Marine Plastics: Field Sampling and Policy Review

Submitted by Lowenna Bethany Jones to the University of Exeter as a thesis for the degree of
Masters by Research in Biological Sciences
In May 2020.

This thesis is available for Library use on the understanding that it is copyright material and that no quotation from the thesis may be published without proper acknowledgement.

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Signature: ………………… ……………………………………………

THESIS SUMMARY

Synthetic debris, more specifically plastic pollution, is a major concern to ocean ecosystems and wildlife globally. Five major accumulation zones (*i.e.* gyres) are identified to hold vast quantities of floating debris with concerns the Arctic is fast becoming a sixth. Despite growing research and political action, rates of production and emission continue to rise, with recent reports estimating around 10 million tonnes of plastic leaks into the marine environment every year (Boucher and Friot, 2017). This number forecast to increase in coming years (Geyer, Jambeck and Law, 2017).

In **Chapter 1** I present comparable assessment of sea-surface debris concentrations across three ocean basins. Using a single methodology, sea-surface trawl samples (n=44) were obtained from numerous locations within Arctic (ARC), Atlantic (ATL) and Pacific (PAC) Ocean basins, reporting a 100% incidence of synthetic material. Although particles appear ubiquitous, I report great variability in composition and type with concentrations varying greatly over spatial scale. With most identified particles offering no clear origin or form, except for pellets or microbeads, it is likely a vast proportion of sea-surface debris is of secondary origin, likely to have been floating at sea for some time. To the best of our knowledge, this is the first study of its kind to successfully utilise a single methodology to analyse and compare sea-surface concentrations of floating marine debris in numerous ocean basins, providing data in support of theories that the Arctic Ocean is fast becoming the world's sixth major gyre.

Chapter 2 sees me discuss and critically evaluate current attempts to combat the issue of marine plastic pollution. Encompassing both ‘hard’ (legally binding) and ‘soft’ (non-legally binding) policy, alongside preventative, mitigative, removal and behavioural strategies and solutions, developments, challenge and fragmented or flawed efforts are evaluated. Identifying ten focal point suggestions for the development of an effective global treaty, this Chapter sees me discuss avenues of research or policy - built on previous experience and success - necessary for the construction of a global agreement to combat marine plastic pollution.

The findings presented in this thesis contribute to the understanding of marine plastic pollution as a trans-boundary planetary threat demanding immediate global action. They also highlight the need for collaborative action and research between global stakeholders, organisations, maritime industry and researchers stimulating coordinated attempts to mitigate its effect. Especially considering its support in theories suggesting concentrations of global plastic pollution in our oceans is increasing. Lastly it is hoped that both Chapter 1 and 2 provide useful criteria for methodologies (Chapter 1) and focal points (Chapter 2), to aid in the collection of baseline data, generate awareness and fundamentally aid in preventing vast quantities of plastic waste entering waterways across the globe.

ACKNOWLEDGEMENTS

I am incredibly grateful to a number of individuals, organisations and crews, without which this research would not have been possible. Firstly, I would like to thank my supervisors Professor Brendan Godley and Dr Eva Jimenez-Guri, for their support, patience, guidance and belief throughout the process of this research. I would like to thank The *Sail Against Plastic* research expedition team for their efforts in planning, fundraising and supporting research in the Arctic and allowing the data to be utilised for my project. A huge thank you to Maybe Sailing for the unique opportunity to carry out the *Sail Against Plastic* expedition and offer me a position as crew scientist during a circumnavigation of the North Atlantic. Particularly to Captain Grace Metcalfe and Captain Chris Rose; Engineers: Gordon Douglas and Pau Garcia; and crew members Kate Varberg and Jack Cartwright for their continual support and assistance. *eXXpedition* for kindly providing PAC samples obtained during their voyage through the North Pacific Gyre in the summer of 2018. Thanks to *eXXpedition* for kindly providing samples from the Pacific as well as support from major donors and sponsors; Ecover®, Fugro® and TOMRA®. Thank you to David Santillo and colleagues of the Marine Vertebrate Research Group at the University of Exeter for their advice and guidance, allowing me to develop as a researcher and gain confidence in my ability. A special thank you to my supervisors for allowing me to follow my heart and my friends and family for their encouragement, belief, love and laughter through the constant ups and downs of this project.

TABLE OF CONTENTS

LIST OF FIGURES & TABLES

Chapter 1:

Chapter 2:

LIST OF ACRONYMS

ARC: Arctic Ocean
ATL: Atlantic Ocean
CE: Circular Economy
CSR: Corporate Social Responsibility
DRS: Deposit Return Scheme
EPR: Extended Producer Responsibility
FT-IR: Fourier Transform – Infra-red
HDPE: High-density polyethylene
LDPE: Low-density polyethylene
mm: Millimetre
MP: Microplastic
nm: Nautical mile
PA: Polyamide
PAC: Pacific Ocean
PE: Polyethylene
PET: Polyethylene terephthalate (polyester)
POP: Persistent Organic Pollutant
PP: Polypropylene
PS: Polystyrene
PUTR: Polyurethane
PVC: Polyvinyl chloride
SPP: Suspected Plastic Particle
SDG's: Sustainable Development Goals
µm: Micrometre / micron
UNEP: United Nations Environmental Programme

AUTHORS DECLARATION

Unless stated below, Lowenna B. Jones carried out all literary searches, data collection, processing, manipulation, analysis, manuscript writing, thesis compilation and formatting. Professor Brendan Godley, and Dr Eva Jimenez-Guri provided guidance and comments throughout the project, Dr Josh Martin provided additional guidance on Chapter 2.

Meret Jucker and Flora Rendell-Bhatti aided FT-IR analysis of *Sail Against Plastic* samples, under the supervision of David Santillo in Greenpeace Labs at the University of Exeter. Dr Winnie Courtene-Jones, Dr Emily Duncan, Meret Jucker and Flora Rendell-Bhatti provided additional comments on Chapter 1.

eXXpedition collected and provided samples from their North Pacific voyage (2018), Lowenna B. Jones carried out analysis and processing under the same methodology as Arctic and Atlantic samples.

INTRODUCTION

The current era now more commonly deemed the ‘Anthropocene' (Crutzen, 2006; Steffen, Crutzen and McNeill, 2007), has witnessed growing human populations and associated demand for resource, affect and critically transform nature (Steffen *et al*., 2007). Amongst a number of major human induced drivers, environmental pollution is transforming ecosystems worldwide: affecting ocean health, climatic stability, food security, sustainable development and the viability of global populations (Barange *et al*., 2014; Alava *et al*., 2017). Amongst other forms of pollution (*e.g*. atmospheric, chemical), marine pollution or ‘litter’, (that defined as “any persistent, manufactured or processed material discarded, disposed of or abandoned in the marine and coastal environment”, UNEP, 2009) is a growing planetary threat. In recent years the phrase “plastic pollution” has largely been used to refer to synthetic debris or industrial material entering the natural (or marine) environment. Due to its lightweight, inexpensive and durable nature (Laist, 1997; Sigler *et al.,* 2014), plastic is now considered one of the most pervasive pollutants, persisting in nature for long periods of time (Hansen, 1990). It is now predicted that every ocean and waterway across the globe is polluted with plastic (Morissey, 2019), with recent studies highlighting that all plastic ever produced likely persists somewhere on earth today (Bergmann *et al*., 2019; Rochmann *et al.,* 2019).

In the last decade alone, plastic production is predicted to have increased almost 50% (Plastics Europe, 2016). Typically derived from oil or fossil-fuel based feedstocks (Laist, 1997; Lambert and Wagner, 2018), ‘plastic’ is produced using numerous chemical, synthetic or semi-synthetic compounds (or polymers). Despite large-scale production only dating back to the 1950’s (Steffen et al., 2007; Shah *et* *al.,* 2008; Steffen *et al.*, 2015), it is difficult to envision a world without plastic, with a significant reliance on its use in all aspects of modern-day life (*e.g*. medicine, agriculture, construction). However, with a lack of understanding or control over discarded waste, both on land and at-sea, it remains that the overall mass of plastic entering the ocean is not fully understood, with predictions (*e.g.* Jambeck *et al.,* 2015) likely underestimating the true quantity (Lebreton *et al.,* 2018).

Once in the ocean, plastic particles, more specifically microplastic (MP) (particles <5mm, Thompson et al., 2004), become available to a wealth of marine taxa (Goldstein *et al*. 2012; Wright *et al.,* 2013; Fazey and Ryan 2016; Germanov *et al.,* 2018; Duncan *et al.*, 2019). Known to significantly impact a wide range of organisms (Cole *et al.,* 2011; Schuyler *et al.,* 2014; van Franeker and Law, 2015; Duncan *et al.*, 2019), habitats (Cózar *et al*., 2014; Bergmann *et al.*, 2019; Jamieson *et al.,* 2019) and ecosystems (Eerkes-Medrano *et al.*, 2015; Cózar et al., 2017; Horton *et al*., 2017; Waller *et al.*, 2017), whilst more recently it has been suggested plastic could indirectly lead to a rise in global temperatures (Villarrubia-Gomez *et al.,* 2018).

Given its rapidly growing production, persistence, and significant risk of harm (O'Hara *et al.,* 2019), scientific research has understandably increased drastically in recent years (Gall and Thompson, 2015; Covernton *et al.,* 2019), with studies around the subject having exploded four-fold in just a few decades (Bergmann *et al*., 2015; Dauvergne, 2018). Whilst awareness of its persistence and ecological consequence grows, alongside other planetary threats (*e.g.* Global warming, climate change), plastic pollution is increasingly considered as a planetary threat, demanding urgent global action (Kuhn *et al.,* 2015; Villarrubia-Gomez *et al.,* 2018).

There are difficulties in knowing how our oceans and waterways are connected, with uncertainty persisting in how marine litter accumulates and is transported across the globe (Hardesty *et al.*, 2018). Connecting remote areas and continents across the globe, populating volcanic islands with seeds (Renner *et al.,* 2004), providing food for marine life, sinking particles *(e.g*. marine snow) to support ecosystems on the ocean floor, in addition to shaping climatic cycles (Dupont *et al*., 2009), the world's oceans play an integral role in the transport of material over long distances. No longer is this process limited solely to natural processes: coupling its persistent nature and natural buoyancy allowing wide-scale dispersion, plastic debris has the ability to be transported on oceanic currents to locations far from its origin (Carvalho and Baptista Neto, 2016).

Captain Charles Moore first identified large patches of floating plastic litter during a shortcut through the North Pacific in 2001 (Moore *et al.,* 2001). Efforts have since focused on the identification and modelling of large areas of accumulation of the open ocean (*i.e.* ocean gyres; *e.g.* Eriksen *et al.,* 2013; Cozar *et al.,* 2014; Lebreton *et al.,* 2018), reported to hold concentrations of floating marine debris significantly greater than that elsewhere (*e.g.* the open ocean; Brach *et al.,* 2018). The most famous and well-studied of earths accumulation zones sitting in sub-tropical waters between California and Hawaii, the 'Great Pacific Garbage Patch ' (GPGP) is predicted to hold nearly 50% (46%) of all plastic mass floating in the upper ocean (Lebreton *et al.,* 2018). More recently, studies have begun to focus on locations such as the poles, where plastic has been found on beaches (Bergmann *et al.,* 2017), trapped within sea ice or sediment (Bergmann *et al*., 2017; Peeken *et al*., 2018; Kanhai *et al*., 2019) and floating on the sea surface (Lusher *et al*., 2015; Bergmann *et al*., 2015, Cózar *et al.,* 2017, Kanhai *et al*., 2018).

Understanding densities of debris at sea, areas of accumulation and the factors in which its distribution can be influenced (*e.g.* ocean currents, physical characteristics, sources and pathways) is necessary in generating baseline data. Unfortunately, disparities in methodologies, reporting units and terminology often result in ambiguous communication and the generation of incomparable data. This, alongside research constraints and economic or logistical challenge is generating large gaps in data, with studies often lacking synthesis or use at the global scale.

To address the lack of synthesis and comparability of global research, Chapter 1 sees me develop and use a single methodology to compare floating marine debris across three ocean basins (Arctic, Atlantic and Pacific). During three citizen science, commercial or expedition operations, Arctic, Atlantic and Pacific ocean basins were analysed to compare and contrast the composition and concentration of sea-surface debris. Whilst Atlantic and Pacific ocean basins have long reported high concentrations of floating plastic debris in both their North and South sub-tropical gyres, it remains unclear to what extent remote areas like the Arctic are becoming increasingly susceptible to plastic pollution.

Development in research and increased awareness of harm, boasts the power to increase political salience of the issue with recent years seeing attention focus on political responses, legislative tools and strategies to formulate urgent solutions (Covernton *et al.,* 2019). Whilst numerous responses or protocols have been pursued (Chen, 2015), it is clear that gaps remain in the way science is translated into policy (Vince and Hardesty, 2018). It is increasingly apparent that current legislative attempts are failing to stem the tide of plastic waste entering oceans and waterway across the globe, with rates of production and emission continuing to rise to unmanageable levels (Barnes *et al.,* 2009; Geyer *et al.,* 2017).

Given its growing threat and increasing calls for action, in Chapter 2 I evaluate existing political frameworks across national and international scales, pointing to the challenges and shortcomings that have so far impeded efforts to combat the issue of marine plastic pollution. I further this research, discussing preventative, mitigative, removal and behavioural strategies or solutions, identifying limitations impeding current progress and possible developments for future change. With emphasis on a more holistic and interdisciplinary approach to ocean governance, underpinned with fact-based scientific research, the Chapter concludes with ten focal point suggestions essential in the design of a future global treaty to more effectively combat the issue of plastic pollution. Given the numerous threats we as a planet are facing, turning the tide on plastic pollution must be at the forefront of immediate action, as we step ever closer to a point of no return for world health and survival (UNEP, 2019).

CHAPTER 1
A comparison of floating marine debris across three ocean basins

ABSTRACT

Synthetic debris, more specifically plastic pollution in ocean ecosystems, is now a global concern. Five major ocean gyres have been identified as holding vast quantities of floating debris, with concerns the Arctic is fast becoming a sixth accumulation zone. Disparities in methodologies and reported results make accurate and reliable comparisons among studies difficult. Here we present a comparable assessment of sea-surface debris concentrations across three ocean basins. Sea-surface trawl samples (n=44) were obtained from locations within the Arctic (ARC n=13), Atlantic (ATL n=24) and Pacific (PAC n=7) Oceans, reporting a 100% incidence of synthetic material. Primarily particles were: <5mm in size (ARC: 98.1%; ATL: 94.2%; PAC: 92.2%), fragmented (ARC: 52%; ATL: 72.4%; PAC: 92%) or fibrous (ARC: 41.2%; ATL: 17.1%; PAC: 4.5%) material and white (ARC: 32.3%; ATL: 44.5%; PAC: 61.6%) or black (ARC: 29.6%; ATL: 15.2%; PAC: 6.2%) in colour. Using Fourier Transform-Infrared Spectroscopy (FT-IR), Polyethylene (PE) (ARC: 32.3%; ATL: 27.7%; PAC: 67.9%) and Polypropylene (PP) (ARC: 10.7%; ATL: 4.9%; PAC: 13.4%) were the most prevalent polymer types identified from a sub-sample of suspected plastic particles (SPP's; n=484 ARC: 65; ATL: 184; PAC: 299). The methodologies utilised here could be utilised by citizen science projects across the globe, generating essential, comparable baseline data of plastic debris whilst furthering awareness and education of the subject.

1. INTRODUCTION

1.1. Marine Plastic Pollution

Due to its lightweight, inexpensive and durable nature coupled with careless disposal (Sigler *et al.,* 2014), plastic has become one of the most pervasive global pollutants (Hansen, 1990). Plastic constitutes nearly 80% of all marine debris (Reisser *et al*., 2015) and is thought to have considerable detrimental effects to the health of marine organisms (Bergmann *et al*., 2019), as a result of entanglement and ingestion (GESAMP, 2010; Sigler *et al*., 2014). Anthropogenic debris can also physically damage marine habitats (Derraik, 2002) and facilitate the transport of invasive species (Barnes *et al*., 2009). Microplastic (MP) particles, less than 5mm in diameter (Thompson *et al.,* 2004) have received a significant amount of interest by researchers due to their increasing presence and bioavailability in marine systems (Phuong *et al.,* 2016). MP can be sub-divided into two major sources (Arthur *et al.*, 2009). Primary MP's are those released directly into the natural environment (*e.g.* microbeads, pellets, abrasives), through domestic and industrial use (*e.g.* ship blasting, cosmetic products) (Arthur *et al*., 2009). Secondary MP's (*e.g.* microfibres, fragments), however, are created due to the break-up and degradation (*e.g.* UV exposure, biofouling, erosion) of discarded macroplastic items (Andrady, 2011; Cole *et al*., 2011).

1.2. Risk to marine species

Once in the ocean, plastics accumulate and are transported across oceans (Barnes *et al*., 2009) becoming available to organisms across all trophic levels (Goldstein *et al*. 2012; Wright *et al.,* 2013; Fazey and Ryan 2016; Germanov *et al.,* 2018; Duncan *et al.*, 2019). Due to their small size and bioavailability, MPs are known to be ingested, often having detrimental physiological and ecological effects (Phuong *et al*., 2016; Galloway, Cole and Lewis, 2017). This includes their ability to be passed through the food chain (*i.e*. trophic transfer, Nelms *et al.*, 2018) and the possibility to act as a vector of chemical compounds or persistent organic pollutants (POP's; *e.g.* Polychlorinated biphenyl (PCB), Dichlorodiphenyltrichloroethane (DDT); Fossi *et al*., 2012; Cole *et al*., 2013).

1.3. Ocean Transport & Gyres

Synthetic debris in the ocean is not constrained by national boundaries, often travelling great distances from its origin (Lebreton *et al*., 2018), making it particularly challenging to identify source locations and implement effective management strategies (Barnes *et al.*, 2009). Using empirical data and models, five areas of the open ocean are identified as zones (*i.e*. gyres) where marine debris may preferentially accumulate (Goldstein *et al.*, 2012; Eriksen *et al*., 2013; Law and Thompson, 2014). Distributed both northward and southward of the equator and the Indian Ocean sub-tropical gyres (depicted in Figure 1.1) comprise up to 40 per-cent of the global sea (25 per-cent of the globe; Sonam *et al.*, 2019), and exhibit debris concentrations frequently orders of magnitude greater than elsewhere in the open-ocean (Brach *et al*., 2018).

Plastic within sub-tropical gyres in the Northern Hemisphere has long been reported in the Atlantic (Carpenter and Smith, 1972; Colton *et al*., 1974; Law *et al.*, 2010) and Pacific (Day *et al.*, 1990; Moore *et al.,* 2001; Hidalgo-Ruz *et al*., 2012), although the Southern hemisphere remains relatively understudied (Cózar *et al.*, 2014). Polar sea ice and sediment are now considered temporary sinks of high plastic debris concentrations (Bergmann *et al*., 2017; Munari *et al*., 2017; Peeken *et al*., 2018; Kanhai *et al*., 2019), likely a combination of long-range transport, local maritime use, sea-based inputs and human activity (Cózar *et al*., 2017; Waller *et al*., 2017; Kulklinski *et al*., 2019). During a global comparison of MP levels, Arctic surface waters evidenced unexpectedly high concentrations of floating debris despite their remote location (Barrows *et al*., 2018), supporting previous reports that suggest the Arctic may be considered the “sixth gyre” (Cózar *et al*., 2017).

1.4. Methodological challenges

Understanding densities of debris at sea, zones of accumulation and the factors which influence its distribution (*e.g.* ocean currents, physical characteristics, sources and pathways) is necessary to underpin a full understanding of likely impacts and potential future mitigation efforts. Thus far, discrepancies in how researchers isolate, identify and quantify marine debris (Hidalgo-Ruz, *et al*., 2012), makes robust and meaningful comparisons difficult. This extends to consensus in mechanisms of categorising (*e.g*. type, size, shape) and reporting units.

1.5. This study

Here we utilise a single methodology to compare sea-surface concentrations of synthetic debris in the Arctic, Atlantic and Pacific (ARC, ATL and PAC) Ocean basins. We seek to further current understanding of floating marine debris in known accumulation zones, gain understanding regarding the composition of floating marine debris, identifying colour, type, polymer, size and concentration. Utilising data gathered through collaborative research expeditions by non-governmental organisations (NGO's) we hope to demonstrate citizen science as a useful platform for marine plastic research; generating essential baseline data that will further inform modelling and other synthetic approaches. This, in turn, may aid in raising awareness and the implementation of effective policy and legislation that leads to positive change. We make all data wholly open access to facilitate feeding into future modelling efforts.

2. MATERIALS & METHODS

2.1. Study sites

Sea-surface samples were taken opportunistically from Arctic (ARC), Atlantic (ATL) and Pacific (PAC) Ocean basins (n=44) (Figure 1.1), during three ocean voyages (June 2018 - May 2019). ARC and ATL samples were obtained aboard the tall ship '*TS Blue Clipper'* during scientific research expedition '*Sail Against Plastic'* (ARC; June - August 2018) and during normal commercial operation (ATL; November 2018 - May 2019). PAC samples were collected during the *eXXpedition*® research mission through the North Pacific Gyre aboard the vessel '*Sea Dragon*' (June - July 2018). Both expeditions were founded on the principle of citizen science, contributing world-class data to global understanding, whilst furthering awareness and exploring avenues of change through a mutli-disciplinary network of individuals.

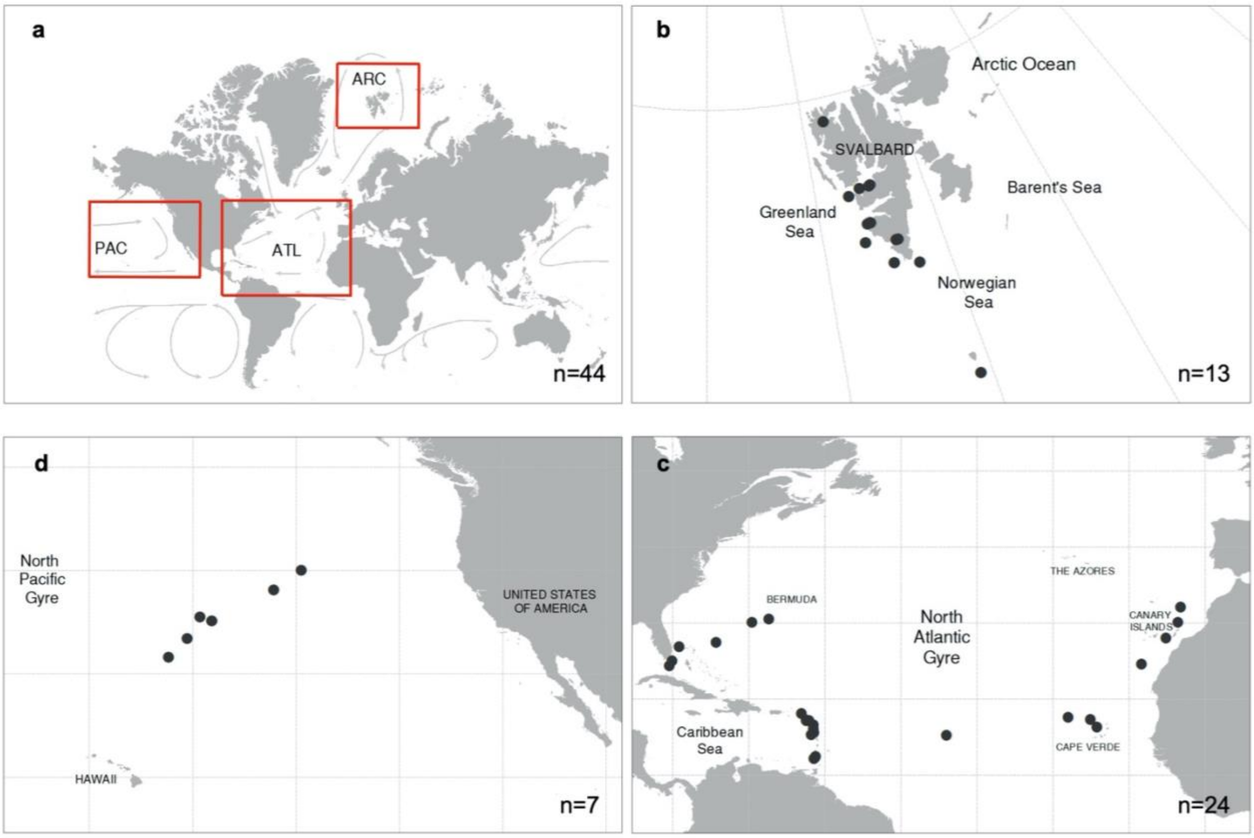

Figure 1.1: Study locations. Location of sea-surface trawls indicated by black dots in sub-figures **a:d,** total sample number (N) noted in bottom right corner of each sub-figure for reference. **(a):** Sample locations for global reference, ocean currents indicate major gyre systems with Arctic (ARC), Atlantic (ATL) and Pacific (PAC) noted for relevance to this study. Red boxes represent location of further inspection in remaining sub-figures. **(b):** ARC sample locations. **(c):** ATL sample locations. **(d):** PAC sample locations. Note difference in scale, latitude and longitude from graticules in **b, c** and **d**.

2.2. Plastic trawling

All samples were gathered using a sea-surface trawl net (*e.g.* manta, neuston), adapting previous methodologies (Law *et al.,* 2010; Eriksen *et al.,* 2014; Lusher *et al.,* 2015; Kovac Virsek *et al.,* 2016; Pan *et al.*, 2019), known to be highly efficient for sampling floating marine debris. ARC / ATL samples utilised a purpose designed Hydrobios® Microplastic Trawl net (0.40 x 0.70 x 2.6m, mesh 330µm) fitted with two lifting buoys for floatation. PAC samples were gathered using a Manta Trawl, built and designed by 5Gyres® (0.57 x 0.25 x 1.64m, mesh 335µm; Eriksen *et al.,* 2014). We consider the minor difference in mesh sizes used (ARC/ATL: 330µm; PAC: 335µm) insignificant for overall comparison using a single methodology. Trawls were towed for 10-60 minutes at an average speed of 1-4 knots, dependent on conditions. Time and location (latitude, longitude) recorded at start and end of each trawl and average boat speed recorded (Table 1.1). All trawl samples were taken opportunistically, outside of the wake of the vessel, on the leeward side only.

2.3. Visual identification of suspected plastic particles (SPPs)

Contents of the net were passed through a series of metal sieves (sizes; 450µm, 200µm) to aid visual identification (Figure 1.2). Non-organic or synthetic items (*i.e*. suspected plastic particles) were identified using the following simple criteria (Kovač Viršek *et al.,* 2016); *i*. No cell structure, *ii*. Uneven (sharp or crooked) edges, *iii*. Uniform thickness and *iv*. Distinctive colouration. All suspected plastic particles (SPPs) were rinsed with de-ionised water before storage in mesh (200µm) and aluminium for transportation to the laboratory for further analysis. No particle inspection or categorisation was carried out on-board the vessel due to risk of contamination.

a b c

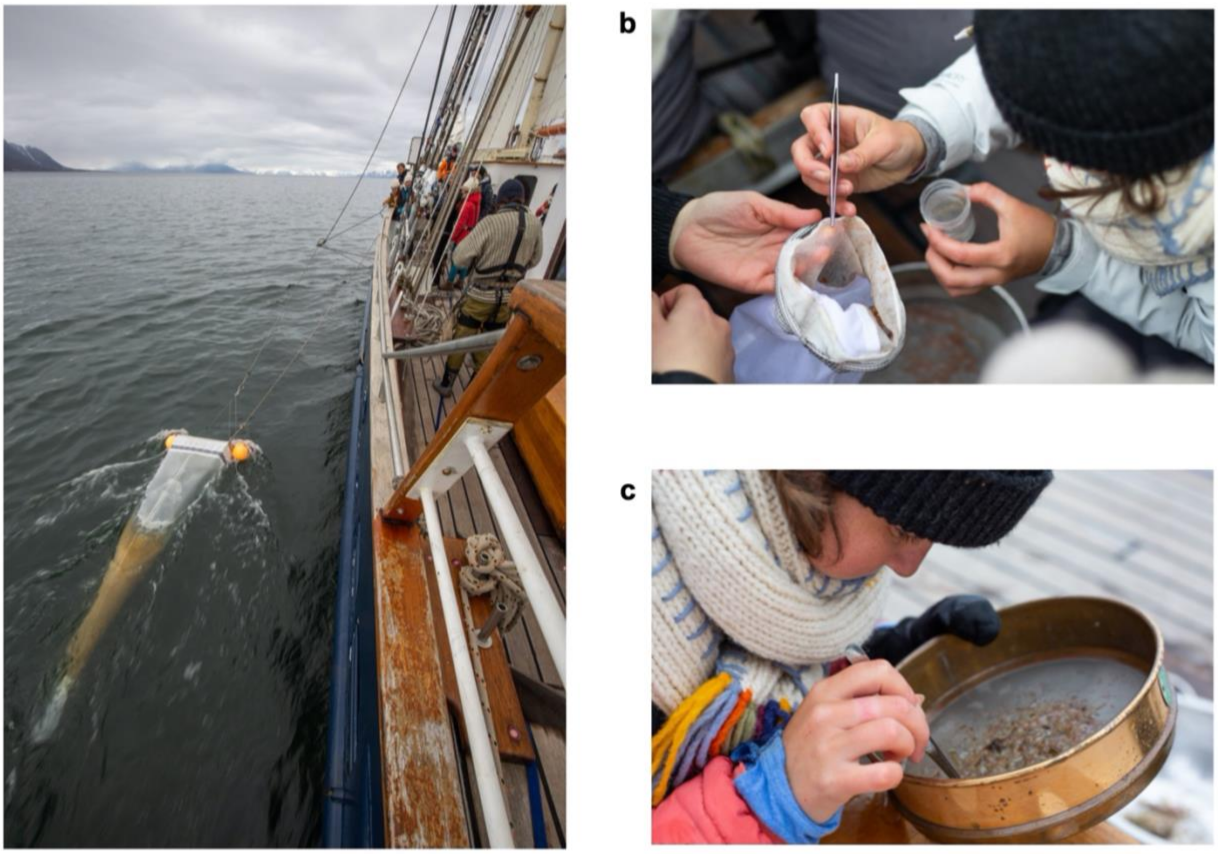

Figure 1.2: Sea-surface plastic trawling and sorting aboard the Tall ship TS Blue Clipper in the surrounding wasters of Svalbard, Arctic Ocean. **a:** Hydro-Bios Microplastic trawl Net (0.40m x 0.70m x 2.6m), mesh size 300μm, fitted with two lifting buoys for floatation. Trawl net rigged using line and steel from the leeward side of the vessel. **b:** Manual inspection of the cod end (200μm) to ensure no particles or fibres were missed. **c:** All samples passed through a 300μm metal sieve following appropriate contamination procedures (see Appendix 3) before manually inspected by eye. All suspected plastic particles collected using tweezers and placed in de-ionised water prior to storage in mesh and aluminium foil.

