Northumbria Research Link

Citation: Mountford, Alethea (2023) Transport of Plastics Within the World's Oceans. In: Plastic Pollution in the Global Ocean. Trends in Aquatic Systems (1). World Scientific, New Jersey, US, pp. 77-96. ISBN 9789811259104, 9789811259128, 9789811259111

Published by: World Scientific

URL: https://doi.org/10.1142/9789811259111_0004 <https://doi.org/10.1142/9789811259111_0004>

This version was downloaded from Northumbria Research Link: https://nrl.northumbria.ac.uk/id/eprint/51413/

Northumbria University has developed Northumbria Research Link (NRL) to enable users to access the University's research output. Copyright © and moral rights for items on NRL are retained by the individual author(s) and/or other copyright owners. Single copies of full items can be reproduced, displayed or performed, and given to third parties in any format or medium for personal research or study, educational, or not-for-profit purposes without prior permission or charge, provided the authors, title and full bibliographic details are given, as well as a hyperlink and/or URL to the original metadata page. The content must not be changed in any way. Full items must not be sold commercially in any format or medium without formal permission of the copyright holder. The full policy is available online: http://nrl.northumbria.ac.uk/policies.html

This document may differ from the final, published version of the research and has been made available online in accordance with publisher policies. To read and/or cite from the published version of the research, please visit the publisher's website (a subscription may be required.)

Northumbria University NEWCASTLE

CUSTOMER SERVICE EXCELLENCE CSE UniversityLibrary

Transport of plastics within the world's oceans

Alethea Mountford (alethea.mountford@northumbria.ac.uk), Northumbria University

Introduction

When thinking about plastics in the world's oceans, typically the "garbage patches" may be the first thing to come to a person's mind, with visions of vast islands of trash the size of Texas that you would be able to walk on. However, the reality of plastic pollution in the oceans is on a much smaller, more pervasive scale. Estimates suggest that less than 1% of the plastics that have entered the world's oceans are present at the sea surface (Mountford and Morales Maqueda, 2019; Wichmann et al., 2019), and the processes that affect the distribution of plastics in the oceans are both complex and interconnected, leaving no region untouched by plastic pollution. Once within the marine environment, plastics are subject to both horizontal and vertical transport. Horizontal transport in the form of currents and wind, for example, moves the plastics away from their point of entry over either short or long distances. Vertical transport, such as through turbulent mixing or sinking, moves the plastics through the water column. Processes such as fragmentation, biofouling, and ingestion can further influence both the horizontal and vertical transport of plastics of all types. The transport of plastics within the world's oceans is complex and interconnected, but largely determined by the plastic itself. As discussed in previous chapters, the composition of a plastic, namely the physico-chemical properties needed for its use and the additives that bring about these properties, give the plastic an inherent density. This density, whether it is smaller or greater than the density of the surrounding seawater, along with the plastic's size and shape, will determine its behaviour and transport within the marine environment. Broadly, a plastic can be less dense than seawater (positively buoyant), denser than seawater (negatively buoyant), or have a density close to that of seawater (neutrally buoyant). Over time, a plastic's density may change through processes such as mechanical degradation and fragmentation, ingestion and egestion from marine organisms, and biofouling. This chapter will discuss the oceanographic transport and biological processes which define the global distribution of plastics within the world's oceans, from the sea surface to the sea floor.

Beaching and coastal retention of plastics

An estimated 80% of plastics enter the marine environment from land-based sources, for example through direct littering, escaping waste management and via wastewater and sewer systems (Auta et al., 2017). Given the ever-visible plastic pollution on beaches globally, it stands to reason that a portion of plastics will remain close to their point of entry at the coastlines. In fact, recent modelling work suggests that between 31% and 95% of positively buoyant plastic debris will beach at some point during its time in the marine environment, and at least 77% remains within 10 km of the shoreline (Onink et al., 2021). In the coastal environment, plastics may become trapped in near-shore sediments, intertidal matrices (such as rockpools), on beaches (both on the surface and below), within mangrove sediments (Martin et al., 2020). While this may be the final resting place for some of these plastics, beaching may only be a temporary sink, leading to a cycle of beaching, resuspension and burial, on a short or long-term basis. This continued process of beaching and resuspension at the shorelines suggests that the coastal regions may be an important site for the generation of secondary microplastics. Mechanical degradation and fragmentation in the sea swash zone, through wave action against sand and/or pebbles, is thought to be the fastest form of degradation (compared to UV and oxidative degradation, for example), with new plastics almost entirely broken down into microplastics after 24 hours in laboratory experiments (Chubarenko et al., 2020). Of course, these degradation processes would likely not occur in isolation in the natural environment (Corcoran et al., 2009). Following formation, the secondary microplastics are at greater risk of being transported offshore than the meso- and macroplastics that they originated from (Isobe et al., 2014). Mesoplastics are preferentially transported offshore, as their larger size and increased buoyancy results in them residing in the upper layers of the sea surface, where wind waves and Stokes drift transport the particles onshore more quickly (Isobe et al., 2014). Microplastics, on the other hand, are free from near-shore trapping and most typically become suspended in the subsurface layers, where they are less under the influence of onshore, surface currents (Zhang, 2017).

With that being said, it is not only beaches in densely populated areas that are littered with plastic debris. Henderson Island is a remote and uninhabited island in the South Pacific, which has an estimated 37.7 million debris items on its shores, although this count is likely far greater now compared to when the study was conducted, given it is thought that over 20 items per metre are accumulating daily (Lavers and Bond, 2017). Instances of marine plastic litter on remote shorelines have been reported in the North and South Atlantic (Andrades et al., 2018; Monteiro et al., 2018), Indian Ocean (Duhec et al., 2015), South Pacific (Perez-

Venegas et al., 2017), Arctic Ocean (Barnes, 2002; Bergmann et al., 2017a) and Southern Ocean (Barnes, 2005). At-sea sources, for example from fishing, tourist or research vessels as well as off-shore structures and aquaculture, may be a significant contributor to the plastics found in remote locations but the role of long-range transport cannot be underestimated (Onink et al., 2021).

Surface transport and accumulations of plastics

Numerical modelling is an invaluable tool for exploring the transport pathways and eventual global distribution of marine plastic pollution. Marine plastic models are typically (although not exclusively) either Lagrangian or Eulerian, which accounts for the way in which the plastics are included in the model (see van Sebille et al. (2018) for a detailed discussion about the use of Lagrangian models). Lagrangian model frameworks consider the behaviour and transport of an individual plastic particle, allowing the tracking of each particle's trajectory within a two- or three-dimensional field. Eulerian formulations, on the other hand, consider plastic particles as a mass or volume concentration, which is then advected by ocean velocity and diffused by turbulence. This approach lends itself to looking at three-dimensional, global transport pathways of large concentrations of plastics (Mountford and Morales Maqueda, 2019). While both frameworks have advantages and disadvantages, they provide a complementary approach to marine plastic modelling, allowing for the exploration of both small- and large-scale behaviour and transport of plastics.

