Measuring the abundance and distribution of microplastics and marine organisms across the surface of the equatorial Pacific using a Manta Net

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Abstract

The increasing production of plastics and their long lifespan have led to concerns about the accumulation of microplastics in marine environments. Due to their ability to be mistaken for food, microplastics act as a source of toxic chemicals in oceanic food chains, posing a threat to organisms that encounter them. To understand how microplastics can harm marine ecosystems, we need better measurements of their abundance and distribution in the global ocean. There remains a large gap in knowledge between statistical predictions of microplastic distribution and field data across the equatorial Pacific as its remote location makes observations difficult. Aboard the R/V *Thomas G. Thompson* from February 23 to March 13, 2023, this study quantified the accumulation of microplastics using a Manta net across a meridional transect from Honolulu, Hawaii to Suva, Fiji. In each net tow, the diversity and relative abundance of surface organisms were quantified to determine the organisms potentially affected by the accumulation of plastics. The highest-counted organisms (20-260 $\#/m^3$) were copepods. Plastic concentrations were highest ($4.2 \times 10^{-2} \#/m^3$) close to the Hawaii coast and lowest ($2.9 \times 10^{-3} \#/m^3$) at the equator (0°) with there being no significant variation between samples collected along the equatorial transect. Available numerical models generally over-predicted plastic concentrations. In situ microplastic measurements, as performed in this study, will provide critical data for improving numerical models to better understand the current state of microplastics in marine ecosystems.

Plain Language Summary

Microplastics are plastics that are smaller than 5 mm (about the size of a pencil top eraser). They have been distributed in all of the world's oceans and are finding their way into the plankton, fish, birds, and marine mammals that are part of these ecosystems. This study collected surface water samples off the coast of Hawaii, USA, and along a transect across the equator to measure the concentration of microplastics to understand what factors may be controlling their abundance and distribution. Concentrations of microplastics were mostly 10x higher near Hawaii than at the equator with most stations near and at the equator having very low microplastic concentrations. A couple of stations near the equator had microplastic concentrations approaching what was observed 300 km SW from Hawaii highlighting the global reach of these pollutants. Microplastic concentrations observed during this study were much lower than predicted by available numerical models highlighting the importance of surveys like this to improve our understanding of the distribution of microplastics in the marine environment.

1. Introduction

Since the discovery of ocean microplastics in the 1960s, scientists have been attempting to understand how this debris is transported through the marine environment and the implications it may have on the health of both ocean and human ecosystems (Thompson et al. 2004). Defined as synthetic organic polymers smaller than 5 mm, microplastics persist throughout the ocean due to their unnatural chemical structure which is highly resistant to bacterial degradation (Arthur et al. 2009). Their small size and low density contribute to their longevity in the upper ocean. Since the plastic boom in the 1950s, plastic production is compounding annually at 8.4% (Geyer et al. 2017) supplying 4.8 - 12.7 million tons of plastic each year to the ocean via beaches and runoff from land (Jambeck et al. 2015). Microplastics can enter into waterways from microbeads (Masura et al. 2015), synthetic materials – e.g., nylon and polyester – (Thompson et al. 2004), fishing gear (Xue et al. 2020), and the weathering of tires (Kole et al. 2017). Nurdles, foam, microbeads, and fibers are among the most common microplastics found in the ocean derived from commonplace products such as styrofoam cups, synthetic clothing, and facial scrubs, and as a byproduct of plastic production (Masura et al. 2015). Wave stress and continuous physical erosion from currents in combination with photooxidation can cause larger fragments of plastics to break down resulting in microplastics (Nguyen et al. 2019). These studies demonstrate a global concern for these micropollutants accumulating in the ocean. With the limited ability to remove the accumulating microplastics, the pollution problems will persist and increase.

Sixty percent of plastics are less dense than seawater allowing them to float at the surface of the ocean where they come into contact with zooplankton (Andrady, 2011; Botterell et al. 2019). While the effects of microplastics on marine life are not fully understood, there is concern the chemical contaminants leaching from this debris will be transferred to these organisms, causing toxicity (Masura et al. 2015) and bioaccumulation into the ocean food chain (Kühn et al. 2015). Therefore, zooplankton can be a source for higher trophic levels to uptake microplastics and their associated chemical contaminants through either ingestion or absorption. Across the Pacific, zooplankton biomass is highest at the equator where upwelling brings up nutrient-rich water from the deep. Of the zooplankton in this community, copepods are the predominant member, suggesting this taxon may be the most affected by the presence of microplastics (Long et al. 2021). The ingestion of plastic debris stresses copepods by obstructing their digestive tracts and decreasing food intake.

Kühn et al. (2015) found elevated levels of microplastics ingested by fish and that the microplastics were similar to concentrations found on the ocean surface. Other studies have shown plastic debris to be found across trophic levels ranging from molluscs (Browne et al. 2008), to seabirds (Amélineau et al. 2016), and to marine mammals (Nelms et al. 2019). The accumulation of plastics within the ocean and the oceanic food chain continues to be a key issue in understanding the species directly impacted by plastic pollution and determining the magnitude of their effect on marine ecosystems.