2.4. Laboratory analysis - categorisation and FT-IR

Physical categorisation of SPPs involved identification of type, colour and size in the laboratory (Figure 1.3). The dominant colour of each individual SPP noted, as was type (fibre, film, foam, fragment and pellet; see Eriksen *et al*., 2013; Eriksen *et al.*, 2014; Hartmann *et al*., 2019). Every SPP classified into the following size ranges; microplastic: <1mm, 1.1-2mm, 2.1-3mm, 3.1-4mm, 4.1-5mm; mesoplastic: 5.1-20mm; microplastic: >20mm. It should be noted that based on mesh size, the minimum detection limit of particles collected in each trawl is 330 µm. A representative sub-sample (Figure 1.4) of identified SPPs (n=548) was analysed using Attenuated Total Reflection Fourier Transform - Infra-Red (ATR FT-IR) Spectroscopy to determine polymer composition (see Appendices for more detail). Only particles with spectral match scores of confidence level of 0.70 or greater (Lusher *et al.,* 2013) and those confirmed upon further detailed microscopic visual inspection (LJ, DS) were considered a reliable match and accepted for further analysis. All particles were categorised, counted and concentration calculated (Appendix 1 and 2) into three reporting units (number of particles m^{-2} / km^{-2} / m^{-3}; Table 1.2) to facilitate overall comparison with the wider literature (see Table 1.3 for detailed literature review).

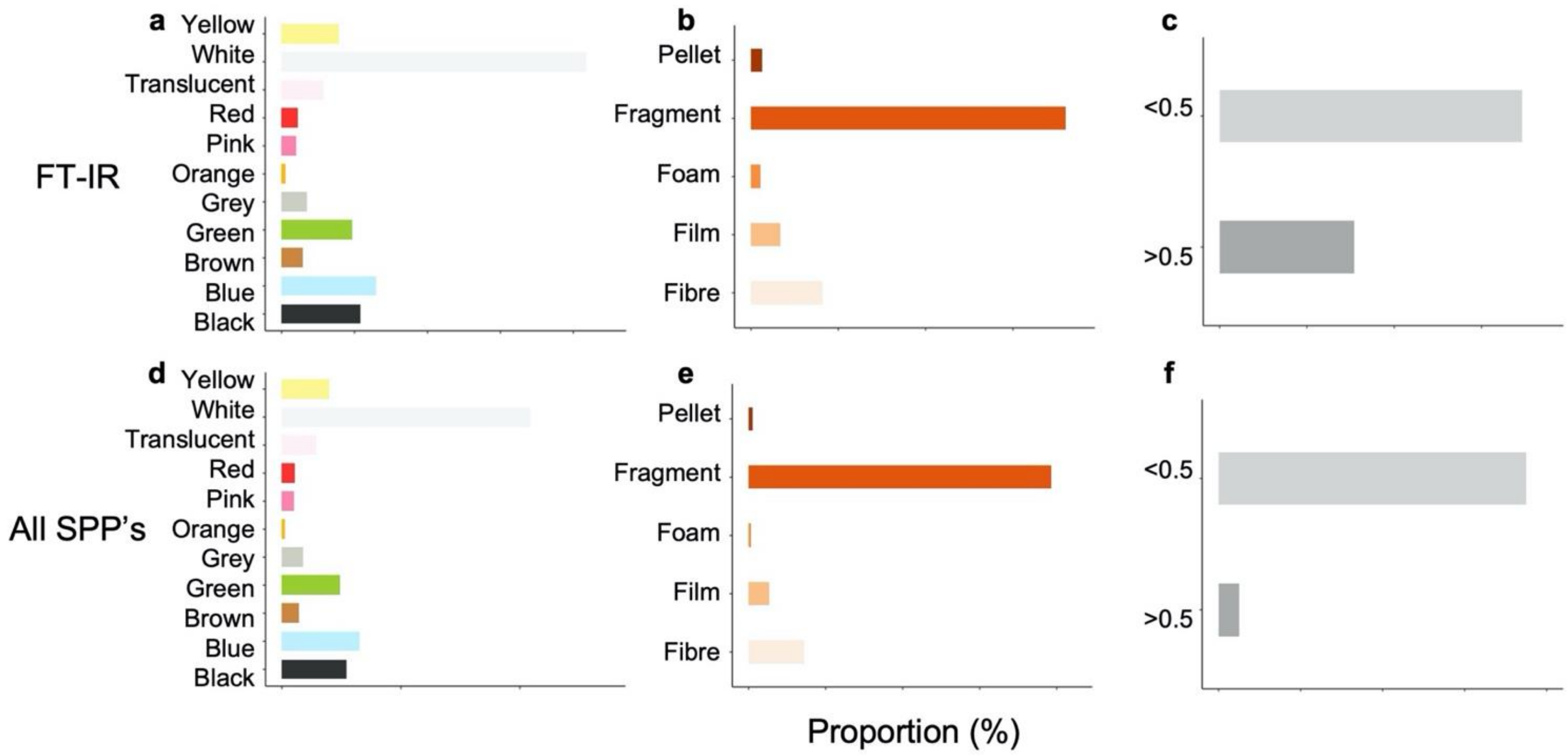

Figure 1.4: Comparison between all Suspected Plastic Particles (SPP's) (N=3627) and those sub-sampled for Fourier Transform-Infra-Red Spectroscopy (n=548) from ocean basins (ARC, ATL, PAC). **(a), (b)** and **(c)** demonstrate proportion of sub-sampled particles used in FT-IR analysis, broken down into the relative proportion of; Colour, Type and Size (>0.5 or <0.5mm), respectively. **(d), (e)** and **(f)** demonstrate overall proportion in Colour, Type and Size (>0.5 or <0.5mm), respectively for all SPP's

Figure 1.3: Sub-sample of suspected plastic particles (SPPs) obtained during a single sample in waters surrounding Svalbard, Arctic Ocean.

2.5. Contamination Control

Strict sampling procedures were maintained throughout, minimising possible contamination of samples during at-sea sampling and laboratory analysis (see Appendix 3 for more detailed information).

3. RESULTS

3.1. Ocean basin variation

Synthetic particles were identified in every trawl sample (n=44) from all ocean basins (ARC: n=13, ATL: n=24, PAC: n=7), demonstrating a 100% incidence rate of synthetic debris pollution. In total, 3627 particles of synthetic origin (ARC: 456; ATL: 1522; PAC: 1649) were counted and analysed. Sea-surface debris concentrations were significantly different across ocean basins (Kruskal-Wallis rank sum test; particles km^{-2}: χ^2 = 12.465, p= 0.001, df= 2). Greatest sea-surface debris concentration occurred in PAC (Dunn's Post-Hoc, ARC-PAC: p < 0.01; ATL-PAC: p < 0.01; ATL-ARC: p= 1.00; Figure 1.5), with all ocean basins demonstrating great variation in concentration across spatial scale (see Table 1.2 for more detailed information).

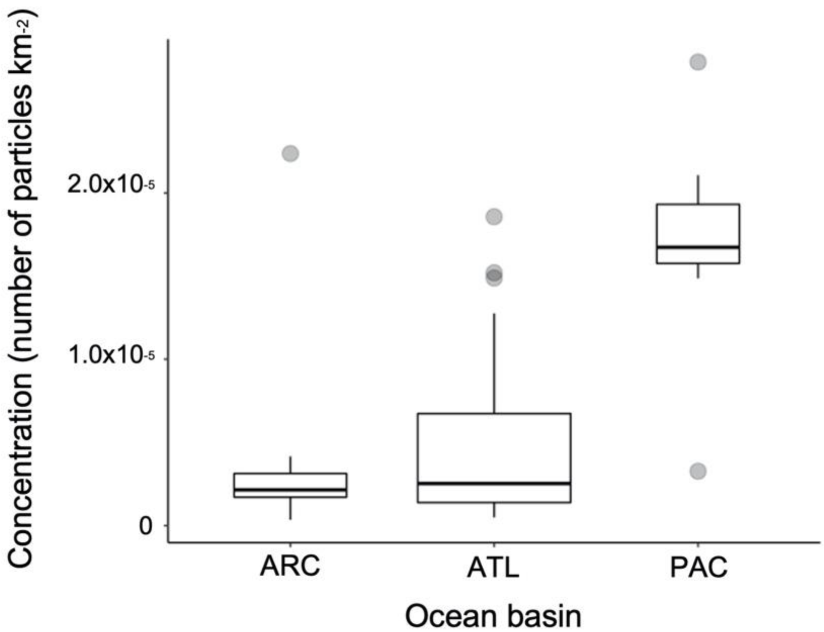

Figure 1.5: Boxplot of sea-surface debris concentration (number of particles km^{-2}), for Arctic (ARC), Atlantic (ATL) and Pacific (PAC) ocean basins. Median value shown from heaviest line with upper quartile (UQ) and lower quartile (LQ) of values demonstrated by upper (UQ) and lower (LQ) bounds of the box. Number of samples (N) within each ocean basin demonstrated from width of each box, (ARC, N=13; ATL, N=24; PAC, N=7).

Table 1.2: Summary of ocean basin variation in sea-surface debris concentrations. Minimum, maximum, median and average concentrations provided in units of measurement as the number of particles per km^{-2} / m^{-2} / m^{-3}.

	ARC			ATL			PAC		
No. particles	km^{-2}	m^{-2}	m^{-3}	km^{-2}	m^{-2}	m^{-3}	km^{-2}	m^{-2}	m^{-3}
Minimum	3,526	0.004	0.018	4,872	0.005	0.024	32,665	0.033	0.284
Maximum	223,696	0.224	1.118	185,669	0.186	0.928	278,703	0.279	2.424
Median	21,471	0.021	0.107	25,281	0.025	0.126	167,304	0.167	1.455
Average	36,321	0.036	0.182	50,032	0.050	0.250	168,619	0.169	1.466

3.2. Type, Colour, Size

Fragments were the dominant type of particle identified in all ocean basins (ARC: 52.0%, ATL: 72.4%, PAC: 92.0%) with fibres second most prominent (ARC: 41.2%, ATL: 17.1%, PAC: 4.5%) (Figure 1.6a). Colour of identified synthetic material among ocean basins was similar, with eleven colours noted in total. Particles were most commonly identified as white (ARC: 32.3%, ATL: 44.4%, PAC: 61.6%) with black second most common (ARC: 29.6%, ATL: 15.2%, PAC: 6.2%) (Figure 1.6b). Debris considered micro (<5mm) in size heavily dominated the range of identified particles (ARC: 98.1%, ATL: 94.2%, PAC: 92.2%), with remaining particles considered meso (5-20mm) (ARC: 1.3%, ATL: 4.5%, PAC: 7.4%) or macro (>20mm) (ARC: 0.6%, ATL: 1.3%, PAC: 0.4%) in scale. Of these micro particles, the <1mm size class dominated in every ocean basin (ARC: 77%, ATL: 54.9%, PAC: 36.7%) comprising a much greater proportion of ARC than ATL and PAC (Figure 1.7).

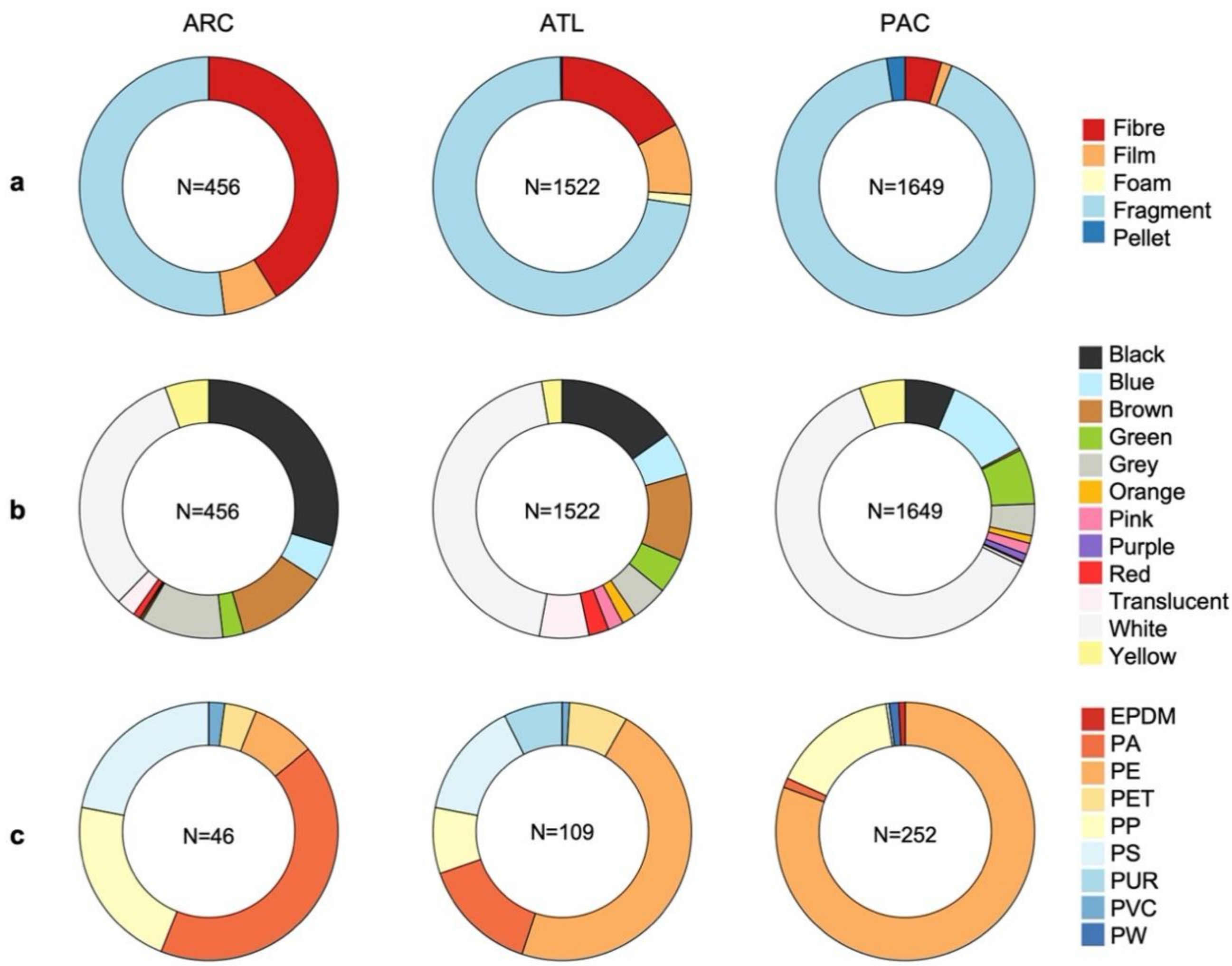

Figure 1.6: Composition of suspected plastic particles (SPP's) obtained in Arctic (ARC), Atlantic (ATL) and Pacific (PAC) ocean basins. Broken down into; Type **(a)**, type of plastic broadly categorised as; fibre, film, foam, fragment or pellet; Colour **(b),** dominant colour of particle and Polymer **(c)**, spectral match results (>0.70) of dominant polymer type identified using Fourier Transform-Infrared Spectroscopy (FT-IR). Commonly found polymer types; Polyethylene (PE), Polypropylene (PP), Polystyrene (PS), Polyethylene terephthalate (PET), Polyvinyl chloride (PVC), Polyamide (PA) and Polyurethane (PUR), Paraffin wax (PW) and Ethylene propylene diene rubber (EPDM). Total number (N) of particles shown in the centre of every doughnut, with each doughnut representing proportion.

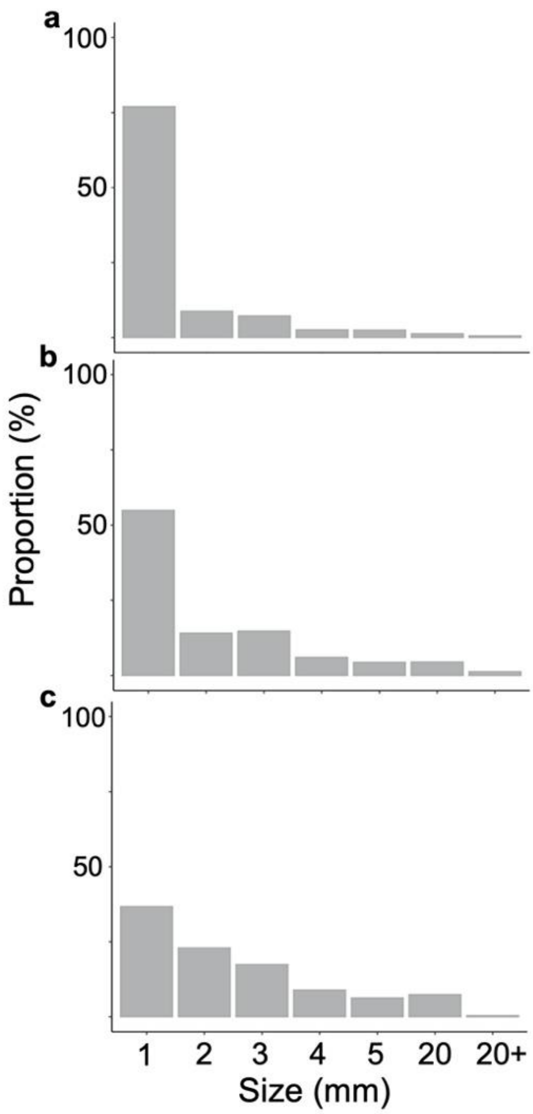

Figure 1.7: Size range of suspected plastic particles (SPP's) obtained in sea-surface trawls in **(a)** Arctic (ARC); **(b)** Atlantic (ATL) and **(c)** Pacific (PAC) ocean basins. Microplastic (<5mm) sub-categorised into: <1mm, 1–2mm, 2.1–3mm, 3.1–4mm & 4.1–5mm; Mesoplastic: 5.1–20mm; Macroplastic: >20.1mm.

3.3. Polymer type and FT-IR

Of the particles analysed using FT-IR, the majority (n=484, 88.3%, ARC: 90.7%; ATL: 84.7%; PAC: 90.0%) were confirmed as material of synthetic origin (Table 1.4). Just 2% of analysed particles were first classified 'unknown' but later confirmed synthetic due to presence of chemical compounds (*e.g.* plasticizers). Not all spectra identified as polymers typically considered 'plastic' with molecules such as EPDM rubber (n=2, PAC) and Paraffin wax (PW) (n=3, PAC) incorporated with confirmed spectra for overall analysis. A minority of particles provided scores <0.70 or provided a spectral match of naturally occurring substances (*e.g.* cellulose, yeast) (n=64, 11.7%, ARC: 9.3%; ATL: 15.3%; PAC: 10.0%). Of particles confirmed with synthetic origin (n=484) spectral characteristics matching those most commonly identified in floating marine debris: polyethylene (PE), polypropylene (PP), polyester (PES), polystyrene (PS), polyethylene terephthalate (PET), and polyamide (PA), comprise over 80% (n=449) of the tested sub-sample. PE was the most commonly identified polymer in all ocean basins (ARC: 32.4%; ATL: 30.2%; PAC: 71.8%) with PA (ARC: 18.6%; ATL: 10.3%; PAC: 1.1%), PP (ARC: 11.9%; ATL: 5.8%; PAC: 14.9%) and PS (ARC: 3.4%; ATL: 10.2%; PAC: 0.4%) also prominent (Figure 1.6c).

4. DISCUSSION

4.1. Overview

To the best of our knowledge, this study is one of the first of its kind to assess composition and provide comparable concentrations of floating marine debris across three major ocean basins utilising a single methodology. Previous reports have successfully provided measured (Eriksen *et al.,* 2013; Law *et al.,* 2010; Kanhai *et al.,* 2018) and predicted (Lebreton *et al.,* 2018) estimates of marine debris (predominantly plastic) in global oceans, however disparities in methods, post-processing and units of estimation limit broad-scale analysis and comparability. The current research helps further understanding of concentrations of floating marine debris in major accumulation zones, providing in-depth categorisation of its composition and type; highlighting possible sources, pathways and leading causes of marine pollution. Utilising non-governmental organisations (NGO's) and cross-collaborative research expeditions (*e.g. eXXpedition, Sail Against Plastic*), the methodologies and tools used in this research provide a standard operating procedure (SOP) with the potential to greatly enhance global understanding and awareness around the threat of marine pollution, suggesting its possible use as a tool to generate large, long-term datasets through citizen science.

4.2. Sea-surface debris concentration

Our current findings concur with previous reports (*e.g.* Lusher *et al.,* 2015; Cozar *et al.,* 2017; Kanhai *et al*., 2018) that the Arctic is becoming a sixth accumulation site of floating marine debris. With gyres known to hold significantly greater concentrations of synthetic debris than surrounding ocean (Goldstein *et al.*, 2012; Eriksen *et al*., 2013; Law and Thompson, 2014; Lebreton *et al.,* 2018), it is no surprise that concentrations of sea-surface debris are significantly greater in locations such as PAC compared to coastal waters or remote areas of ARC. Previous studies report concentrations of PAC debris at 0-120,000 particles km^{-2} (Eriksen *et al*., 2014; Law *et al*., 2014, Pan *et al.*, 2019), averaging 28,698 particles km^{-2} (Eriksen *et al.,* 2013), whilst a long term study of the North ATL average concentrations at 2,500 particles km^{-2} (Law *et al*., 2010) (Table 1.3). Our findings suggest concentrations (ATL, PAC) (Table 1.2) markedly higher, suggestive of how the abundance and concentration of floating marine debris in global oceans is increasing.

4.3. Variance in size and colour

Microplastic, a collective term used to describe a range of small plastic particles typically <5mm in length (Thompson *et al.*, 2004), were the most commonly identified size class of marine debris in all ocean basins (ARC, ATL, PAC). Despite growing efforts in research, there is so far "no internationally agreed definition of the size below which a small piece of plastic should be called a microplastic" (Hartmann *et al*., 2019), with different measurement and size classes frequently reported in studies. Harnessing the most commonly accepted definition (*e.g.* Thompson *et al*., 2004), and following three categories typically used to describe plastic according to size (macroplastic, >20mm; mesoplastic, 5-20mm; microplastic, <5mm; Barnes *et al*., 2009), we chose to further describe particles identified as micro, reporting measurements for each millimetre of diameter, allowing a more accurate comparison with past and future studies. While MP's <330 µm were included in analysis, it is likely these are under-reporting the true extent in nature due to our sampling method and chosen mesh sizes.

Through fragmentation, UV exposure, wave action and weathering, particle size is reduced over time (Arthur *et al*., 2009; Andrady, 2011), for example over the course of two decades (1991-2007) mean size of plastic in the North ATL reduced from 10 to 5mm (Moret-Ferguson *et al.*, 2010). Interestingly the smallest form of MP (those <1mm) was most prevalent in all ocean basins (ARC, ATL, PAC). Despite fragmentation rates of plastic largely being unknown; with most identified particles offering no clear origin or form (except for pellets or microbeads), it is likely a vast proportion of sea-surface debris is of secondary origin, likely to have been floating at sea for some time.

Results from this study contrast to previous reports of plankton and marine species ingestion or environmental seawater and sediment samples which predominantly consisted of black, blue or red particles (Güven *et al*., 2017; Steer *et al*., 2017; Gago *et al*., 2018; Nelms *et al.,* 2018). As plastic degrades in the natural environment, it is known to become more brittle, fragment and lose colour (Gewert *et al.,* 2015), with colourless plastic and those with a yellow hue considered an indicator of oxidation and time spent floating in the ocean (Endo *et al.,* 2005; Ogata *et al*. 2009). The relatively high proportion of white particles in this study could demonstrate a combination of purposefully white products and those that have lost colour due to weathering.

4.4. Debris type

Particles obtained in this study support previous theories stating synthetic particles abundant in sea-surface waters are heterogeneous in their composition, boasting varying characteristics and form between ocean basins. The most commonly identified type of floating synthetic material in all ocean basins was fragments originating from the break-up of larger items (Andrady, 2011; Cole *et al.*, 2011). A large proportion of particles we identified in ARC were categorised as fibre, more often referred to as 'microfibre'. Microfibres have a number of different sources and outputs from both land (tyre wear, degradation of cigarette filters, textile washing and wear) and sea (mechanical and chemical stress of larger items and fragmentation of maritime equipment such as ropes and fishing material; Napper and Thompson, 2016; De Falco *et al.*, 2018). Although a less obvious source of MP pollution, these fibrous plastics are now considered one of the most prolific and commonly observed forms of MP pollution in nature (Gago *et al*., 2018), commonly identified in a number of marine species (Besseling *et al*., 2012; Eriksen *et al*., 2014; Watts *et al.*, 2015; Taylor *et al*., 2016), sediment types (Jamieson *et al.*, 2019; Kanhai *et al.*, 2019) and waterways (Grøsvik, 2018; Bergmann *et al.*, 2019).

4.5. Polymer identification

Using FT-IR analysis, polymers identified in this study are concurrent with those most commonly described in oceans across the globe (Gago *et al.*, 2018). Despite there being over 5000 different synthetic and/or semi-synthetic polymers, blends and additives used and produced in the plastic industry (Lambert and Wagner, 2018), 80% of total plastic entering the marine realm consists of five primary types; Polypropylene (PP), Polyethylene (PE); both high (HDPE) and low (LDPE) density, Polyvinyl chloride (PVC), Polyethylene terephthalate (PET) and Polystyrene (PS) (Lambert and Wagner, 2018). PE and PP are low density polymers typically used in packaging material and single-use disposable products, boasting a short shelf life and predisposition to appearing in the waste stream leaking into the ocean (Gago *et al.*, 2018). It is therefore unsurprising that PE and PP dominate our samples, reflecting previous reports of sea-surface debris (Rios *et al.,* 2010; Hidalgo-Ruz *et al*., 2012; Reisser *et al.,* 2013; Cózar *et al*., 2014; Pedrotti *et al.,* 2016).

Studying synthetic debris in the natural environment provides numerous challenges. The most commonly used method to identify debris type (*i.e.* MP) is visual examination, although useful *in-situ*, boasting low cost and high efficiency, there remains inherent difficulty in distinguishing plastic particles from other synthetic (*e.g.* Rayon, Viscose) or natural (*e.g*. cellulose) material. The use of analytical chemistry (such as FT-IR) to identify particles can be challenging (Silva *et al*., 2018), however understanding the make-up and composition of polymer types can aid in the identification of possible source or fate locations of marine debris (Jung *et al*., 2018; Nelms *et al*., 2018). Despite their appearance and identification as a suspected plastic particle, a small proportion of analysed particles lacked a clear spectral match, reflecting recent reports in the literature (Remy *et al*., 2015; Nelms *et al.*, 2018; Duncan *et al*., 2019). Some material (*e.g.* Synthetic Regenerated Cellulose Fibres; SRCF) such as rayon or viscose, undergo changes in chemical structure at manufacture (Comnea-Stancu *et al.*, 2017; Gago *et al.*, 2018), resulting in slower degradation than pure cellulose fibres. These are an emerging pollutant, as changes in chemical structure or misidentification may under-report the true extent of microplastic (fibre) pollution (Comnea-Stancu *et al.,* 2017; Duncan *et al.,* 2019). In contrast, natural fibres (*e.g.* cotton) can appear visually similar to acrylic fibre (Dyachenko, Mitchell and Arsem, 2017; Silva *et al.,* 2018).

4.6. Call for standardisation among methodologies

A recent report (Coverton *et al.*, 2019) suggests the size and shape of equipment in methods used can greatly influence the qualification and quantification of MP and synthetic debris in natural environments. With most at-sea sampling done using a mesh size 300µm or 330µm which optimises the volume of water sampled whilst attempting to minimise clogging with plankton or organic matter, there remains a trade-off between the volume of seawater sampled and the limit of detection. Inconsistencies and a lack of comparable methods often make it hard to build a global understanding of marine litter accumulation, and researchers have stressed comparison between sampling methods and reporting units (GESAMP, 2016). Defining a common criteria or standard operating procedure (SOP) in estimating the composition, distribution and abundance of synthetic marine debris will be valuable in predicting and understanding contamination in marine environments and food webs across the globe (Doyle *et al*., 2011; Löder and Gerdts 2015).

By adopting methodologies previously used in assessing sea-surface plastic concentrations (Law *et al.,* 2010; Eriksen *et al.,* 2014; Lusher *et al.,* 2015; Kovac Virsek *et al.,* 2016; Pan *et al.*, 2019), this research has utilised a single methodology to provide a comparison of floating sea-surface synthetic debris between ARC, ATL and PAC Ocean basins. Whilst these particles appear ubiquitous, there is a clear need for more studies such as ours to enable an integrated global understanding of spatio-temporal variability, possible sources and pathways and heterogeneity in type of floating marine debris (Rochmann *et al.,* 2019).

4.7. Citizen science as a tool for research

Citizen science programmes are instrumental to research which may otherwise be impossible due to time, financial or logistical constraints (Hidalgo-Ruz and Thiel, 2015). Widely used in the field of marine plastic pollution, citizen science has become a fundamental tool to generate data, however, disparities in methodologies (*e.g.* sampling technique) and survey protocols (*e.g.* researcher effort) is an area of concern, with recent studies calling for standardisation in survey protocols (*e.g.* OSPAR, 2010), to ensure its comparability across the globe (Nelms *et al.,* 2017). Including people of all ages and social spectra, citizen science holds the potential to create positive change in behaviour and attitudes surrounding environmental issues through enhanced awareness and education in the community (Wyles *et al.*, 2016). The latter aspect is particularly significant given the importance and impact of social viewpoints in the acceptance and success of environmental policies or measures (UNEP, 2016). The UN's Clean Seas Campaign (UN Environment, 2017) has been instrumental in calling on local stakeholders, actors and governments to engage the educational and private sector in improved waste management, aid the generation and design principles of circular economy and reduce day-to-day plastic footprints.

With the vast majority of *in-situ* data collection of ocean-going debris and marine pollution obtained opportunistically on commercial vessels, incorporating simple methodologies and citizen science initiatives designed by academic institutions and researchers with maritime users (*e.g*. sailors, fishers) or marine organisations (*e.g*. sail training, expedition cruises), large, long-term, accurate and comparable datasets can be generated across the globe (Wyles *et al.,* 2016). Studies to date, range in the quality and quantity of data provided in research papers with some utilising a small number of samples (*e.g.* Reisser *et al.,* 2015; Pan *et al.,* 2019) and others (*e.g.* Law *et al*., 2010; Eriksen *et al.,* 2014) much greater, providing vast meta-analysis or long-term trends with often decades of data.

Appropriately designed survey methods and analysis such as those used in this research, could minimise concerns regarding the generation of reliable data by collectors whilst providing a logistically feasible method to generate data of baseline sea-surface debris concentration. Our sampling method does not require advanced knowledge or scientific laboratory space during at-sea sampling with minimal running costs following a minor initial expenditure for equipment. It has potential to be utilised by a number of maritime users and marine organisations, our method offers significant contributions of data to researchers and scientists across the globe.

Table 1.2: Summary of total collected data from Arctic (ARC), Atlantic (ATL) and Pacific (PAC) sea-surface trawls. Table lists; ocean basin, date, number of suspected plastic particles (SPP's), distance trawled in nautical miles (nm) and concentration of SPP's (particles m^{-2}; particles km^{-2}; particles m^{-3}).