The inherent buoyancy of almost half of the plastics most readily produced globally (PlasticsEurope, 2020) suggests that much of the plastics that enter the oceans will float at the sea surface, where it is susceptible to transport over long distances (Ryan, 2015). Extensive sampling efforts and numerical modelling have confirmed the presence of "garbage patches" in five subtropical gyres: in the North and South Pacific, the North and South Atlantic, and the Indian Ocean. Contrary to popular belief it is not possible to walk on "trash islands" as the vast majority of these pieces of plastic are classed as microplastics, forming more of a "plastic soup". These accumulations form as a result of Ekman currents at the sea surface and down to depths of around 100 m, which deflects the transport of water inwards, trapping plastics and other pollutants. Ekman transport, alongside geostrophic currents and Stokes' drift is thought to determine the eventual location of the garbage patches (Onink et al., 2019), although their predicted location varies somewhat between numerical modelling studies due to differences in circulation, resolution and plastic inputs (Lebreton et al., 2012; Maximenko et al., 2012; van Sebille et al., 2015; Mountford and Morales Maqueda, 2019; Wichmann et al., 2019). The North Pacific garbage patch (also known as the Great Pacific Garbage Patch) is the most well-known and widespread of these accumulations, estimated to cover an area of approximately 1.6 million km^2, containing between 1.1 and 3.6 trillion pieces of plastic, of which 94% is believed to be microplastics (Lebreton et al., 2018). The North Pacific garbage patch accumulates debris from both the North America to the east via the California current and Asia to the west. The Kuroshio Extension current system is thought to be the greatest transporter of debris from Asia to the patch, highlighted in particular following the 2011 Tohoku earthquake and subsequent tsunami, as debris from the tragedy was discovered within the gyre (Desforges et al., 2014; Lebreton et al., 2018). Long range transport is of particular note for buoyant plastic that resides in the air-sea interface (such as Styrofoam and plastic bottles), as they are subject to the influence not only of sea surface currents but also by winds (Ko et al., 2020). The greater the portion of plastic exposed from the sea surface, the greater the influence of windage, therefore this will be of more consequence to larger debris. Lebreton et al. (2018) estimated that over three quarters of the mass of the debris found within the accumulation in the North Pacific was larger than 5 cm (considered to be macroplastics) but suggested that higher windage debris may pass through and exit the patch itself, with a greater likelihood of beaching. For particularly buoyant plastics, such as expanded polystyrene (the small spherical particles that comprise polystyrene cups, packaging, and insulation, for instance), wind is the dominating transport mechanism, with the potential of wind-driven drift speeds up to four times larger than current speeds and the probability that spherical particles will roll over the sea surface (Chubarenko et al., 2016). This is in contrast to denser polymers, such as polyvinyl chloride, which will sink through the water column, where they will be transported by turbulent mixing processes, before they reach the seafloor to be transported largely by near-bottom currents (Mountford and Morales Maqueda, 2019; Kvale et al., 2020b), as will be discussed later in this chapter. This suggests that for larger plastics in particular, density is likely a factor in determining the dominant transport mechanism.

The epicentre of the North Atlantic garbage patch is in the Western North Atlantic, with small microplastics (categorised as 25−1000 μm in the following study by Poulain et al. (2019)) thought to dominate within the accumulation zone, with between 60 million and 4.5 billion particles km^{-2} small microplastics compared to 13,000 to 188,000 particles km^{-2} of large microplastics (categorised as 1 – 5 mm) (Poulain et al., 2019). This high proportion of small microplastics compared to larger plastics is thought to partly explain why previous studies reported no observed change in plastic abundance between 1986 and 2008 (Law et al., 2010). The combination of these smaller particles likely being overlooked in early studies and the continuous influx and breakdown of larger plastics may account for the lack of observed change. However, differences in sampling locations and protocols may also contribute to these observational differences. (Law et al., 2010; Wilcox et al., 2019). The South Atlantic and South Pacific garbage patches (and the Southern Hemisphere as a whole) is largely understudied and undersampled. Although surface drifter models predicted the location of the patches in the South Atlantic and South Pacific, the presence of the accumulations were not confirmed by observational data until 2014 (Ryan, 2014) and 2013 respectively (Eriksen et al., 2013). In 2013, the average abundance of microplastics in the South Pacific subtropical gyre was reported to be 26,898 particles km^{-2} (Eriksen et al., 2013), although since this initial study, there have been no further observational estimates of the plastic abundance in the South Pacific. While not focused specifically on the South Atlantic gyre, Pabortsava and Lampitt (2020) assessed the levels of plastic pollution along a 10,000 km North-South transect in the Atlantic Ocean. They found lowest concentrations of plastics at the sampling stations within the South Atlantic gyre, although polyethylene and polypropylene particles were found in subsurface samples in the remote South Atlantic, including comparably high concentrations around South Georgia (up to 2553 and 726 particles m^{-3} respectively). There is significant work to be done in the Southern Hemisphere in particular in order to gain a more thorough understanding of the significance of these accumulations.

The garbage patch in the Indian Ocean is the least well defined and studied, despite large coastal and riverine inputs. The Indian Ocean gyre is thought to be the weakest attractor of surface plastic pollution, due to its complex and interconnected surface circulation, and it has been argued that the plastic accumulation in the Southern Indian Ocean does not exist in the same sense as those in the North Pacific and North Atlantic (van der Mheen et al., 2019). Despite the vast majority of plastic pollution entering the Indian Ocean in the Northern Hemisphere, the patch itself resides in the Southern Hemisphere; due to a lack of a subtropical gyre in the Northern Indian Ocean, plastics that remain in the north end up beached along the rim (Pattiaratchi et al., 2021). The interconnectivity between the Southern Indian Ocean and both the South Atlantic Ocean and South Pacific Ocean results in a “leaky” garbage patch. Stokes’ drift, as well as surface ocean circulation and wind-driven transport, has been shown to play an important role in the transport of plastic debris into the South

Atlantic, as the influence of Stokes' drift causes the epicentre of the accumulation to drift towards the west of the basin (Dobler et al., 2019; van der Mheen et al., 2019). Plastics are transported into the South Pacific via a "superconvergence pathway" (Maes et al., 2018), following the Leeuwin Current along the west coast of Australia (Waite et al., 2007) before joining the Tasman Leakage (van Sebille et al., 2014), which connects the Southern Indian and South Pacific.