The prevalence of this anthropogenic debris is not limited to the coast as its global ocean distribution is influenced by wind-driven vertical mixing, ocean currents, particle density, and its proximity to sources (Silvestrova and Stepanova 2021). Ocean currents transport micropollutants globally, where they persist for years before reaching distant shorelines or ending up in one of five global gyres (Maximenko et al. 2012). With a surface area of 1.6 million square kilometers (Isobe et al. 2019), the accumulation of plastic in the North Pacific Gyre is the largest repository of oceanic plastics. Controlled by Ekman and geostrophic currents, the gyre moves clockwise, following the North Equatorial Current west to Japan where it joins the Kuroshio Current and deflects to the east into the North Pacific Current that feeds south into the California Current (Makimenko et al. 2012). This highlights a path by which microplastics released in Asia can eventually reach western North American coastal systems.

Understanding how microplastics are affecting the environment requires a better understanding of their abundance and distribution throughout the world's oceans. To quantify the vast amount of debris circulating globally, Isobe et al. (2019) utilized transoceanic surveys and mathematical models to estimate microplastic abundance across the Pacific Ocean. Across a meridional transect from Antarctica to Japan, microplastic concentrations decreased exponentially from the North Pacific across the equator with the highest concentrations found north of the equator near Japan. It was hypothesized that the oceanic distribution observed was due to the Northeast Pacific having the greatest input of plastics and that the transect was located relatively close to land (Isobe et al. 2019). Cózar et al. (2014) observed that non-converging currents, such as the Kuroshio Current off the coast of Japan, can contain high microplastic concentrations when the current is close to a source of plastics (i.e., land). Findings from Maximenko et al. (2012), similar to Isobe et al. (2019), found the lowest microplastic concentrations were observed at the equator and highest within the North Pacific Gyre.

Many studies quantify the abundance of microplastics using numerical models due to the difficulties of collecting sufficient measurements in situ. However, these models rely on in situ data from previous field studies, limiting model accuracy to ocean areas where transects have already been explored (Isobe et al. 2019). Additionally, many of these studies do not account for other environmental factors that could affect the mass concentration of particles, such as sinking (Silvestrov and Stepanova, 2021). Due to its remote location, the equatorial Pacific has remained relatively unobserved. Although mathematical models provide insight into the potential global distribution of micropollutants, van Sebille et al. (2015) found estimations of microplastics between models strongly differed in equatorial regions but roughly agreed for the North and South Pacific Gyres. Although most models report their lowest measurement of plastic abundance at the equator, counts of microplastics can differ by factors of 100 (van Sebille et al. 2015). This lack of agreement highlights the need for in situ measurements along the equator.

The equator is dominated by three main ocean currents: The North and South Equatorial Currents (westward) and the Equatorial Countercurrent (eastward). Controlled by the Northeast Trade Winds, the North Equatorial Current splits near the Philippines, moving south towards the Equatorial Countercurrent and north to join the North Pacific Current. Approximately 480 km wide and flowing up to 500 m deep, the Equatorial Countercurrent travels across the equator before diverging to the adjacent currents (https://www.britannica.com/science/equatorial-current, January 23, 2023). The South Equatorial Current is controlled by the Southeast Trade Winds and divides north into the Equatorial Countercurrent at 180°E and south into the East Australian Current or the South Pacific Gyre. These currents drive the distribution and transport of micropollutants in the tropical Pacific Ocean.

My hypothesis is that the Northern Pacific currents will have higher microplastic concentrations than those in the Southern Pacific due to the much larger plastic sources in the Northern Pacific. The speed and location of ocean currents will be an important indicator as to how microplastics will be transported with faster currents leaving less time for plastic to accumulate. Of the organisms collected during manta net trawls, my expectation is for copepods to be the predominant taxon due to their high abundance in this region. As the equator is a relatively understudied region of the Pacific, knowledge of how plastic distributions change relative to their location and the speed of currents is vital in understanding the oceanic circulation of microplastics.

2. Methods

2.1 Onboard Sample Collection

Sampling was conducted aboard the R/V *Thomas G. Thompson* from February 23 to March 13, 2023, between Honolulu, HI, USA, and Suva, Fiji (Fig. 1). Microplastics were collected using a Manta net (333 µm) towed for 15 mins at 1-2 knots along the sea surface at each station. It was towed along the side of the ship to avoid wave breaks. After towing, the net was pulled up and thoroughly rinsed with water to ensure all of the sample was collected in the cod end. The sample was transferred to a 6 oz jar for onboard analysis.

