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

[課程博士・論文博士共通]

博士学位論文内容要旨

Abstract of Dissertation

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論文題目 Title	Studies on the distribution and dynamics of microplastics in the benthic zone: A case study of Tokyo Bay		

In recent years, plastics' production, use, and subsequent pollution have increased substantially. These materials are used widely in various applications due to their lightweight, inertness, and durability. However, these same characteristics are what make plastics an environmental concern. 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 in the ocean. The benthic zone is a habitat for various organisms including macrofauna (0.5-2mm size). 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 there are even fewer that study benthic macrofauna. 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 Two analyzed the concentration and characteristics of microplastics (MPs) in the benthic environment, specifically the near-bottom water, sediments, and macrofauna from four stations in Tokyo Bay. Samples from these four stations 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). The environmental parameters measured included the depth, total organic matter (TOM), and sediment grain size, whereby TOM was highest in the headward station and reduced towards the mouth of the bay. The sediment 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 compartment, an average of 16.6±8.0 pcs g^{-1} D.W was recorded. The highest concentration was reported from Station 2 with 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 in 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. The feeding mode with the highest ingestion of microplastics was deposit feeders with 6.7±7.2 followed by predators with 4.2±4.1. Filter feeders had the lowest ingestion of microplastics with 3.3±4.1 pcs ind^{-1}. The highest polymer recorded in macrofauna was PE and PA which 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 in Tokyo Bay were very small in all compartments, increasing the bioavailability of the MPs to macrofauna and thus a pathway of MPs into the food web.

In **Chapter Three** the deposition of microplastics in Tokyo Bay was analyzed. Triplicate sediment cores having depths of 35 cm were collected on board *RV* Seiyo Maru. 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 that led to the release of nuclear material from the Daiichi Fukushima power plant. The second peak corresponded with the Chernobyl accident. Based on these two peaks the

sedimentation rate was calculated and was found to be 0.8 plus or minus 0.2 cm y^{-1}. 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 last depth with 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 higher particle sizes in all depth sizes where it was present, while polyethylene had the smallest particle size. The aspect ratio had a similar trend to the size whereby the PET had a higher aspect ratio compared to the other polymer type. The increase of MPs in the ocean corresponds with the annual increase in the production of plastic and thus proper measures need to be taken to minimize plastic pollution.

In **Chapter Four**, 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. Generally, the CI values were relatively high, indicative of a higher degree of degradation. The CI values in the sediments were slightly higher than those recorded in water. Station-wise analysis of PE for CI indicated a higher value of CI 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. The CI analysis is an important measure of degradation and can be used to understand the dynamics of microplastics in the marine benthic environment.

Chapter Five was the conclusion of these studies and a focus on the dynamics of MPs in Tokyo Bay based on the preceding chapters. 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 (CI) of MPs, specifically PE and PP. This means that MPs in the Bay arrive via rivers, and undergo degradation, deposition, and erosion (by bed shear stress), before settling back into the seabed. The MPs particles were small enough to be ingested by 90% of the macrofauna with sediments having a more influential role than near-bottom water, however, no bioaccumulation was observed based on the trophic analysis. Once deposited in the sediment, the MPs are buried via continuous sediment deposition in the bay, with the concentration of MPs in each depth layer 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 in the bay.

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. Continuous monitoring and mitigation efforts are required to address microplastic pollution in impacted regions like Tokyo Bay.