Ocean	Date	Latitude	Longitude	Time (mins)	SPP's	Distance	Volume (m^3)	m^{-2}	km^{-2}	m^{-3}
ARC	25/06/18	78.138960	14.202610	20	54	1.20	311.1	0.167	166,622	1.449
	26/06/18	77.438170	14.445240	20	43	1.06	274.8	0.211	210,773	1.833
	27/06/18	77.450290	14.440260	20	9	1.06	274.8	0.149	148,652	1.293
	28/06/18	76.593230	15.474100	20	68	1.26	326.7	0.167	167,304	1.455
	28/06/18	77.008830	16.315220	20	18	0.73	189.3	0.279	278,703	2.424
	29/06/18	77.006390	16.163030	20	16	0.70	181.1	0.176	175,613	1.527
	02/07/18	78.027950	13.111270	20	27	0.97	251.5	0.033	32,665	0.284
	03/07/18	78.142850	15.085870	21	41	1.05	272.2	0.029	29,157	0.146
	03/07/18	78.155360	15.242880	21	37	1.30	337.1	0.025	24,543	0.123
	12/07/18	79.538280	12.255750	6	87	0.30	77.8	0.014	13,976	0.070
	16/07/18	76.466660	17.501060	30	8	1.75	453.7	0.066	66,247	0.331
	01/08/18	77.098000	13.587600	30	8	1.75	453.7	0.025	24,777	0.124

	04/08/18	74.086500	19.214050	31	40	1.81	469.3	0.036	35,569	0.178
ATL	15/11/18	30.060370	-13.574300	22	79	2.09	541.9	0.019	18,513	0.093
	22/11/18	28.012800	-15.199000	22	42	1.32	342.2	0.186	185,699	0.928
	24/11/18	24.521450	-18.406240	21	26	1.44	372.1	0.011	11,324	0.057
	10/12/18	17.309800	-25.092500	17	73	0.85	220.4	0.070	70,349	0.352
	11/12/18	17.537760	-28.028630	18	53	1.65	427.8	0.128	127,572	0.638
	18/12/18	15.209640	-44.005250	20	83	1.80	466.7	0.010	9,714	0.049
	13/01/19	12.129400	-61.452250	20	16	0.67	172.8	0.012	12,397	0.062
	15/01/19	12.260620	-61.310000	18	65	0.27	70.0	0.031	30,610	0.153
	16/01/19	12.429890	-61.210400	20	23	1.57	406.2	0.093	92,564	0.463
	22/01/19	17.132190	-62.412740	25	76	0.83	216.1	0.013	13,430	0.067
	27/01/19	18.064600	-63.076650	13	43	0.26	67.4	0.046	45,915	0.230
	31/01/19	17.171990	-62.437580	23	14	1.11	288.2	0.005	4,872	0.024
	01/02/19	17.130980	-62.406440	20	15	0.93	242.0	0.024	24,105	0.121
	03/02/19	15.563330	-61.425090	14	25	0.63	163.3	0.026	25,786	0.129
	08/02/19	16.590240	-61.501300	5	30	0.25	64.8	0.022	22,039	0.110
	08/02/19	17.138050	-62.104730	14	13	0.75	193.6	0.149	148,828	0.744

	18/02/19	16.078190	-61.476500	27	75	1.26	326.6	0.011	10,776	0.054
	21/02/19	15.271980	-61.783940	40	16	2.53	656.8	0.152	152,000	0.760
	01/04/19	24.360450	-80.404550	14	35	1.12	290.4	0.035	34,712	0.174
	01/04/19	25.008480	-80.069660	14	39	1.17	302.5	0.031	31,291	0.156
	02/04/19	26.839890	-79.139800	21	21	0.74	190.6	0.007	6,549	0.033
	06/04/19	27.386210	-74.259000	20	328	1.70	440.7	0.042	41,629	0.208
	08/04/19	30.035970	-69.536750	17	19	1.36	352.6	0.019	19,020	0.095
	09/04/19	30.503420	-67.348730	19	312	1.58	410.5	0.018	17,631	0.088
PAC	30/06/18	31.598486	-152.327453	37	197	1.12	136.0	0.021	21,471	0.107
	01/07/18	33.380128	-150.488234	32	178	0.80	97.1	0.030	30,120	0.151
	02/07/18	35.493115	-149.244405	30	204	1.30	157.8	0.022	21,954	0.110
	03/07/18	35.103035	-148.148440	31	219	1.24	150.5	0.224	223,696	1.118
	03/07/18	35.117089	-148.105737	30	559	1.90	230.7	0.004	3,526	0.018
	06/07/18	38.102027	-142.118817	30	241	1.30	157.8	0.004	3,526	0.018
	07/07/18	40.031361	-139.478606	31	50	1.45	176.0	0.017	17,047	0.085

Table 1.3: Comparison of marine debris concentration studies from across the globe, in the present day. Identifying; Location, year of study, methodologies used, number of samples (N), proportion containing synthetic debris (%), concentration (particles km^{-2} m^{-2} m^{-3}, size categories and properties identified in each study. Boxes highlighted grey demonstrate reported concentrations in the research with remaining concentrations (boxes remaining white) calculated for comparison where possible.

Location	**Year**	**Methodology**	**N**	**%**	**Concentration (particles)** km^{-2}	m^{-2}	m^{-3}	**Size (mm)**	**Property**	**Reference**
ATLANTIC										
Atlantic	2007-2013	Manta trawl	1571	92	$1.3x10^{-5}$	0.13		0.33 – 1.0 1.10 – 4.75 4.76 – 200 >200		Eriksen *et al.*, 2014
Atlantic	2015	Sub-surface pump FT-IR	76				1.15	0.25 – 0.5 0.50 – 0.75 0.75 – 1.0 1.00 – 2.0 2.00 – 5.0	Type Polymer	Kanhai *et al*., 2015
NW Atlantic	1986-2008	Surface net tow	6136	62	2500	0.0025				Law *et al*., 2010
NE Atlantic	2013	Sub-surface pump (11m) Raman spectroscopy	470	94			2.46	<1.25 1.25 – 2.5 2.50 – 5.0 5.00 – 7.5 7.50 – 10 >10	Type Polymer	Lusher *et al*., 2014

North Atlantic Gyre	2014	Multi-level trawl Raman spectroscopy	12				1.69	0.5 – 1.0 1.5 – 2.0 2.5 – 3.0 3.5 – 4.0 4.5 – 5.0 >5.5	Polymer	Reisser *et al*., 2015
ARCTIC										
Arctic Central Basin	2016	Sub-surface pump (8.5m) FT-IR	58				0.7	0.25 – 0.50 0.50 – 0.75 0.75 – 1.00 1.00 – 2.00 2.00 – 5.00	Type Colour Polymer	Kanhai *et al*., 2018
Arctic	2014	Manta trawl Sub-surface pump (6m) FT-IR	96	93			1.31 – 2.68	<5.0	Polymer	Lusher *et al*., 2015
Greenland & Barents seas	2013	Sub-surface tow		63	$6.3x10^{-3}$	0.006		>0.5	Type	Cozar et al., 2017
MEDITERRANEAN										
NW Mediterranean	2010	Manta trawl	40	90	116,000	0.116		0.3 – 5.0	Type	Collignon *et al*.,2012
Central-Western Mediterranean	2012-2013	Manta trawl	30	100			0.15	<5.0	Type	De Lucia *et al*., 2014
NW Mediterranean	2014-2016	Surface net tow	43	100	100,000	0.1		<5.0		Schimdt *et al*., 2018
PACIFIC										
South Pacific Gyre	2011	Manta trawl	48	96	26,898	0.0026		0.355 – 0.499 0.500 – 0.709 0.710 – 0.999 1.000 – 2.79 2.800 – 4.749 >4.75	Type	Eriksen *et al*., 2013

Pacific	2007-2013	Manta trawl Visual survey	1571	92	1.2x10^{-5}	0.012		0.33 –1.0, 1.1 – 4.75, 4.76 –200, >200		Eriksen *et al.*, 2014
NE Pacific	2009-2010	Manta trawl Sub-surface trawl (210m) FT-IR	137		21,000 – 448,000	0.021 – 0.448		20 – 100 100 – 300 >300	Type Colour Polymer	Goldstein *et al.*,2013
Eastern Pacific	2001-2012	Surface net tow	2529	42	0 – 10^{-6}	0.1				Law *et al.*, 2014
NW Pacific	2017	Manta trawl Raman spectroscopy	18	100	1.0x10^{-4}	0.01		0.5 – 1.0 1.0 – 2.5 2.5 – 5.0	Type Colour Polymer	Pan *et al.*, 2019
WORLDWIDE										
Laurentian Great Lake	2012	Manta trawl	21	95	43,000 – 466,000	0.04 – 0.46		0.355 – 0.999 1.000 – 4.749 >4.75	Type	Eriksen *et al.*, 2013
Seto Inland sea	2010-2012	Surface net tow			6.3x10^{-4}	0.06		<4.0 4.0 – 10.0 >10		Isobe *et al.*,2014
East Asian Sea	2014	Surface net tow			1,720,000	1.72		<5.0 >5.0		Isobe *et al.*, 2015
Southern Ocean	2016	Surface net tow	5	100	100,000	0.1		<5.0		Isobe *et al.*, 2017
Australia	2012	Surface net tow Manta trawl FT-IR	57	80	4256.4	0.004		<2.5 2.5 – 4.9 5.0 – 10.0 >10	Type Polymer	Reisser *et al.*, 2013
East China Sea	2013	Surface net tow	15	90			0.167	0.5 – 5.0 >5.0	Shape	Zhao *et al.*, 2014

Table 1.4: Results from subsample of isolated suspected plastic particles from Arctic (ARC), Atlantic (ATL) and Pacific (PAC) basins, analysed with FT-IR.

Origin	**Group**	**FT-IR spectra**	**PAC**	**ATL**	**ARC**
Synthetic	Polymer	Polyethylene (PE)	203	51	21
		Polypropylene (PP)	40	9	7
		Polystyrene (PS)	1	16	2
		Polyamide (PA)	3	16	11
		Polyvinyl chloride (PVC)		1	1
		Polyethylene terephthalate (PET)		8	4
		Polyurethane (PUR)		8	
		Paraffin wax (PW)	3		
		Ethylene propylene diene rubber (EPDM)	2		
	Unknown	Poly (diallyl isophthalate)		1	
		Plym 550 plasticizer		3	
		Stearamidopropyl Dimeth-beta-hydroxyethylam	1	1	
		Plasticizer CHCL3		5	
		Zinc oxide		1	
		BBP12-4, Indust P-174-1 Msha, IRS		1	
		Octadecyl 3 (3,5 di-tert-butyl-4-hydroxyphenyl)		1	
	Other	Phenoxy Resin			1
		Poly (dimethylsiloxane) PDMS		5	
		Polyphenylene-sulfide (PPS)	2	3	
		Hydroxypropyl (methacrylamide) HPMA			
		Polyvinylidene-flouride (PVDF)	1	1	
		Polyacrylonitrile (PAN)		1	
		Polytetrafluoroethylene (PTFE)		3	
		Poly (vinylidene chloride) (PVDC)	9		
Non-synthetic	Organic	Cellulose	6	7	2
		Oxytocin biochemika		8	2
		Animal protein	2	4	6
		Brewers yeast	5	9	1
		Soya bean powder		4	
		Alcohol	3	3	
		Milk agar		3	

CHAPTER 2

A critical evaluation of global solutions to the marine plastic pollution problem

ABSTRACT

Marine plastic is known to have polluted waterways and oceans across the globe. Despite growing awareness of threat, and recent consideration as a trans-boundary planetary threat demanding urgent global attention: plastic production and emission continues to rise. A number of ‘hard’ (legally binding) and ‘soft’ (non-legally binding) policies, conventions and declarations encompass current global attempts surrounding marine pollution law. Similarly; social solutions, from preventative and mitigative strategies to removal attempts and behavioural change have developed in recent years with growing knowledge and awareness around the issue. However it remains that almost every environmental compartment on earth is polluted with plastic, as modern day society increases its reliance on the material for everyday life. This research sees the critical evaluation and discussion of an expansive, but not complete, range of policies and solutions enacted at the global scale. Identifying challenges, loopholes, success and demands – we illustrate the advantages posed from a number of international legal agreements, social solutions and strategies with examples drawn from policy and law, business and economics to growing consumer pressure and awareness. Surmising ten focal point suggestions for the development of a global treaty, encompassing a number of systemic solutions whilst maintaining the ability to adapt.

1. INTRODUCTION

Marine litter (that defined as "all human-created material that has been discharged into the environment", Williams and Rangel-Buitrago, 2019), is fast accumulating in oceans and waterways across the globe. Alongside vast quantities of waste including metals, glass, ceramics, textiles, paper and timber (Eriksen *et al.*, 2014; Schneider *et al.*, 2018), plastic is now considered one of the fastest growing, most pervasive pollutants in global oceans (Beaumont *et al.,* 2019; Pierdomenico *et al.,* 2019), critically affecting and transforming nature (Steffen *et al*., 2007).

Plastic is a threat of great environmental concern. Its presence creating a myriad of problems and challenges: biologically (Garcia-Vazquez *et al.*, 2018; Ivkic *et al.*, 2019; Gracia and Rangel-Buitrago, 2020); economically (Jang *et al*., 2014; Portmann and Brennan, 2017; Wilson and Verlis, 2017) and more recently health-related (Araujo and Costa, 2019; Campbell *et al.*, 2019; Rangel-Buitrago *et al.*, 2020). In recent years, research efforts have focused on the emerging threat of microplastic (particles <5mm, Thompson *et al.*, 2004) (Maes *et al*., 2019). Formed, either intentionally (*i.e.* primary microplastic; Arthur et al., 2009) or through the break-up of larger macroplastic items (*i.e.* secondary; Andrady, 2011; Cole *et al.,* 2011), microplastic abundance and distribution has grown steadily over the past decades (Cole *et al.,* 2011; Thompson *et al.,* 2015), with the average size of marine plastic decreasing (Barnes *et al*., 2009).

The problem of marine plastic pollution is not recent and, as will be discussed below, various measures have already been undertaken at local, regional, and international level (Chen, 2015). Growing consequence and impact of marine (plastic) pollution, is acting as a catalyst within ocean governance. Increasingly, international bodies, governments and non-state actors across the globe are recognising the need to address and combat such threats in myriad disparate ways. A primary means of doing so is through political and legal action. Recent years have seen the growth and advent in both legally binding ('hard') and non-legally binding ('soft') government regulation (Abbott & Snidall, 2000; Sheridan, 2020). Developed to address and appropriately manage the production, use and disposal of plastic, these laws are a political attempt to soften the negative impact of marine plastic pollution already felt across the globe. Offering the opportunity for law and policy, enforceable through both international and domestic courts, such governance shows promise in its commitment, state agreement, principles and understanding but appears to lack strength in both enforceability (*i.e.* saction for non-compliance) and in its abilty to adapt.

Community action and social response, complimentary to but independent of state or global governance, is encouraging consumer driven solutions at both small and large scale (Bergmann *et al*., 2015). Societal solutions can be generally encompassed within Preventative *(i.e.* minimising production, preventing release); Mitigative (*i.e.* reducing spread); Removal (*i.e.* extraction from natural environment) and Behavioural (*i.e*. increase awareness for positive change in behaviour) strategies (Kuo and Huang, 2014; Bergmann *et al.,* 2015; Kiessling *et al.,* 2017). Such solutions, developed and implemented at the level of civil society, generating a shift in control and responsibility from the hands of policymakers to corporate industries, economic markets and consumer choice.

This work attempts to provide an overview of existing voluntary and legally binding efforts in ocean governance and policy, alongside strategic tools and solutions developed at the level of society to more effectively combat the issue of plastic pollution in the natural environment. Through critical evaluation and identification of potential flaws and challenges that have so far impeded current efforts, this work ends with ten focal-point suggestions for a global treaty. Given, simply putting a stop to the pollutant remains difficult, findings presented in this research demonstrate the importance and complexity of the marine plastic pollution crisis, demanding immediate, multi-disciplinary and collaborative effort across global scales.

2. GLOBAL GOVERNANCE & POLICY

Historically, laws governing the marine environment so far broadly exist on a legally (*i.e*. hard law) and non-legally (*i.e*. soft law) binding basis (Table 2.1) (Abbott & Snidall, 2000; ECCHR, 2020). The latter (soft law) generally used to denote weaker and less stringent obligation such as agreements, principles and declarations, whilst hard law refers to more precise, legally binding obligations - enforceable through domestic and international court, with appropriate third-party delegation (Abbott & Snidall, 2000; ECCHR, 2020). Both 'hard' and 'soft' legislative tools and frameworks evaluated below are discussed in a problem-oriented manner, relative to the issue of marine plastic. This by no means provides a thorough representation of all global policy, legislative framework or convention but rather provides understanding of challenges to marine governance, highlighting areas of weakness, strength and gaps in governance

(Table 2.1): to aid in the development of an effective global treaty for marine plastic pollution.

2.1. LEGALLY BINDING (HARD-LAW) POLICY

Adopted in 1972, the *Convention for the Prevention of Marine Pollution by Dumping of Wastes and other Matter,* more commonly known as the '*London Convention'*, acts as one of the earliest 'global rules and standards' (London Convention, 1972) designed, under the International Maritime Organisation (IMO), to promote protection of the marine environment from any polluting source (London Convention, 1972). Complemented by its 1996 'Protocol', the London Convention and Protocol (London Protocol, 1996) further prohibit the dumping at sea of any waste or other matter, except materials listed in Annex I (*e.g*. fish waste, dredged material). Most notably, this included plastic and other persistent synthetic material (London Protocol, 1996), however, did not come into effect as a global ocean treaty until a decade later (2006). As a lead global attempt in combating the issue of marine pollution, the most important innovation fostered by the London Protocol, 1996, is the adoption of the precautionary approach or 'polluter-pays principle' (Gaines, 1991). Which despite numerous annexes and amendments, encompassing detailed and legally binding scientific regulation, it remains that effectiveness of the London Protocol, 1996, largely relies on its ability to attract participation and environmental responsibility, through 'guidelines' and awareness in contrast to more traditional enforcement, punishable by law (Vince and Hardesty, 2018).

At a similar time (1973), the *International Convention for the Prevention of Pollution from Ships* (MARPOL) was adopted, again under the IMO

(Raubenheimer, 2016; Simon and Schulte, 2017). Composed of six annexes, MARPOL aims to prevent pollution of the marine environment, and dumping from ships due to operational loss or accident at sea, namely dealing with: oil, noxious liquid substance, harmful substances, sewage, garbage (rubbish) and air pollution. Following its first introduction, 2011 saw an important revision (*Annex V*) to MARPOLs commitment. Signed by more than 150 countries, *Annex V* (entering into force in 2013) prohibits the 'deliberate' release and disposal of plastic (such as rope, fishing net, plastic bags) and waste from ships (not including 'black' or 'grey' water), however fails to incorporate unintentional loss of plastic (*e.g*. hull blasting, gear loss). Further with signatories and states having to provide their own framework for compliance, the year 2000 witnessed adoption of the *Port Reception Facilities Directive* (2000/59/EC) to help facilitate effective enforcement of MARPOL, specifically aimed at increasing use and prevalence of port reception facilities to ensure a cleaner and more sustainable marine environment.

However, since MARPOLs enactment and adoption of aforementioned amendments, no significant decrease in the levels of marine debris have been observed in areas of high fishery and merchant activity (*e.g*. The North Sea, Unger and Harrison, 2016). Likely the result of inadequate enforcement, particularly in lesser developed regions that lack facilities and resources (Tan, 2012; Chen and Liu, 2013) or a lack of regulation, especially considering MARPOL fails to incorporate land-based sources of pollution (Reisser *et al.,* 2015; Maximenko et al., 2019), known to contribute approximately 80% of all marine debris (Tanaka, 2016). Additionally, a recent study concluded that amendments to *Annex V* and adoption of the *Port Reception Facilities Directive*

(2000/59/EC) could aid the encouragement of illegal dumping of waste at sea, due to often significant economic cost (Unger and Harrison, 2016).

Building on the London Protocol, 1996 and MARPOL, the 1982 *United Nation Convention on the Law of the Sea* (UNCLOS) – particularly Part XII – provides a mandate that regulatory states take action in preventing, reducing and gaining control in pollution of the marine environment, from any source (United Nations, 1982; Raubenheimer & Urho, 2020). With support from its 168 parties, including the European Union, this treaty focuses on the preservation and protection of all aspects of the marine environment (*e.g*. marine life, maritime activity, water quality) including those of risk or harm to human health (Culin and Bielic, 2016; Rech *et al.,* 2016; Alina *et al*., 2018). Most notably, UNCLOS extends its mandate (Article 207) to terrestrial environments, adopting measures and procedure to mitigate the pollution of waste and harmful substances originating on land (Kirk, 2018).

Despite recognising six different sources of pollutants from land-based sources to seabed activities, and pollution through the atmosphere, UNCLOS lacks detail on the types of pollutants its legislation encompasses (Palassis, 2011). In alignment with other global treaties (*e.g.* MARPOL), UNCLOS set no official documentation on what legislation should entail, with no specific instrument or ruling mechanism for compliance (Schmalenbach, 2019). Rather, it gives legislative power to its member states, requiring them to develop their own legislation in accordance with the IMO to establish regulatory rules for ship-based sources of pollution (Vince and Hardesty, 2018), and stakeholder liability in the case of non-compliance on land.

Whilst UNCLOS aids in the vital reduction of large quantities of debris entering the natural or marine environment from land, a vital issue remains. Despite the vast majority of marine plastic pollution originating on land (Pettipas *et al.,* 2016; Landon-Lane, 2018), the nature of the pollutant (*e.g*. lightweight, persistent; Laist, 1997) ensure it is not constrained within national boundaries (Liu *et al*., 2016). Often travelling great distances from its source (Lebreton *et al.,* 2018) to areas beyond national jurisdiction (ABNJ) or even the high seas (Raubenheimer, 2016; UTas Interview, 2018), making legislation, responsibility and enforcement within international water, increasingly difficult.

Additionally, raw virgin plastic and recycled or waste material is frequently traded between countries, crossing continents and borders with intention (Ten Brink *et al.,* 2017). More commonly known as the '*Basel Convention'*, the *Convention on the Transboundary Movements of Hazardous Wastes and Their Disposal,* adopted in 1989, regulates the transfer of 'hazardous' waste and 'other' (*e.g*. household, incinerator ash). Using steps and measures to ensure the environmentally sound management of waste material, the Convention aims to protect the environment and human health against possible adverse effects of such waste (Article 2.8). At time of its development, plastics were not yet considered 'hazardous', hence were not included in the Convention, however following a formal proposal (Norway, 2018) at the fourteenth Conference of the Parties (COP), the Convention was amended to include plastic waste (Annex II, VIII and IX). Perhaps most notably the Basel Convention was the first of its kind to encompass societal health effects. Whilst its aims and definitions could be viewed too vague, given its ability to adapt, core belief to reduce production of plastic and efforts in reducing the trade of waste, the importance of the Basel Convention in the fight against plastic pollution is sure to be increasingly relevant.

Despite member states or country-to-country efforts in the prevention, mitigation and removal of marine plastic debris (Borelle *et al.*, 2017), the complexity highlighted within the issue of marine plastic pollution (*e.g.* ABNJ, trade, sources, movement) ensures it is increasingly difficult to enforce effective legislation. Whether legally binding or voluntary, when treaties provide no higher authority, measure or control to effectively legislate and guarantee enforcement in the case of non-compliance, it must become “self-enforcing” (Finus, 2001), with set and measurable targets.

Following growth in global unity and commitment in the success of the Millennium Development Goals (MDGs), September 2015 witnessed the United Nation (UN) General Assembly adopt and ratify the Sustainable Development Goals (SDGs), as part of an agreement to overcome global challenges and improve sustainability by 2030 (UN, 2015). Addressing a wide range of issues, 17 interconnected goals relevant across the globe including themes such as poverty, environmental degradation, food insecurity, climate change, gender inequality and the sustainable development, incorporate specific targets – 169 in total – with indicators used to measure, review and monitor their progression.

Most notably the issue of environmental pollution and plastic waste - some of the Goals commit to the treatment of wastewater (SDG 6), waste management (SDG 11), and the prevention and reduction of air, soil and marine pollution, including litter (SDG 3), whilst more broadly, conservation of oceans, seas and marine resources (SDG 14) is at the forefront of its agenda. A document entitled 'Our ocean, our future: call for action' developed at a UN meeting (2017) explicitly identifies the reduction of plastic (and microplastic) as a matter of urgency (UN Environment, 2017).

With law, more particularly legally binding and international law, providing a useful tool in obtaining global commitment to declared targets and objectives, many of the SDGs include a legal component. With follow-up and review at the national, regional and global level, ensuring state responsibility and action in regard to progress, goals, targets and implementation. For instance, a minimum of ten percent of global oceans, coastal and marine areas are to be conserved subject to area-based protection by 2020 (Target 14.5) (Freestone, 2020). Similar to aforementioned conventions, there remains a great deal of 'ambiguity' with member states lacking guidance on effective or appropriate tools and measures required to successfully adopt targets. Alternatively, the UN acknowledge regional and national discrepancy or ability, providing a framework of adaptability to member states (Wise, 2014; Fleming, 2016; Collof, 2017), encouraging transition through a smaller scale, context-dependent, evolutionary and non-linear process, encompassing success as well as failure (Bowen *et al.*, 2017; Van Asche *et al.*, 2014).

In similarity; legislative tools (*e.g.* tax / levy / charge), that penalise behaviour which increase waste sent to landfill are designed to generate positive actionable change through market control (Ten Brink *et al*., 2009; Oosterhuis *et al.*, 2014; Shortle and Horan, 2017). Where a ban may otherwise be impossible or considered damaging to the market, such tools act as a concrete example of the “polluter pays” principle (Gaines, 1991), requiring manufacturers and consumers to make a more conscious decision regarding behavioural choices (Knoblauch *et al*., 2018).

Denmark, was the first offer a tax on plastic bag production (1993) with retailers enforcing mandatory charges on consumers, successfully reducing plastic bag consumption among Danes to just four bags a year (Daur, 2018). Similarly, in 2002, Ireland introduced a small €0.15 levy on general purpose plastic bags, immediately reducing consumption by 90% in a single year (UNEP, 2018). Wales did something similar in 2011, introducing a charge on bag use at food (70-96% decrease) and fashion retailers (68-75% decrease) (Welsh Government, 2012), with England later enforcing a 5 pence charge on single-use plastic bags in large retailers (85% decrease) in 2015 (Guardian, 2016). All demonstrating significant positive impact on bag use and pollution (WRAP, 2013). Similar bans in India (1999), Bhutan (1999) and Bangladesh (2002) however failed to see success, with failure in the ban likely the result of poor implementation or enforcement and lack of affordable alternatives available (Earth Policy Institute, 2013; Prata *et al.*, 2018). Additionally, with economically competitive and financially strong corporations often the primary producers of plastic, it remains unclear whether the implementation (or subsequent lack) of small penalties (levies or taxes) in domestic law will be sufficient enough to hinder production or use. There are also concerns that charges or taxes for correct and appropriate disposal may incentivise fly-tipping or illegal landfill.

Despite the large number, this by no means provides an exhaustive evaluation of all ‘hard’ law attempts, rather it underlines the comprehensive and perhaps detailed nature of legally binding ocean governance, demonstrating its complex and evolving nature. Policy and law, particulary at international level, is often criticised in the way it develops – boasting a tendency to be slow and fragmented, requiring little consensus. Large gaps remain, however it remains that integration of ‘hard’ law policy throughout the international community has use in the way forward for ocean governance – particularly when managing activities that pose significant risk to the natural environment at a global scale, which currently lack viable alternative.

2.2. NON-LEGALLY BINDING (SOFT-LAW) POLICY

International regulations regarding marine litter are more commonly found on a ‘soft’ law basis (Sheridan, 2020), with commitments (*e.g*. Honolulu) or frameworks (*e.g.* GPML) in which states pledge to commit, without legal obligation. Despite ‘hard’ law appearing to demonstrate increased enforcement (*i.e.* sanction for non-compliance), it could be argued that soft law offers increased implementation, through state understanding and control when compared to its hard, legally binding alternative (*e.g.* MARPOL) (Table 2.1).

Through the collaboration of the United Nations Environmental Programme (UNEP) and the US National Oceanic and Atmospheric Administration (NOAA), the *Honolulu Strategy* was adopted as a global framework to combat marine litter in 2012. Consisting of three over-arching principles, the *Honolulu Strategy* attempts to reduce marine litter within every marine habitat, with strategies to:

(i) reduce the amount and impact of land-based litter / solid waste; *(ii)* reduce the amount and impact of sea-based sources of debris, including solid waste, abandoned, lost or discarded fishing gears (ALDFG) and lost or abandoned cargo; and *(iii)* reduce the amount and impact of accumulated marine debris on shorelines and in benthic and pelagic habitats across the globe (UNEP, 2016). Perceived to be “more about public and international education than concrete commitments and expressions of responsibility and/or liability” (UNEP and NOAA, 2012; Stoett, 2016), the *Honolulu Strategy* is increasingly considered as a planning framework. Utilised as an awareness tool to reduce global impacts of harm through appropriate management, prevention and awareness (UNEP and NOAA, 2012; Ten Brink *et al.*, 2016), rather than simply legislating against ‘bad’ behaviour.

Guided by the *Honolulu Strategy*, the *Global Partnership of Marine Litter* (GPML), under the auspicious arm of the *Manila Declaration* (Furthering the Implementation of the Global Programme of Action for the protection of the Marine Environment from Land-based Activities) is an international multi-stakeholder initiative, with a primary focus to implement principles of the *Honolulu Strategy* (UNEP, 2016). Implemented in the same year (2012), GPML is freely and easily accessible to a multitude of organisations, authorities and stakeholders: both open-ended and voluntary it requires no formal or legally binding sanction in case of non-compliance. Officially launched at Rio20+, GPML acts as a coordinating forum to exchange tools for success, examples of failure and adequate measures for compliance (Chen, 2015; Lohr *et al.*, 2017). Additionally having identified a lack of understanding and awareness as a barrier to conservation at high political agendas (*e.g.* G7, Convention on

Biological Diversity, Conference of the Parties), GPML has more recently focused its attention on developing educational material (*e.g.* Massive Open Online Course on Marine Litter).

The G7 group of nations (consisting of Canada, France, Germany, Italy, Japan, the United Kingdom and the United States of America), first released the *Action Plan to Combat Marine Litter* in 2015, pledging to address both land and sea-based sources of marine litter (G7, 2015). Two years later (2017), the *G20 Action Plan on Marine Litter* was launched where the remaining thirteen stakeholder governments and countries, banded with the previous G7 coalition, in commitment to "take action and reduce marine litter of all kinds, including from single-use plastics and microplastics" (G20, 2017). Largely in response to commitments made in support of the 2030 Agenda for Sustainable Development (*e.g*. Sustainable Development Goals) (UN, 2015), marine litter and environmental pollution entered the forefront of political discussion. Although only agreed upon by five of the seven G7 nations (Canada, France, Germany, Italy and the UK), 2018 witnessed development of the most recent action plan, the *Ocean Plastics Charter*, with a sole intention of addressing marine plastic pollution. This was the first action plan to provide explicit targets or actionable timelines for change. Pledging to work with industry in the resolve of taking a more life-cycle approach in product design and stewardship both on land and at sea, promoting the re-use, recovery and recyclability of plastic items where viable alternatives do not yet exist (Simon *et al.,* 2018).

Although at smaller scale, in line with the *Ocean Plastics Charter*, the European Commission released the *European Strategy for Plastics in a Circular Economy*

(Circular Economy Action Plan) communication in January 2018. Adopting the first ever Europe-wide strategy on plastics, its principle objective is transitioning to a circular economy (Liu *et al.*, 2018), where “the design and production of plastics and plastic products fully respect reuse, repair and recycling needs and more sustainable materials developed and promoted” (European Commission, 2018).

Following its launch, the Directive has since been amended to include recycling targets, with the *Waste Framework Directive* (EU, 2008), as its fundamental core (European Parliament, 2008). This has aided the generation of targets to reduce waste sent to landfill, increase quantity and ability for reuse of plastic products, and further recycling of primary waste streams (*e.g*. plastic packaging) (European Commission, 2020). Alongside targets such as 100% of EU plastic packaging available for reuse or recycling by 2030 and more recently the EU ban on single-use plastic (SUP) (*e.g*. cutlery, straws, cotton buds) (European Commission, 2018), transitioning to a more circular economy will undoubtedly aid in reducing the unnecessary release of plastic waste into the natural environment. Unfortunately, there are growing concerns that manufacturers and producers could market single-use plastic items as ‘re-usable’ to avoid the EU ban. However, with the EU encompassing some of the world’s largest producers of plastic, this commitment may provide a significant opportunity to regain control and create systemic change.