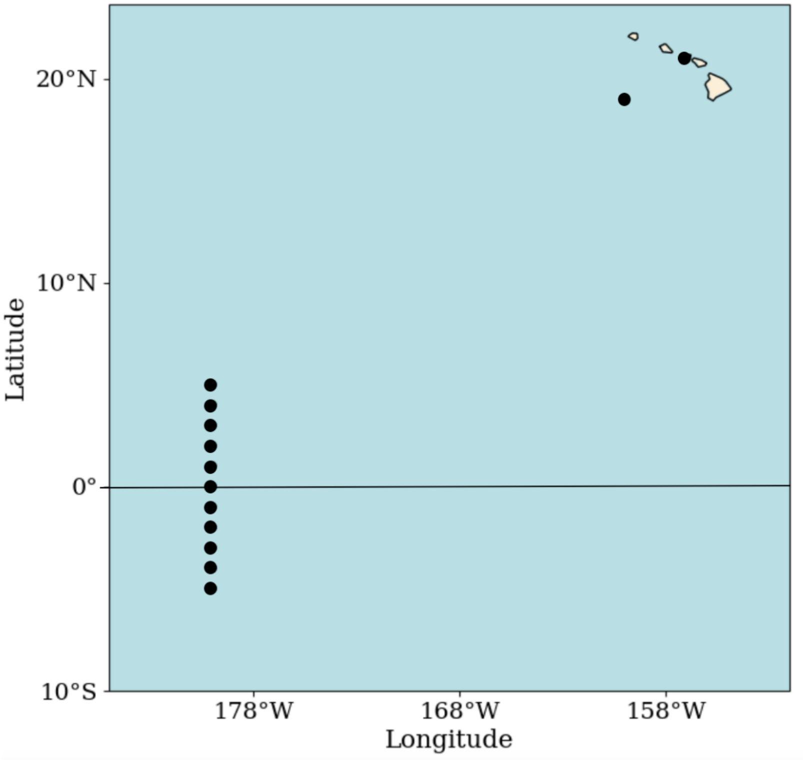

Figure 1: Stations of microplastic collection from Honolulu, HI, USA to Suva, Fiji. The black line marks the equator.

Using a dissecting microscope, the relative abundance and diversity of the collected surface organisms were determined. Organisms were classified into one of five categories: copepods, jellies, snails, fish, and larvae. Large organisms were rinsed and removed while the rest of the sample was sieved through a 0.3 mm sieve to discard material that does not fall within the size qualifications of a microplastic. This material was transferred to 10 mL vials to be brought back to the University of Washington for further analysis.

The volume of the water sampled was determined using a flow meter attached to the mouth of the net. Wind-driven mixing was not accounted for as done in previous studies with models from Kukulka et al. (2012) and Reisser et al. (2015). However, wind stress and sea state were recorded using an onboard anemometer and the Beaufort sea scale to account for changing conditions and variable measurements.

2.2 Sample Analysis in Lab

Samples were processed at the University of Washington according to the method described by Masura et al. (2015) to dissolve organic material and non-plastic debris. Net samples were mixed with 20 mL of 0.05 M Fe(II) solution and 20 mL of hydrogen peroxide and left at room temperature for 5 minutes before being placed on a hot plate. They were heated to 75°C for 30 minutes or until organic matter was no longer visible. 6g of salt was added for every 20 mL of liquid and the sample was transferred to a funnel for density separation. The sample was left overnight to allow any particulates that could not be dissolved (i.e., paint and sediment) to settle. Any particles floating at the top of the funnel were assumed to be potential plastics. Particulates settled at the bottom of the funnel were drained into a 0.3 mm sieve and examined in case some microplastics were attached to any of the settled matter. Using a Wild dissecting microscope, the particles were identified according to Hidalgo-Ruz et al. (2012) and classified as pellets, microbeads, fibers, fragments, films, or foams. Items with uniform shapes and lacking cellular structure were determined to be microplastic. A hot needle test was conducted on particles difficult to identify with the assumption plastic would melt at the touch of the needle.

Lab blanks were run as control samples according to Masura et al. (2015) to assess for any contamination. In addition, cotton clothing was worn during a lab analysis, and samples were covered with foil when not in the process of being examined.

Microplastic counts were divided by the amount of water sampled at each station to get data in items per volume ($\#/m^3$). For comparison to statistical models, plastic concentrations were also calculated in items per area ($\#/m^2$) for consistency between in situ measurements and models. Data was exported to Python for further analysis.

3. Results

3.1 Microplastic Abundance and Classification

The highest microplastic count was found at 21°N just off the coast of Hawaii, USA (Fig. 2). Plastic concentrations at 3°N-0° were significantly lower than abundance at other equatorial stations. 4°S had a similar abundance to 19°N and was an order of magnitude higher than counts observed at the other equatorial stations.