Aside from the garbage patches, the Mediterranean is believed to be one of the regions most impacted by plastic pollution. As a semi-enclosed sea with an estimated coastal population of around 150 million, plastic waste inputs are thought to amount to approximately 100,000 tonnes per year, much of which remains trapped within the Mediterranean region itself (Cincinelli et al., 2019; Liubartseva et al., 2018). Van Sebille et al. (2015) estimated a total mass of microplastics trapped within the Mediterranean between 4.8 and 30.3 million tonnes (based on three ocean circulation models), with an estimated particle load of between 3.2 and 28.2 x 10^{12} particles. While the total estimated mass in other basins exceeded that of the Mediterranean, the particle count was the greatest of all the basins in all of the model outcomes, with the exception of the North Pacific in one of the ocean circulation models, suggesting a higher proportion of smaller particles and/or less dense polymer types.

Surface transport to remote regions

Surface-dwelling plastics are also making their way north into the Arctic, with a proposed garbage patch developing in the Barents Sea (van Sebille et al., 2012) (although the presence of this garbage patch has not been observed), as well as high concentrations in coastal areas. As population density north of 60ºN is comparatively low, local sources are not thought to be a significant contributor of plastic pollution, suggesting the majority of plastics found in the Arctic must be from further afield. Thermohaline circulation (Cózar et al., 2017) and Stokes' drift (Onink et al., 2019) have both been suggested as important transport vectors of plastic pollution from the North Atlantic into the Arctic. The Greenland, Barents and Kara seas are thought to be particularly affected by floating plastics (Bergmann et al., 2016; Tošić et al., 2020), acting somewhat as a trapping zone for the buoyant plastics, leading to claims that the Arctic is a "dead end" for floating plastic pollution (Cózar et al., 2017). Deep water formation in the Arctic, such as in the Labrador Sea, can lead to the transport of microplastics through the water column, towards the sea floor. Cózar et al. (2017) hypothesise that the Arctic seafloor will be the final resting place for much of the plastic pollution that enters the

Arctic region, and while substantial quantities of macro- and microplastics have been recorded on the seafloor (e.g. Bergmann et al., 2017b; Tekman et al., 2020), microplastics have also been discovered within Arctic sea ice (Peeken et al., 2018; Kanhai et al., 2020), at concentrations comparable to those within subtropical gyres (Obbard et al., 2014). Although the process of microplastic incorporation into sea ice is not yet fully understood, it is believed that there may be a preferential uptake and enrichment of small, low density, irregular shaped microplastics (Obbard et al., 2014; Geilfus et al., 2019). The seasonal cycle of sea ice growth and retreat means that while sea ice may not be a permanent sink for microplastics, it could be an important temporal sink for microplastic pollution (Obbard et al., 2014). Once trapped in sea ice, microplastics can be transported from the Eurasian basin (where the majority of microplastics are entrained within sea ice) across the Arctic basin via the Transpolar Drift towards the Fram Strait, where microplastic-laden melt water may be exported from the Arctic once more (Peeken et al., 2018).

Antarctica was once considered to be the last pristine region on Earth, as the Antarctic Circumpolar Current and Polar Front systems have long been thought to protect the Antarctic Continent from debris travelling southwards, due to the dominant northward Ekman transport. Waller et al. (2017) provided the first review of the state of microplastic research in the Southern Ocean and surrounding the Antarctic continent, and highlighted the need for more observational data. While concentrations of floating macro- and microplastics in the Southern Ocean have been shown to be the lowest globally (Suaria et al., 2020), there is evidence of the presence of plastics all around the Antarctic continent, with reports of microplastics present at the sea surface (Cincinelli et al., 2017), within Antarctic sea ice (Kelly et al., 2020), and within sediments (Munari et al., 2017; Reed et al., 2018; Cunningham et al., 2020). The Pacific Ocean sector of the Southern Ocean has been suggested to be the most prevalent source of buoyant microplastics to the waters surrounding Antarctica, although deep water transport of neutrally buoyant plastics or local sources, such as scientific bases and increased ship traffic may be a more likely source of microplastics (Cincinelli et al., 2017; Munari et al., 2017; Mountford and Morales Maqueda, 2021). A thorough review of plastics in polar samples can be found in Tirelli, Suaria and Lusher (2020) as well as in the ‘Plastics in the Antarctic and Southern Ocean’ chapter.

Vertical transport of plastics

Despite the majority of plastics being produced and, as a consequence, entering the world's oceans being less dense than seawater, estimates of plastics floating at the sea surface account for less than 1% of the total amount of plastics believed to have entered the oceans. The location of the "missing plastics" has been the focus of much research in recent years.

The sinking behaviour of plastics (aside from entrainment in marine snow and under the effects of biofouling) is determined by its inherent density, size and, perhaps most importantly, its shape. Macro- and microplastics alike are heterogeneous in terms of their shape, but this difference in shape and its impact on sinking is particularly relevant for microplastics. The most frequently encountered forms of microplastics are fibres, films, fragments, foams and beads, with secondary microplastics typically having a more irregular morphology and primary microplastics which have not yet been weathered or degraded having a more regular (and often spherical) shape (Chubarenko et al., 2016; Khatmullina and Isachenko, 2017). Weathering and degradation (through UV radiation, mechanical or biological degradation) can lead to changes to the shape, surface texture and weight of a particle, and fragmentation from larger into smaller plastics is likely to modify a plastic's rise or sink velocity. Within the water column, plastics may settle out when they reach an area of similar density, for example at a thermo- or pycnocline (Zobkov et al., 2019). The water column may be an important repository for neutrally buoyant plastics, which remain at depths of equal buoyancy, unless they are drawn towards to the seafloor by biofouling, turbulence, deep water formation or downwelling. While possible residence times for plastics in the water column under biofouling conditions have been reported, with polyethylene fibres estimated to spend 6 – 8 months in the euphotic zone before sinking (Chubarenko et al., 2016), residence times for neutrally buoyant plastics and a wider range of fouled buoyant plastics are still lacking.