Voluntary agreements and conventions (*e.g. Honolulu Strategy*), amendments (*e.g*. *Annex V*, MARPOL) or developments to legally binding conventions (*e.g*. UNCLOS) are promising new developments, as they incorporate land-based sources of marine litter and plastic into their frameworks (UNEP, 2012; 2017) (Table 2.1). Acting as voluntary agreement with the lack of legally binding instruments and tools; governance or enforcement is left primarily to domestic regulation: particularly challenging considering the far-reaching and persistent nature of the pollutant (GESAMP, 2016, Ten Brink *et al.,* 2017).

Summary

At both the national and international scale, countries around the world are taking legal approaches in addressing the marine plastic pollution problem from legislation and policy to action plans and agreements. Generally speaking, existing global efforts to combat the plastic pollution crisis are dominated by softer more domestic law. Lacking a legally binding policy such attempts rely on established targets and follow up by stakeholders, signatories and states. However there remains complexity in the multi-faceted contribution and role of numerous responses, be them legally binding or not.

It is not yet clear how effective policies and legislation, such as those listed above, have been in sufficiently conserving and protecting ecosystems from the threat of marine plastic pollution. Though undoubtedly well-intended, with little coordination between states, inconsistent standards, systemic illegalities or loopholes, and erratic implementation (Dauvergne, 2018) – it is unsurprising that the United Nations Environment Assembly (UN Environment, 2017) describe current frameworks as “fragmented and uncoordinated”. With some organisations suggesting efforts should focus on the development of a new global framework (Hugo, 2018; Simon *et al.*, 2018), with current piecemeal attempts lacking strength or comprehension needed to effectively stem the tide of plastic (Dauvergne, 2018; DeSombre, 2018).

3. SOLUTIONS

With growing awareness and understanding around the subject of marine plastic pollution, numerous fronts of solution-oriented action are continuously developed to combat environmental pollution. Policy and legislation is only as effective as the implementation of societial behavioural change – not through sanctions or enforcement – but through changing expectations, furthering education and generating awareness around the impacts of marine debris (Derraik, 2002). Harnessing consumer power, steering change through the momentum and pressure from environmental groups and embedding localised social objectives within larger governmental or community efforts has the potential to have substantial impact in reducing marine pollution, establishing effective, bottom-up, community led governance solutions.

Broadly, solutions can be defined as belonging to one of four categories (Kuo and Huang, 2014; Kiessling *et al.*, 2017): *(i)* Prevention: solutions to minimise or prevent litter entering the environment, avoiding production and limiting its spread; *(ii)* Mitigation: tools to reduce the generation of litter through adequate collection or disposal; *(iii)* Removal: strategies in which accumulated litter or waste is extracted and removed from the natural environment; and *(iv)* Behavioural Change: a cross-cutting solution with the aim to alter or influence stakeholder behaviour and thought pattern, encouraging greater custodianship and more environmentally kind activity (Bergmann *et al.,* 2015).

3.1. STRATEGIES FOR PREVENTION

Be it the generation of primary plastics (*e.g*. pellets, nurdles, microbeads) (Arthur *et al*., 2009) or secondary items (*e.g*. fragments and fibres) (Andrady, 2011; Cole *et al.*, 2011): simply avoiding the generation of virgin plastic, or using phase-outs and bans, is likely the most effective way to prevent plastic litter entering the marine environment and stop the pollutant at its source. In recent times, society has witnessed dramatic growth in production and use of alternative, more sustainable 'plastic' material (*e.g*. bioplastic), as a developing instrument of change on the market.

3.1.1. PHASE-OUTS & BANS

Phasing out or banning plastic material items, from (partial) bans, taxes or fees to voluntary measures is a strategy increasingly seen within regional, national and even international legislation to prevent use, and reduce demand of everyday plastic items (Table 2.2) (Xanthous and Walker, 2017).

The last decade has witnessed a rapid growth in awareness and intervention regarding bans or restrictions in the sale and use of microbeads (plastic beads <1mm in size). With growing pressure and public outrage from consumers and anti-microbead activist groups, following dissemination of evidence of persistence and harm, an increasing number of industries, corporations and states are taking action to remove microbeads from industrial (*e.g*. ship blasting) and commercial (*e.g*. cosmetic and personal care) products. A number of large cosmetic companies (*e.g*. Unilever, L'Oreal) and supermarket chains (*e.g*. Waitrose) rolled out voluntary microbead phaseouts from their products and/or company prior to legislative change (Xanthous and Walker, 2017; Dauvergne, 2018): a useful sales technique, whilst beneficial to both the planet and consumer. Similarly, plastic bags have received increasing attention after developing countries initiated strict regulatory action against their use in the 1990's, after poor waste management and lack of recycling made the littering of plastic bags more apparent (*e.g*. on beaches, rivers) and impactful (*e.g*. blocking drains, flooding) (Figure 2.2). In time, interventions have advanced significantly in countries across the globe, with governments, organisations and large-scale corporations since introducing bans (varying in range and scope) in the sale of plastic bags, applying voluntary or mandatory charges (*i.e*. levy) and even generated income (*i.e*. tax) from their sale (Xanthous and Walker, 2017).

3.1.2. ALTERNATIVE MATERIALS

With plastic now conspicuous in modern day life, efforts to promote the development and use of 'bio-degradable' plastic – promoting faster and more friendly breakdown of an item – has grown significantly in recent years. As a result, more environmentally 'compostable', 'degradable 'and 'bio-degradable ' alternatives are increasingly seen on the market (Table 2.2). In contrast to traditional oil-based plastic (*i.e*. petroleum), natural polymers used to produce more environmentally sustainable plastic can be entirely or partly derived from renewable: typically, plant, or biological material (*e.g.* corn, sugarcane). Unlike conventional polymers, those made using plant material (*i.e*. bio-plastic (BP)) are stated to degrade easily under conditions commonly found in the natural environment, over short periods of time, aided by the presence of microorganisms (Balestri *et al.*, 2017): most notably, with no harmful affect (Haider *et al.,* 2019).

Materials such as PLA (Poly-lactic Acid), now produced in large scale factories (*e.g*. ethanol plants), form the vast proportion of bio-plastic (BP) material utilised in food packaging, plastic bottles, utensils, textiles and medical devices (National Geographic, 2018). BP material provides a more sustainable and environmentally friendly way of producing plastic, requiring less damaging resource and energy in its production (Gross and Kalra, 2002; Bioplastic Feedstock Alliance, 2016; Trucost, 2016). However, production remains low, with BP material (including polylactic acid (PLA), polyhydroxyalkanoate (PHA), polyhydroxybutyrate (PHB), and polyhydroxybutyrate (PHV)) accounting for less than 1% of annual 'plastic' production (European Bioplastics, 2019). Unsurprising considering costs of BP production are often 3-10 times that of conventional plastic (Luyt and Malik, 2019).

It remains unclear as to whether BP materials are in fact 'safer' from an eco-toxicological perspective (Haider *et al.*, 2019) or if they even fully degrade (Napper and Thompson, 2019). Recently, cases (such as Musiol *et al.,* 2017; Napper and Thompson, 2019) have shown that most BP materials (*e.g*. PLA) do not biodegrade as effectively as first thought, requiring specific conditions found only within industrial composting facilities (*i.e*. temperatures above 50 degrees Celsius, specific pH and humidity, constant exposure to ultra-violet light). In contrast, polymer Poly-hydroxy-alkanoate (PHA), is fully degradable (rate dependent on conditions) in a marine environment (Gross and Kalra, 2002). Additionally, experts report that BP may in fact accelerate the formation of microplastic due to accelerated break down (Eyheraguibel *et al.*, 2018; Markowicz *et al.*, 2019), and further plastic leakage through improper disposal encouraging consumers to “abandon it in the environment or add it to their private compost” (Simon *et al.,* 2018).

Although the term itself lacks clear definition (Gold *et al*., 2014; Haider *et al.*, 2019), use of the label ‘bio’ offers potential source of confusion to consumers wanting to make more environmentally conscious decisions (Van Sebille, 2016). Commonly deemed ‘Greenwashing’; concerns exist regarding the use of ‘bio’ as a marketing and sales tool (Brennan and Binney, 2008), misleading consumers to influence their purchasing choice regarding the environmental conduct or content of a product or service (Schmuck *et al*., 2018).

In a process commonly known as ‘down-grading’ (Hopewell, Dvorak and Kosior, 2009), materials such as paper, cardboard or glass are increasingly seen as a more sustainable alternative to plastic, with increasing numbers of retailers and producers offering plastic-free alternatives. Demanding increased water and energy in production and boasting greater economic cost (Ellen MacArthur Foundation, 2016) switching to material such as paper can too pose its challenges and may not provide an appropriate substitute for conventional plastic in its current form (Rujnićsokele and Pilipović, 2017). This is not to mention the demand on already threatened resources such as wood or food crop (given levels of food insecurity and deforestation) to produce a disposable resource.

Market innovation

Rapid expansion of ‘zero-waste’ (Table 2.3) and ‘plastic-free’ stores worldwide, is allowing consumer driven economic change, following an increasing desire for products free of waste (Ellen MacArthur Foundation, 2016; Dauvergne, 2018). Many of these stores utilise re-usable packaging or require customers to bring personal food containers, reducing both packaging and unnecessary food waste (Bepakt, 2016; Eriksen et al., 2018). Alongside large UK food retailers (*e.g*. Tesco, Sainsburys, Lidl) aspiring to 100% re-usable, recyclable or compostable packaging by 2025 (Guardian, 2018), the UK supermarket chain, Iceland, recently pledged to eliminate plastic from its aisles by 2023. Instead utilising bamboo and sugar cane in the development of ready-meal trays, pulp packaging for fresh items (*e.g*. vegetables, chicken, fish) and removing plastic from its operations and consumables department (Iceland, 2018).

Although such developments have their benefits (*e.g*. reducing the demand for oil, returning feedstock to the soil (Chinaglia *et al.*, 2018), there is no single conclusive fix (Table 2.3). Developments using unconventional feedstock (*e.g*. mushroom, algae, seaweed) and growth in reusable (*e.g*. coffee cups, bottles) or degradable items (*e.g.* ovenware, cutlery, straws) offer considerable advancement (Packaging News, 2017; Bakey's India, 2018; COLPAC, 2018; Table 2.2), decoupling the production and demand of primary virgin plastic from fossil-fuel feedstocks where alternatives exist (Schweitzer *et al.* 2018).

Biomimicry

Through time, animal and plant evolution has given rise to time-tested patterns and solutions to some of nature's most complex problems (French, 1996; Benyus, 1997). Alongside developments of alternative material and bio-plastic products (Table 2.3), inspiration is turning to nature, providing effective solutions (*e.g.* feedstock; Monnier *et al.*, 1998), engineering (*e.g.* strength technology; Gordon, 1976) and material (*e.g.* natural polymers; Carlson *et al.,* 2012). Whilst synthetic (typically plastic) material has been engineered by humans for decades (Cole *et al*., 2011), current advancements are unable to provide the necessary complexity or working functionality of natural polymers. Through an approach known as 'biomimicry' (Benyus, 1997), or 'biomimetics' (Bhushan, 2009) natural polymers (*e.g.* glucose, starch) or processes (*e.g.* hydrodynamics, flight) identified within strong material (*e.g*. cotton, hemp, wood), species (*e.g*. sharks, bees, birds) or those with well-designed structure (*e.g.* spider silk) are providing innovative solutions to modern day challenges (Bhushan, 2009; Ellen MacArthur Foundation, 2016).

3.2. STRATEGIES FOR MITIGATION

Achieving zero plastic use or production is deemed near impossible due its preferable characteristics (lightweight, cheap, durable and versatile; Laist, 1997; Figure 2.1). Once produced or consumed in the market, attempts turn to limit the damage and leakage of plastic into the natural environment, require exhaustive and environmentally sound efforts of disposal.

3.2.1. RECYCLING

Despite recycling fast becoming the most widely utilised waste management strategy at the consumer level (Table 2.3) it remains that only a small percentage of waste is effectively prevented entering landfill (Geyer, Jambeck and Law, 2017). A 2015 study reported surprisingly low rates of recycling, with just 9% of all discarded plastic effectively recycled, whilst 80% enters landfill and the remainder (11%) incinerated (Geyer, Jambeck and Law, 2017). Further, a more recent study predicts global (recycling) rates at approximately 14% (Daur, 2018), however just 5% is effectively recycled (Daur, 2018), meaning that once plastic has entered the recycling stream (*e.g.* roadside collection schemes, recycling plants), there remains room for significant leakage.

Fifty percent of all globally recycled plastic is exported across the globe, with China accounting for almost half (45%) of imports (Brooks, Wang and Jambeck, 2018). This process symbolises what Clapp (2002) denotes “the distancing of waste”. Through both the mental and physical distancing of modern society from enormous amounts of waste, citizens believe that by putting their waste in a recycling bin, they have contributed to a cleaner and healthier environment (Clapp, 2002), whether or not it is effectively recycled by the importing country.

Another flaw in the simplistically, linear process of recycling is the apparent lack of ability to deal with diversity in design and composition of plastic items. Frequently derived from a number of polymers (Figure 2.1), colourings, toxic additives and chemicals (*e.g*. phthalates, flame retardants) (Groh *et al.*, 2018), variation and complexity within plastic products can be problematic, challenging recycling systems to maintain quality and efficiency. As an example, black plastic – such as that used in food packaging and trays – is often missed or rejected by recycling facilities, due to infra-red technology failing to detect it as plastic. Additionally, regardless of complexity, unlike alternative materials (*e.g.* paper, steel, glass), plastic does not recycle as effectively second time round (Table 2.3) (Ellen McArthur Foundation 2016), meaning some items enter the environment through incineration or landfill following only a single recycling (Geyer *et al.*, 2017). Further, it is possible that ‘bio-plastic’ may contaminate recycling or compositing facilities following improper disposal (Napper and Thompson, 2019), with less than 5% contamination, problematic for industrial recycling systems (Samper *et al*., 2018). Eighty percent entering landfill sites across the globe (Geyer, Jambeck and Law, 2017).

Despite recycling remaining the primary and most accessible strategy for consumers to reduce plastic pollution, it only slows the inevitable fate of plastic in the natural environment. With advanced separation technology, increased awareness and responsibility, effective labelling and removal of colour or contaminates, recycling could provide an effective mitigation technique, whilst it may also balance tremendous economic cost associated with the disposal of throwaway plastic items (*e.g*. Cole, 2017; Simon *et al*., 2018).

3.2.2. CIRCULAR ECONOMY

Shifting to a Circular Economy – which seeks to retain the greatest value of products parts and materials throughout a continuous 'looping' lifecycle (Ellen MacArthur Foundation, 2016) – is increasingly seen as an alternative model to help minimise costs associated with marine plastic pollution (Figure 2.2). Shifting from the current, economically demanding, 'production-consumption-disposal' system of linearity, into a system of redesign, re-use and repair will help maintain value of biological and technical resource (Ellen MacArthur Foundation, 2012; 2015; Figure 2.2). Reducing ecological footprints of goods and services whilst generating less waste, long-term resilience and economic opportunity, a circular economy boasts potential to instigate systemic change in human thought and behaviour (Boulding, 1966).

Fundamentally, the transition to a circular economy, where “the nature of environmental impacts derived from a product can be minimized and even avoided during the early design phase of product development” (Williams *et al.*, 2019), has the potential to create significant ecological and economic value (ten Brink *et al.,* 2017). With an estimated US$ 80-120 billion per year (in natural capital) lost to the global economy through single-use plastic packaging (Ellen MacArthur Foundation, 2016), up to US$ 8 billion per year (in natural capital) is lost simply by the presence of plastic in the natural environment (UNEP, 2014).

Sadly, in accordance with the development of alternative ‘bio-plastic’ material, concerns have arisen that the apparent branding of a ‘circular economy’ or green pledges made by corporations, may enter into the same phase of Greenwashing (Bruno, 1997; Smith, 2010; Lane, 2012), with businesses increasing sales or developing new market territory (*e.g*. Zink and Geyer, 2017). However, despite advancing practices and infrastructure, whilst the demand for recycled plastic (*e.g*. 6% in Europe, European Commission, 2018) and item re-use remains low, the development of a circular economy will struggle to see success within the global community (Table 2.3).

Plastics Pact

The UK Plastics Pact is a collaborative initiative led by the Ellen MacArthur Foundation’s New Plastics Economy and the UK Government (*e.g*. WRAP, 2018), attempting to create a circular economy for plastics by 2025 (Ellen MacArthur Foundation, 2018; European Commission, 2018). Uniting the entire plastic packaging chain (*e.g.* producers, consumers, recyclers), the projects aim is to *(i)* reduce the quantity of plastic packaging, *(ii)* develop re-usable alternatives and *(iii)* find solutions to overcome challenges in recycling of day-to-day goods (*e.g*. black plastic). With ambitious targets, the Plastic Pact hopes to transform the UK packaging sector, stimulating new and innovative business models, with a common vision, to reduce plastic packaging whilst generating environmental, economic and social sustainability.

UK retailers

Large UK corporations and retail outlets are already showing interest or action in reducing plastic packaging and produce with a number of retailers sourcing alternative material and textile when possible. Leading UK supermarket, Morrisons, pledged to introduce traditional brown paper bags (100% recyclable) in September 2018, saving 150 million plastic bags currently used for loose fresh fruit and vegetables, whilst 81% (by weight) of Morrisons plastic packaging is already widely recyclable through roadside collection systems (Morrisons, 2018). The retailer, Marks and Spencer, have recently removed all black plastic packaging from their disposable ready-meal trays, as part of their 'Plan A' environmental scheme (Marks and Spencer, 2020), alongside their long-standing 'schwopping' scheme, which has seen more than 7.7 million items of clothing donated to charity (Oxfam) rather than discarded as waste (Marks and Spencer, 2008). Similarly, John Lewis is beginning to buy back old and preloved textiles and electrical goods for repurpose, in an attempt to reduce the quantity of waste entering landfill every year (The Guardian, 2018).

3.2.3. EXTENDED PRODUCER RESPONSIBILITY (EPR)

Responsibility for waste is beginning to shift upstream from consumers to producers and corporate actors. As an extension of the 'polluter pays' principle;

in that costs associated with the recovery and disposal of a product become the producers responsibility, Extended Producer Responsibility (EPR) is an environmental policy concept incentivising manufacturers and producers to incorporate environmental consideration in the design of products (OECD, 2001; Kunz *et al.,* 2018; GIZ, 2018). In practice, EPR includes the shift of both, physical and financial responsibility (fully or partially), from consumers and taxpayers to producers and manufacturers. Already successful in Norway, mandatory EPR schemes are entering into effect within the European Union, holding explicit 2025 targets for recycling (65% packaging, 50% plastic), complemented by the 'Circular Economy Action Plan' (see point 2.2) to see manufacturers take responsibility and re-design products to be more sustainable (European Parliament, 2019).

3.2.4. CORPORATE SOCIAL RESPONSIBILITY (CSR)

In a world of growing consumer pressure, demanding interest and commitment to the development, life cycle and disposal of products, brand image is becoming a critical tool, with companies identifying sustainable branding as a primary driving force for economic gain. Corporate Social Responsibility (CSR) sees Trans-national Corporations (TNC's) (*e.g*. Coca-Cola®) voluntarily integrate social and environmental concerns into core business principles (Crane *et al.*, 2008), in an attempt to counter-balance associated harm (Landon-Lane, 2018) and develop 'eco-consumerism' (Dauvergne, 2016; Cutler and Dietz, 2017; Landon-Lane, 2018). Whilst it may seem TNC's are leading a "green revolution" (Humes, 2011), offering a sense of stewardship and care, it is increasingly apparent that gains or promises from CSR often do not result in global solutions. For example, despite global beverage corporation 'Coca-

Cola'® stating its packaging vision is 'zero-waste' (The Coca-Cola Company, 2018), it remains that only 7% of plastic used to produce a single bottle is sourced from recycled material (Laville and Taylor, 2017).

CSR donations to funds such as the *Marine Responsibility Fund* (MRF) (Simon and Schulte, 2017), where actors and industry members provide monetary support for effective management of waste, or innovation in technology and engineering offers at least some level of acceptance and responsibility. However, economic savings are more frequently used to re-invest in new or better products (Clapp, 2012; Dauvergne and Lister, 2012), with the TNC's themselves ultimately in control of funds, policies or social license. Again, despite Coca-Cola® using donated funds to develop recycling facilities, this provided the ability to create smaller and lighter bottles, reducing costs of transportation yet increasing overall production of plastic (Coca-Cola Company, 2017).

3.2.5. DEPOSIT RETURN SCHEMES

Tools rewarding 'good behaviour' such as Deposit Return (also refund) Schemes (DRS) or 'pay-as-you-throw' are those which reward consumers who "by offering the refund of a deposit that was charged upon the purchase of the potentially polluting product" (Geyer, Jambeck and Law, 2017). Designed to encourage recycling and re-use of material, deposits on polluting items (*e.g*. bottles) are refunded once the item or packaging material is effectively returned to manufacturers and/or an established point of return (Ochiewo *et al.*, 2007; McIlgorm *et al.*, 2011), offering significant contribution in the reduction of litter entering landfill, the natural environment and waste disposal systems (EPA, 2001; Ecorys, 2011; Hogg *et al*., 2011).

It remains difficult to establish success of DRS on waste reduction as it becomes hard to solely determine the impact against other policies and initiatives (OECD, 2016). Evidencing high success in the return rate of pollutants (Oosterhuis *et al.,* 2009; Ten Brink *et al.*, 2009; Ecorys, 2011) when applied both voluntarily or as public policy (*e.g*. in Denmark, Germany and a number of US states; Kulshreshtha *et al.*, 2001), DRS could be considered more efficient than roadside recycling largely due to its monetary incentive (Ashenmiller, 2009). However, this ignores significant economic cost (Hill *et al.*, 2008) associated with the implementation and use of DRS (*e.g*. infrastructure, maintenance, retaining unclaimed deposits), as well as the loss in market gain through the reduced sale of items. Additionally, deposit and collection points are few and far between, meaning recovered packaging often travels great distances to producers and manufacturers from recovery locations, harnessing further environmental burden (Hopewell, Dvorak and Kosior, 2009).

Looking forward, deposit costs must be set at a level which incentivise the return of items whilst ensuring a purchase. This remains challenging; too much and consumers will look elsewhere for a cheaper purchase, but too little and DRS may fail to influence correct recycling (Kulshreshtha *et al.*, 2001).

3.3. STRATEGIES FOR REMOVAL

Adopting tools, people power and technology to aid in the removal of plastic waste already in the marine environment (Chen, 2015) is receiving increasing innovation and thought (Zielinski *et al*., 2019), rapidly gaining support and momentum from members of the scientific community, politicians and civil society (Rambonnet *et al.*, 2019). Appearing a 'win-win' approach; removal strategies decrease the persistence of waste in the natural environment, play an increasingly important role in the generation of qualitative and quantitative data used to guide management programs and influence political agenda, whilst furthering awareness and environmental consciousness.

3.3.1. CLEAN-UP

Clean-up programmes (*e.g. Surfers Against Sewage* (SAS), *Marine Conservation Society* (MCS*), Ocean Conservancy, International Coastal Cleanup)* are one of the most commonly employed activities across the globe to remove litter from the natural environment (most commonly the water-land interface). However, despite their immediate aesthetic result, clean-ups are often time consuming and costly (Newman *et al*., 2015), focusing only on areas of waste accumulation (*i.e*. a sink), clean-up activities fail to target a vast proportion of litter that has since become trapped (*e.g*. ice) or been transported to locations far out of reach (*e.g*. the ocean floor), capturing only a fraction of the overall polluting litter. Further, clean-up strategies provide no benefit or contribution in reducing primary production of plastic waste or preventing it entering the coastal environment (*i.e*. the source). There remains confusion as to the correct disposal or use of plastic litter once it has been removed from the natural environment, to prevent its re-entry.

However, clean-ups provide a valuable contribution to the collection of data (*e.g*. Nelms *et al.,* 2017; Nelms *et al*., 2020), and further promote custodianship and responsibility of care to ocean communities across the globe (Hidalgo-Ruz and Thiel, 2013; Hong *et al.*, 2014; Smith and Edgar, 2014). The simple act of picking up everyday waste litter items is thought to encourage those that participate to think critically of their own actions, questioning how behavioural choices can have ecological (*i.e.* biological harm), economic (*i.e*. clean-up costs, damage) or social (*i.e*. attitudes, enjoyment) implication (Storrier *et al*., 2006; Bravo *et al.*, 2009).

3.3.2. INNOVATION

Albeit witnessing great success in the removal of plastic debris, acting as a powerful motivator of hope and custodianship, removal strategies have up to now only touched the surface of the problem. Pahl *et al*., (2017) surmise the strategy as “akin to fixing an overflowing bath by mopping up the water spilling onto the floor rather than turning off the tap”. Combining alternate ways of thinking with technology and engineering, scientists across the globe have developed methods to both prevent waste entering our oceans (*e.g*. waste management) and aid in its removal (*e.g*. clean-up).

Engineering

Designed in Australia by two water-loving boat builders, The Seabin Project® was one of the first of its kind to design a marine ‘bin’, built with the intention of sieving out and capturing plastic waste (*e.g.* plastic bags, bottles) (Figure 2.3). Having generated a significant global following and over 700 bins worldwide implemented in just five years, the bin is since reported to capture less than a fifth (18%) of microfibres, with efforts focusing increasingly on man-made litter entering ports and harbours across the globe (Seabin Project, 2013). Under the guise of The Ocean Cleanup® (The Ocean Cleanup, 2013), Dutch inventor Boyan Slat aided the curation of six 100 metre drifting booms (Figure 2.3), aiming to rid the North Pacific Gyre of 40% of its litter within a decade. Following trials (summer 2018), models predict that a full-scale expansion of the clean-up system (approximately 60 systems) has the potential to remove 50% of the Great Pacific Garbage Patch by 2025 (The Ocean Cleanup, 2018). Despite being widely criticized for its significant economic cost, distraction from the problem "further upstream" and apparent ignorance to the scale of the problem (The Guardian, 2016; The Inertia, 2017; Science, 2018; Morrison *et al.,* 2019) it is projected that 90% of the oceans plastic could be removed using this technology by 2040 (The Ocean Cleanup 2018). With Slat arguing we must focus on cleaning up what is already in the ocean, alongside efforts to "intercept plastic before it becomes ocean plastic" (The Inertia, 2017).

Microfibres

Micro plastic fibres (microfibres) (*e.g.* acrylic, polyamide, polyester) have a number of different sources, from both land (*e.g.* tyres, cigarette filters, textiles) and sea (*e.g.* fragmentation and stress of maritime equipment, rope, fishing material) (Napper and Thompson, 2016; De Falco *et al*., 2018). In recent years, microfibres have become increasingly problematic with growing research into its loss and shedding, following use in the clothing and upholstery business (Pirc *et al.*, 2016). Browne *et al.*, (2011) reported a single garment to shed more than 1900 fibres (<1mm) during a single machine wash whilst Napper and Thompson (2016) suggest over 700,000 fibres can be released during an average 6kg load. Although a less obvious source of pollution, these fibrous plastics are now considered one of the most prolific and commonly observed forms of plastic pollution in nature (Gago *et al.*, 2018), identified to impact a number of marine species (Besseling *et al.,* 2012; Eriksen *et al.,* 2014; Watts *et al.*, 2015; Taylor *et al.*, 2016), habitat types (Jamieson *et al.*, 2019; Kanhai *et al.*, 2019) and ecosystems (Grøsvik, 2018; Bergmann *et al.,* 2019), across the globe.

Attempts to limit the quantity of microfibres entering waste systems and eventually the aquatic environment include washing machine (lint) filters, designed to trap fibres that shed off clothes (87% capture) (McIlwraith *et al.,* 2019), and machine friendly objects designed to collect fibres during a wash (*e.g.* Cora Ball; Cora Ball, 2020). Environmentally conscious brands such as Patagonia® have collaborated with developers GUPPYFRIEND® to produce laundry bags (*e.g*. 'guppy bags'; Gear of the Future, 2016; Fake Plastic Fish, 2017), which hold fibrous clothes during machine washing, containing and trapping released fibres, preventing their loss. However it remains unclear as to the most efficient disposal of fibres once trapped to prevent entry through alternative means (*e.g*. waste disposal).

Abandoned, lost or discarded fishing gear

Abandoned, lost or discarded fishing gear (ALDFG) contributes a significant load of marine plastic pollution to global oceans every year (Lebreton *et al*., 2018), posing harm to marine organisms primarily through entanglement and ingestion (Anastasopolou *et al.,* 2013; de Stephanis *et al.,* 2013; Kuhn *et al.,* 2015; Lusher *et al.,* 2015). Advances are being made to accurately identify equipment and discarded gear through personal identification numbers and codes (*e.g*. lobster pot tags) in an effort to reduce the quantity of discarded and lost gear, attaching responsibility of waste to its individual user. However, with vast quantities of ALDFG already in the environment, efforts are being made to utilise and remove it to minimise risk. Organisations (*e.g.* Networks®, Fishy Filaments UK®, Global Ghost Gear Initiative) and designers (*e.g*. Henry Holland®, Fourth Element®, French Connection®) are utilising ALDFG for active recovery and re-purposing of the material. In turn creating sustainable nylon (*e.g*. Econyl) used in the textile and clothing industry (*e.g.* swimwear, underwear, t-shirts) (Econyl, 2020), to create filament for 3D printers (Chong *et al.,* 2016) whilst less developed communities utilise the material to produce carpets and rugs to be sold on, generating income (Networks, 2012).

Enzymes

Despite being at an early stage of its development, bacterial enzymes are providing significant optimism around the breakdown of plastic products, offering a new definition for what could be considered ‘bio-degradable’ (Austin *et al*., 2018; Carrington, 2018; Wierckx *et al.,* 2018). Following novel work carried out by Yoshida *et al.*, (2016) the engineered enzyme *Ideonella sakaiensis* (201-F6, Yoshida *et al.,* 2016) was shown to consume the common polymer polyethylene terephthalate (PET), utilising it as a major source of energy and carbon. Reports state the enzyme could completely degrade a fine sheet of PET in just six weeks at a high temperature (308 degrees Celsius) under controlled settings. Further research is required to identify and engineer bacterial enzymes to allow for more efficient and logistically feasible mechanism for the breakdown of plastic material (Wierckx *et al.,* 2018).

3.4. STRATEGIES FOR BEHAVIOURAL CHANGE

Actions have thus far dealt with the symptoms of marine plastic pollution, production streams and poor waste management (Blühdorn, 2007), however it should be noted that such strategies are likely only successful with awareness of the problem and responsible consumer behaviour (Haider *et al.*, 2018). Andrady and Neal (2009) state that the problem is less that of increased production or incorrect disposal of plastic waste; but rather it is a behavioural problem, thus hypothesising possible solutions lie within broad scale societal change (Andrady and Neal, 2009). Behavioural economics has long examined which factors most effectively influence the strength and longevity of cultural trends (*i.e.* norms). Weak political or corporate resistance, intense activism and consolidating evidence of harm, alongside education within the community have been identified as some of the ways in which norms generally diffuse and gain strength within a culture (Sunstein and Thaler, 2009; Alger and Dauvergne, 2017; Dauvergne, 2018). Strategies that target behavioural change (*e.g*. encouraging activities that eliminate, remove, or reduce quantities of litter in the natural environment) are possibly the most effective, albeit challenging tool (see Bergmann *et al*., 2015; Pahl *et al.,* 2017).