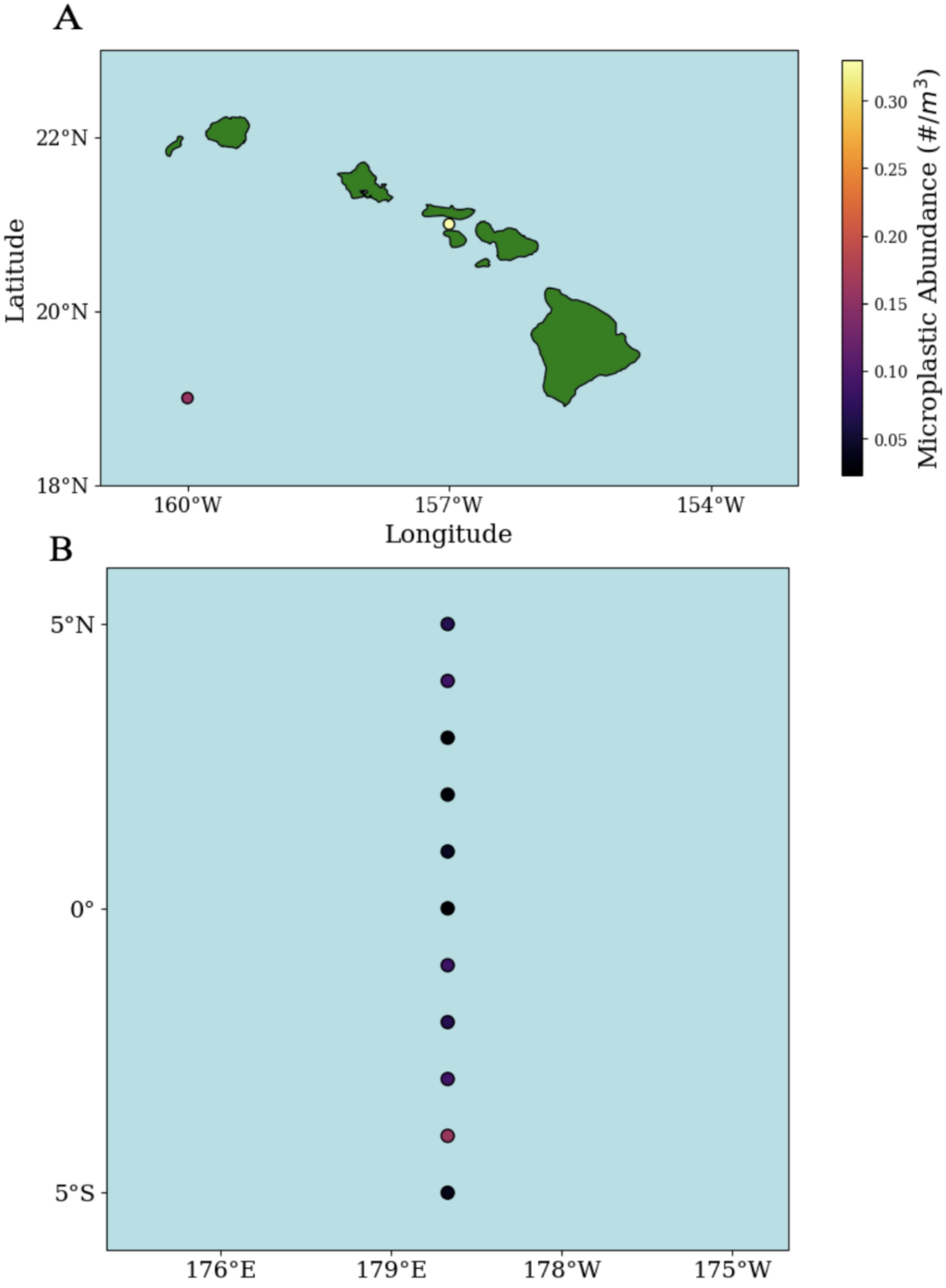

Figure 2: The concentration of microplastics according to visual analysis for each station off the coast of (A) Honolulu, HI, and across an (B) equatorial transect. Dark circles represent stations of low microplastic abundance while bright circles represent stations of high abundance.

Plastic abundance decreased towards the equator with abundance highest at the ends of the equatorial transect (5°N, 5°S) and with a general trend of increasing plastic moving into the Southern Hemisphere (Fig. 3).

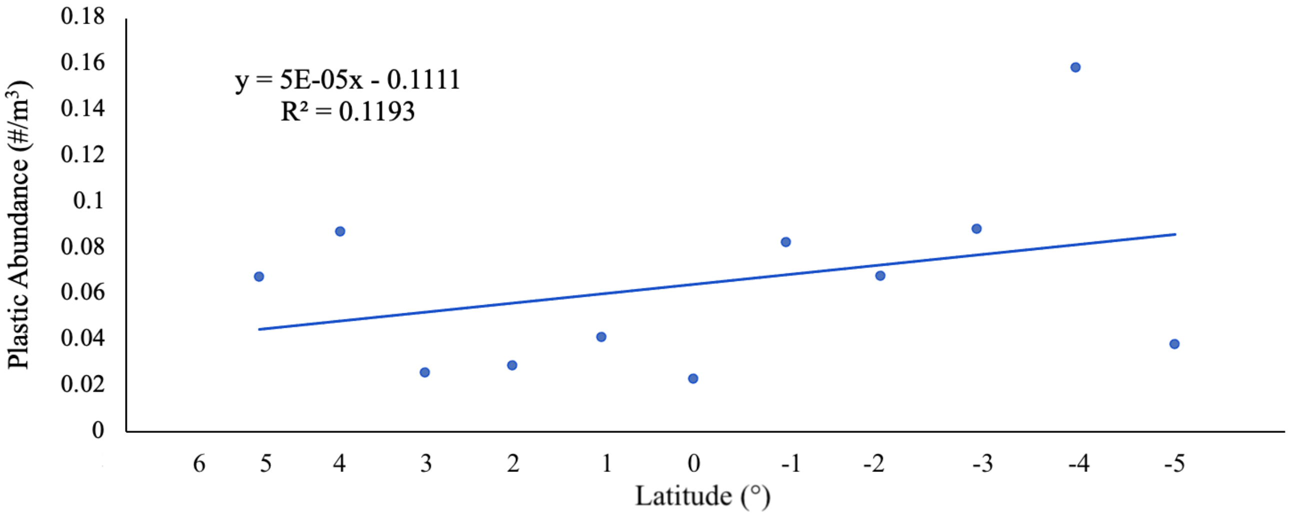

Figure 3: The abundance of microplastics across the equatorial transect going from North to South. Points are fitted with a linear trendline.