Through processes such as biofouling, fragmentation and ingestion/egestion, floating plastics may lose their buoyancy and hence sink out of the sea surface layer. There has been an observed paucity of smaller plastics (i.e. microplastics) at the sea surface (Cózar et al., 2014), as with decreasing size there is also decreasing buoyancy, with small micro- and nanoplastics hypothesised to be essentially neutrally buoyant (Kooi et al., 2017). Evidence of fallout of positively buoyant plastics from the North Pacific Garbage Patch has been recorded with over half of the particles (52%) detected in the water column being smaller than 1.5 mm in size (Egger et al., 2020). These smaller particles are more susceptible to processes such as turbulence and downwelling and are able to be drawn down into the water column. Pabortsava and Lampitt (2020) similarly observed elevated concentrations of microplastics in the Atlantic Ocean, with the top 200 m estimated to contain between 11.6 and 21.1 million tonnes of microplastics (32 – 651 μm) of only the three most littered plastics (polyethylene, polypropylene and polystyrene. Wind-driven mixing has been shown to mix plastic particles of positive buoyancy downward through the upper water column, both through observational data (Reisser et al., 2015) and modelling experiments (Kukulka et al., 2012). As well as these wind-driven processes, heat-driven turbulence is also a potential mechanism whereby buoyant particles are also transported below the sea surface. Kukulka et al. (2016) observed a significant increase in surface plastics during surface heating and a significant decrease during surface cooling and hypothesise that the transport of buoyant plastics out of the sea surface layer is enhanced at night.

The formation of a biofilm occurs within seconds after submersion, with colonising species of bacteria adhering to the surface of the material and releasing a conditioning matrix of extracellular polymeric substances (EPS). This initial biofilm encourages the settlement of further microorganisms, such as bacteria and diatoms. Biofouling succession eventually leads to the potential adhesion of macroalgae and organisms such as mussels, polychaetes and bryozoans to larger debris. Biofouling, whether it is on a micro- or macro-scale, affects the density of plastics and can cause positively and neutrally buoyant plastics to become negatively buoyant. After these particles sink, they may settle out at depth once they reach an area of equal buoyancy, most likely out of the euphotic zone. This lack of light, in combination with grazing, can lead to “defouling”, in which fouling organisms detach, and density decreases (Ye and Andrady, 1991; Andrady, 2011). This cycle of biofouling and defouling can lead to an oscillation effect of sinking and resuspension of plastics over time (Kooi et al., 2017). The density changes and timescales of this biofouling/defouling cycle is dependent upon the initial density and size of the particle. Modelling work by Kooi et al. (2017) explores the trade-off between particle size (radius) and the surface area to volume ratio. The results suggest that larger particles (that is, with a larger radius) have the potential to lose buoyancy more rapidly than smaller particles as they are more likely to collide with algae. However, smaller particles need fewer algal cells to increase their density to the point of sinking.

The presence of biofouling material on the surface of microplastics may encourage grazing (and thus ingestion) in species that use chemoreception to detect prey; this has been observed in a number of copepod species (Cole et al., 2013), although the opposite was observed in some hard coral species (Allen et al., 2017). Ingestion of both clean and biofouled plastics has been observed on both a macro- and microscale, and while the digestive tracts of organisms is a temporary sink for the plastics, the subsequent egestion can influence a plastic particle’s vertical distribution within the water column. This is particularly true of microplastics, which become incorporated within faecal pellets. Microplastics can alter the density and sinking rates of the faecal pellets, and vice versa, with faecal pellets believed to be a vector for transporting buoyant plastics away from the sea surface and into the ocean interior (Cole et al., 2016). Faecal pellets, and the microplastics contained within, form aggregates with detritus, particulate organic matter (POM), phytoplankton, extrapolymeric substances (EPS) and other matter, forming marine snow, an essential component of the biological carbon pump, and the export of organic matter to the deep ocean (Coyle et al., 2020; Zhao et al., 2017). Kvale et al. (2020a) found that if pollution were to stop, marine snow and aggregates would be able to transport most existing surface microplastics to the seafloor within two years, suggesting that marine snow may be a significant removal mechanism of floating microplastics.

Plastics that are inherently denser than seawater (or those that lose buoyancy over time, due to processes such as biofouling or aggregation) that reach the seafloor, similarly to plastics that remain in coastal regions, will either become trapped within sediments where they settle initially, or will be subject to horizontal transport by bottom currents. As discussed previously, coastal sediments are a likely temporary sink for plastics, although there is the potential for them to be sequestered within coastal sediments over longer time scales. Those plastics that do not become trapped within near-shore sediments are then subject to bottom or near-bottom currents, which transport them away from their point of entry. Far less is known about the distribution of plastic pollution on the seafloor compared to at the sea surface. Despite this, instances of both macro- and microlitter have been recorded on the seafloor and within seafloor sediments in all major ocean basins, albeit with a focus on sampling in coastal regions, European seas, the Western Pacific and North America, as detailed by Canals et al. (2020). As mentioned earlier in this chapter, the Mediterranean is thought to be one of the most affected regions, with floating plastic concentrations to rival those of the garbage patches (Suaria et al., 2016). It stands to reason, therefore, that the Mediterranean seafloor is also a likely hotspot of plastic pollution. While there is no comprehensive review of the state of plastic pollution on the Mediterranean seafloor at present, the region has been the focus of studies since the 1990s (Galgani et al., 1995; Galgani et al., 1996) and the MEDiterranean International bottom Trawl Survey (MEDITS) has provided the opportunity for monitoring the state of seafloor litter across the Mediterranean (e.g. García-Rivera et al., 2018; Alomar et al., 2020; Garofalo et al., 2020 among others). In the Indian Ocean alone, for example, it has been estimated that the sediments may contain up to 4 billion plastic fibres per square kilometre, which equates to approximately 1.4 billion tonnes of plastic (Woodall et al., 2014; Coppock et al., 2017). Once on the seafloor, bioturbating organisms, such as mussels (Van Colen et al., 2021), clams and polychaetes (Näkki et al., 2017), are able to transport small plastics into deeper layers of marine sediments.

Plastic accumulation in the deep sea

Despite the focus on the coastal seafloor, in part due to the relative ease of collecting observational data in these regions, abyssal and hadal plains and trenches are thought to be the "ocean's ultimate trashcan", as once plastics enter these deep ocean areas, the exit is near-impossible (Peng et al., 2020). Turbidity currents are believed to be an important mechanism for transporting microplastics away from the continental shelf and into submarine canyons, where a portion of the plastics may be buried, in particular fibres, which are preferentially removed from suspension by these currents (Pohl et al., 2020). Once off the continental slope, thermohaline currents are able to pick up microplastics deposited by turbidity currents and transport them further oshore leading to microplastic "hotspots" in the deep sea, with the reported highest concentration of microplastics ever found in sediments, of up to 3800 microplastics kg^{-1} (Kane et al., 2020). Finally, funnelling mechanisms along submarine canyons and hadal trenches concentrates plastics into these regions, with little opportunity for escape due to steep slopes (Peng et al., 2020). Micro- and macroplastics have been found down to depths of 10,927 m in the Challenger Deep, and in other abyssal plains and hadal trenches in the Western Pacific Ocean (Chiba et al., 2018; Street, 2019; Peng et al., 2020). The concentrations that microplastic pollution reaches at these depths is not insignificant, reaching abundances of over 100 items per kg of dry weight of sediment. Many of the fibres recovered from these deep ocean locations were polymers of a lower density than seawater (Peng et al., 2020), suggesting that they were either small enough to have reached neutral buoyancy and been drawn down into the deep ocean through turbulent mixing or downwelling processes, or perhaps more likely, may have lost buoyancy through biofouling or incorporation into marine snow, for example.