3.4.1. EDUCATION & AWARENESS

Recent years have seen growth in the size of demonstrations (Hardiman, 2013, *e.g.* Extinction Rebellion, 2018), campaigns and commitment (*e.g. EU Ban on Single-use Plastic / Circular Economy Action Plan*, European Commission, 2018), support for 'plastic-free' initiatives (*e.g.* ReFill, City to Sea, 2015; Beat the Microbead, 2015) and collaborative platforms (*e.g.* SHiFT, 2020; Plastic Solutions Fund, 2020). As a result, growing media attention and awareness of the plastic problem is causing a societal shift, nudging individuals, consumers and societies, with a multitude of "bottom-up", community-led activism (*e.g.* strikes, campaigns, non-violent protests) rapidly proliferating at the turn of the decade (Derraik, 2002; Rambonnet *et al.,* 2019; Vince and Stoett, 2020). Building momentum for environmental causes (such as reducing marine plastic pollution), communicating effectively (Dietz, 2003) and developing social networks – governance solutions from communities are changing the nature in which environmental governance and policies are developed, implemented and enforced (Rambonnet *et al.,* 2019).

Environmental problems, and their relative solutions, are fundamentally anchored in society and modern ways of living. Hence, it could be considered, the most effective solutions to combat such threats lie in than hands of individuals and society. Education (that defined "the process of facilitating learning, or the acquisition of knowledge, skills, values, beliefs and habits") was listed recently as one of the 'best practices' to successfully reduce marine waste (Loizidou *et al.,* 2014; Willis *et al.,* 2018) - since Hartley *et al.*, (2015) identified children as crucial agents of change, shaping the perception of others encouraging and influencing their friends, family and surrounding community to take more action (Hartley *et al*., 2015).

Alongside awareness campaigns (*e.g*. ‘Oceans Day’, UN Clean Seas Campaign), the inclusion of environmental topics (such as ocean pollution, recycling, waste management) within the school curricula, is an effective way to target children. These have boasted significant effect in the adoption of pro-environmental behaviour (Derraik, 2002; McPherson, 2015; Prata *et al.*, 2018), whilst also reporting to improve behaviour (Hartley, Thompson, and Pahl, 2015) and enhance future participation in environmental activities (Hidalgo-Ruz and Thiel, 2013). TeachWild, an Australian collaboration with Earthwatch, Shell Australia and the Commonwealth Scientifc and Industrial Research Organisation (CSIRO) build on awareness activities, actively engaging students in citizen science; tracking marine debris, inclusion in the scientific method and contributing to analysis (Department of the Environment, 2015; Jambeck & Johnsen, 2015). Increasing engagement and interaction around environmental issues, between communities and scientists is fundamental to the filtering of behavioural change and material use within a broader demographic – providing a consistent message of the role and value society provides around environmental change (*e.g.* removing plastic from the marine and coastal environment) (Jambeck & Johnsen, 2015).

MOOC on Marine Litter

MOOCs or *Massive Open Online Courses* are widely accessible, often free, online education platforms providing courses and lectures on a broad range of subjects (*e.g.* Economics, Fashion design, Languages). In collaboration with the

United Nations (UNCLOS), the Open University of the Netherlands ran the first ‘MOOC on Marine litter’ in 2015 (https://www.unenvironment.org/explore-topics/oceans-seas/what-we-do/addressing-land-based-pollution/global-partnership-marine-2; UNEP, 2015) – developed with the fundamental aim “to educate people on the issue of marine litter, and equip them to become leaders in their communities capable of inspiring local action on the issue” (UNEP, 2015). A second course (2017) later designed to target a range of sectors and stakeholders, enhancing their knowledge and stimulating leadership and responsibility (Lohr *et al.,* 2017). Through this, policymakers and governments, private business and industries, non and inter-governmental organisations and academics were offered an array of material around the subject, including the identification and reduction of land-based and sea-based sources, practical and innovative solutions, and further evidence of environmental, economic and social impact (Lohr *et al.,* 2017).

3.4.3. NON-GOVERNMENTAL ORGANISATIONS (NGOs)

Non-governmental organisations (NGOs) play a fundamental role in the creation of data, generating awareness and creating large scale political and ecological change through clean-up and legislative campaigns. Serving as a communicative bridge between science, academia, policy and industry, and education, NGOs are becoming a critical tool to provide and inform on practical solutions to global problems (*e.g*. marine litter) (Ocean Wise interview, 2018). From issue-specific organisations such as Sea Shepard (*e.g.* protecting marine wildlife; Sea Shepard, 1977) and the World Wildlife Fund (*e.g.* endangered species conservation; WWF, 1961) to organisations campaigning for growth in knowledge and transparency (*i.e.* Beat the Microbead 'App', 2015) or activism *(e.g*. Greenpeace,1971) – NGOs act as influential factors in community governance.

Global NGO, *Parley for the Oceans*, provides a collaborative space where "creators, thinkers and leaders come together to raise awareness for the beauty and fragility of our oceans" to "end their destruction" (Parley, 2020). Collaborating with large industrial players (*e.g*. Adidas®), Parley are working to develop alternative business models (*i.e.* Parley A.I.R) and ecologically sensible products (*i.e*. Econyl) to prevent the pollution of our oceans with plastic, providing everyday more sustainable alternatives. Through collaborative projects (such as those with Adidas) and global events (UN x Parley, General Assembly), Parley is creating a wave of change, including global education programs, supporting at risk communities and generating global economic solutions.

Media

Visual and media tools become especially useful when actions and impact are vastly disconnected (*e.g*. land-based sources vs coastal or marine pollution) (Pahl *et al.,* 2017). For instance, applying a similar approach to plastic products, like that used by anti-smoking campaigns (*e.g.* packaging), has the potential to influence behaviour around the consumption and disposal of products (Pahl *et al.,* 2017). The UK charity 'Surfers Against Sewage' (SAS, 2018) has long utilised images, creative tools and infographics to generate awareness around campaigns. More recently (SAS, 2017) constructing a replica made military boat (Figure 2.4) using plastic bottles obtained through beach cleans to educate communities along the South Coast of England of the problem whilst similar campaigns exist around the use of plastic pellets (*i.e.* nurdles) (Arnold, 2016), flip flops (The Flipflopi, 2018) and cigarette filters (The Cigarette Surfboard, 2017) (Figure 2.4). Additionally, opinion pieces and fact-based commentary in widely read journals or magazines can herald great coverage and considerable media attention (Parker, 2018), such as the June 2018 edition of National Geographic boasting a 50-page special on plastic pollution. When aired on mainstream television, (such as the BBC documentary series Blue Planet II), viewers that may otherwise be ignorant of the problem are reached (SAPEA, 2019), whilst also instigating enhanced compassion toward a ‘narrative’ or story to generate intrinsic motivation for change (Dahlstrom, 2014). Alternatively, media and communicative tools presenting negative environmental problems (such as pollution) can mobilise emotions of fear or disgust, such as so-called ‘pollution fatigue’ rather than generating action or positive change (Lupton, 2014).

3.4.4. RISK TO HUMAN HEALTH

The full extent of potential health repercussions of our current ‘throwaway lifestyle’ is not yet fully understood (Landrigan *et al.,* 2017; Easman *et al.*, 2018; Lotze *et al.*, 2018). However, an emerging question – which has the ability to generate a shift in conversation and action among consumers – is whether plastic poses a threat of significant harm to human health. From navigational hazards at sea (Macfadyen *et al.*, 2009; Gold *et al.,* 2013), to injury of maritime (Cheshire *et al.,* 2009) and beach users (Campbell *et al.*, 2019), plastic pollution can boast a number of threats. In addition to those particles that are ingested (*e.g*. microplastics) following accumulation in shellfish (*e.g*. crustaceans, bivalves) and commercial fish species (van Cauwenberghe and Janssen, 2014), with reports from European countries estimating up to 11,000 micro plastic particles (size range 5 – 1000 μm) are ingested with average seafood consumption of two to three times per week (van Cauwenberghe and Janssen, 2014). Particularly concerning considering the presence of toxic chemical building blocks (*e.g*. Bisphenol A) and additives (*e.g.* phthalates) that leach from ocean plastic (Teuten *et al.,* 2007; Rios *et al.,* 2010; Gauquie *et al.,* 2015). Identified as an endocrine disrupting compound, Bisphenol A has been linked to disruption in development, early puberty, obesity, hyperactivity and learning difficulties (Rubin, 2011; Canesi and Fabbri, 2015), whilst phthalates are known to implicate male reproductive systems (Dalsenter et al., 2006) and lead to insulin resistance (Bonefeld-Jørgensen *et al.,* 2007; Pak, McCauley and Pinto-Martin, 2011; U.S. EPA, 2016). However it remains unclear as to whether current levels of daily exposure to humans - of toxic chemicals such as BPA and phthalates - is significant enough to cause harm. Especially given human data is limited when compared to the large body of research documenting developmental or reproductive effects on animals (Kumar, 2018).

From a psychological perspective, plastic pollution on beaches or in the natural environment is known to hinder the restorative value of nature, with a locations aesthetic value or ‘pristineness’ (absence of litter) identified as psychologically damaging (Tudor and Williams, 2008; Wyles *et al*., 2016). Of particular importance to combatting threats of environmental concern as stronger or greater connection with nature and more restorative and positive experience, is linked to more environmentally kind behaviour (Hartig, Kaiser and Bowler, 2001; Hartig, Kaiser and Strumse, 2007). A study by Klockner (2013) identified a series of attributes known to influence processes and principles of human behaviour. Among others: awareness of consequence, positive (*e.g.* hope) and negative (*e.g.* worry) emotion, attitude and pro-environmental-self-identity are thought to be associated with behavioural actions (Klockner, 2013; Pahl and Wyles, 2017).

It remains challenging to say for certain whether plastic pollution is having severe effect on human health, due to the numerous and multi-faceted factors incorporated into human society (*e.g.* air pollution, diet, healthy lifestyle). However, since risk is often not presented in a form identifiable to everyday existence, it is only when the perceived risk or effect to human health seems tangible and significant enough to warrant concern, that behavioural change or political action occur (Haines *et al*., 2009; Albayrak, Aksoy and Caber, 2013). Due to the fact that human emotion, needs or mentalities rarely change overnight, behavioural change strategies and educational tools provide increasingly long-term, holistic solutions to global environmental change, within day-to-day life: rather than a short-term, unsustainable fix.

Summary

Arguably, conservations around plastic production, use and emission are growing within society. Fortunately, unlike other environmental threats, both the cause and solution to the plastic pollution problem is solely attributed to humans (Pahl and Wyles, 2017), meaning we as a species hold the power to fully combat the issue. Prevention is perhaps the simplest and most effective solution in minimising the influx of plastic pollution into natural and marine environments, stopping the pollutant at its source. Whilst the shift to safe ‘biodegradable' and alternative material is on-going, attempts to shift responsibility and cost on to the consumer has seen success. With consumers holding significant influence on markets – preventative methods and incentives to reduce use (*i.e.* bans, 'zero-waste' stores) is changing the way plastic is utilised in goods and everyday life. Despite increase in awareness and consumer pressure, it remains that achieving zero plastic production and use within society is near impossible, whilst there is no replacement material, yet to demonstrate as preferable characteristics as plastic. Mitigative techniques from effective recycling systems, shifts to a more circular economy and proactive regulation (*e.g.* EPR, CSR) provide exhaustive, consumer friendly solutions in an attempt to prevent leakage and limit damage of plastic into the environment, post-production.

Whilst preventative and mitigative solutions demonstrate effective approach in curbing the flow of plastic pollution, strategies for removal (e.g. clean-ups, innovation) provide valuable contribution to the reduction of plastic waste already in the environment. Essential, not only in its ability to decrease quantities of waste circulating in the natural environment but also has an increasingly important role in shifting behaviour through increased awareness. Changes in behaviour or shifts in environmental norms are perhaps the most challenging solutions; requiring broad-scale societal change these are often met with resistance within both the community and governance. However, as noted, strategies for prevention, mitigation and removal rely to some extent on the support and awareness of responsible consumers. Any solution, be it removing waste from the marine environment, advent of new global policies and governance or simply increasing awareness and education around the issues of planetary change – all have significance. It is only in combination of such efforts, with more interdisciplinary research, science and policy that efforts to reduce plastic marine debris will succeed.

4. SUGGESTIONS FOR A GLOBAL TREATY

With growing efforts to reduce amounts of waste being sent to landfill, through increased roadside recycling schemes (Lohr *et al.*, 2017), removal strategies (Dauvergne, 2018), implementation of bans and levies (Knoblauch *et al.*, 2018), growing consumer pressure, and increasing numbers of corporations taking drastic steps to reduce plastic consumption, it appears that global governance, in the case of marine plastic pollution is improving. However, it remains that the amount of plastic flowing in to the ocean by the year 2025 is predicted to be double that of 2010 (Dauvergne, 2018), whilst it is plausible that up to 33 billion tons of plastic could be manufactured or produced by 2050, likely finding its way into natural environments across the globe (Rochmann *et al.*, 2013; Geyer *et al.,* 2017). Despite current efforts, there remains a lack of solitary, integrated management or agreement at a global level (UNEP, 2017; 2019), it is therefore no surprise that key players and stakeholders are voicing the need for a new global agreement (Simon, 2016; Borrelle *et al.,* 2017; Raubenheimer and McIlgorm, 2017; Worm *et al.*, 2017).

Critically evaluating the current legislative challenges, strategic flaws and growth in innovation identified in this research, below sees the proposal of ten focal point suggestions to aid the potential development of a global treaty designed to combat the tide of plastic pollution entering natural and marine environments.

4.1. Based on scientific evidence

Firstly, it is essential that at the fundamental core of any political agreement or legislative tool, peer-reviewed scientific literature and fact-based evidence provide the backbone of its narrative. Unfortunately, it remains that there is a gap between scientific findings or propositions and the way in which they are interpreted or translated into policy, meaning necessary steps for more sustainable practices, enforcement and understanding are increasingly muddled.

4.2. Ability to adapt to change

Similarly, for a treaty to be successful it must be able to adapt within changing global conditions, environmental demands and political circumstances (Chayes and Chayes, 1995). With current findings and research around the subject of plastic pollution increasing, a global plastics treaty must be designed with the flexibility and fluidity to adapt alongside scientific developments, altering severity, control and time frames of its targets. For example, the Montreal Protocol (*i.e*. Controlling for the use of Ozone depleting substances, UN Environment, 1987), allowed the addition of further substances of harm to be added to the list of banned substances as well as more radical timeframes for phase out.

4.3. Engage and educate stakeholders

Encompassing preventative, mitigative and removal strategies, behavioural change, resulting from the education and mobilisation of communities will aid in the enactment of both new and pre-existing measures, thus shifting environmental norms and cultural trends. These approaches appear more favourable against traditional policy measures, enhancing long-term engagement, increasing waste management and recycling, whilst obtaining a more desirable spill-over of environmental education into other avenues of pro-environmental behaviour (*e.g*. in the fight against climate change) (Mayer, 2004).

4.4. Phase out oil-based plastic

Given the legislative strategies and tools outlined in this report, an outright ban on oil-based plastics would appear on the surface the most impactful option, simply stopping the pollutant at its source. However, the development of a global treaty should recognise that given modern day reliance on plastics, and wider socio-economic context, an outright ban could be considered impossible and highly unlikely to succeed. Focusing a ban on the most polluting items where alternatives exist (*e.g*. straws, plastic bags), like the EU's single-use plastic ban, could provide a significant initial step in the reduction of plastic pollution. Conversely, transitioning to a more circular economy – where special attention is devoted to the design of plastic, ensuring its sustainability, broad-scale function or ability for re-use – phasing out use and market dominance of oil-based plastic boasts the potential to minimise eco-toxicological, biological and economic impacts across the globe.

4.5. Support innovation and design

Shifting from a linear to circular economy demands more effective design and re-use of plastic material, thereby avoiding the creation of single-use products, which inevitably find their way into the natural environment. Policies must promote the transition to developments with a more circular flow of material, encouraging the design of readily recycled or re-usable products, diverting quantities of waste from landfill, whilst improving the yield of manufactured goods. This includes the application of chemical additives used to improved mechanical and thermal stability of plastic polymers, which should pass a series of environmental criteria. Technological innovations that demonstrate the potential to support large scale production, shifting toward material that allows for increased recyclability, whilst maintaining functionality alongside enhancing separation technologies for multi-material or alternative (biomass) packaging is essential.

4.6. Create competitive and viable markets for alternative plastic products

A fundamental factor is the economy. It is essential that established market alternatives to environmentally damaging plastics are both available and successful within the market, meeting consumer demand for recycled, re-used or renewable material. In other words, there must be a viable economic supply and demand chain (Young, 2011). However, unlike the aforementioned Montreal Protocol – there are currently no (or very little) viable market alternatives for plastic. Ignoring costs associated to extraction and use of fossil fuel - costs of production, processing and purchase of alternative materials are at present, significantly greater than those of virgin, oil-based material (Raubenheimer & Urho, 2020). Alternatives to plastic will only see success in a global treaty when markets begin to favour alternatives that de-materialise the plastics industry.

4.7. Improve waste management

To better the efficiency and success of current industry practices, a global treaty must attempt to expand and improve the collection and processing of waste material, whilst coping with the impossibility of infinite exports of goods abroad. Emphasis must focus on improving infrastructure, maximising collective quantities and type, increasing recovery rate and reducing leakage into the natural environment, thus ensuring that recycling becomes a convenient and efficient option. The treaty must work alongside international organisations, regional actors and industry to provide the most appropriate methods of collection (given the economy, level of development, infrastructure), both on land and at sea. Although less desirable, when waste management systems and infrastructure cannot support effective recycling, investment must also focus on sanitary landfills.

4.8. Specific targets and effective enforcement

Treaties and legislation witness increased success when targets and goals are clear, strategic and achievable, alongside effective enforcement and a sufficient degree of consequence in the case of non-compliance. If enforcement is insufficient or there is no higher authority to guarantee it, a treaty will ‘only exist on paper', contributing little to effective change (ISOE interview, 2018). Enforcement becomes simpler at the national or regional level, with states using their own legal measures of national sovereignty and geographic or socio-economic awareness to mitigate more effectively (David Suzuki Foundation interview, 2018). Determining the most suitable factors for success or determining enforcement methods most appropriate is where legislation at global scale falls short (Finus, 2001), retaining flexibility and understanding in strategic tools will allow for more effective enforcement and legislative success.

4.9. Communication

One of the main hurdles regarding any environmental crisis or political framework is language (Dietz et al., 2003). From scientific terms and phrases used in research to the range of market-based tools, variation within recycling processes or definitions for increasingly 'degradable' alternatives, conversation surrounding current practices bring little clarity. A treaty's array of instruments and tools will be greatly enhanced if manufacturers and governmental bodies simplify terminology, labelling and procedures to allow increased understanding and transparency, harmonise objectives, share knowledge and overcome challenges. In turn, stakeholders and citizens feel empowered to make a more informed, educated decision, which utilises their own ability and resource to more effectively combat the issue of plastic pollution.

4.10. Interdisciplinary

Lastly, a new global approach must be interdisciplinary. Like the numerous societal impacts of plastic pollution (*e.g.* ecological, biological, economical), the needs and demands of stakeholders and strategic solutions are just as diverse. Used in isolation, policy instruments are often ineffective. To be truly successful, a treaty should be designed as a long-term, flexible and interdisciplinary process, aligning growth from the ground level, complimenting other strategies and solutions with scientific research and data as its fundamental backbone

(Vince and Stoett, 2018). With no singular “silver bullet” solution (Worm *et al.,* 2017), a global treaty must build on the strengths of humans (Pahl *et al.,* 2017) as a social, adaptive and collaborative species to contribute significantly in the fight to stem the tide of plastic pollution entering oceans and waterways across the globe.

Table 2.1: Summary table of hard and soft law policies listed in this research. Identifying: its year of ratification, primary aims and objectives, policy amendments, major outcomes and drawbacks of each policy. It should be noted that evaluating the outcome of each treaty remains difficult, especially considering variation (or lack thereof) in measures and targets each treaty imposes and the challenge in quantifying success, however for use in this research, aspects considered fundamental to the success or failings of each treaty is noted above. NA = not applicable.

Policy	Framework or Strategy	Year	Aim	Amendments	Outcomes	Drawbacks
Hard	*The London Convention*	1972	Prevention of marine pollution by dumping of wastes and other matter at sea.	(1996) *Protocol*.	One of the first global conventions to deal with the impact of human activity on the environment. Offers guidelines to assist authorities and stakeholders implement strategies.	Only encompasses polluting of the ocean from ships, platforms or aircrafts (sea-based sources). Plastic not listed as pollutant to be prevented.
	MARPOL	1973	Prevent pollution of the marine environment and dumping from ships due to operational loss or accident.	*Annex V* (2011) prohibits the 'deliberate' release and disposal of plastic waste.	International Maritime Organisation (IMO) enforcement and guidelines. Signed by 150 countries. *Port Reception facility* adopted 2000. Discharge and release of plastic waste into the sea prohibited.	Only prevents pollutions from ships (sea-based sources), difficulty with flags of convenience. Does not prohibit 'unintentional' release (*i.e.* hull blasting or 'black' and 'grey' water until 2011. No mention of plastic until Annex V (2011).

						High cost of port reception waste facilities could promote improper / illegal disposal.
	UNCLOS	1982	Preventing, reducing and gaining control in the pollution of the marine environment from any source.	*Article 207* extends mandate to terrestrial environments mitigating pollution and harmful substances originating on land.	Support from 168 parties. Covers all aspects of the marine environment (*e.g.* estuarine, coastal) Addresses six sources of marine pollution.	UNCLOS provides no official documentation, specific ruling mechanisms or instruments for compliance. No specific mention of plastics.
	The Basel Convention	1989	Ensure the environmentally sound management of identified waste material and regulate the transfer of ‘hazardous’ material.	(2018) 14th Conference of the Parties formal proposal (Norway), coming into force in 2021 (except the US)	Ability to adapt, inclusion and flexibility in materials considered ‘hazardous’ with advancing research.	Difficult to enforce, lacking specific targets or timelines, whilst aims and definitions considered vague.
	Sustainable Development Goals (SDGs)	2015	Address the global challenges and improve global sustainability by 2030 (UN, 2015).	NA	Number of SDGs include a legally binding component (*e.g.* target 14.5). Goals committed to the treatment of wastewater (SDG 6) and waste management (SDG 11). SDG 3 aims to prevent and reduce air, soil and marine pollution, including litter with SDG 14 more broadly conserving oceans, seas and marine resources.	Great deal of ambiguity, targets are both difficult to enforce and to measure effectively. No real clarity or guidance in how targets can be assessed on a rolling basis. Concerns goals are too far-fetched and unachievable.

					Legislative power given to stakeholder countries and member states.	
Soft	*Honolulu*	2012	Reduce marine litter within every marine habitat	NA	Principles to reduce: *i* – land-based / solid waste *ii* – sea-based / solid waste / abandoned, lost or discarded fishing gear *iii* – waste on shorelines, benthic habitats and coastal environments Identified as a planning framework for management, education and awareness among stakeholders.	Lacks commitment from signatories. Increasingly considered an 'on paper' planning framework and awareness tool to reduce global impacts of harm rather than legislating against 'bad' behaviour.
	The Circular Economy Action Plan	2018	Transition to a circular economy to develop a sustainable, low carbon, resource efficient and competitive economy.	Specific recycling targets - *Waste Framework Directive* (2008) at fundamental core.	First ever Europe wide strategy. Critical component in the EU's effort to develop a circular economy (European Commission, 2018). EU ban on single-use plastic (SUP) (*e.g.* cutlery, straws, cotton buds). Specific re-use and recycle targets and timelines for change (*e.g.* 100% of EU plastic packaging available for reuse or recycling by 2030).	Potential for greenwashing and dishonesty within marketing (*e.g*. producers marketing material as 're-usable' to avoid the ban). No clear definition for single use or bio-degradable items.
	GPML	2012	Acts as a coordinating forum to exchange information of success,	NA	Aided the development of regional programmes and activities to raise awareness,	Lacks commitment from signatories, both open-ended and voluntary, it requires no formal or legally binding

			failure and adequate measures for compliance.		understanding and educate stakeholders on the impacts, losses and movement of debris in the marine environment (*e.g.* Online marine litter network, 'MOOC on Marine litter'). Incorporates connectivity between the terrestrial, freshwater, coastal and marine ecosystems.	sanction or agreement in case of non-compliance. Mirrors Honolulu strategy. Could offer up confusion and lack of commitment if numerous strategies and frameworks are adopted.
	G7 and G20 Action Plans	2015	'*Action Plan to combat Marine Litter'* – pledging to address both land and sea-based sources of marine litter, involving over-arching principles and tools in actions of removal, education and community outreach.	NA		Small scale commitment from only a handful of key global players.
		2017	'*G20 Action Plan on Marine Litter'* – committing to take action in reducing marine litter of all kinds, notably including single-use plastic and microplastic.	NA	In line with the development of 2030 SDG's, remaining thirteen stakeholder countries banded with previous 7 (G7, 2015) committing to take action.	Small scale commitment from only a handful of key global players.
		2018	'*Ocean Plastics Charter'* – work with industry in the resolve of taking a more life-cycle approach in the design and stewardship of a product both on land and at sea, promoting the re-use, recovery and recyclability of plastic items where viable alternatives do not yet exist (Simon *et al.,* 2018).	NA	Promote the transition to a more circular economy. This was the first of all action plans to provide explicit targets or actionable timelines for change, ensuring both measurable progress and apparent failings.	Small scale commitment from only a handful of key global players. Commitment only from five of the seven G7 nations (Canada, France, Italy, Germany and the UK).

Table 2.2: Summary of top 15 plastic producing items, consumption and waste production across Norway for 2018. Data adapted as part of a collaborative project between the Norwegian Environment Agency European Union and EUNOMIA to reduce littering of single use plastic (Norwegian Environment Agency, 2019). Table also lists viable 'plastic-free' alternatives already on the market. EU data was used if Norwegian data unavailable, for reference. As it is uncertain whether bio-degradable plastics do not harm the environment to a similar extent to regular plastic they have not been included as a viable alternative. It should be noted that fishing items or those used by the maritime industry were not included in the study. ND = not defined.

	Item	Consumption (millions pa)	Waste generated (tonnes)	Litter entering marine environment (tonnes)	% of single-use plastic item recycled	Alternative
1	Drink cartons	1,361	18,240	7.5	56	Glass, cardboard and wax, re-usable bottle
2	Lightweight plastic carrier bags	1,033	7,030	29.4	38	Paper bag, re-usable bag (*e.g.* heavyweight plastic), natural alternative (*e.g.* hessian, tote, jute)
3	Cigarette butts and filters	800	96	ND	0	No suitable alternative
4	Drink bottles, caps and lids	632	22,570	7.2	87	Glass bottles, re-usable bottle
5	Cotton buds	631	150	0.54	1	Paper stick cotton bud
6	Wet wipes	599	650	1.0	0	Re-usable or single use cotton pads, cotton flannel
7	Straws and stirrers	526	260	0.11	1	Paper, wood, re-usable (metal)
8	Sanitary towels, tampons and	478	2,780	20.8	0	Menstrual cup, bamboo alternative, re-usable sanitary cloths

	tampon applicators					
9	Cutlery	455	1,180	0.31	1	Wood, biomass alternative (*e.g.* sugarcane)
10	Contact lenses	274	3.4	ND	0	No suitable alternative
11	Crisp packet / sweet wrapper	184	990	1.0	9	No suitable alternative
12	Take-away food packaging (non-EPS)	137	2,750	3.7	5	Card and wax alternative, re-usable alternative, bio-mass alternative (*e.g.* bamboo)
13	Cigarette packaging	126	1	ND	0	No suitable alternative
14	Take-away food packaging (EPS)	122	610	0.8	0	Card and wax alternative, re-usable alternative, bio-mass alternative (*e.g*. bamboo)
15	Hot beverage cups and lids	106	1,490	4.8	3	Paper cup, biomass alternative lid, re-usable cup

Table 2.3: Available waste streams with their intended outcomes, positives and drawbacks for disposed plastic waste. How waste streams are currently or could be developed into a circular economy also noted.

Waste stream	Outcome	Positives	Drawbacks	Solutions for a CE
Zero waste	Materials and resources designed with end of life fate and lifecycle in mind to ensure items are re-used or disposed of without harm (Zero Waste Alliance).	Environmentally kind: Ideally products become assimilated by either technical or biological systems with positive effect. Zero carbon and water emission. Minimise waste: No waste sent to landfill or disposed of through the below processes (regardless of recycling stream), minimising non-degradable waste entering natural and marine environments. Economical: Greater economic efficiency.	Infrastructure: Heavily relies on systems and economies designed for effective and affordable re-use and zero waste society (*i.e.* circular economy). Cost: Initial expenditure on heavy-duty (re-usable) material or long-life products (*e.g.* glass) for re-fill and re-use, greater than economic cost of plastic, both in production and transport.	Zero waste provides the 'ideal' waste stream for material re-use and re-purpose within a circular economy. Increased innovation and reduced cost will aid in the implementation of zero waste streams throughout society for a circular economy.
Closed Loop (primary mechanical recycling) "cradle-to-cradle"	Used material recycled and converted into (almost) the same raw virgin material (Ignatyev, Thielemans and Vander Beke, 2014).	Efficient: Maintains high quality of the material through cycling products into the same application (*e.g*. from PET bottle to PET bottle) or of similar quality (Ellen McArthur Foundation, 2016). Long term: Materials can be recycled indefinitely without degradation.	Harm: Plastic resin manufactured by a non-renewable resource such as petroleum. Can release volatile organic compounds (VOC's) both in use and in processing. Energy input: Energy (*e.g.* heat, electric) required to process the material damaging to the environment. Degradation: Polymers can degrade under certain processing conditions (*e.g*. heat, oxidation, light) common when dealing with mixed material items.	Increase capacity for cleaning and sorting technologies. To retain the greatest value and quality of the material as possible, at each step of recycling and reprocessing, intensive cleaning, polymer identification and separation will be required (PP).

Open Loop (secondary mechanical recycling) "cradle-to-grave"	Used and recycled plastic reprocessed into a different material to the one originally recovered.	Broad use: Useful for most polymers utilised on the market, acts as the most common method of recycling. Widely applicable: Entire product (both functional and obsolete), non-functional or old and already recycled, re-used or scrap material can be utilised. Resource: Delays disposal of an already used product, minimising the extraction of new resource as raw material.	In addition to the drawbacks of Closed Loop streams (see above): Value: Leads to a loss in value of both the polymer and its economic value along the recycling chain (i.e. down-grading) (Ellen McArthur Foundation, 2016). Inefficient: Waste is usually limited to a single round of recycling before the material eventually finds its way to landfill.	In addition to the solutions of Closed Loop streams (see above): Advances in cleaning technologies to extract additives and contaminants advantageous to maximise product purity and allow easier processing to precise targets and material specifications. Chemical separation will ensure polymers remain intact whilst they are separated from other polymers, allowing recycling into mono-material pellets for raw material afterwards (currently possible for PP and PE only).
Chemical (tertiary or feedstock recycling)	Polymers broken down into monomer (or other hydrocarbons), serving as primary building blocks (feedstock) for the production of new virgin-like material.	Number of techniques: Processes involve: depolymerisation, catalytic cracking, pyrolysis (Ellen McArthur Foundation, 2016). Widely applicable: Viable option for after-use plastic and multi-material packaging that cannot be mechanically recycled due to complexity or the number of cascading cycles has been fulfilled (Ellen McArthur Foundation, 2016).	Economics: Significant high cost attached to the processes in which satisfactory level feedstock can be produced, due to requiring advanced technology. Use: Not yet developed at large scale.	Chemical waste stream processes such as depolymerisation and catalytic cracking that incorporate end of life design should be developed within a circular economy, providing potential waste streams for plastic already in use, where mechanical recycling is not possible. Chemical recycling is a relatively newly developed form of waste management. Ecological and economic impacts must be assessed and conceptualised so material output and efficiency is defined.