The types of plastics were determined using visual analysis with the particles divided into three groups: fibers (90%), foam (7.5%), and fragments (2.5%) (Fig. 4).

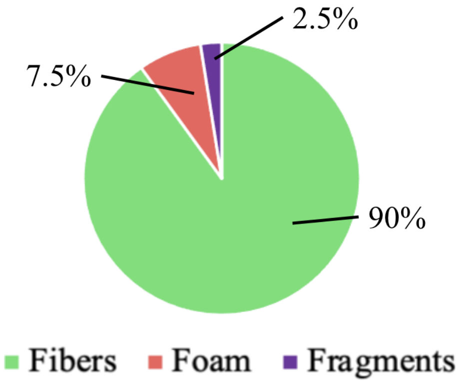

Figure 4: Assortment of microplastic collected from samples. Green represents fiber particles, red represents foam, and purple represents fragmented plastic.

Microplastic abundance was compared to values projected by three independent models: Maximenko et al. (2012), van Sebille et al. (2012), and Lebreton et al. (2012) (Tab. 1).

Table 1: Microplastic abundance at each station from collected samples and three independent models: Maximenko et al. (2012), van Sebille et al. (2012), and Lebreton et al. (2012).

Station	**Location**	**Sea State (Beaufort Scale)**	**Microplastic Abundance ($\#/m^2$)**	**Maximenko ($\#/m^2$)**	**Van Sieblle ($\#/m^2$)**	**Lebreton ($\#/m^2$)**
1	(21°N, 157°W)	4	4.2×10^{-2}	1	10	10
2	(19°N, 160°W)	4	1.9×10^{-2}	1	10	10
3	(5°N, 180°)	3	8.6×10^{-3}	10^{-6}	10^{-2}	10^{-4}
4	(4°N, 180°)	3	1.1×10^{-2}	10^{-6}	10^{-2}	10^{-4}
5	(3°N, 180°)	3	3.3×10^{-3}	10^{-6}	10^{-2}	10^{-4}
6	(2°N, 180°)	3	3.7×10^{-3}	10^{-6}	10^{-2}	10^{-4}
7	(1°N, 180°)	3	5.2×10^{-3}	10^{-6}	10^{-2}	10^{-4}
8	(0°N, 180°)	2	2.9×10^{-3}	10^{-6}	10^{-2}	10^{-4}
9	(1°S, 180°)	1	1.0×10^{-2}	10^{-6}	10^{-2}	10^{-4}
10	(2°S, 180°)	2	8.6×10^{-3}	10^{-6}	10^{-2}	10^{-4}
11	(3°S, 180°)	2	1.1×10^{-2}	10^{-6}	10^{-2}	10^{-4}
12	(4°S, 180°)	2	2.0×10^{-2}	10^{-6}	10^{-2}	10^{-4}
13	(5°S, 180°)	2	4.8×10^{-3}	10^{-6}	10^{-2}	10^{-4}

The Maximenko model had the greatest similarity to in situ measurements for stations off the coast of Hawaii (21°N and 19°N) but these values were still off by two orders of magnitude. This model also had the least similarity to counts found at the equator. The van Sebille and Lebreton models predicted equatorial plastic counts falling between 10^{-2} - 10^{-4} $\#/m^3$ respectively. In situ measurements for this location ranged from 10^{-2} - 10^{-3} $\#/m^3$ with van Sebille most accurately predicting abundance. However, these two models had estimates three magnitudes greater than what was measured in the region 19°N - 21°N.

Low contamination was measured in field and lab blanks (0 - 10^{-4} $\#/m^3$) with the highest sources of contamination occurring at the field site. The sample counts were corrected for particles found within their respective control. Values of microplastic abundance were not corrected for wind mixing, but wind and current speeds on the days of sample collection were recorded for data comparison.

3.2 Wind and Current Speeds

The lowest current speeds were off the coast of Hawaii, USA where there was the highest concentration of plastics (Fig. 5). Current speeds in the region of 5°N - 5°S were around 0.4 m/s on average with the exception of station 4 (4°N) which exhibited a current speed eight times greater than stations 1 and 2 (21°N and 19°N) and three times greater than other stations along the equatorial transect. 4°N had similar plastic abundances to those found at 19°N.

The highest wind speeds were recorded off the coast of Hawaii, USA with the lowest wind speeds occurring in the equatorial region (Fig. 5). Stations 3 (5°N) and 5 (3°N) had faster winds, but similar plastic counts to other stations along the equatorial transect.