Large accumulations of plastics on the sea floor, such as the large debris dumps discovered in Xisha Trough, South China Sea, have the potential to provide a new ecosystem for organisms, resulting in biodiversity hotspots, particularly for sessile organisms (Song et al., 2021). Since bottom currents are essential for transporting the nutrients and oxygen that support biodiversity, it is not surprising that (micro)plastics are transported along the same pathways, and flourishing ecosystems emerge on plastic accumulations (Kane et al., 2020). However, plastics accumulating on the seafloor may be releasing high concentrations of additives, as has been observed in Sagami Bay, Japan, and the West Pacific Ocean, in which over 1,500 kg of additives (dibutyl phthalate butylated hydroxytoluene, bis (2-ethylhexyl) phthalate and 1,2,4-trichlorobenzene) were estimated to be present on the seafloor under the Kuroshio Extension and its recirculation gyre (Yamauchi et al., 2021). The release of these chemicals could have damaging effects on local ecosystems and may also be transported away from the region via ocean currents.

Conclusion

The transport and ultimate fate of plastics in the world’s oceans is largely defined by its inherent buoyancy, that is whether it is more, less or equally as dense as the surrounding seawater. The coastlines represent an important temporary (or potentially permanent) sink for marine plastics of all densities, although cycling or beaching followed by resuspension can lead to the generation of secondary microplastics, which are preferentially transported away from the coastal regions. Broadly, many buoyant plastics find their way into the subtropical garbage patches and are also readily transported northwards into the Arctic, thought to be a potential “dead end” for plastic pollution. Floating plastics that lose their buoyancy and small micro- and nanoplastics are largely assumed to have neutral buoyancy and are at the mercy of ocean currents transporting them vertically through the water column. The water column itself is likely a large repository for microplastic pollution, although processes such as biofouling and aggregation can result in the export of these particles towards the seafloor. The seafloor, in particular abyssal and hadal plains and trenches, are thought to be the final resting place for the majority of plastics that enter the world’s oceans.

References:

Allen, A.S., Seymour, A.C. and Rittschof, D., 2017. Chemoreception drives plastic consumption in a hard coral. Marine Pollution Bulletin, 124(1), pp.198-205.

Alomar, C., Compa, M., Deudero, S. and Guijarro, B., 2020. Spatial and temporal distribution of marine litter on the seafloor of the Balearic Islands (western

Mediterranean Sea). Deep Sea Research Part I: Oceanographic Research Papers, 155, p.103178.

Andrades, R., Santos, R.G., Joyeux, J.C., Chelazzi, D., Cincinelli, A. and Giarrizzo, T., 2018. Marine debris in Trindade Island, a remote island of the South Atlantic. Marine Pollution Bulletin, 137, pp.180-184.

Andrady, A.L., 2011. Microplastics in the marine environment. Marine Pollution Bulletin, 62(8), pp.1596-1605.

Auta, H.S., Emenike, C.U. and Fauziah, S.H., 2017. Distribution and importance of microplastics in the marine environment: a review of the sources, fate, effects, and potential solutions. Environment international, 102, pp.165-176.

Barnes, D.K., 2002. Invasions by marine life on plastic debris. Nature, 416(6883), pp.808-809.

Barnes, D.K., 2005. Remote islands reveal rapid rise of southern hemisphere sea debris. The Scientific World JOURNAL, 5, pp.915-921.

Bergmann, M., Sandhop, N., Schewe, I., D'Hert, D., 2016. Observations of floating anthropogenic litter in the Barents Sea and Fram Strait, Arctic. Polar Biology 39, 553-560.

Bergmann, M., Lutz, B., Tekman, M.B. and Gutow, L., 2017a. Citizen scientists reveal: Marine litter pollutes Arctic beaches and affects wild life. Marine Pollution Bulletin, 125(1-2), pp.535-540.

Bergmann, M., Wirzberger, V., Krumpen, T., Lorenz, C., Primpke, S., Tekman, M.B. and Gerdts, G., 2017b. High quantities of microplastic in Arctic deep-sea sediments from the HAUSGARTEN observatory. Environmental science & technology, 51(19), pp.11000-11010.

Canals, M., Pham, C.K., Bergmann, M., Gutow, L., Hanke, G., Van Sebille, E., Angiolillo, M., Buhl-Mortensen, L., Cau, A., Ioakeimidis, C. and Kammann, U., 2020. The quest for seafloor macrolitter: a critical review of background knowledge, current methods and future prospects. Environmental Research Letters, **16** 023001.

Chiba, S., Saito, H., Fletcher, R., Yogi, T., Kayo, M., Miyagi, S., Ogido, M. and Fujikura, K., 2018. Human footprint in the abyss: 30 year records of deep-sea plastic debris. Marine Policy, 96, pp.204-212.

Chubarenko, I., Bagaev, A., Zobkov, M. and Esiukova, E., 2016. On some physical and dynamical properties of microplastic particles in marine environment. Marine Pollution Bulletin, 108(1-2), pp.105-112.

Chubarenko, I., Efimova, I., Bagaeva, M., Bagaev, A. and Isachenko, I., 2020. On mechanical fragmentation of single-use plastics in the sea swash zone with different types of bottom sediments: insights from laboratory experiments. Marine Pollution Bulletin, 150, p.110726.

Cincinelli, A., Martellini, T., Guerranti, C., Scopetani, C., Chelazzi, D. and Giarrizzo, T., 2019. A potpourri of microplastics in the sea surface and water column of the Mediterranean Sea. TrAC Trends in Analytical Chemistry, 110, pp.321-326.

Cole, M., Lindeque, P., Fileman, E., Halsband, C., Goodhead, R., Moger, J. and Galloway, T.S., 2013. Microplastic ingestion by zooplankton. Environmental Science & Technology, 47(12), pp.6646-6655.

Cole, M., Lindeque, P.K., Fileman, E., Clark, J., Lewis, C., Halsband, C. and Galloway, T.S., 2016. Microplastics alter the properties and sinking rates of zooplankton faecal pellets. Environmental Science & Technology, 50(6), pp.3239-3246.

Coppock, R.L., Cole, M., Lindeque, P.K., Queirós, A.M. and Galloway, T.S., 2017. A small-scale, portable method for extracting microplastics from marine sediments. Environmental Pollution, 230, pp.829-837.