Energy Recovery (Incineration)	Synthetic polymers incinerated after use to produce energy (typically heat, electricity).	Widely applicable: Available when mechanical, chemical recycling not possible. Can be used on mixed or contaminated waste (*i.e.* medical) (Ignatyev, Thielemans and Vander Beke, 2014). Economical: Most frequently used waste stream for managing discarded plastic waste in Europe (41%). Efficient: Reduces (plastic) waste to approximately 1% of its initial volume.	Inefficient: Initial effort, finance and resource used to create initial product, lost. Harm: Large quantities of greenhouse gases, toxins and volatile organic compounds (VOC's) released into the atmosphere (Ellen McArthur Foundation, 2016).	Material recovery loops, integrating hydrocarbon outputs and / or products as a feedstock into the chemical industry must be developed to see energy recovery become part of a circular economy (*i.e.* no waste output).
Disposal (landfill)	Used items directly enter the natural environment (typically landfill) without waste management.	Cost: Little economic cost for collecting and processing waste.	Harm: Open disposal sites (*e.g.* dumps) provide little to no environmental protection. Plastics can easily enter the natural (or marine) environment through the wind, due to lack of adequate containment or microparticles and chemical contaminants leach into soil and waterways. Waste is often openly burned (especially in remote communities); releasing VOC's.	Landfill does not feed into solutions for a circular economy due to resource being lost from the biological or technical material flow. Landfill is to be used as a last resort for items already produced or 'in flow'.

Figure 2.1: Resin identification codes of recyclable plastic and their applications. Source adapted from Project Mainstream Analysis.

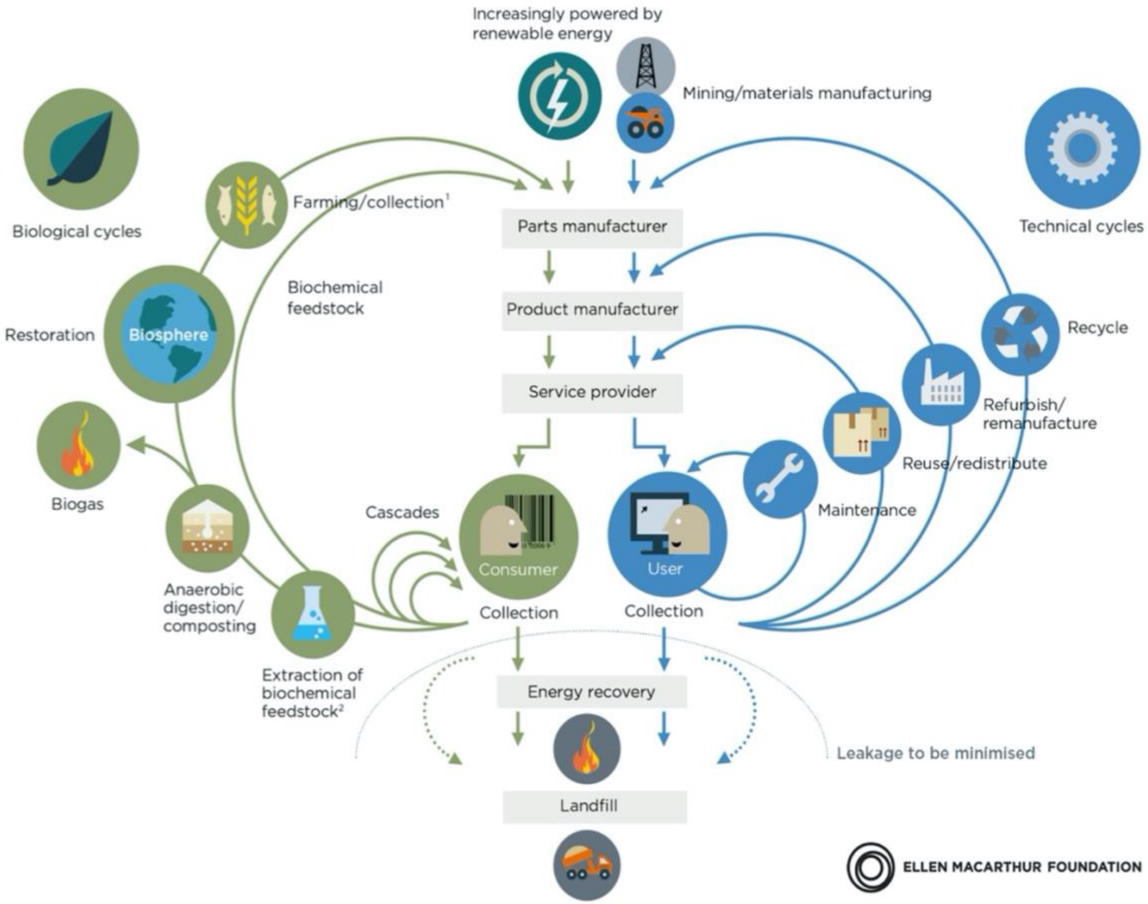

Figure 2.2: Principles of a Circular economy. Diagram demonstrates the continuous system flow of technical and biological material through the 'value flow'. Infographic sourced: Ellen McArthur Foundation, SUN, and McKinsey Center for Business and Environment, Drawing from Braungart & McDonough Cradle to Cradle (C2C), (Ellen MacArthur Foundation, 2016).

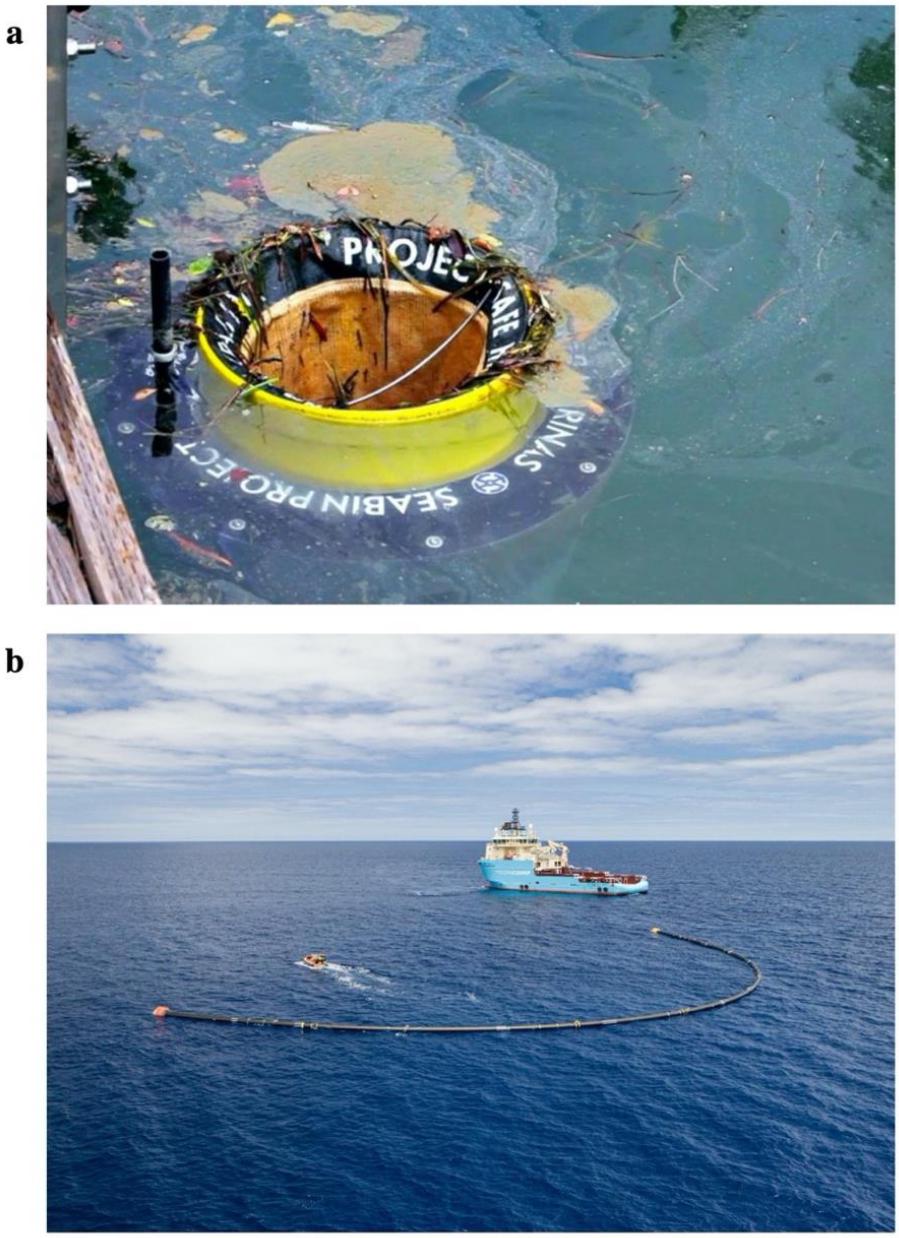

Figure 2.3: Clean-up engineering programmes. **(a)** The Seabin Project® marine 'bin'; **(b)** The Ocean Cleanup® drifting booms.

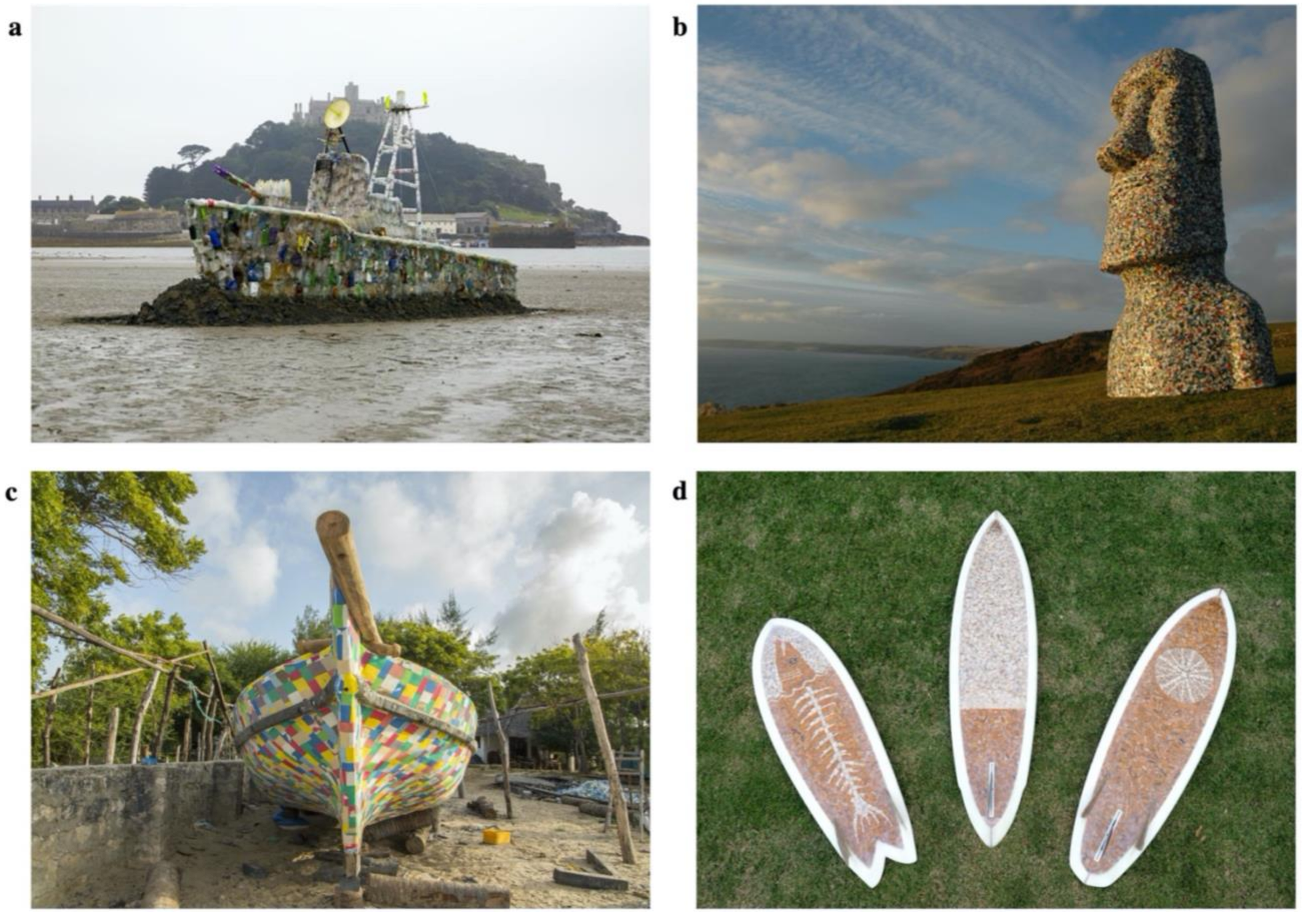

Figure 2.4: Existing campaigns around the use of plastic items to shift environmental norms. **(a)** SAS Military boat (SAS, 2017); **(b)** Easter island nurdle head (Arnold, 2016); **(c)** The Flipflopi traditional vessel (The Flipflopi, 2018); **(d)** Cigarette Surfboards (The Cigarette Surfboard, 2017).

DISCUSSION

This research

The work in this thesis makes a significant contribution to understanding in the presence, composition and fate of marine plastic pollution, across a global scale. By adapting methodologies previously used in assessing sea-surface plastic concentrations, Chapter 1 sees the utilisation of a single methodology to accurately compare the concentration and composition of floating marine debris among the Arctic (ARC), Atlantic (ATL) and Pacific (PAC) ocean basins. These methods have the capacity to be expanded for wider use in maritime research, incorporating citizen science and educational programs to further the understanding of the distribution of floating marine debris in global oceans - research that could help underpin policy and legislation and even a global treaty to address the issue of marine plastic pollution.

As noted in Chapter 2, current political frameworks are failing to stem the tide of plastic pollution. Difficulties arising due to the far-reaching and transborder nature of the pollutant including Areas Beyond National Jurisdiction, the fact that a significant proportion of plastic enters the environment from sources lacking effective control (*i.e.* land-based pollutants, at-sea enforcement), and that current frameworks and policies are fragmented in their efforts. The work of Chapter 2 highlights the enormity in scale of the challenge and barriers to progress, critically evaluating both legally binding and voluntary treaties alongside current preventative, mitigative, removal and behaviour changing strategies. In doing so, I highlight ten focus points for the development of a new Global Treaty, utilising current practices and effective enforcement protocols to help curb the tide of plastic pollution entering the natural (marine) environment.

Challenge of assessing floating marine debris

With gyres known to hold significantly greater concentrations of synthetic debris than the surrounding ocean (Lebreton *et al.,* 2012; Eriksen *et al.,* 2013; Brach *et al.*, 2018), it is no surprise that concentrations of sea-surface debris are significantly greater in locations close to so called ‘convergence zones’ (PAC) compared to coastal (ATL) or remote (ARC) areas. So far, efforts have focused on studying areas of known accumulation (*i.e.* gyres) due to vast quantities of waste providing the most visible manifestation of plastic debris. Research in these locations both increases our understanding of the composition and persistence of possible pollutants, and furthers awareness of the issue within society. However, whilst uncertainty persists regarding understanding of source, pathways and fate of polluting items (Hardesty *et al.*, 2018), efforts must begin to focus on determining possible ‘sinks’ as well as sources.

Lack of consistency in methods, terminology and reporting units (Hidalgo-Ruz *et al.,* 2012) limits global understanding. A recent report (Covernton *et al.*, 2019) suggests the size and shape of equipment can greatly influence the qualification and quantification of marine plastic or synthetic debris when assessing natural environments. Smaller particles and long fibres can readily pass through large mesh sizes due to their relatively small width (Barrows *et al.,* 2017), whilst smaller mesh sizes, more commonly used in techniques such as Grab (whole-water) sampling (*e.g.* Lusher *et al.,* 2015) capture greater numbers of synthetic particles. With most at sea-sampling using a mesh size typically 300μm or 330μm, there remains a trade-off between the volume of seawater sampled and limit of detection. Numerous reports argue that manta, bongo and plankton nets are almost certainly underestimating concentrations of microplastic fibres, compared to whole-water methods due to their larger mesh size (Chubarenko *et al*., 2016), they remain, however, the most commonly used and effective method for sea-surface analysis.

Whilst research in Chapter 1 reports a 100% incidence of synthetic debris within all surface trawls and particles appear ubiquitous, it seems there is vast spatial variability, heterogeneity of type and composition, pointing to numerous possible sources and pathways (Rochmann *et al.,* 2019). Demonstrating - how plastic pollution (and more specifically micro plastic, <5mm, Thompson *et al.,* 2004) - requires global attention and shared responsibility. Particularly within already fragile and vulnerable ecosystems such as the Arctic, where increased "last chance" tourism and polar exploration is putting increased pressure on waste management and resource infrastructure (Forbes, Monz and Tolvanen, 2004).

Challenge of marine plastic pollution policy

The last decade has witnessed a growing number of stakeholders (*e.g*. non-governmental organisations, governments, citizen scientists, industry) with an interest in researching, documenting and preventing plastic pollution in our oceans (Covernton *et al.*, 2019). Recent awareness campaigns and an increasing number of published studies have highlighted the issue as a robust field of scientific research (Kuhn *et al.,* 2015). Unfortunately, as it stands, current legal frameworks for ocean governance are fragmented in approach, especially on the topic of plastic pollution where ocean currents, atmospheric processes and climatic circulation ensure plastic (as with other environmental pollutants *e.g.* greenhouse gases) is not constrained by national boundaries. Additionally, marine plastic pollution poses further challenge in that harm caused is often geographically or temporally distanced from its predominantly land-based polluters, hence largely invisible to everyday citizens. It has long been argued (*e.g.* Clapp's 'Distancing of Waste', Clapp, 2002) that such distance or ignorance to impact, is associated with perceived lack of urgency, motivation or relevance to an individual or community, hampering effective change (Moser and Dilling, 2007).

National, Regional & International frameworks

Whilst a global treaty appears the most influential and called for intervention in governance and policy, synthesis from this thesis highlights the need for global infrastructure which in turn encompasses national and regional frameworks.

Such regional or national frameworks could take the form of conventions or action plans such as the *Circular Economy Action Plan* (EU), incorporating resource management, alongside scientific research and economic development for an increasingly sustainable production system. Similarly, conventions such as the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) may set out rulings or regulations for measures involved in frameworks, providing self-management, data generation and progress reports (Vince and Hardesty, 2018). Such regional conventions and frameworks have been rolled out in locations across the globe, all with a common purpose to combat marine plastic pollution. It could be argued that these (regional frameworks) alongside 'soft', non-legally binding policy actions (*e.g.* Sustainable Development Goals), reap greater success. More aware of their political, logistical or economic challenge, a global treaty that passes responsibility and governance to member states or regions will be better equipped to combat the issue of marine plastic pollution at its source. Additionally, considering the significance of harm to both ecosystem and human health, it would be in the best interest of the region or member state to maintain a minimal level of pollution. It should be noted that this of course does not take into account, pollutants transported to such locations from outside its jurisdiction, however, with 80% of all litter entering the oceans attributed to land-based sources (Reisser *et al.,* 2015) effective control and enforcement on land will likely see a decline in pollutants, limiting potential for transport.

It is increasingly apparent that the threat and impact of plastic is not equal across the globe. Geography, disparity in wealth, level of development and population growth just some of the key factors identified to influence quantities of marine plastic pollution (Jambeck *et al.,* 2017). A study by Jambeck *et al.,* (2017) identified that out of 192 countries, over 80% (83%) of plastic debris entering the world's oceans is attributed to just 20 countries. Of these, predominantly island nations (*e.g.* Sri Lanka), countries with archipelagos (*e.g.* The Philippines) and those with long coastlines (*e.g.* USA, China) contribute the greatest quantities (Jambeck *et al.,* 2017). This demonstrates that although marine plastic pollution is a global issue, the key to success could be in improving waste management within a small suite of countries, to stem the flow of plastics accumulating in oceans on a global scale (Ocean Conservancy, 2015; Jambeck *et al.*, 2017).

Socio-cultural and behavioural change

Fundamentally, no matter the strategic (preventative, mitigative, removal), or legislative (convention, declaration, agreement*)* tools developed to combat marine plastic pollution, it will see limited success if there is not support, understanding and willingness within communities (Haider *et al.,* 2018). Without a shift in human mindsets, a newly developed treaty will fail to see actionable change or responsibility toward lowering emissions to reduce the flow of plastic pollution into natural (marine) environments. Utilising tools that encompass behavioural change (*e.g.* education / citizen science, Boulding,1966; Bergmann *et al.,* 2015; Haider *et al.,* 2018; Rambonnet *et al.*, 2019) demonstrate the ability to not only increase awareness and educate around issues of environmental pollutants, but so too for other environmental crises (*e.g.* climate change), (Van Sebille, 2016; Prata *et al*., 2018; Rambonnet *et al.*, 2019).

Across both regional and international scales, increased awareness and understanding of modern-day crises has triggered a broad change in the way citizens and societies evaluate or perceive their environment (Dauvergne, 2016; Cutler and Dietz, 2017; Landon-Lane, 2018). With increasing efforts to shift towards an increasingly sustainable civilization, emphasis is no longer solely on meeting the needs and demands of today but encompassing needs and environment of the future (Rangel-Buitrago *et al.,* 2017). The last few years have witnessed an uprising of activism and ‘rebellion’, stimulating positive actionable change, through consumer pressure and global responsibility in the fight against pressing environmental issues (Landon-Lane, 2018; Covernton *et al.,* 2019; Rambonnet *et al.,* 2019). Where policy is failing, individuals and groups are taking governance into their own hands, raising the voice of planetary issues whilst re-inventing the wheel of activism (*e.g.* Greenpeace, 1971; Friends of the Earth, 1996; Extinction Rebellion, 2018) (Hardiman, 2013). Appearing in environmental campaigns and gaining media attention, plastic pollution has emerged as a critical feature of 'rebellion' in recent years, in doing so, shifting attitudes toward its production and use: ultimately changing the *status quo*.

The future of marine policy and governance

Compared to agreements on climate change and global warming (*e.g.* the UN Framework Convention on Climate Change (UNFCCC)), current political agreements on plastic pollution, at the global scale, are lagging by some decades, with an effective treaty not likely to come into effect for another fifteen or twenty years. By which point, emissions are expected to have quadrupled, with more plastic (by weight) than fish in the sea (Ellen MacArthur Foundation, 2017). However, there is hope in that there are currently no fact-based denials that plastic pollution is a global problem (unlike climate change), and whilst the two issues are in reality somewhat connected (oil extraction, production of fossil fuels), there is already ample evidence to warrant immediate action.

Many unknowns remain around the issue of marine debris (Mendenhall, 2018), however, regardless of strategy (*e.g.* prevention, mitigation, removal, behaviour), it is first essential to understand sources, pathways and fate of plastic debris. This includes the need for harmonised research methods and terminology (Hidalgo-Ruz *et al*., 2012; Besley *et al*., 2017), whilst it remains essential that science attempts to understand environmentally relevant concentrations, ensuring *ex situ* investigations in a laboratory setting are realistic, representing the true extent of ecological risk in the natural environment.

In the case of marine plastic pollution, a reliable and comparable detection protocol for floating synthetic debris (Nelms *et al*., 2017), is essential for strengthening the ability to accurately assess ecological risk, identify potential 'source' and 'sink' locations and generate a global assessment of the plastic pollution problem (GESAMP, 2015; 2016; Koelmans *et al.,* 2017; Covernton *et al.,* 2019). Governance and policy with comprehensive, accurate and reliable scientific knowledge necessary for more effective regulation and monitoring. Given logistical and often financial difficulties in obtaining reliable data, it is increasingly necessary to rely on contributions from other academics, institutions and organisations to generate data. Tools such as citizen science are likely to be an essential contributor in developing understanding, however it is crucial that methodologies used incorporate the question being asked, ensure its use as a tool for global comparison.

Secondly, although it is not currently possible to prevent all plastic waste emission, preventative strategies which attempt to slow its release, play a fundamental role in drastically reducing quantities of debris entering the environment. From enhanced waste management, to growth in alternative technologies or engineering and even educational awareness campaigns: developing preventative strategies to simply stop the pollutant at its source are critical.

Given a cultural change or behavioural shift is not likely to happen overnight, such strategies or solutions must give rise to innovation. Whether it's in the form of replacement material (*i.e.* biomass) or technology (*i.e.* waste management), or alternative clean up and removal methods (*i.e*. plastic eating bacteria), future policy or governance must support the development of increasing numbers of 'out-of-the-box' ideas, allowing flexibility and adaptability with changing science.

Lastly, despite the wealth in advancements of clean-up and removal technology, there is so far little understanding around what is physically or economically possible. Whilst efforts to generate baseline data is vital, this in itself presents a far greater issue, posing the common question of 'to what extent must we restore our oceans to ensure a 'healthy' state?'. Unlike understanding of other planetary processes or climatic variability where baseline data (*e.g.* cores, geological rock formation) persists, for novel entities, such as marine plastic, there is no such baseline.

Conclusion

The problem of marine litter is like no other we have faced so far in human history. With costs (*e.g*. biological, ecological, economical) significant whilst production and emission continue to rise, it is paramount we act quickly (Dauvergne, 2018). Effective legislation and policy are requiring a coordinated and integrated approach encompassing economic, technical and social viability, across regional and global scales (Rangel-Buitrago *et al*., 2018). Curbing the flow of plastic into our oceans is a complicated and multi-faceted issue: nevertheless, it is not an impossible task, demanding new perspective, global unity and planetary action.

REFERENCES

Abbott, K and Snidal, D. (2000). Hard and Soft Law in International Governance. *International Organization*, 54, pp.421-456.

Alava, J., Cheung, W., Ross, P. and Sumaila, R. (2017). Climate change-contaminant interactions in marine food webs: towards a conceptual framework, *Global Change Biology*. 23, pp.3984-4001.

Albayrak, T., Aksoy, Ş. and Caber, M. (2013). The effect of environmental concern and scepticism on green purchase behaviour. *Marketing Intelligence & Planning*. 31, pp.27-39.

Alger, J. and Dauvergne, P. (2017). The global norm of large marine protected areas: explaining variable adoption and implementation. *Environmental Policy Government*. 27, pp.298-310

Alger, J. and Dauvergne, P. (2017). The politics of Pacific Ocean conservation: lessons from the Pitcairn Islands Marine Reserve*. Pacific Affairs*. 90, pp. 9-50.

Amélineau, F., Bonnet, D., Heitz, O., Mortreux, V., Harding, A., Karnovsky, N., Walkusz, W., Fort, J. and Grémillet, D. (2016). Microplastic pollution in the Greenland Sea: Background levels and selective contamination of planktivorous diving seabirds. *Environmental Pollution*. 219, pp.1131-1139.

Anastasopoulou, A., Mytilineou, C., Smith, C. and Papadopoulou, K. (2013). Plastic debris ingested by deep-water fish of the Ionian Sea (Eastern Mediterranean). *Deep Sea Research Part I: Oceanographic Research Papers*. 74, pp.11-13.

ANCORS. (2018). *Australian National Centre for Ocean Resources and Security*. [Interview by Lead Author, Name Withheld].

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

Andrady, A. (2015). Persistence of plastic litter in the oceans. In: Bergmann, M., Gutow, L. and Klages, M. (Eds). *Marine Anthropogenic Litter*. Springer: New York. 16, pp. 29-56.

Andrady, A. and Neal, M. (2009). Applications and societal benefits of plastics. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, 364, pp. 1977-1984

Araujo, M. and Costa, M. (2019). A critical review of the issue of cigarette butt pollution in coastal environments. *Marine Pollution Bulletin*. 172, pp.137-149.

Arnold, R. (2016). *From waves of plastic to inspiring art | Keep Britain Tidy*. [online] Keepbritaintidy.org. Available at: https://www.keepbritaintidy.org/news/waves-plastic-inspiring-art [Accessed 15 Apr. 2020].

Arthur, C., Baker, J. and Bamford, H. (2009). *Proceedings of the International Research Workshop on the Occurrence, Effects and Fate of Microplastic Marine Debris, Sept 9-11, 2008*. NOAA Technical, Memorandum.

Arthur, C., Opfer, S. and Bamford, H. (2009). Standardization of Field Methods for Collection of Marine Debris. Society for Environmental Toxicology and Chemistry North American Meeting, New Orleans, LA, FP 138.

Ashenmiller, B. (2009). Cash recycling, waste disposal costs, and the incomes of the working poor: evidence from California. *Land Economics*. 85, pp.539-551.

Athanassiou, M. and Zabaniotou, A. (2008). Techno-economic Assessment of Recycling Practices of Municipal Solid Wastes in Cyprus. *Journal of Cleaner Production*. 16, pp.1474.

Austin, H., Allen, M., Donohoe, B., Rorrer, N., Kearns, F., Silveira, R., Pollard, B., Dominick, G., Duman, R., El Omari, K., Mykhaylyk, V., Wagner, A., Michener, W., Amore, A., Skaf, M., Crowley, M., Thorne, A., Johnson, C., Woodcock, H., McGeehan, J. and Beckham, G. (2018). Characterization and engineering of a plastic-degrading aromatic polyesterase. *Proceedings of the National Academy of Sciences*. 115, pp.E4350-E4357.

Balestri, E., Menicagli, V., Vallerini, C. and Lardicci, C. (2017). Biodegradable plastic bags on the seafloor: A future threat for seagrass meadows? *Science of the Total Environment*. 605–606, pp.755-763

Barange, M., Merino, G., Blanchard, J., Scholtens, J., Harle, J., Allison, E., Allen, J., Holt, J. and Jennings, S. (2014). Impacts of climate change on marine ecosystem production in societies dependent on fisheries. *Nature Climate Change*. 4, pp.211-216.

Barnes, D. Walters, A. and Gonçalves, L. (2010). Macroplastics at sea around Antarctica. *Marine Environmental Research*. 70, pp.250-252

Barnes, D., Galgani, F., Thompson, R. and Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transactions of the Royal Society B: Biological Sciences*. 364, pp.1985-1998.

Barrett, S. (2003). *Environment And Statecraft: The Strategy of. Environmental Treaty-Making*. Oxford University Press: Oxford.

Barrett, S. (2007). *Why Cooperate?: The Incentive to Supply Global Public Goods*. Oxford University Press: Oxford.

Barrows, A., Cathey, S. and Petersen, C. (2018). Marine environment microfiber contamination: Global patterns and the diversity of microparticle origins. *Environmental Pollution*. 237, pp.275-284.

Barrows, A., Neumann, C., Berger, M. and Shaw, S. (2017). Grab vs. neuston tow net: a microplastic sampling performance comparison and possible advances in the field. *Analytical Methods*. 9, pp.1446-1453.

Beaumont, N., Aanesen, M., Austen, M., Börger, T., Clark, J., Cole, M., Hooper, T., Lindeque, P., Pascoe, C. and Wyles, K. (2019). Global ecological, social and economic impacts of marine plastic. *Marine Pollution Bulletin*.142, pp.189-195.

Benedick, R. (2009). *Ozone Diplomacy: New Directions in Safeguarding the Planet*. Harvard University Press: Cambridge.

Benyus, J. (1997). *Biomimicry: innovation inspired by nature*. Harper Perennial: New York.

Bepakt. (2016). *List of packaging-free shops*. [online] Available at: <https://bepakt.com/packaging-free-shops/> [Accessed 4 April 2020].