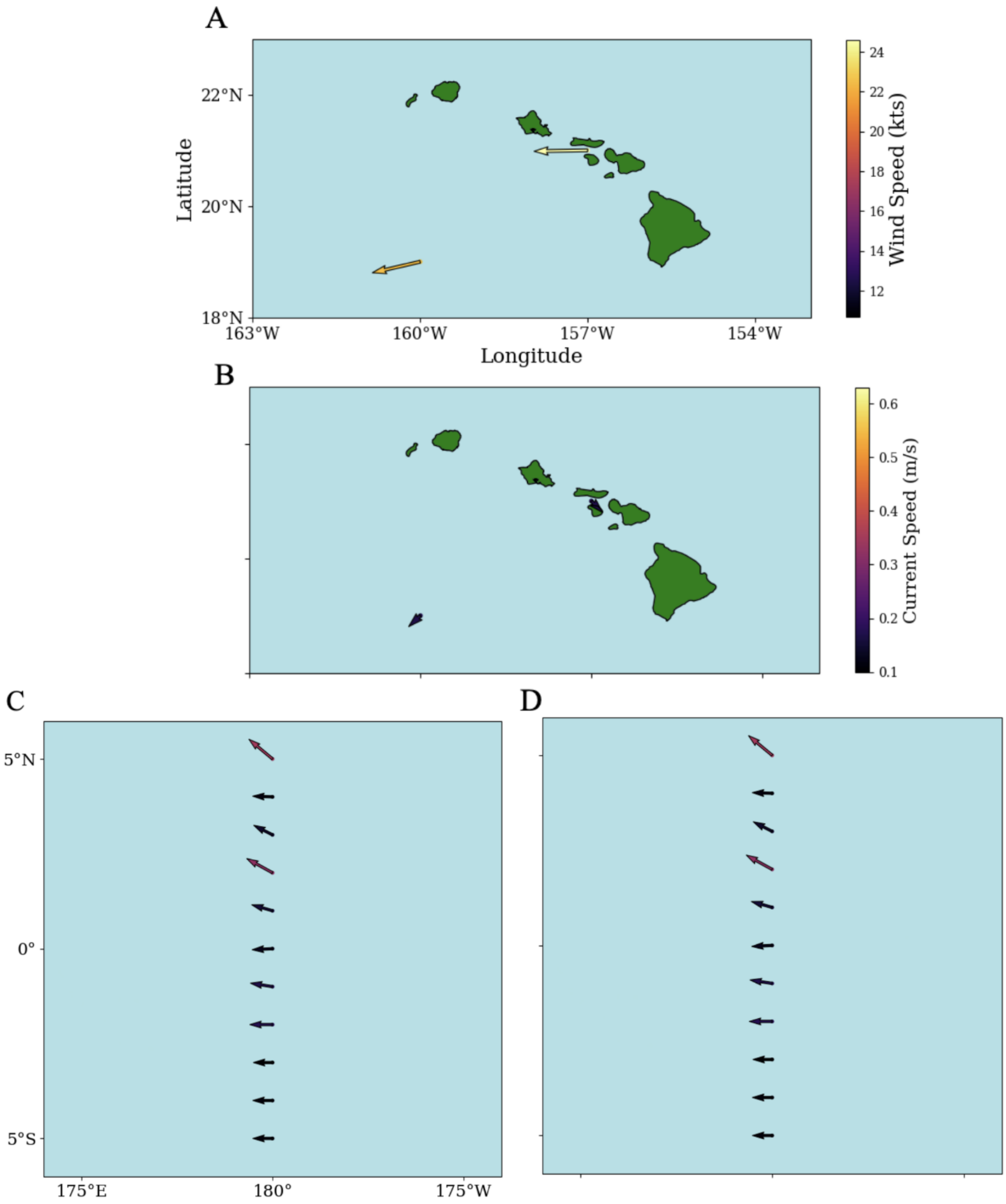

Figure 5: (A, C) Wind speed and direction and (B, D) current speed and direction for each station off the coast of Honolulu, HI, and across an equatorial transect. Magnitude of arrows is proportional to wind and current speeds.

3.3 Organism Abundance

Organism abundance was compared against microplastic concentrations collected aboard the R/V *Thomas G. Thompson*. Copepods (20-260 #/m^3) were the most abundant organism across the equatorial transect followed by larvae, jellies, snails, and fish (Fig. 6).