Corcoran, P.L., Biesinger, M.C. and Grifi, M., 2009. Plastics and beaches: a degrading relationship. Marine pollution bulletin, 58(1), pp.80-84.

Coyle, R., Hardiman, G. and O’Driscoll, K., 2020. Microplastics in the marine environment: A review of their sources, distribution processes, uptake and exchange in ecosystems. Case Studies in Chemical and Environmental Engineering, 2, p.100010.

Cózar, A., Echevarría, F., González-Gordillo, J.I., Irigoien, X., Úbeda, B., Hernández-León, S., Palma, Á.T., Navarro, S., García-de-Lomas, J., Ruiz, A. and Fernández-de-Puelles, M.L., 2014. Plastic debris in the open ocean. Proceedings of the National Academy of Sciences, 111(28), pp.10239-10244.

Cózar, A., Martí, E., Duarte, C.M., García-de-Lomas, J., Van Sebille, E., Ballatore, T.J., Eguíluz, V.M., González-Gordillo, J.I., Pedrotti, M.L., Echevarría, F. and Troublè, R., 2017. The Arctic Ocean as a dead end for floating plastics in the North Atlantic branch of the Thermohaline Circulation. Science advances, 3(4), p.e1600582.

Cunningham, E.M., Ehlers, S.M., Dick, J.T., Sigwart, J.D., Linse, K., Dick, J.J. and Kiriakoulakis, K., 2020. High abundances of microplastic pollution in deep-sea sediments: evidence from Antarctica and the Southern Ocean. Environmental Science & Technology, 54(21), pp.13661-13671.

Desforges, J.P.W., Galbraith, M., Dangerfield, N. and Ross, P.S., 2014. Widespread distribution of microplastics in subsurface seawater in the NE Pacific Ocean. Marine pollution bulletin, 79(1-2), pp.94-99.

Dobler, D., Huck, T., Maes, C., Grima, N., Blanke, B., Martinez, E. and Ardhuin, F., 2019. Large impact of Stokes drift on the fate of surface floating debris in the South Indian Basin. Marine Pollution Bulletin, 148, pp.202-209.

Duhec, A.V., Jeanne, R.F., Maximenko, N. and Hafner, J., 2015. Composition and potential origin of marine debris stranded in the Western Indian Ocean on remote Alphonse Island, Seychelles. Marine Pollution Bulletin, 96(1-2), pp.76-86.

Egger, M., Sulu-Gambari, F. and Lebreton, L., 2020. First evidence of plastic fallout from the North Pacific Garbage Patch. Scientific reports, 10(1), pp.1-10.

Eriksen, M., Maximenko, N., Thiel, M., Cummins, A., Lattin, G., Wilson, S., Hafner, J., Zellers, A. and Rifman, S., 2013. Plastic pollution in the South Pacific subtropical gyre. Marine pollution bulletin, 68(1-2), pp.71-76.

Galgani, F., Jaunet, S., Campillo, A., Guenegen, X. and His, E., 1995. Distribution and abundance of debris on the continental shelf of the north-western Mediterranean Sea. Marine Pollution Bulletin, 30(11), pp.713-717.

Galgani, F., Souplet, A. and Cadiou, Y., 1996. Accumulation of debris on the deep sea floor off the French Mediterranean coast. Marine Ecology Progress Series, 142, pp.225-234.

Galgani, F., Brien, A.S.O., Weis, J., Ioakeimidis, C., Schuyler, Q., Makarenko, I., Griffiths, H., Bondareff, J., Vethaak, D., Deidun, A. and Sobral, P., 2021. Are litter, plastic and microplastic quantities increasing in the ocean?. Microplastics and Nanoplastics, 1(1), pp.1-4.

García-Rivera, S., Lizaso, J.L.S. and Millán, J.M.B., 2018. Spatial and temporal trends of marine litter in the Spanish Mediterranean seafloor. Marine pollution bulletin, 137, pp.252-261.

Garofalo, G., Quattrocchi, F., Bono, G., Di Lorenzo, M., Di Maio, F., Falsone, F., Gancitano, V., Geraci, M.L., Lauria, V., Massi, D. and Scannella, D., 2020. What is in our seas? Assessing anthropogenic litter on the seafloor of the central Mediterranean Sea. Environmental Pollution, 266, p.115213.

Geilfus, N.-X., Munson, K., Sousa, J., Germanov, Y., Bhugaloo, S., Babb, D., Wang, F., 2019. Distribution and impacts of microplastic incorporation within sea ice. Marine pollution bulletin 145, 463-473.

Hinata, H., Mori, K., Ohno, K., Miyao, Y. and Kataoka, T., 2017. An estimation of the average residence times and onshore-offshore diffusivities of beached microplastics based on the population decay of tagged meso-and macrolitter. Marine Pollution Bulletin, 122(1-2), pp.17-26.

Isobe, A., Kubo, K., Tamura, Y., Nakashima, E. and Fujii, N., 2014. Selective transport of microplastics and mesoplastics by drifting in coastal waters. Marine Pollution Bulletin, 89(1-2), pp.324-330.

Kane, I.A., Clare, M.A., Miramontes, E., Wogelius, R., Rothwell, J.J., Garreau, P. and Pohl, F., 2020. Seafloor microplastic hotspots controlled by deep-sea circulation. Science, 368(6495), pp.1140-1145.

Kanhai, L.D.K., Gardfeldt, K., Krumpen, T., Thompson, R.C., O'Connor, I., 2020. Microplastics in sea ice and seawater beneath ice floes from the Arctic ocean. Scientific Reports 10, 1-11.

Kelly, A., Lannuzel, D., Rodemann, T., Meiners, K., Auman, H., 2020. Microplastic contamination in east Antarctic sea ice. Marine Pollution Bulletin 154, 111130.

Khatmullina, L. and Isachenko, I., 2017. Settling velocity of microplastic particles of regular shapes. Marine Pollution Bulletin, 114(2), pp.871-880.

Ko, C.Y., Hsin, Y.C. and Jeng, M.S., 2020. Global distribution and cleanup opportunities for macro ocean litter: a quarter century of accumulation dynamics under windage effects. Environmental Research Letters, 15(10), p.104063.

Kooi, M., Van Nes, E.H., Scheffer, M., Koelmans, A.A., 2017. Ups and downs in the ocean: Effects of biofouling on the vertical transport of microplastics. Environmental Science & Technology.

Kukulka, T., Proskurowski, G., Morét-Ferguson, S., Meyer, D.W. and Law, K.L., 2012. The effect of wind mixing on the vertical distribution of buoyant plastic debris. Geophysical Research Letters, 39(7).

