A Model that Establishes a Parallel Behave Between Varying Chemicals and the Presence of Microplastics in the Ocean

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The box model is a commonly utilized tool for understanding oceanic phenomena, particularly regarding the spatial distribution of chemicals. In our study, we aimed to establish parallels between existing models that account for the input of various chemicals and the potential flux of microplastics within the ocean. Our objective was to bridge the gap between conventional chemical dynamics and the emerging concern of microplastic pollution. To achieve this, we examined the accumulation of microplastics within the ocean and their uptake by marine organisms while also considering processes such as mineralization and demineralization. Our model treated microplastics as constituents akin to traditional chemical elements like phosphorus (P) and oxygen (O), viewing the ocean as a dynamic system with inputs and losses. Through this modeling framework, we sought to identify our approach's strengths and weaknesses. One key observation was the realization that the ocean receives a significant influx of microplastics, surpassing its capacity for degradation or bioaccumulation. This recognition underscores the urgency of addressing microplastic pollution and highlights the need for effective management strategies to mitigate its impact on marine ecosystems.
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Introduction

Microplastics, generally defined as polymers with a size ranging from 1 µm to 5 mm [1,2], are released into soils, rivers, and oceans, where they undergo progressive fragmentation due to various environmental factors such as mechanical abrasion, ultraviolet radiation, and biological degradation by microorganisms [3].

Even during degradation, microplastics can act as vectors of contamination by interacting with and adsorbing pollutants such as non-essential metals, dichloro-diphenyl-trichloroethane (DDTs), polychlorinated biphenyls (PCBs), bisphenol A (BPA), pesticides, and others [4]. They also provide a habitat for microorganisms, leading to synergistic contamination and exacerbating negative impacts on exposed organisms and ecosystems [5,6].

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In recent years, microplastics have garnered increased attention as they have been discovered in habitats near areas with human activity and in isolated islands in the middle of the ocean and polar regions [7]. This accumulation of plastic waste in marine animals has raised concerns. Due to their small size, microplastics are considered bioavailable to organisms throughout the food chain. In the marine environment, persistent organic pollutants and plasticizers/additives can enter food chains once ingested by marine fauna, leading to toxic effects [8,9], further amplified by the bioaccumulation process prevalent in marine environments. Humans, often at the top of the trophic chain, may experience digestive system issues due to the presence of microplastics [10] or harmful impacts on the respiratory system [9,11,12].

This study aimed to develop a predictive model for the dynamics of microplastics in the ocean, comparing them with the behavior of variable chemical elements in the ocean, such as Ca and N, using the box construction strategy [13]. Predictive models for the distribution of microplastics in the ocean can provide insights into the environmental impact caused by these pollutants in this specific environment.

Materials and Methods

Several premises were considered to establish the model:

a) The ocean was conceptualized as a closed system [1,9], where the input and output balance of all elements is zero. This means that the concentrations of nutrients are influenced by their release from rocks, while anthropogenic activities supply microplastics in equal quantities.

b) The behavior of microplastics in water was assumed to be similar to that of spatially variable elements such as calcium (Ca) and nitrogen (N) but with constant concentration patterns (Figure 1).

c) Changes in the amount of microplastics in the ocean were attributed to the bioaccumulation potential of living beings, resembling the processes of mineralization and demineralization of Ca and N [13-15].

d) The movement of the oceans was considered a dispersal mechanism for microplastics.

e) All depth zones in the ocean were treated as equal in the model construction.

f) The hypothesis of kinetic control was assumed, which considers the composition and concentration of microplastics in the environment and their removal.

g) No material losses (chemicals or microplastics) were assumed to occur in the oceans.