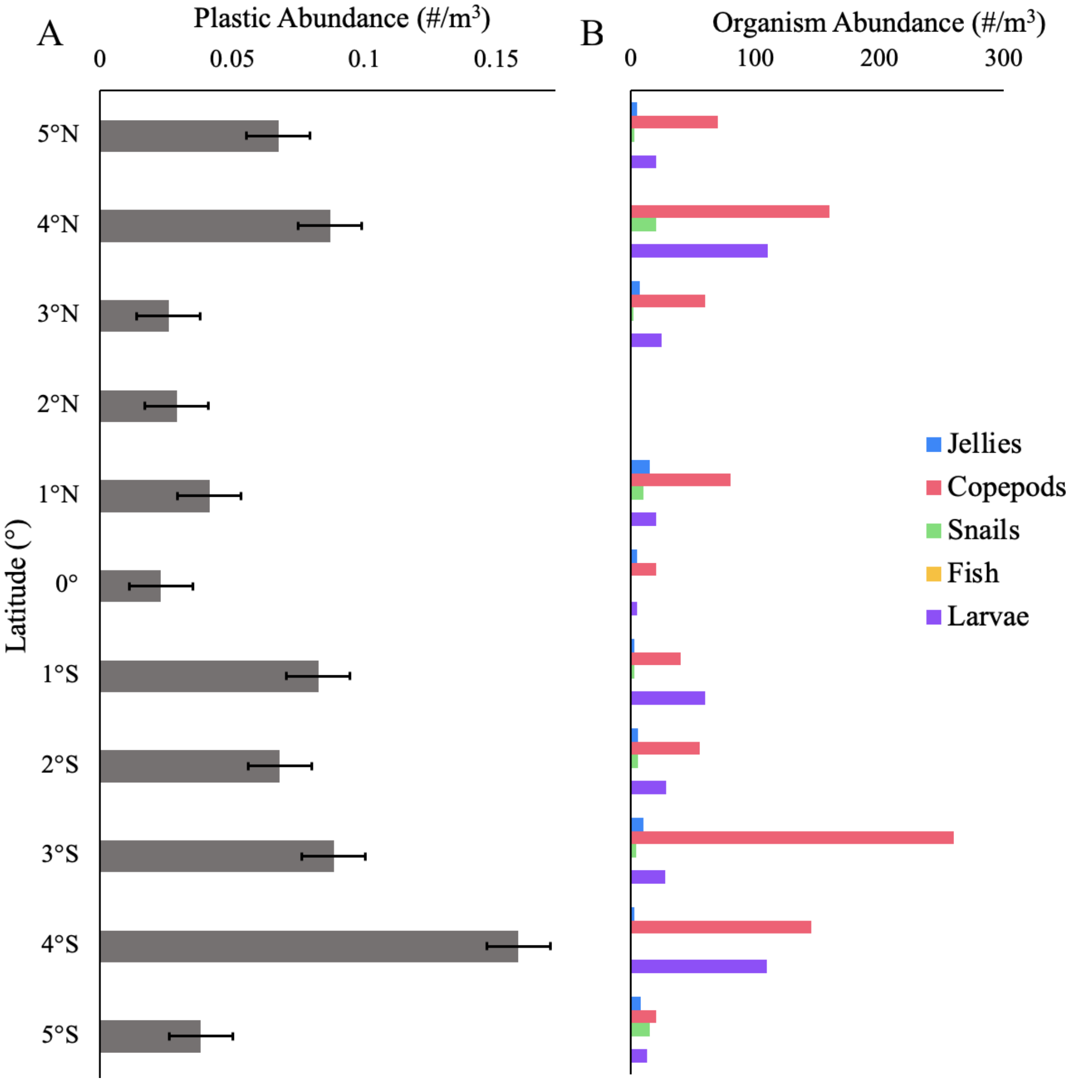

Figure 6: (A) Microplastic abundance and (B) marine diversity across the equatorial transect. In a, error bars represent standard error. In b, each bar represents the abundance of a different type of organism. Organisms were not counted at 2°N.

The organisms and microplastics had similar trends of increasing and decreasing abundance across the equatorial transect. Both had their lowest concentrations (plastic 0.029 $\#/m^3$; organisms >20 $\#/m^3$) at 0° and their highest concentrations in the southern hemisphere. According to the Shannon-Wiener diversity index, there was little species diversity across the transect with all values of H under 1.29 (Tab. 2).

Table 2: Diversity of surface organisms collected across an equatorial transect. Organisms were not examined at 2°N.

Location	**Shannon Weiner (H')**	**Evenness**
5°N	0.644	0.400
4°N	0.831	0.517
3°N	1.071	0.666
2°N	—	—
1°N	0.792	0.493
0°	0.964	0.600
1°S	0.894	0.556
2°S	1.075	0.668
3°S	0.483	0.300
4°S	0.736	0.456
5°S	1.291	0.802

4. Discussion

4.1 Factors Affecting Microplastic Abundance

No apparent relationship between current speeds and microplastic abundance could be determined with this data. Plastic concentrations were highest (21°N) where current speeds were the lowest suggesting slow currents may contribute to the accumulation of plastics at the sea surface (Fig.2, Fig. 5). However, plastic counts remained similar across the equatorial transect despite large current speeds at 4°N. It is possible that due to the low plastic counts at the station along the equatorial transect a notable difference between regions of high and low current speeds was not observable. For this reason, it cannot be determined if low plastic concentrations relate to the current speed or the remoteness of the transect.

High wind speeds can increase vertical mixing, reducing the amount of microplastics collected at the surface (Kukulka et al. 2012; Reisser et al. 2015). This can lead to a low plastic abundance. The equator has weak winds due to it being a low-pressure area and this was consistent with the observations made during sample collection. However, the equator is also an area of upwelling and this could have introduced more vertical mixing to the area, possibly decreasing microplastic concentrations along the surface. High winds along the Hawaii coastline did not lead to lower plastic abundance when being compared to samples along the equatorial transect. However, these winds may be an explanation as to why abundance was lower than what was predicted by numerical models (van Sebille et al. 2015).

The abundance of plastics increased moving away from the equator with slightly higher plastic concentrations in the Southern Hemisphere. Despite less shipping traffic and a smaller human population, the Southern Pacific can accumulate plastics to the same extent as other oceanic regions. The Antarctic circumpolar currents carry debris across the South Pole which receives plastic from other currents and oceans. This traveling debris can then get picked up by the Peru current that eventually feeds into the South Equatorial current and South Pacific gyre.