Kukulka, T., Law, K.L. and Proskurowski, G., 2016. Evidence for the influence of surface heat fluxes on turbulent mixing of microplastic marine debris. Journal of Physical Oceanography, 46(3), pp.809-815.

Kvale, K.F., Friederike Prowe, A.E. and Oschlies, A., 2020a. A critical examination of the role of marine snow and zooplankton fecal pellets in removing ocean surface microplastic. Frontiers in Marine Science, 6, p.808.

Kvale, K., Prowe, A.E.F., Chien, C.T., Landolfi, A. and Oschlies, A., 2020b. The global biological microplastic particle sink. Scientific reports, 10(1), pp.1-12.

Lavers, J.L. and Bond, A.L., 2017. Exceptional and rapid accumulation of anthropogenic debris on one of the world’s most remote and pristine islands. Proceedings of the National Academy of Sciences, 114(23), pp.6052-6055.

Law, K.L., Morét-Ferguson, S., Maximenko, N.A., Proskurowski, G., Peacock, E.E., Hafner, J. and Reddy, C.M., 2010. Plastic accumulation in the North Atlantic subtropical gyre. Science, 329(5996), pp.1185-1188.

Lebreton, L. C.-M., Greer, S. D. and Borrero, J. C., 2012. Numerical modelling of floating debris in the world's oceans. Marine Pollution Bulletin, 64(3), 653–661.

Lebreton, L., Slat, B., Ferrari, F., Sainte-Rose, B., Aitken, J., Marthouse, R., Hajbane, S., Cunsolo, S., Schwarz, A., Levivier, A. and Noble, K., 2018. Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. Scientific Reports, 8(1), pp.1-15.

Liubartseva, S., Coppini, G., Lecci, R. and Clementi, E., 2018. Tracking plastics in the Mediterranean: 2D Lagrangian model. Marine Pollution Bulletin, 129(1), pp.151-162.

Maes, C., Grima, N., Blanke, B., Martinez, E., Paviet-Salomon, T. and Huck, T., 2018. A surface “superconvergence” pathway connecting the South Indian Ocean to the subtropical South Pacific gyre. Geophysical Research Letters, 45(4), pp.1915-1922.

Martin, C., Baalkhuyur, F., Valluzzi, L., Saderne, V., Cusack, M., Almahasheer, H., Krishnakumar, P.K., Rabaoui, L., Qurban, M.A., Arias-Ortiz, A. and Masqué, P., 2020. Exponential increase of plastic burial in mangrove sediments as a major plastic sink. Science Advances, 6(44), p.eaaz5593.

Maximenko, N., Hafner, J. and Niiler, P., 2012. Pathways of marine debris derived from trajectories of Lagrangian drifters. Marine Pollution Bulletin, 65(1-3), 51–62.

Monteiro, R.C., do Sul, J.A.I. and Costa, M.F., 2018. Plastic pollution in islands of the Atlantic Ocean. Environmental Pollution, 238, pp.103-110.

Mountford, A.S. and Morales Maqueda, M.A., 2019. Eulerian Modeling of the Three-Dimensional Distribution of Seven Popular Microplastic Types in the Global Ocean. Journal of Geophysical Research: Oceans, 124(12), pp.8558-8573.

Mountford, A. S., and Morales Maqueda, M. A., 2021. Modeling the accumulation and transport of microplastics by sea ice. Journal of Geophysical Research: Oceans, 126, e2020JC016826. https://doi.org/10.1029/2020JC016826.

Munari, C., Infantini, V., Scoponi, M., Rastelli, E., Corinaldesi, C. and Mistri, M., 2017. Microplastics in the sediments of Terra Nova Bay (Ross Sea, Antarctica). Marine Pollution Bulletin, 122(1-2), pp.161-165.

Näkki, P., Setälä, O. and Lehtiniemi, M., 2017. Bioturbation transports secondary microplastics to deeper layers in soft marine sediments of the northern Baltic Sea. Marine Pollution Bulletin, 119(1), pp.255-261.

Obbard, R.W., Sadri, S., Wong, Y.Q., Khitun, A.A., Baker, I., Thompson, R.C., 2014. Global warming releases microplastic legacy frozen in Arctic Sea ice. Earth's Future 2, 315-320.

Onink, V., Wichmann, D., Delandmeter, P. and van Sebille, E., 2019. The role of Ekman currents, geostrophy, and stokes drift in the accumulation of floating microplastic. Journal of Geophysical Research: Oceans, 124, 1474–1490. https://doi.org/10.1029/2018JC014547.

Onink, V., Jongedijk, C., Hoffman, M., van Sebille, E., Laufkötter, C., 2021. Global simulations of marine plastic transport show plastic trapping in coastal zones. Environmental Research Letters. In Press: https://doi.org/10.1088/1748-9326/abecbd.

Pabortsava, K. and Lampitt, R.S., 2020. High concentrations of plastic hidden beneath the surface of the Atlantic Ocean. Nature communications, 11(1), pp.1-11.

Pattiaratchi, C., van der Mheen, M., Schlundt, C., Narayanaswamy, B.E., Sura, A., Hajbane, S., White, R., Kumar, N., Fernandes, M. and Wijeratne, S., 2021. Plastics in the Indian Ocean–sources, fate, distribution and impacts. Ocean Science Discussions, pp.1-40.

Peeken, I., Primpke, S., Beyer, B., Gütermann, J., Katlein, C., Krumpen, T., Bergmann, M., Hehemann, L., Gerdts, G., 2018. Arctic sea ice is an important temporal sink and means of transport for microplastic. Nature Communications 9, 1505.

Peng, G., Bellerby, R., Zhang, F., Sun, X. and Li, D., 2020. The ocean's ultimate trashcan: Hadal trenches as major depositories for plastic pollution. Water Research, 168, p.115121.

Perez-Venegas, D., Pavés, H., Pulgar, J., Ahrendt, C., Seguel, M. and Galbán-Malagón, C.J., 2017. Coastal debris survey in a Remote Island of the Chilean Northern Patagonia. Marine Pollution Bulletin, 125(1-2), pp.530-534.

PlasticsEurope, 2020. Plastics – the Facts 2020: An analysis of European plastics production, demand and waste data. Available at: https://www.plasticseurope.org/en/resources/market-data.

Pohl, F., Eggenhuisen, J.T., Kane, I.A. and Clare, M.A., 2020. Transport and burial of microplastics in deep-marine sediments by turbidity currents. Environmental Science & Technology, 54(7), pp.4180-4189.

Poulain, M., Mercier, M.J., Brach, L., Martignac, M., Routaboul, C., Perez, E., Desjean, M.C. and Ter Halle, A., 2018. Small microplastics as a main contributor to plastic mass balance in the North Atlantic Subtropical Gyre. Environmental science & technology, 53(3), pp.1157-1164.