Assuming that the ocean's V is a constant given by the first-order relationship in concentration, ocean V_A equals $k_A C_A$, where K is the constant rate of removal per year, and F is the inflow of materials through rivers. About microplastics, this would be due to the process of bioaccumulation in living beings. Thus, the differential equation becomes $C_{A, ocean}$ = average concentration of A (microplastics) in the ocean (μmol m^{-3}). Note that the mass of A in the ocean is equal to the concentration of also in this environment ($M_{Aocean} = C_{A\,ocean}$), where V_{ocean} is the total number of moles of A in the ocean. Then, the model can be mathematically written as d/dt $M_{A,\,ocean}$ = input - losses. Assuming that the ocean's V is a constant given by the first-order relationship in concentration, ocean V_A equals $k_A C_A$, where K is the constant rate of removal per year, and F is the inflow of materials through rivers. About microplastics, this would be due to the process of bioaccumulation in living beings. Thus, the differential equation becomes:

$$\frac{d}{dtMA} = CA = input - losses$$
$$= (FriverCAriverVocean)$$
$$-KAoceanCAocean$$

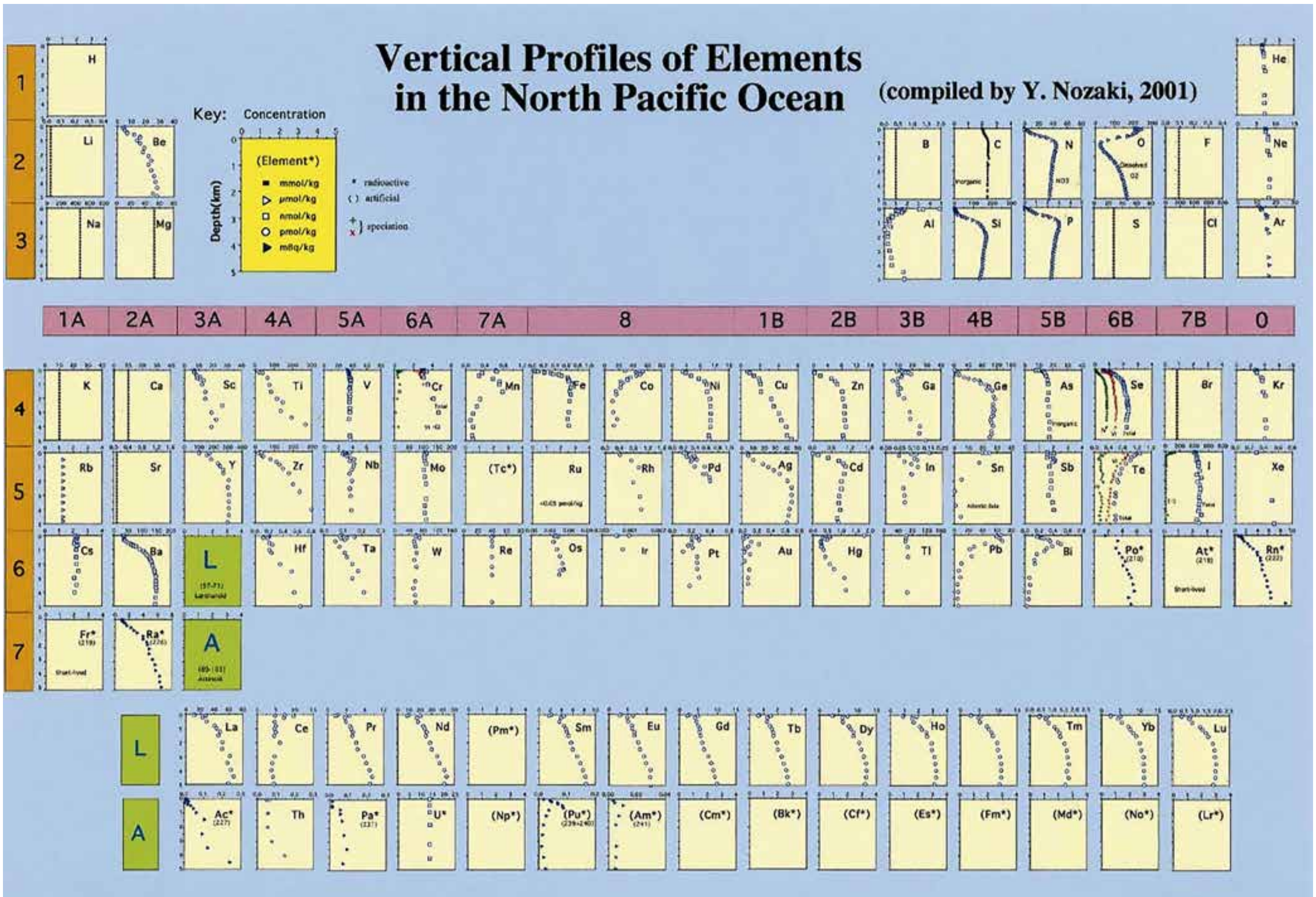
Results and Discussion

For this work, the hypothesis of kinetic control in the ocean, denoted as C_A, was assumed. This control observes the composition by balancing nutrient input and removal via bioaccumulation. Thus, the characteristic response constant is represented by k_A^{-1}, which is mathematically equivalent to the accumulation in concentration over time, given by τA. Large equations denote the process of scale elements, or microplastics, tending to undergo bioaccumulation in living beings. Therefore, the rapid response to disturbance and a rapid differential equation become:

$$\frac{d}{dtMA} = CA = (FriverCAriverVocean)$$
$$-KAoceanCAocean$$

After the cash recovery in the state of concentration, as the model establishes, deposition in rivers continues to increase, and an increasing number of living beings are found containing microplastics in their bodies. The amount of this material can vary due to bioaccumulation (Figure 2) and result in a slight decrease in the amount,

Figure 1. Spatial distribution of chemical elements in the ocean.



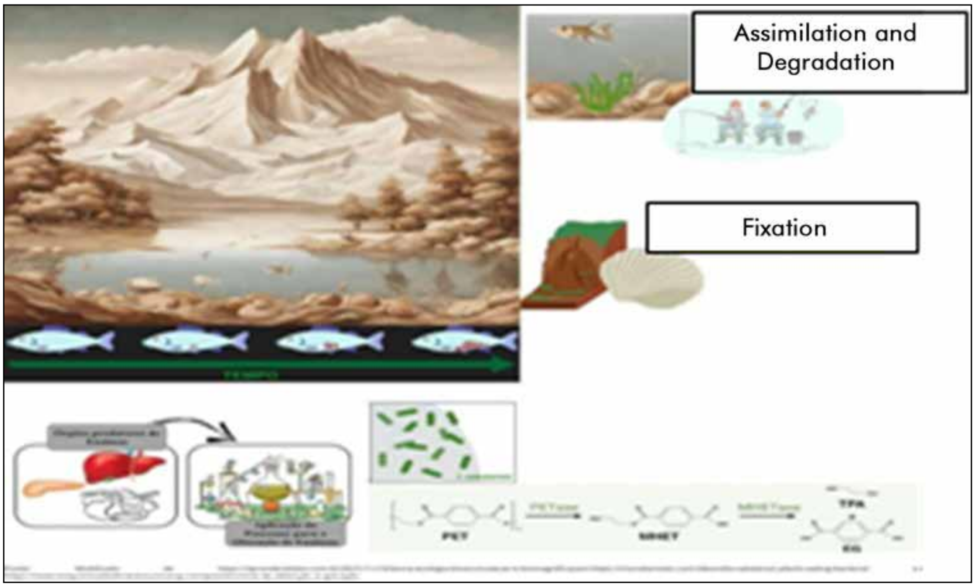
Source: Nozaki and Tsunogai [6].

considering that the living beings bioaccumulate may have intestinal flora or enzymes capable of degrading this waste. However, even if it degrades, the plastic waste resulting from degradation will be released into the environment, indicating that the microplastics have only changed the size of the polymer chain or degradation into a breakdown derivative, but the same general concentration remains.

Local deposition events influence the quantity since they can be affected to a greater or lesser extent by the movement of currents, making the variables of time and speed of microplastic flow in the ocean important. Therefore, the proposed box model has the potential to explain the behavior of a wide range of microplastic concentrations, mainly due to variations in the K_A removal rate, which indicates bioaccumulation, showing a crucial role of control mechanisms in the amount of microplastics.