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

Bergmann, M., Mützel, S., Primpke, S., Tekman, M., Trachsel, J. and Gerdts, G. (2019). White and wonderful? Microplastics prevail in snow from the Alps to the Arctic. *Science Advances*. 5, pp.1157.

Bergmann, M., Sandhop, N., Schewe, I. and D'Hert, D. (2015). Observations of floating anthropogenic litter in the Barents Sea and Fram Strait, Arctic. *Polar Biology*. 39, pp.553-560.

Besseling, E., Wegner, A., Foekema, E., van den Heuvel-Greve, M. and Koelmans, A. (2012). Effects of Microplastic on Fitness and PCB Bioaccumulation by the Lugworm Arenicola marina (L.). *Environmental Science & Technology*. 47, pp.593-600.

Beyerlin, U., Stoll, P. and Wolfrum, R. (2007). *Conclusions Drawn from the Conference on Ensuring Compliance With MEAs*. 2, pp.359-370.

Bhushan, B. (2009). Biomimetics: lessons from nature–an overview. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*. 367, pp.1445-1486.

Bioplastic Feedstock Alliance. (2016). *Bioplastics*. [online] Available at: <https://bioplasticfeedstockalliance.org/bioplastics/> [Accessed 4 April 2020].

Bonefeld-Jørgensen, E., Long, M., Hofmeister, M. and Vinggaard, A. (2007). Endocrine-Disrupting Potential of Bisphenol A, Bisphenol A Dimethacrylate, 4- n -Nonylphenol, and 4- n -Octylphenol in Vitro : New Data and a Brief Review. *Environmental Health Perspectives*. 115, pp.69-76.

Borelle, S., Rochman, C., Liboiron, M., Bond, A., Lusher, A., Bradshaw, H. and Provencher, J. (2017). Why we need an international agreement on marine plastic pollution, *Proceedings of the National Academy of Sciences*. 114, pp. 9994-9997.

Boucher, J. and Friot, D. (2017). *Primary Microplastics In The Oceans: A Global Evaluation Of Sources*. IUCN.

Bowen, K., Cradock-Henry, N., Koch, F., Patterson, J., Ha¨ yha¨, T., Vogt, J. and Barbi, F. (2017). Implementing the "Sustainable Development Goals": towards addressing three key governance challenges — collective action, trade-offs, and accountability. *Current Opinion in Environmental Sustainability*. 26, pp.90-96.

Brach, L., Deixonne, P., Bernard, M., Durand, E., Desjean, M., Perez, E., van Sebille, E. and ter Halle, A. (2018). Anticyclonic eddies increase accumulation of microplastic in the North Atlantic subtropical gyre. *Marine Pollution Bulletin*. 126, pp.191-196.

Bravo, M., Luna-Jorquera, M., Nuñez, G., Vasquez, P and Thiel, N. (2009). Anthropogenic debris on beaches in the SE Pacific (Chile): results from a national survey supported by volunteers. *Marine Pollution Bulletin*. 58, pp.1718-1726.

Brennan, L. and Binney, W. (2008). *Is it Green Marketing, Greenwash or Hogwash? We Need to Know if We Want to Change Things, Partnerships, Proof and Practice* - International Non-profit and Social Marketing Conference 2008, University of Wollongong.

Brooks, A., Wang, L. and Jambeck, J. (2018). The Chinese import ban and its impact on global plastic waste trade. *Science Advances*. 4, pp.1-7.

Browne, M., Crump, P., Niven, S., Teuten, E., Tonkin, A., Galloway, T. and Thompson, R. (2011). Accumulation of Microplastic on Shorelines Worldwide: Sources and Sinks. *Environmental Science & Technology*. 45, pp.9175-9179.

Browne, M., Underwood, A., Chapman, M., Williams, R., Thompson, R. and van. Franeker, J. (2015). Linking effects of anthropogenic debris to ecological impacts, *Proceedings of the Royal Society B*. 282, 20142929.

Bruno, K. (1997). The World of Greenwash, CorpWatch, [online] Available at: <https://www.cor pwatch.org/campaigns/PCD,jsp? articleid=244>

Campbell, M., Peters, L., McMains, C., Cruz, M. and R. Sargisson. (2019). Are our beaches safe? Quantifying the human health impact of anthropogenic beach litter on people in New Zealand. *Science of the Total Environment.* 651, pp.2400-2409

Canesi, L. and Fabbri, E., 2015. Environmental Effects of BPA. *Dose-Response*. 13, pp.155932581559830.

Carlson, J., Ghaey, S., Moran, S., Tran, C. and Kaplan, D. (2005). *Biological materials in engineering mechanisms, Biomimetics—Biologically Inspired Technologies*. CRC Press: Florida, pp.365-380.

Carpenter, E. and Smith, K. (1972). Plastics on the Sargasso Sea Surface. *Science*. 175, pp.1240-1241.

Carrington, D. (2018). *Scientists Accidentally Create Mutant Enzyme That Eats Plastic Bottles*. [online]. Available at: <https://www.theguardian.com/environment/2018/apr/16/scientists-accidentally-create-mutant-enzyme-that-eats-plastic-bottles> [Accessed 22 April 2020].

Chayes, A. and Chayes, A. (1995). *The New Sovereignty: Compliance With International Regulatory Agreements.* Harvard University Press: Cambridge.

Chen, C. (2015). Regulation and management of marine litter. In: Bergmann, M., Gutow, L. and Klages, M. (Eds). *Marine Anthropogenic Litter*. Springer: New York. 16, pp.395-428.

Chen, C. and Liu, T. (2013). Fill the gap: developing management strategies to control garbage pollution from fishing vessels. *Marine Pollution Bulletin*. 40, pp.34-40.

Cheshire, A., Adler, E., Barbière, J., Cohen, Y., Evans, S., Jarayabhand, S., Jeftic, L., Jung, R., Kinsey, S., Kusui, E., Lavine, I., Manyara, P., Oosterbaan, L., Pereira, M., Sheavly, S., Tkalin, A., Varadarajan, S., Wenneker, B. and Westphalen, G. (2009). UNEP/IOC Guidelines on Survey and Monitoring of Marine Litter. *Regional Seas Reports and Studies.*186.

Chinaglia, S., Tosin, M. and Degli-Innocenti, F., 2018. Biodegradation rate of biodegradable plastics at molecular level. *Polymer Degradation and Stability*. 147, pp.237-244.

Chong, S., Pan, G., Khalid, M., Yang, T., Hung, S. and Huang, C. (2016). Physical Characterization and Pre-assessment of Recycled High-Density Polyethylene as 3D Printing Material. *Journal of Polymers and the Environment*. 25, pp.136-145.

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, pp.105-112.

Clapp, J. (2002).“The distancing of waste: overconsumption in a global economy. In: Princen, T. (Eds.). *Confronting Consumption*. MIT Press: Cambridge, pp.155-176.

Clapp, J. (2012).The Rising tide against plastic waste: unpacking industry attempts to influence the debate. In: Mazzolini, E. and Foote, S. (Eds.) *Histories Of The Dustheap*. MIT Press: Cambridge, pp.199-295.

Clean Seas Coalition. (2020). [online] Available at: <http://cleanseascoalition.org/> [Accessed 30 March 2020].

Coca-Cola Company. (2017). *Coca-Cola Company 2016 Sustainability Report*. Atlanta.

Coca-Cola Company. (2018). *A World Without Waste: Coca-Cola Announces Ambitious Sustainable Development Goal.* [online] Available at: <http://www.coca-colacompany.com/stories/world-without-waste> [Accessed 19 March 2020].

Coe, J. and Rogers, D. (1996). *Marine Debris, Sources, Impacts and Solutions*. Springer: New York

Cole, C. (2017). *China Bans Foreign Waste – But What Will Happen To The World's Recycling?*. The Conversation.

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

Cole, M., Lindeque, P., Halsband, C. and Galloway, T. (2011). Microplastics as contaminants in the marine environment: A review. *Marine Pollution Bulletin*. 62, pp.2588-2597.

Collignon, A., Hecq, J., Glagani, F., Voisin, P., Collard, F. and Goffart, A. (2012). Neustonic microplastic and zooplankton in the North Western Mediterranean Sea. *Marine Pollution Bulletin*. 64, pp.861-864.

Colloff, M., Martín-López, B., Lavorel, S., Locatelli, B., Gorddard, R., Longaretti, P., Walters, G., van Kerkhoff, L., Wyborn, C., Coreau, A., Wise, R., Dunlop, M., Degeorges, P., Grantham, H., Overton, I., Williams, R., Doherty, M., Capon, T., Sanderson, T. and Murphy, H. (2017). An integrative research framework for enabling transformative adaptation. *Environmental Science & Policy*. 68, pp.87-96.

Colpac. (2018). *Colpac Ltd: Sustainable Supplier Of Food Packaging Solutions*. [online] Available at: <https://colpacpackaging.com/> [Accessed 8 April 2020].

Colton, J., Burns, B. and Knapp, F. (1974). Plastic Particles in Surface Waters of the Northwestern Atlantic. *Science*.185, pp.491-497.

Comnea-Stancu, I., Wieland, K., Ramer, G., Schwaighofer, A. and Lendl, B. (2017). On the Identification of Rayon/Viscose as a Major Fraction of Microplastics in the Marine Environment: Discrimination between Natural and Manmade Cellulosic Fibers Using Fourier Transform Infrared Spectroscopy. *Applied Spectroscopy*. 71, pp.939-950.

Conkle, J., Báez Del Valle, C. and Turner, J. (2017). Are We Underestimating Microplastic Contamination in Aquatic Environments?. *Environmental Management*. 61, pp.1-8.

Cora Ball. (2020). *Cora Ball - The World's First Microfiber Catching Laundry Ball*. [online] Available at: <https://coraball.com/> [Accessed 5 May 2020].

Covernton, G., Pearce, C., Gurney-Smith, H., Chastain, S., Ross, P., Dower, J. and Dudas, S. (2019). Size and shape matter: A preliminary analysis of microplastic sampling technique in seawater studies with implications for ecological risk assessment. *Science of The Total Environment*. 667, pp.124-132.

Cox, P., Niewohner, J., Pidgeon, N., Gerrard, S., Fischhoff, B. and Riley, D. (2003). The use of mental models in chemical risk protection: Developing a generic workplace methodology, *Risk Analysis*. 23, pp.311-324.

Cózar, A., Echevarria, F., Gonzalez-Gordillo, J., Irigoien, X., Ubeda, B., Hernandez-Leon, S., Palma, A., Navarro, S., Garcia-de-Lomas, J., Ruiz, A., Fernandez-de-Puelles, M. and Duarte, C. (2014). Plastic debris in the open ocean. *Proceedings of the National Academy of Sciences*. 111, pp.10239-10244.

Cózar, A., Martí, E., Duarte, C., García-de-Lomas, J., van Sebille, E., Ballatore, T., Eguíluz, V., González-Gordillo, J., Pedrotti, M., Echevarría, F., Troublè, R. and Irigoien, X. (2017). The Arctic Ocean as a dead end for floating plastics in the North Atlantic branch of the Thermohaline Circulation. *Science Advances*. 3, pp.1600582.

Crain, C., Kroeker, K. and Halpern, B. (2008). Interactive and cumulative effects of multiple human stressors in marine systems. *Ecology Letters*. 11, pp.1304-1315.

Crutzen, P. (2006). The “Anthropocene”. In: Ehlers, E. and Krafft, T. (Eds) *Earth System Science in the Anthropocene*. Springer: Berlin.

Culin, J. and Bielic, T. (2016). Plastic pollution from ships. *Journal of Maritime and Transportation Science*. 51, pp.57-66.

Cutler, A. and Dietz, T. (2017). *The Politics Of Private Transnational Governance By Contract*. Taylor & Francis: New York.

Dahlstrom, M. (2014). Using narratives and storytelling to communicate science with nonexpert audiences. *Proceedings of the National Academy of Sciences*. 111, pp.13614-13620.

Dalsenter, P., Santana, G., Grande, S., Andrade, A. and Araújo, S. (2006). Phthalate affect the reproductive function and sexual behavior of male Wistar rats. *Human & Experimental Toxicology*, 25, pp.297-303.

Dauvergne, P. (2018). The power of environmental norms: marine plastic pollution and the politics of microbeads. *Environmental Politics.* 27, pp.579-597.

Dauvergne, P. (2018). Why is the global governance of plastic failing the oceans?. *Global Environmental Change*. 51, pp.22-31.

Dauvergne, P. and Alger, J. (2018). A Research Agenda for Global Environmental Politics. *Ocean Governance.* 9

Dauvergne, P. and Lister, J. (2012). Big brand sustainability: governance prospects and environmental limits. *Global Environmental Change*. 22, pp.36-45

David Suzuki Foundation. (2018). [Interview by Lead Author, Name Withheld]

Day, R., Shaw, D. and Ignell, S. (1990). “The quantitative distribution and characteristics of neuston plastic in the North Pacific Ocean, 1984–1988” In: Shomura, R.S., Godfrey, M.L. (Eds.), Proceedings of the Second International Conference on Marine Debris, April 2–7, 1989, Honolulu, Hawaii. U.S. Department of Commerce, NOAA Technical Memorandum. pp. 247–266.

de Carvalho, D. and Baptista Neto, J. (2016). Microplastic pollution of the beaches of Guanabara Bay, Southeast Brazil. *Ocean & Coastal Management*, 128, pp.10-17.

De Falco, F., Gullo, M., Gentile, G., Di Pace, E., Cocca, M., Gelabert, L., Brouta-Agnésa, M., Rovira, A., Escudero, R., Villalba, R., Mossotti, R., Montarsolo, A., Gavignano, S., Tonin, C. and Avella, M. (2018). Evaluation of microplastic release caused by textile washing processes of synthetic fabrics. *Environmental Pollution*. 236, pp.916-925.

de Lucia, G., Caliani, I., Marra, S., Camedda, A., Coppa, S., Alcaro, L., Campani, T., Giannetti, M., Coppola, D., Cicero, A., Panti, C., Baini, M., Guerranti, C., Marsili, L., Massaro, G., Fossi, M. and Matiddi, M. (2014). Amount and distribution of neustonic micro-plastic off the western Sardinian coast (Central-Western Mediterranean Sea). *Marine Environmental Research*. 100, pp.10-16.

de Stephanis, R., Giménez, J., Carpinelli, E., Gutierrez-Exposito, C. and Cañadas, A. (2013). As main meal for sperm whales: Plastics debris. *Marine Pollution Bulletin*. 69, pp.206-214.

Derraik, J. (2002). The pollution of the marine environment by plastic debris: a review. *Marine Pollution Bulletin*. 44, pp.842-852.

DeSombre, E. (2018). *Ocean Governance*. In Dauvergne, P. and Alger, J. (Eds). *A Research Agenda for Global Environmental Politics*. Cheltenham: Edward Elgar. 9.

Devall, B. (1980). The deep ecology movement. *Natures Resource Journal*. 299.

Dietz, T. (2003). The Struggle to Govern the Commons. *Science*. 302, pp.1907-1912.

Doyle, M., Watson, W., Bowlin, M. and Sheavly, S. (2011). Plastic particles in coastal pelagic ecosystems of the Northeast Pacific Ocean. *Marine Environmental Research*. 71, pp.41-52.

Dugdale, J. (2015). The ocean cleanup plan so crazy it just might work. [online] Available at: <http://www.outsideonline.com/1999216/ocean-doubt> [accessed 23 April 2020].

Duis, K. and Coors, A. (2016). Microplastics in the aquatic and terrestrial environment: sources (with a specific focus on personal care products), fate and effects. *Environmental Sciences Europe*. 28.

Duncan, E., Broderick, A., Fuller, W., Galloway, T., Godfrey, M., Hamann, M., Limpus, C., Lindeque, P., Mayes, A., Omeyer, L., Santillo, D., Snape, R. and Godley, B. (2019). Microplastic ingestion ubiquitous in marine turtles. *Global Change Biology*. 25, pp.744-752.

Dupont, J., Magnin, S., Rousseau, F., Zbinden, M., Frebourg, G., Samadi, S., Richer de Forges, B. and Gareth Jones, E. (2009). Molecular and ultrastructural characterization of two ascomycetes found on sunken wood off Vanuatu Islands in the deep Pacific Ocean. *Mycological Research*. 113, pp.1351-1364.

Dyachenko, A., Mitchell, J. and Arsem, N. (2017). Extraction and identification of microplastic particles from secondary wastewater treatment plant (WWTP) effluent. *Analytical Methods*. 9, pp.1412-1418.

Earth Policy Institute. (2013). *Plan B Updates - 123: The Downfall Of The Plastic Bag: A Global Picture* | *EPI*. [online] Available at: <http://www.earth-policy.org/plan_b_updates/2014/update123> [Accessed 8 April 2020].

Easman, E., Abernethy, K. and Godley, B. (2018). Assessing public awareness of marine environmental threats and conservation efforts. *Marine Pollution*. 87, pp. 234-240.

ECCHR. (2020). *Hard Law/Soft Law*. [online] Available at: <https://www.ecchr.eu/en/glossary/hard-law-soft-law/> [Accessed 7 December 2020].

Econyl. (2020). *Econyl*. [online] Available at: <https://www.econyl.com/> [Accessed 9 April 2020].

Ecorys. (2011). *The Role of Market-based Instruments in Achieving a Resource Efficient Economy.* The European Commission.

Eerkes-Medrano, D., Thompson, R. and Aldridge, D. (2015). Microplastics in freshwater systems: A review of the emerging threats, identification of knowledge gaps and prioritisation of research needs. *Water Research*. 75, pp.63-82.

Ellen MacArthur Foundation. (2012). *Towards The Circular Economy Vol. 1: An Economic And Business Rationale For An Accelerated Transition*. [online] Available at:

<https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf.> [Accessed 19 March 2020].

Ellen MacArthur Foundation. (2015). *Growth Within: A Circular Economy Vision For A Competitive Europe*. [online] Available at: <https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_Growth-Within_July15.pdf.> [Accessed 19 March 2020].

Ellen MacArthur Foundation. (2016). *The New Plastics Economy – Rethinking the Future of Plastics.* [online] Available at: <https://www.ellenmacarthurfoundation.org/publications/the-new-plastics-economy-rethinking-the-future-of-plastics> [Accessed 19 March 2020].

Ellen MacArthur Foundation. (2017). *The New Plastics Economy: Rethinking the Future of Plastics & Catalysing Action.* [online] Available at: <https://www.ellenmacarthurfoundation.org/publications/the-new-plastics-economy-rethinking-the-future-of-plastics-catalysing-action> [Accessed 19 March 2020].

EPA. (2001). *The United States Experience with Economic Incentives for Protecting the Environment Office of Policy, Economics, and Innovation.* Office of the Administrator U.S. Environmental Protection Agency, Washington.

Eriksen, M., Cummins, A., Maximenko, N., Thiel, M., Lattin, G., Wilson, S., Hafner, J., Zellers, A. and Rifman, S. (2013). Plastic Pollution in the South Pacific Subtropical Gyre. *Plastics Engineering*. 69, pp.38-44.

Eriksen, M., Lebreton, L., Carson, H., Thiel, M., Moore, C., Borerro, J., Galgani, F., Ryan, P. and Reisser, J. (2014). Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea. *PLoS ONE*. 9, pp.e111913.

Eriksen, M., Thiel, M., Prindiville, M. And Kiessling, T. (2018). Microplastic: What are the Solutions? In: Wagner, M. And Lambert, S. (Eds). *Freshwater Microplastics*. 58, pp. 273-297

European Commission. (2015). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - *Closing The Loop – An EU Action Plan For The Circular Economy*. [online] Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614> [Accessed 19 March 2020].

European Commission. (2018). *Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions - A European Strategy For Plastics In A Circular Economy*. [online] Available at: <https://eurlex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX:52018DC0028&from=EN> [Accessed 19 March 2020].

European Commission. (2020). *Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions - A new Circular Economy Action Plan For a cleaner and more competitive Europe.* [online] Available at: <https://eurlex.europa.eu/legalcontent/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN> [Accessed 4 April 2020].

European Parliament. (2008). *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain directives.* [online] Available at: <https://eur-lex.europa.eu/eli/dir/2008/98/oj> [Accessed 4 April 2020].

Extinction Rebellion, (2018) . *Home - Extinction Rebellion UK*. [online] Available at: <https://extinctionrebellion.uk/> [Accessed 18 December 2020].

Eyheraguibel, B., Leremboure, M., Traikia, M., Sancelme, M., Bonhomme, S., Fromageot, D., Lemaire, J., Lacoste, J. and Delort, A. (2018). Environmental scenario for the degradation of oxo-polymers. *Chemosphere*. 198, pp.182-190.

Fake Plastic Fish. (2017). *Guppy friend microfiber catching laundry bag.* [online] Available at: <https://myplasticfreelife.com/2017/07/review-guppyfriend-microfiber-catching-laundry-bag/> [Accessed 4 April 2020].

Falkner, R. (2005). *The business of ozone layer protection: corporate power in regime evolution.* In Levy, D. and Newell, P. (Eds). *The Business of Global Environmental Governance.* MIT Press: Boston, pp.105-134.

Fazey, F. and Ryan, P. (2016). Debris size and buoyancy influence the dispersal distance of stranded litter. *Marine Pollution Bulletin*. 110, pp.371-377.

Finus, M. (2001). *Game Theory and International Environmental Cooperation*. Edwar Elgar: Cheltenham.

Fleming, A. and Howden, S. (2016). Ambiguity: a new way of thinking about responses to climate change. *Science of the Total Environment*. 571, pp.1271-1274.

Forbes, B., Monz, C. and Tolvanen, A. (2004). Ecological Impacts of Tourism in Terrestrial Polar Ecosystems. In: Buckley, R. (Eds). *Environmental Impacts of Ecotourism*. 2, pp.155-170.

Fossi, M., Panti, C., Baini, M. and Lavers, J. (2018). A Review of Plastic-Associated Pressures: Cetaceans of the Mediterranean Sea and Eastern Australian Shearwaters as Case Studies. *Frontiers in Marine Science*. 5.

Fossi, M., Panti, C., Guerranti, C., Coppola, D., Giannetti, M., Marsili, L. and Minutoli, R. (2012). Are baleen whales exposed to the threat of microplastics? A case study of the Mediterranean fin whale (Balaenoptera physalus). *Marine Pollution Bulletin*. 64, pp.2374-2379.

Freestone, D. (2020). Sustainable Development, Ocean Governance and Marine Protected Areas. *Asia-Pacific Journal of Ocean Law and Policy*. 4, pp.127-141.

French, M. (1996). *Invention And Evolution*. Cambridge University Press: Cambridge.

Friends of the Earth (1996). *Friends Of The Earth | Home*. [online] Available at: <https://friendsoftheearth.uk/> [Accessed 18 December 2020].

G20. (2017). *G20 Action Plan on Marine Litter*. [online] Available at: <https://www.mofa.go.jp/mofaj/files/000272290.pdf> [Accessed 4 April 2020].

G7. (2015). *G7 Action Plan To Combat Marine Litter*. [online] Available at: <https://www.env.go.jp/water/marine_litter/07_mat13_2_%EF%BC%93-2ALD.pdf> [Accessed 4 April 2020].

G7. (2018). *Ocean Plastics Charter*. [ebook] Available at: <http://www.international.gc.ca/worldmonde/assets/pdfs/international_relations-relations_internationales/g7/2018-06-09- healthy_oceans-sante_oceans-annex-en.pdf> [Accessed 4 April 2020].

Gago, J., Carretero, O., Filgueiras, A. and Viñas, L. (2018). Synthetic microfibers in the marine environment: A review on their occurrence in seawater and sediments. *Marine Pollution Bulletin*. 127, pp.365-376.

Gaines, S. (1991). The Polluter-Pays Principle: From Economic Equity to Environmental Ethos. *International Law Journal*. 463.

Galgani, F., Hanke, G. and Maes, T. (2015). Global distribution, composition and abundance of marine litter. In: Bergmann, M., Gutow, L. and Klages, M. (Eds). *Marine Anthropogenic Litter*. Springer: New York.

Gallo, F., Fossi, C., Weber, R., Santillo, D., Sousa, J., Ingram, I., Nadal, A. and Romano, D. (2018). Marine litter plastics and microplastics and their toxic chemicals components: the need for urgent preventive measures. *Environmental Sciences Europe*. 30.

Galloway, T., Cole, M. and Lewis, C. (2017). Interactions of microplastic debris throughout the marine ecosystem. *Nature Ecology and Evolution*. 1.

Garcia-Vazquez, E., Cani, A., Diem, A., Ferreira, C., Geldhof, R., Marquez, L., Molloy, E. and Perché, S. (2018). Leave no traces – beached marine litter shelters both invasive and native species. *Marine Pollution Bulletin*. 131, pp.314-322.

Gauquie, J., Devriese, L., Robbens, J. and De Witte, B. (2015). A qualitative screening and quantitative measurement of organic contaminants on different types of marine plastic debris. *Chemosphere*. 138, pp.348-356.

Gear of the Future. (2016). *The Great Outdoors*. [online] Available at: <http://www.tgomagazine.co.uk/gear-news/gear-of-the-future/> [Accessed 4 April 2020].

Germanov, E., Marshall, A., Bejder, L., Fossi, M. and Loneragan, N. (2018). Microplastics: No Small Problem for Filter-Feeding Megafauna. *Trends in Ecology and Evolution*. 33, pp. 227-232.

GESAMP. (2010). Proceedings of the GESAMP International Workshop on Plastic Particles as a Vector in Transporting Persistent, Bio-Accumulating and Toxic Substances in the Oceans – Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection. *Reports and Studies Series*. 82, International Maritime Organization, London.

GESAMP. (2016). *Sources, fate and effects of microplastics in the marine environment: part two of a global assessment* – Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection. *Reports and Studies Series.* 93, International Maritime Organization, London.

GESAMP. (2019). *Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean* – Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection. *Reports and Studies Series*. 99, United Nations Environment Programme, New York.

Gewert, B., Plassmann, M. and MacLeod, M. (2015). Pathways for degradation of plastic polymers floating in the marine environment. *Environmental Science: Processes & Impacst.* 17, pp.1513-1521.

Geyer, R., Jambeck, J. and. Law, K. (2017). Production, use, and fate of all plastics ever made. *Science Advances.* 3.

GIZ. (2018). *Marine Litter Prevention*. [online] Available at: <https://www.giz.de/de/downloads/giz2018_marine-litterprevention_web.pdf> [Accessed 19 March 2020].

Gold, M., Mika, K., Horowitz, C., Herzog, M. and Leitner, L. (2013). Stemming the tide of plastic marine litter: A global action agenda. *Pritzker Environmental Law and Policy Briefs*. 5, pp.1-30.

Gold, M., Mika, K., Horowitz, C., Herzog, M. and Leitner, L. (2014). Stemming the tide of plastic marine litter: a global action agenda. *Tulane Environmental Law Journal*. 27, pp.165-204.

Goldstein, M., Rosenberg, M. and Cheng, L. (2012). Increased oceanic microplastic debris enhances oviposition in an endemic pelagic insect. *Biology Letters*. 8, pp.817-820.

Goldstein, M., Titmus, A. and Ford, M. (2013). Scales of Spatial Heterogeneity of Plastic Marine Debris in the Northeast Pacific Ocean. *PLoS ONE*. 8, pp.e80020.

Goncalves, L. and Faure, M. (2019). International Law Instruments To Address The Plastic Soup. *William and Mary Environmental Law and Policy Review.* 43, pp.871-945

Gordon, J. (1976). *The New Science of Strong Materials, or Why You Don't Fall Through the Floor*. 2, PelicanPenguin: London, pp.1-287.

Gracia, A. and Rangel-Buitrago, N. (2020). The invasive species Perna viridis (Linnaeus, 1758 - Bivalvia: mytilidae) on artificial substrates: a baseline assessment for the Colombian Caribbean Sea. *Marine Pollution Bulletin.* 152, pp.110926.

Granberg, M., Ask, A. and Gabrielsen, G. (2017). Local contamination in Svalbard, Overview and suggestions for remediation actions. Brief report 044. *Norwegian Polar Institute.* Tromso, Norway.

Greene, J. (2014). *Sustainable Plastics: Environmental Assessments of Biobased, Biodegradable, and Recycled Plastics.* Wiley: Hoboken.

Greenpeace, (1971). [online] Available at: <https://www.greenpeace.org/global/> [Accessed 18 December 2020].

Groh, K., Backhaus, T., Carney-Almroth, B., Geueke, B., Inostroza, P., Lennquist, A., Leslie, H., Maffini, M., Slunge, D., Trasande, L., Warhurst, A. and Muncke, J. (2019). Overview of known plastic packaging-associated chemicals and their hazards. *Science of The Total Environment*. 651, pp.3253-3268.

Gross, R. and Kalra, B. (2002). Biodegradable polymers for the environment. *Science.* 297, pp.803–807

Grøsvik, B., Prokhorova, T., Eriksen, E., Krivosheya, P., Horneland, P. and Prozorkevich, D. (2018). Assessment of Marine Litter in the Barents Sea, a Part of the Joint Norwegian–Russian Ecosystem Survey. *Frontiers in Marine Science*, 5.

Guardian. (2016). *England's Plastic Bag Usage Drops 85% Since 5P Charge Introduced*. [online] Available at: <https://www.theguardian.com/environment/2016/jul/30/england-plastic-bag-usage-drops-85-per-cent-since-5p-charged-introduced> [Accessed 8 April 2020].

Guardian. (2018). *Money for old socks – John Lewis to buy back clothes to cut waste*. [online] Available at: <https://www.theguardian.com/business/2018/jun/18/money-for-old-socks-john-lewis-to-buy-back-clothes-to-cut-waste> [Accessed 4 April 2020].

Guardian. (2018). *UK Supermarkets Launch Voluntary Pledge To Cut Plastic Packaging*. [online] Available at: <https://www.theguardian.com/environment/2018/apr/26/uk-supermarkets-launch-voluntary-pledge-to-cut-plastic-packaging> [Accessed 8 April 2020].

Güven, O., Gökdağ, K., Jovanović, B. and Kıdeyş, A. (2017). Microplastic litter composition of the Turkish territorial waters of the Mediterranean Sea, and its occurrence in the gastrointestinal tract of fish. *Environmental Pollution*. 223, pp.286-294.

Haas, P. (1992). *Knowledge, Power, And International Policy Coordination*. MIT Press: Cambridge.

Haider, T., Völker, C., Kramm, J., Landfester, K. and Wurm, F., (2019). Plastics of the Future? The Impact of Biodegradable Polymers on the Environment and on Society. *Angewandte Chemie International Edition.* 58, pp.50-62.

Hansen, J. (1990). Draft position statement on plastic debris in marine environments. *Fisheries.* 15, pp.16–17.

Hardesty, B., Good, T. and Wilcox, C. (2015). Novel methods, new results and science-based solutions to tackle marine debris impacts on wildlife. *Ocean Coast Management*. 115, pp.4-9.

Hardesty, B., Harari, J., Isobe, A., Lebreton, L., Maximenko, N., Potemra, J., van Sebille, E., Vethaak, A. and Wilcox, C. (2017). Using Numerical Model Simulations to Improve the Understanding of Micro-plastic Distribution and Pathways in the Marine Environment. *Frontiers in Marine Science*. 4.

Hardesty, B., Wilcox, C., Lawson, T., Lansdell, M. and van der Velde, T. (2014). *Understanding the Effects of Marine Debris on Wildlife*. A Final Report to Earthwatch Australia.

Hardiman, D. (2013). Towards a History of Non-violent Resistance. *Economic and Political Weekly*, 48, pp.41-48.

Hartig, T., Kaiser, F. and Bowler, P. (2001). Psychological restoration in nature as a positive motivation for ecological behavior. *Environment & Behaviour*. 33, pp.590-607.