Not all plastic floats and, in addition, it can be distributed by vertical mixing and currents to waters deeper than a Manta net can collect. Pabortsava and Lampitt (2020) found mass amounts of microplastics below the surface ocean (up to depths of 270m) where the vertical location was dependent on the type of plastic. It cannot be ruled out that the low abundance of plastics along the equator may be due to higher concentrations lying beneath the sea surface. This data demonstrates a need for more research done on the abundance and distribution of microplastics with depth, not only across surface transects.

4.2 Comparison of Microplastic Abundance to Models

Van Sebille et al. (2012) best predicted the concentration of microplastics along the equator out of the three models while Maximenko et al. (2012) best predicted concentrations off the coast of Hawaii. The lower concentrations predicted by the Maximenko model may be attributed to the addition of sinking plastic (e.g., the ability of plastic to return to shore and sink below surface layers) in the model. Data across all models did not account for plastic fragmentation (from UV degradation and erosion) or buoyancy loss. The weight of microbes colonizing debris and the aggregation of microplastic to marine snow leads to the sinking of these particles throughout the water column. The addition of these chemical and biological processes to statistical models could account for plastic loss at the surface and produce predictions more closely aligned with the in situ measurements found in this study.

4.3 Types of Identified Plastic

A majority of the collected microplastics were identified as fibers with only 7.5% identified as foam and 2.5% as fragments. This is consistent with past studies that found the accumulation of foam to be rare (Silvestrova and Stepanova 2021) and more likely to be found in high quantities along coastlines (North Carolina Coastal Federation 2023). The foams that were identified were found off the coast of Hawaii, USA at 21°N and 19°N. The low density and high production of fibers allow them to spread across the global ocean in large numbers. Synthetic fibers account for two-thirds of textile production due to the low cost of manufacturing (Suaria et al. 2020). As a result of poor management of laundry, textiles, and sewer wastewater, large amounts of microfibers enter waterways worldwide, making up over 92% of microplastics found in the remote Arctic (Ross et al. 2021). Fiber concentrations may be even higher than what is measured due to traditional sampling methods (i.e., Manta net, 0.3 mm sieve) allowing fibers to slip through the net depending on their orientation. Ryan et al. (2020) found fiber concentrations increased as mesh size decreased from 300-500 um to 20 um, suggesting finer nets can lead to less variability between measurements and improve the collection of plastics.

4.4 Organism Abundance and Chlorophyll Concentrations

Upwelling at the equator is responsible for supplying nutrients that support phytoplankton blooms, corresponding to higher amounts of copepods. However, the lowest copepod abundances were at the equator (0°) where upwelling is strongest. This may be correlated to the diel vertical migration of zooplankton as this Manta net tow was taken during the day when zooplankton typically remain deeper in the water column to avoid predation. Stations 3°N, 3°S, and 4°S with the highest copepod abundance (>100 $\#/m^3$) were taken during the night suggesting these differences in population may be due to the times of sample collection.

Zooplankton, specifically copepods (Fig. 6) appear to be the most abundant surface organism and thus will be the most affected by floating microplastics. Research has revealed plastics are found in copepods (0.05–2.6 mm^3/L), suggesting zooplankton may be a standard entryway for other organisms to consume microplastics (Andrady, 2011; Botterell et al. 2019). These particles are accumulating up trophic levels as Rochman et al. (2019) found 20% of California Bay Area fish have ingested microplastics. While jelly populations were not as high as copepods, they represent a crucial species being affected by plastics. The mucus produced by jellies acts as a biopolymer for attracting plastic (Lengar et al. 2021) with Iliff et al. (2020) finding 77% of their analyzed jellies contained microplastics. This creates a path by which the long-lived marine animals that consume jellyfish (e.g., turtles and whale sharks) ingest large amounts of plastic.

5. Conclusion

No one factor is responsible for increasing or decreasing microplastic abundance as demonstrated by this study. However, the additional collection of in situ measurements to improve numerical models can lead to a more accurate understanding of the circulating path of debris and the exposure of plastic to marine organisms. While these studies suggest an increase in accumulating microfibers, Suaria et al. (2020) found a majority of fibers are misidentified during visual analysis. Only 8.2% of their study's identified fibers were actually synthetic in nature with most of the material being derived from cellulose or animal origins. As research techniques develop and Fourier Transform Infrared Spectroscopy (FTIR) becomes more common, future research could focus on chemically testing microplastics in addition to visualization before classification. While low concentrations of plastics were found along the equator, these values are only expected to increase. At the current rate of plastic accumulation within the global ocean, concentrations are predicted to reach 145 million tonnes by 2030 (Suaria et al. 2020). This study found plastic concentrations lower than predictions by available models suggesting the need for future research on microplastic concentrations with depth. The absence of plastics in certain regions, like the equator, may be due to loss of buoyancy and vertical mixing, leading to lower surface estimates. Without accounting for the debris affecting marine organisms at various depths, we cannot accurately understand the environmental impact of microplastics on a regional or global scale.

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