Despite the first-order process in the concentration of microplastics being considered highly theoretical and an initial test, as the real world of the ocean is complex and not all processes are directly proportional to the concentrations of elements, it was necessary to limit the study to the chosen model. Finally, as the level of environmental impact of microplastics is high, especially in the oceans and coastal regions, this intensity may vary depending on the events, whether on land or coastal, regional or local. Therefore, future research should focus on non-linear models, encompassing other factors present in the ocean, such as temperature and ultraviolet radiation, among others, responsible for the degradation process of plastic waste.

Figure 2. Bioaccumulation of microplastics in the living beings and degradation process.



Source: Adapted from Caixeta and colleagues [2].

Additionally, other experiments will take points of microplastics deposition in the ocean using georeferencing and statistical tools to make a better comparison with varying elements. A model admits premises and discards others to seek to understand the natural world through simplified parts of reality that, due to the lack of sufficient technology or understanding of its complexity, allow understanding the parts or making a specific process in nature understandable or replicable. Considering that microplastics, according to the model, behave as an entity bioaccumulative, passive of being a selective agent (as there is a tendency for the survival of living beings capable of degrading it, using it as a substrate or simply adding it to the body), it is understood that the deposition of plastic waste in the oceans reaches balances that change over time and are subject to an accumulation rate. Ultimately, the level of environmental impact may vary more if the analysis is considered local, where there is a greater possibility of observation and broad measurement of the factors that affect the flow of microplastics.

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References

1. Abou-Zeid D-M, Muller R-J, Deckwer WD. Degradação de poliésteres naturais e sintéticos em Philos Trans R Soc B 2009;364:1985-98.
2. Caixeta D et al. Microplástico como indicadores de poluição ambiental e seus efeitos sobre os organismos. Enciclopedia Biosfera 2022;19(40).
3. Khalid N, Ageel M, Noman A, Hashem M, MostafaYS et al. Linking effects of microplastics to ecological impacts in marine environments. Chemosphere 2021;264(2). Avaiable at: https://doi.org/10.1016/j.chemosphere.2020.128541>.10.1016/j.chemosphere.2020.128541[Acessed Oct. 10, 2023].
4. Ali I, Cheng Q, Ding T, Yiguang Q, Yuechao Z, Sun H, Peng C, Naz I, Liu J. Micro- and nanoplastics in the environment: Occurrence, detection, characterization andtoxicity–A critical review. Journal of Cleaner Production 2021;313:127863.
5. Cole M, Lindeque P, Halsband C, Galloway TS. Microplastics as contaminants in the marine environment: a review. Marine pollution bulletin 2011;62(12):2588- 2597.

6. Nozaki Y, Tsunogai S. A simultaneous determination of lead-210 and polonium-210 in sea water. Anal Chim Acta 1973;64:209–216.
7. Raddadi N, Fava F. Biodegradationofoil-based plastics in the environment: Existing knowledge and need so fresearch and innovation. Science of the Total Environment 2019;679:148-158.
8. Lwanga EH, Vega JM, Quej VK et al. Field evidence for transfer of plastic debrisalong a terrestrial food chain. Scientific Reports 2017;7(1):14071.
9. Sarmiento J et al. Sensitivity of O_2 concentration and ocean anoxia. Oxford Press. 1988.
10. Galloway TS. Micro-and nano-plastics and human health. Marine Anthropogeniclitter 2015:343-366.
11. Dong CD, Chen CW, Chen YC, Chen HH, Lee JS, Lin CH. Polystyrene microplastic particles: in vitro pulmonary toxicity assessment. Journal of Hazardous Materials 2020;385:121575.
12. Sarmiento J et al. Ocean carbon cycle and atmospheric pCO_2. Oxford Press.1988.
13. Broecker WS. A kinetic model for the chemical composition of sea water. Quaternary Research 1971;1:188-207.
14. Tyrrel T. High-impact Nature paper answering long-standing question on the role of P and N in oceanic primary production. Oceanography 1999.
15. Yool A, Tyrrel T. Role of diatoms in regulating the nitrogen cycle. Oceanography 2003.