Reed, S., Clark, M., Thompson, R. and Hughes, K.A., 2018. Microplastics in marine sediments near Rothera research station, Antarctica. Marine Pollution Bulletin, 133, pp.460-463.

Reisser, J., Slat, B., Noble, K., Du Plessis, K., Epp, M., Proietti, M., de Sonneville, J., Becker, T. and Pattiaratchi, C., 2015. The vertical distribution of buoyant plastics at sea: an observational study in the North Atlantic Gyre. Biogeosciences, 12(4), pp.1249-1256.

Ryan, P.G., 2014. Litter survey detects the South Atlantic ‘garbage patch’. Marine Pollution Bulletin, 79(1-2), pp.220-224.

Ryan, P.G., 2015. Does size and buoyancy affect the long-distance transport of floating debris? Environmental Research Letters, 10(8), p.084019.

Song, X., Lyu, M., Zhang, X., Ruthensteiner, B., Ahn, I.Y., Pastorino, G., Wang, Y., Gu, Y., Ta, K., Sun, J. and Liu, X., 2021. Large Plastic Debris Dumps: New Biodiversity Hot Spots Emerging on the Deep-Sea Floor. Environmental Science & Technology Letters, 8(2), pp.148-154.

Street, F., 2019. Deepest ever dive finds ’plastic bag’ at bottom of Mariana Trench. https://edition.cnn.com/travel/article/victor-vescovo- deepest-dive-pacific/index.html.

Suaria, G., Perold, V., Lee, J.R., Lebouard, F., Aliani, S. and Ryan, P.G., 2020. Floating macro-and microplastics around the Southern Ocean: Results from the Antarctic Circumnavigation Expedition. Environment International, 136, p.105494.

Tekman, M.B., Wekerle, C., Lorenz, C., Primpke, S., Hasemann, C., Gerdts, G. and Bergmann, M., 2020. Tying up loose ends of microplastic pollution in the Arctic: distribution from the sea surface through the water column to deep-sea sediments at the HAUSGARTEN observatory. Environmental Science & Technology, 54(7), pp.4079-4090.

Tirelli V., Suaria G., Lusher A.L. (2020) Microplastics in Polar Samples. In: Rocha-Santos T., Costa M., Mouneyrac C. (eds) Handbook of Microplastics in the Environment. Springer, Cham. https://doi.org/10.1007/978-3-030-10618-8_4-1.

Tošić, T.N., Vruggink, M. and Vesman, A., 2020. Microplastics quantification in surface waters of the Barents, Kara and White Seas. Marine Pollution Bulletin, 161, p.111745.

Van Colen, C., Moereels, L., Vanhove, B., Vrielinck, H. and Moens, T., 2021. The biological plastic pump: Evidence from a local case study using blue mussel and infaunal benthic communities. Environmental Pollution, 274, p.115825.

van der Mheen, M., Pattiaratchi, C. and van Sebille, E., 2019. Role of Indian Ocean dynamics on accumulation of buoyant debris. Journal of Geophysical Research: Oceans, 124(4), pp.2571-2590.

van Sebille, E., Sprintall, J., Schwarzkopf, F.U., Sen Gupta, A., Santoso, A., England, M.H., Biastoch, A. and Böning, C.W., 2014. Pacific-to-Indian Ocean connectivity: Tasman leakage, Indonesian Throughflow, and the role of ENSO. Journal of Geophysical Research: Oceans, 119(2), pp.1365-1382.

van Sebille, E., Wilcox, C., Lebreton, L., Maximenko, N., Hardesty, B.D., Van Franeker, J.A., Eriksen, M., Siegel, D., Galgani, F. and Law, K.L., 2015. A global inventory of small floating plastic debris. Environmental Research Letters, 10(12), p.124006.

Van Sebille, E., Griffies, S.M., Abernathey, R., Adams, T.P., Berloff, P., Biastoch, A., Blanke, B., Chassignet, E.P., Cheng, Y., Cotter, C.J. and Deleersnijder, E., 2018. Lagrangian ocean analysis: Fundamentals and practices. Ocean Modelling, 121, pp.49-75.

Waite, A.M., Thompson, P.A., Pesant, S., Feng, M., Beckley, L.E., Domingues, C.M., Gaughan, D., Hanson, C.E., Holl, C.M., Koslow, T. and Meuleners, M., 2007. The Leeuwin Current and its eddies: An introductory overview. Deep Sea Research Part II: Topical Studies in Oceanography, 54(8-10), pp.789-796.

Waller, C.L., Griffiths, H.J., Waluda, C.M., Thorpe, S.E., Loaiza, I., Moreno, B., Pacherres, C.O. and Hughes, K.A., 2017. Microplastics in the Antarctic marine system: an emerging area of research. Science of the total environment, 598, pp.220-227.

Wichmann, D., Delandmeter, P. and van Sebille, E., 2019. Influence of near-surface currents on the global dispersal of marine microplastic. Journal of Geophysical Research: Oceans, 124(8), pp.6086-6096.

Wilcox, C., Hardesty, B.D. and Law, K.L., 2019. Abundance of floating plastic particles is increasing in the Western North Atlantic Ocean. Environmental science & technology, 54(2), pp.790-796.

Woodall, L.C., Sanchez-Vidal, A., Canals, M., Paterson, G.L., Coppock, R., Sleight, V., Calafat, A., Rogers, A.D., Narayanaswamy, B.E. and Thompson, R.C., 2014. The deep sea is a major sink for microplastic debris. Royal Society open science, 1(4), p.140317.

Yamauchi, T., Nakajima, R., Tsuchiya, M., Yabuki, A., Kitahashi, T., Nagano, Y., Isobe, N. and Nakata, H., 2021. Plastic additives in deep-sea debris collected from the western North Pacific and estimation for their environmental loads. Science of The Total Environment, 768, p.144537.

Ye, S. and Andrady, A.L., 1991. Fouling of floating plastic debris under Biscayne Bay exposure conditions. Marine Pollution Bulletin, 22(12), pp.608-613.

Zhang, H., 2017. Transport of microplastics in coastal seas. Estuarine, Coastal and Shelf Science, 199, pp.74-86.

Zhao, S., Danley, M., Ward, J.E., Li, D. and Mincer, T.J., 2017. An approach for extraction, characterization and quantitation of microplastic in natural marine snow using Raman microscopy. Analytical Methods, 9(9), pp.1470-1478.

Zobkov, M.B., Esiukova, E.E., Zyubin, A.Y. and Samusev, I.G., 2019. Microplastic content variation in water column: The observations employing a novel sampling tool in stratified Baltic Sea. Marine Pollution Bulletin, 138, pp.193-205.