs, whereby large dense MPs settled close to the rivers establishing evidence that rivers are a source of MPs in Tokyo Bay. The MPs sizes were indicative of longer residence time in the Bay which was further supported by the high degradation levels. Once deposited in the sediment, the MPs are buried via continuous sediment deposition in the bay corresponding to global plastic production positively. However, constant mechanical fragmentation results in the exposure of less degraded layers resulting in a reduction of CI with depth.

This study provides a comprehensive analysis of the MPs in Tokyo Bay and exposes the role of environmental factors and MPs characteristics in shaping their distribution and accumulation, with their implications for marine ecosystems.