Hartig, T., Kaiser, F. and Strumse, E. (2007). Psychological restoration in nature as a source of motivation for ecological behaviour. *Environmental Conservation*. 34, pp.291-299.

Hartley, B., Pahl, S., Veiga, J., Vlachogianni, T., Vasconcelos, L., Maes, T., Doyle, T., d'Arcy Metcalfe, R., Öztürk, A., Di Berardo, M. and Thompson, R. (2018). Exploring public views on marine litter in Europe: Perceived causes, consequences and pathways to change. *Marine Pollution Bulletin*. 133, pp.945-955.

Hartley, B., Thompson, R. and Pahl, S. (2015). Marine litter education boost children’s understanding and self-reported actions. *Marine Pollution Bulletin*. 90, pp.209-217.

Hartmann, N., Hüffer, T., Thompson, R., Hassellöv, M., Verschoor, A., Daugaard, A., Rist, S., Karlsson, T., Brennholt, N., Cole, M., Herrling, M., Hess, M., Ivleva, N., Lusher, A. and Wagner, M. (2019). Are We Speaking the Same

Language? Recommendations for a Definition and Categorization Framework for Plastic Debris. *Environmental Science & Technology*. 53, pp.1039-1047.

Hawkins, G., Potter, E. and Race, K. (2015). *Plastic Water: The Social and Material Life of Bottled Water*. MIT Press: Cambridge.

Hidalgo-Ruz, V. and Thiel, M. (2015). The Contribution of Citizen Scientists to the Monitoring of Marine Litter. In: Bergmann, M., Gutow, L. and Klages, M. (Eds). *Marine Anthropogenic Litter*. Springer: New York. 16, pp.430-447.

Hidalgo-Ruz, V. and Thiel, M. (2015). The Contribution of Citizen Scientists to the Monitoring of Marine Litter. In: Bergmann, M., Gutow, L. and Klages, M. (Eds). *Marine Anthropogenic Litter*. Springer: New York. 16, pp.430-447.

Hidalgo-Ruz, V., Gutow, L., Thompson, R. and Thiel, M. (2012). Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification. *Environmental Science & Technology*. 46, pp.3060-3075.

Hill, J., Hislop, H. and Bégin, A. (2008). *Good Product, Bad Product? Making the Case for Product Levies*. Green Alliance, London, UK.

Hogg, D., Sherrington, C. and Vergunst, T. (2011). *A Comparative Study on Economic Instruments Promoting Waste Prevention.* Final Report to Bruxelles Environnment. Bristol, UK.

Homonoff, T. (2018). Can Small Incentives Have Large Effects? The Impact of Taxes versus Bonuses on Disposable Bag Use. *American Economic Journal: Economic Policy*. 10, pp.177-210.

Hong, S., Lee, J., Kang, D., Choi, H. and Ko, S. (2014). Quantities, composition, and sources of beach debris in Korea from the results of nationwide monitoring. *Marine Pollution Bulletin*. 84, pp.27-34.

Hopewell, J., Dvorak, R. and Kosior, E. (2009). Plastics recycling: Challenges and opportunities. *Philosophical Transactions of the Royal Society B*. 364, pp.2115-2126.

Horton, A., Walton, A., Spurgeon, D., Lahive, E. and Svendsen, C. (2017). Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. *Science of The Total Environment*. 586, pp.127-141.

Hugo, T. (2018). *The Case for a Treaty on Marine Plastic Pollution*. Norwegian Academy of International Law. [online] Available at: <https://intlaw.no/wp-content/uploads/2018/11/The-case-for-a-TMPP-Nov-2018-WEB.pdf> [Accessed 19 March 2020].

Humes, E. (2011). *Force of Nature: The Unlikely Story of Wal-Mart's Green Revolution.* Harper Collins: New York.

Iceland. (2018). *Plastics Pledge Progress – About Iceland*. [online] Available at: <https://about.iceland.co.uk/pledge-progress/> [Accessed 8 April 2020].

Ignatyev, A., Thielemans, B. and Vander Beke, B. (2014). Recycling of Polymers : A Review. *Chemistry, Energy, Sustainability Materials*. 7, pp.1579.

Ipsos. (2019). *New Research Reveals The Power Of Blue Planet II And How It's Changed Attitudes And Behaviour*. [online] Available at: <https://www.ipsos.com/ipsos-mori/en-uk/new-research-reveals-power-blue-planet-ii-and-how-its-changed-attitudes-and-behaviour> [Accessed 19 March 2020].

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

Isobe, A., Uchida, K., Tokai, T. and Iwasaki, S. (2015). East Asian seas: A hot spot of pelagic microplastics. *Marine Pollution Bulletin*. 101, pp.618-623.

Isobe, A., Uchiyama-Matsumoto, K., Uchida, K. and Tokai, T. (2017). Microplastics in the Southern Ocean. *Marine Pollution Bulletin*. 114, pp.623-626.

ISOE Interview. (2018). *Institute for Social-ecological Research*. [Interview by Lead Author, Name Withheld]

Ivkic, A., Steger, J., Galil, B. and Albano, P. (2019). The potential of large rafting objects to spread Lessepsian invaders: the case of a detached buoy. *Biological Invasions*. 2, pp.1887-1893.

Jambeck, J., Roland, G., Chris, W. and Theodore, R. (2015). Plastic waste inputs from land into the ocean. *Science*. 347, pp.768-771.

Jamieson, A., Brooks, L., Reid, W., Piertney, S., Narayanaswamy, B. and Linley, T. (2019). Microplastics and synthetic particles ingested by deep-sea amphipods in six of the deepest marine ecosystems on Earth. *Royal Society Open Science*. 6, pp.180667.

Jang, Y., Lee, J. and Hong, S. (2014). Sources of plastic marine debris on beaches of Korea: more from the ocean than the land. *Ocean Sciences*. 49, pp.151-162.

Jung, M., Horgen, F., Orski, S., Rodriguez C., V., Beers, K., Balazs, G., Jones, T., Work, T., Brignac, K., Royer, S., Hyrenbach, K., Jensen, B. and Lynch, J. (2018). Validation of ATR FT-IR to identify polymers of plastic marine debris, including those ingested by marine organisms. *Marine Pollution Bulletin*. 127, pp.704-716.

Kanhai, L., Gårdfeldt, K., Lyashevska, O., Hassellöv, M., Thompson, R. and O'Connor, I. (2018). Microplastics in sub-surface waters of the Arctic Central Basin. *Marine Pollution Bulletin*.130, pp.8-18.

Kanhai, L., Johansson, C., Frias, J., Gardfeldt, K., Thompson, R. and O'Connor, I. (2019). Deep sea sediments of the Arctic Central Basin: A potential sink for microplastics. *Deep Sea Research Part I: Oceanographic Research Papers*. 145, pp.137-142.

Kanhai, L., Officer, R., Lyashevska, O., Thompson, R. and O'Connor, I. (2017). Microplastic abundance, distribution and composition along a latitudinal gradient in the Atlantic Ocean. *Marine Pollution Bulletin*. 115, pp.307-314.

Kiessling, T., Salas, S., Mutufoglu, K. and Thiel, M. (2017). Who cares about dirty beaches? Evaluating environmental awareness and action on coastal litter in Chile. *Ocean Coast Management*. 137, pp.82-95.

Kinzig, A., Ehrlich, P., Alston, L., Arrow, K., Barrett, S., Buchman, T., Daily, G., Levin, B., Levin, S., Oppenheimer, M., Ostrom, E. and Saari, D. (2013). Social Norms and Global Environmental Challenges: The Complex Interaction of Behaviors, Values, and Policy. *BioScience*. 63, pp.164-175.

Kirk, E. and Poppotanachai, N. (2018). Marine plastics: Fragmentation, effectiveness and legitimacy in international lawmaking. *Review of European, Comparative and International Law*. 27, pp.222-233.

Klöckner, C. (2013). A comprehensive model of the psychology of environmental behaviour—A meta-analysis, *Global Environmental Change*. 23, pp.1028-1038.

Knoblauch, D., Mederake, L. and Stein, U. (2018). Developing countries in the lead—What drives the diffusion of plastic bag policies? *Sustainability.*10. pp.1994.

Kovač Viršek, M., Palatinus, A., Koren, S., Peterlin, M., Horvat, P. and Kržan, A. (2016). Protocol for Microplastics Sampling on the Sea Surface and Sample Analysis. *Journal of Visualized Experiments.* 118. e55161.

Kratochwill, L. (2016). *Too Good To Be True? The Ocean Cleanup Project Faces Feasibility Questions*. [online] the Guardian. Available at: <https://www.theguardian.com/environment/2016/mar/26/ocean-cleanup-project-environment-pollution-boyan-slat> [Accessed 16 November 2020].

Kühn, S., Schaafsma, F., van Werven, B., Flores, H., Bergmann, M., Egelkraut-Holtus, M., Tekman, M. and van Franeker, J. (2018). Plastic ingestion by juvenile polar cod (Boreogadus saida) in the Arctic Ocean. *Polar Biology*. 41, pp.1269-1278.

Kühn, S., Van Franeker, J. and Bravo Rebolledo, E. (2015). Deleterious effects of litter on marine life. In: Bergmann, M., Gutow, L. and Klages, M. (Eds). *Marine Anthropogenic Litter*. Springer: New York. 4, pp.75–116

Kuklinski, P., Wicikowski, L., Koper, M., Grala, T., Leniec-Koper, H., Barasiński, M., Talar, M., Kamiński, I., Kibart, R. and Małecki, W. (2019). Offshore surface waters of Antarctica are free of microplastics, as revealed by a circum-Antarctic study. *Marine Pollution Bulletin*. 149, pp.110573.

Kulshreshtha, P. and Sarangi, S. (2001). "No Return, No Refund": An Analysis of Deposit–Refund Systems. *Journal of Economic Behavior and Organization*. 379, pp.379-394.

Kumar, P. (2018). Role of Plastics on Human Health. *The Indian Journal of Pediatrics*, 85, pp.384-389.

Kunz, N., Mayers, K. and Van Wassenhove, L. (2018). Stakeholder views on extended producer responsibility and the circular economy. *California Management Review.* 60, pp. 45-70.

Kuo, F. and Huang, H. (2014). Strategy for mitigation of marine debris: analysis of sources and composition of marine debris in northern Taiwan. *Marine Pollution Bulletin*. 83, pp. 70-81

Laist, D. (1997). Impacts of Marine Debris: Entanglement of Marine Life in Marine Debris Including a Comprehensive List of Species with Entanglement and Ingestion Records. In: Coe, J. and Rogers, D. (Eds). *Marine Debris*. Springer Series on Environmental Management. Springer: New York.

Lambert, S. and Wagner, M. (2018). Freshwater Microplastics Emerging Environmental Contaminants?. *The Handbook of Environmental Chemistry*. 58, pp.1-25.

Landon-Lane, M. (2018). Corporate social responsibility in marine plastic debris governance. *Marine Pollution Bulletin*. 127, pp.310-319.

Landrigan, P., Fuller, R., Hu, H., Caravanos, J., Cropper, M., Hanrahan, D., Sandilya, K., Chiles, T., Kumar, P. and Suk, W. (2018). Pollution and Global Health – An Agenda for Prevention. *Environmental Health Perspectives*. 126, pp.084501.

Lane, E. (2012). Green Marketing goes Negative: The Advent of Reverse Greenwashing. *European Journal of Risk Regulation.* 3, pp.582-588.

Laville, S. (2018). *Will A 25p Charge Change Britain's Throwaway Coffee Cup Culture?*. [online] Available at: <https://www.theguardian.com/environment/2018/jan/05/will-a-25p-charge-change-britains-throwaway-coffee-cup-culture> [Accessed 8 April 2020].

Laville, S. and Taylor, M. (2017). *A Million Bottles a Minute: World's Plastic Binge 'as Dangerous as Climate Change'*. [online] Available at: <https://www.theguardian.com/environment/2017/jun/28/a-million-a-minute-worlds-plastic-bottle-binge-as-dangerous-as-climate-change> [Accessed 19 March 2020].

Law, K. and Thompson, R. (2014). Microplastics in the seas. *Science*. 345, pp.144-145.

Law, K., Morét-Ferguson, S., Goodwin, D., Zettler, E., DeForce, E., Kukulka, T. and Proskurowski, G. (2014). Distribution of Surface Plastic Debris in the

Eastern Pacific Ocean from an 11-Year Data Set. *Environmental Science & Technology*. 48, pp.4732-4738.

Law, K., Moret-Ferguson, S., Maximenko, N., Proskurowski, G., Peacock, E., Hafner, J. and Reddy, C. (2010). Plastic Accumulation in the North Atlantic Subtropical Gyre. *Science*. 329, pp.1185-1188.

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

Lebreton, L., Slat, B., Ferrari, F., Sainte-Rose, B., Aitken, J., Marthouse, R., Hajbane, S., Cunsolo, S., Schwarz, A., Levivier, A., Noble, K., Debeljak, P., Maral, H., Schoeneich-Argent, R., Brambini, R. and Reisser, J. (2018). Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. *Scientific Reports*. 8, pp.4666.

Lebreton, L., Van der Zwet, J., Damsteeg, J., Slat, B., Andrady, A. and Reisser, J. (2017). River plastic emissions to the world's oceans. *Nature Communications*. 8, pp.15611.

Liu, J., Feng, Y., Zhu, Q. and Sarkis, J. (2018). Green supply chain management and the circular economy: Reviewing theory for advancement of both fields. *International Journal of Physical Distribution & Logistics Management*. 48, pp.794-817.

Liu, J., Mickley, L., Sulprizio, M., Dominici, F., Yue, X., Ebisu, K., Anderson, G., Khan, R., Bravo, M. and Bell, M. (2016). Particulate air pollution from wildfires in the Western US under climate change. *Climatic Change*. 138, pp.655-666.

Loder, M. and Gerdts, G. (2015). Methodology Used for the Detection and Identification of Microplastics—A Critical Appraisal. In: Bergmann, M., Gutow, L. and Klages, M. (Eds). *Marine Anthropogenic Litter*. Springer: New York. pp.201-227.

Löhr, A., Savelli, H., Beunen, R., Kalz, M., Ragas, A. and Van Belleghem, F. (2017). Solutions for global marine litter pollution. *Current Opinion in Environmental Sustainability.* 28, pp.90-99.

Loizidou, X., Loizides, M. and Orthodoxou, D. (2014). A novel best practices approach: The MARLISCO case. *Marine Pollution Bulletin*. 88, pp.118-128.

London Convention and Protocol. (1996). *1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter.*

London Convention. (1972). *Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter.*

Lotze, H., Guest, H., Apos Leary, J., Tuda, A. and Wallace, D. (2018). Public perceptions of marine threats and protection from around the world*. Ocean Coast Management*. 152, pp.14-22.

Lupton, D. (2014). The pedagogy of disgust: the ethical, moral and political implications of using disgust in public health campaigns. *Critical Public Health*. 25, pp.4-14.

Lusher, A. (2015). Microplastics in the Marine Environment: Distribution, Interactions and Effects. In: Bergmann, M., Gutow, L. and Klages, M. (Eds). *Marine Anthropogenic Litter*. Springer: New York. pp.245–307.

Lusher, A., Burke, A., O’Connor, I. and Officer, R. (2014). Microplastic pollution in the Northeast Atlantic Ocean: Validated and opportunistic sampling. *Marine Pollution Bulletin*. 88, pp.325-333.

Lusher, A., McHugh, M. and Thompson, R. (2013). Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. *Marine Pollution Bulletin*. 67, pp.94-99.

Lusher, A., O'Donnell, C., Officer, R. and O'Connor, I. (2015). Microplastic interactions with North Atlantic mesopelagic fish. *ICES Journal of Marine Science*. 73, pp.1214-1225.

Lusher, A., Tirelli, V., O’Connor, I. and Officer, R. (2015). Microplastics in Arctic polar waters: the first reported values of particles in surface and sub-surface samples. *Scientific Reports*. 5, pp.14947.

Luyt, A. And Malik, S. (2019). Can Biodegradable Plastics Solve Plastic Soil Waste Accumulation?. *Fuel, Chemicals and Sustainability Implications*. pp.403-423.

MacBride, S. (2012). *Recycling Reconsidered: The Present Failure and Future Promise of Environmental Action in the United States*. MIT Press: Cambridge.

Macfadyen, G., Huntington, T. and Cappell, R. (2009). *Abandoned, Lost Or Otherwise Discarded Fishing Gear*. Food and Agriculture Organization of the United Nations, Rome.

Maes, T., Perry, J., Alliji, K., Clarke, C. and Birchenough, S. (2019). Shades of grey: Marine litter research developments in Europe. *Marine Pollution Bulletin*. 146, pp.274-281.

Malinkauskaithe, J., Juhara, H. and Spencer, N. (2017). Waste prevention and technologies in the context of the EU Waste Framework Directive: lost in translation?. *European Energy and Environmental Law Review*. 26, pp.69.

Markowicz, F., Król, G. and Szymańska-Pulikowska, A. (2019). Biodegradable package–Innovative purpose or source of the problem. *Journal of Ecological Engineering*. 20, pp.228-237.

Marks & Spencer. (2008). *Schwopping*. [online] Available at: <https://www.marksandspencer.com/c/plan-a-shwopping> [Accessed 4 April 2020].

Marks & Spencer. (2020). *Our Plastics Plan*. [online]. Available at: <https://corporate.marksandspencer.com/sustainability/quick-reads/our-plastics-plan> [Accessed 4 April 2020].

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

Mayer, F. and Frantz, C. (2004). The connectedness to nature scale: A measure of individuals' feeling in community with nature, *Journal of Environmental Psychology*. 24, pp.503-515.

McBain, B., Lenzen, M., Wackernagel, M. and Albrecht, G. (2017). How long can global ecological overshoot last? *Global Planetary Change*. 155, pp.13-19.

McIlgorm, A., Campbell, H. and Rule, M. (2011). The economic cost and control of marine debris damage in the Asia-Pacific region. *Ocean and Coastal Management*. 54, pp.643-651.

McIlwraith, H., Lin, J., Erdle, L., Mallos, N., Diamon, M. and Rochmann, C. (2019). Capturing microfibers – marketed technologies reduce microfiber emissions from washing machines. *Marine Pollution Bulletin*. 139, pp.40-45.

McPherson, K. (2015). *Charting a course for oceans education and environmental studies, sustainable oceans.* In: Proceedings of the Healthy Oceans Healthy Canada Conference, Dalhousie University.

Mendenhall, E. (2018). Oceans of plastic: a research agenda to propel policy development. *Marine Policy*. 96, pp.291-298.

Monnier, J., Tourigny, G., Soveran, D., Wong, A., Hogan, E. and Stumborg, M. (1998). Conversion of biomass feedstock to diesel fuel additive. *Fuel and Energy Abstracts*. 39, pp.283.

Moore, C., Moore, S., Leecaster, M. and Weisberg, S. (2001). A Comparison of Plastic and Plankton in the North Pacific Central Gyre. *Marine Pollution Bulletin*. 42, pp.1297-1300.

Morét-Ferguson, S., Law, K., Proskurowski, G., Murphy, E., Peacock, E. and Reddy, C. (2010). The size, mass, and composition of plastic debris in the western North Atlantic Ocean. *Marine Pollution Bulletin*. 60, pp.1873-1878.

Morrisons. (2018). *The UK Plastic PACT* **|** *Morrisons*. [online] Morrisons. Available at: <https://my.morrisons.com/uk-plastics-pact/> [Accessed 8 April 2020].

Morrison, E., Shipman, A., Shrestha, S., Squier, E. and Stack Whitney, K. (2019). Evaluating The Ocean Cleanup, a Marine Debris Removal Project in the North Pacific Gyre, Using SWOT Analysis. *Case Studies in the Environment*, 3, pp.1-6.

Morrissey, K. (2019). Aligning Ocean Plastic Pollution and Human Health a Co-benefits Approach. *Journal of Ocean and Coastal Economics*. 6.

Moser, S. C., & Dilling, L. (2007). Toward the social tipping point: creating a climate for change. In: *Creating a climate for change: Communicating climate change and facilitating social change.* Cambridge University Press. 16, pp.675-713.

Mu, J., Qu, L., Jin, F., Zhang, S., Fang, C., Ma, X., Zhang, W., Huo, C., Cong, Y. and Wang, J. (2019). Abundance and distribution of microplastics in the surface sediments from the northern Bering and Chukchi Seas. *Environmental Pollution*. 245, pp.122-130.

Munari, C., Scoponi, M. and Mistri, M. (2017). Plastic debris in the Mediterranean Sea: Types, occurrence and distribution along Adriatic shorelines. *Waste Management*. 67, pp.385-391.

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, pp.161-165.

Muralidharan, S. and Sheehan, K., 2017. “Tax” and “Fee” Frames in Green Advertisements: The Influence of Self-Transcendence in Reusable Bag Usage. *Journal of Promotion Management*. 23, pp.851-871.

Musioł, M., Rydz, J., Janeczek, H., Radecka, I., Jiang, G. and Kowalczuk, M. (2017). Forensic engineering of advanced polymeric materials Part IV: Case study of oxo-biodegradable polyethylene commercial bag – Aging in biotic and abiotic environment. *Waste Management*. 64, pp.20-27.

Napper, I. and Thompson, R. (2016). Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions. *Marine Pollution Bulletin*. 112, pp.39-45.

Napper, I. and Thompson, R. (2019). Environmental deterioration of biodegradable, oxo-biodegradable, compostable, and conventional plastic carrier bags in the sea, soil, and open-air over a 3-year period. *Environmental Science and Technology*. 53, pp.4775-4783.

National Geographic. (2018). *What You Need To Know About Plant-Based Plastics*. [online] Available at: <https://www.nationalgeographic.com/environment/2018/11/are-bioplastics-made-from-plants-better-for-environment-ocean-plastic/> [Accessed 4 April 2020].

Nelms, S., Coombes, C., Foster, L., Galloway, T., Godley, B., Lindeque, P. and Witt, M. (2017). Marine anthropogenic litter on British beaches: A 10-year nationwide assessment using citizen science data. *Science of The Total Environment*. 579, pp.1399-1409.

Nelms, S., Galloway, T., Godley, B., Jarvis, D. and Lindeque, P. (2018). Investigating microplastic trophic transfer in marine top predators. *Environmental Pollution*. 238, pp.999-1007.

Net-Works. (2012). *Home - Net-Works*. [online] Available at: <https://net-works.com/> [Accessed 9 April 2020].

Neumann, B., Vafeidis,A., Zimmermann, J. and Nicholls, R. (2015). Future coastal population growth and exposure to sea-level rise and coastal flooding-a global assessment. *PLoS One*. 10, e0131375.

Norwegian Environment Agency. (2019). *Reduced Littering of Single Use Plastics.* [online] Available at: <https://www.eunomia.co.uk/reports-tools/reducing-littering-of-single-use-plastics/> [Accessed 23 April 2020].

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

Ocean Conservancy. (2014). *Turning the tide on trash*. International Coastal Cleanup, Washington. 28.

Ocean Conservancy. (2015). *Trash Free Seas Alliance*. International Coastal Cleanup, Washington.

Ocean Wise. (2018). [Interview by Lead Author, Name Withheld]

Ochiewo, J., Rasolofojaona, H., Seewoobaduth, J., Pereira, M., Gonzalves, C., Ryan, P. and Lukambusi, L. (2007). *Regional Overview and Assessment of Marine Litter Related Activities in the West Indian Ocean Region*. WIOMSA Report to the United Nations Environment Programme (UNEP).

OECD, (2001). *Extended producer responsibility: Guidance manual for governments.* [online] Available at <https://read.oecd-ilibrary.org/environment/extended-producer-responsibility_9789264189867-en#page1> [Accessed 19 March 2020].

Oosterhuis, F., Bartelings, H., Linderhof, V. and van Beukering, P. (2009). *Economic Instruments and Waste Policies in the Netherlands.* Inventory and Options for Extended Use.

Oosterhuis, F., Papyrakis, E. and Boteler, B. (2014). Economic instruments and marine litter control. *Ocean & Coastal Management*. 102, pp.47-54.

OSPAR. (2010). *OSPAR Commission, Protecting And Conserving The North-East Atlantic And Its Resources*. [online] Available at: <https://www.ospar.org> [Accessed 20 March 2020].

Pacheco-Vega, R. (2018). *Toward an understanding of the global political economy of plastic water bottles.* Unpublished Conference Paper Presented at the International Studies Association Annual Conference, San Francisco.

Packaging News. (2017). *Herald Plastic Introduces Edible Straw*. [online] Available at: <https://www.packagingnews.co.uk/news/markets/foodservice/herald-plastic-introduces-edible-straw-23-05-2017> [Accessed 8 April 2020].

Pahl, S. and Wyles, K. (2017). The human dimension: how social and behavioural research methods can help address microplastics in the environment. *Analytical Methods*. 9, pp.1404-1411.

Pahl, S., Wyles, K. and Thompson, R. (2017). Channeling passion for the ocean towards plastic pollution. *Nature Human Behaviour*. 1, pp.697-699.

Pak, V., McCauley, L. And Pinto-Martin, J. (2011). Phthalate Exposures and Human Health Concerns: A Review and Implications for Practice. *AAOHN Journal*. 59, pp.234-235.

Palassis, S. (2011). Marine pollution and environmental law. In: Baird, R. and Rothwell, D. (Eds) *Australian coastal and marine law*. The Federation Press: Australia.

Pan, Z., Sun, X., Guo, H., Cai, S., Chen, H., Wang, S., Zhang, Y., Lin, H. and Huang, J. (2019). Prevalence of microplastic pollution in the Northwestern Pacific Ocean. *Chemosphere*. 225, pp.735-744.

Parker, L. (2018). *We Made Plastic. We Depend On It. Now We're Drowning In It*. [ebook] Available at: <https://www.imphaltimes.com/pdf/2019/April/4%20April%20Page%202.pdf> [Accessed 6 April 2020].

PARLEY. (2020). *PARLEY*. [online] Available at: <https://www.parley.tv/#fortheoceans> [Accessed 9 April 2020].

Pearson, E., Mellish, S., Sanders, B. and Litchfield, C. (2014). Marine wildlife entanglement: assessing knowledge, attitudes, and relevant behaviour in the Australian community. *Marine Pollution Bulletin*. 89, pp.136-148.

Pedrotti, M., Petit, S., Elineau, A., Bruzaud, S., Crebassa, J., Dumontet, B., Martí, E., Gorsky, G. and Cózar, A. (2016). Changes in the Floating Plastic Pollution of the Mediterranean Sea in Relation to the Distance to Land. *PLOS ONE*. 11, e0161581.

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

Pellini, G., Gomiero, A., Fortibuoni, T., Ferrà, C., Grati, F., Tassetti, A., Polidori, P., Fabi, G. and Scarcella, G. (2018). Characterization of microplastic litter in the gastrointestinal tract of Solea solea from the Adriatic Sea. *Environmental Pollution*. 234, pp.943-952.

Pettipas, S., Bernier, M. and Walker, T. (2016). A Canadian policy framework to mitigate plastic marine pollution. *Marine Policy*. 68, pp.117-122.

Pham, C., Ramirez-Llodra, E., Alt, C., Amaro, T., Bergmann, M., Canals, M., Company, J., Davies, J., Duineveld, G., Galgani, F., Howell, K., Huvenne, V., Isidro, E., Jones, D., Lastras, G., Morato, T., Gomes-Pereira, J., Purser, A., Stewart, H., Tojeira, I., Tubau, X., Van Rooij, D. and Tyler, P. (2014). Marine Litter Distribution and Density in European Seas, from the Shelves to Deep Basins. *PLoS ONE*. 9, e95839.

Phuong, N., Zalouk-Vergnoux, A., Poirier, L., Kamari, A., Châtel, A., Mouneyrac, C. and Lagarde, F. (2016). Is there any consistency between the microplastics found in the field and those used in laboratory experiments?. *Environmental Pollution*. 211, pp.111-123.

Pierdomenico, M., Casalbore, D. and Latino, F. (2019). Massive benthic litter funneled to deep sea by flash-flood generated hyperpycnal flows. *Scientific Reports*. 9, pp.5330.

Pirc, U., Vidmar, M., Mozer, A. and Kržan, A. (2016). Emissions of microplastic fibers from microfiber fleece during domestic washing. *Environmental Science and Pollution Researc*h. 23, pp.22206-22211.

PlasticsEurope. (2008). *The Compelling Facts About Plastics: An Analysis of Plastics Productions, Demand and Recovery for 2006 in Europe*, pp.24.

PlasticsEurope. (2010). *Plastics - The Facts 2010.*

PlasticsEurope. *(2016). Plastics - The Facts 2016.*

PlasticsEurope. (2018). *Plastics - The Facts 2017: An Analysis of European Plastics Production, Demand and Waste Data.*

Plastic Solutions Fund, (2020). *Home - Plastic Solutions Fund*. [online] Available at: <https://plasticsolution.org/> [Accessed 18 December 2020].

Portman, M. and Brennan, R. (2017). Marine litter from beach-based sources: case study of an Eastern Mediterranean coastal town. *Marine Pollution Bulletin*. 69, pp.535-544.

Prata, J. (2018). Plastic Litter in Our Oceans: A Case for Government Action. *Ocean Yearbook Online*. 32, pp.283-313.

Rambonnet, L., Vink, S., Land-Zandstra, A. and Bosker, T. (2019). Making citizen science count: best practices and challenges of citizen science projects on plastics in aquatic environments. *Marine Pollution Bulletin*. 145, pp.271-277.

Rangel-Buitrago, N., Williams, A., Costa, M. and de Jonge, V. (2020). Curbing the inexorable rising in marine litter: An overview. *Ocean & Coastal Management*. 188, pp.105133.

Raubenheimer, K. (2016). *Towards an Improved Framework to Prevent Marine Plastic Debris*. Doctor of Philosophy Thesis, Australian National Centre for Ocean Resources and Security (ANCORS).

Raubenheimer, K. and McIlgorm, A. (2017). Is the Montreal protocol a model that can help solve the global marine plastic debris problem? *Marine Policy*. 81, pp.322–329.

Raubenheimer, K. and Urho, N. (2020). Rethinking global governance of plastics – The role of industry. *Marine Policy*. 113, pp.103802.

Raubenheimer, K., McIlgorm, A. and Oral, N. (2018**).** Towards an improved international framework to govern the life cycle of plastics. *Review of European, Comparative and International Environmental Law*. 27, pp. 210-221.

Raubenheimer, K., Oral, N. and McIlgorm, A. (2017). *Combating marine plastic litter and microplastics: An assessment of the effectiveness of relevant international, regional and subregional governance strategies and approaches*. A report to UN Environment.

Rech, S., Borrell, Y. and García-Vazquez, E. (2016). Marine litter as a vector for non-native species: what we need to know. *Marine Pollution Bulletin*. 113, pp.40-43.

Reed, S., Clark, M., Thompson, R. and Hughes, K. (2018). Microplastics in marine sediments near Rothera Research Station. *Antarctica Marine Pollution Bulletin*. 133, pp.460-463.

Reisser, J., Shaw, J., Wilcox, C., Hardesty, B., Proietti, M., Thums, M. and Pattiaratchi, C. (2013). Marine Plastic Pollution in Waters around Australia: Characteristics, Concentrations, and Pathways. *PLoS ONE*. 8, e80466.

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, pp.1249-1256.

Remy, F., Collard, F., Gilbert, B., Compère, P., Eppe, G. and Lepoint, G. (2015). When Microplastic Is Not Plastic: The Ingestion of Artificial Cellulose Fibers by Macrofauna Living in Seagrass Macrophytodetritus. *Environmental Science & Technology*. 49, pp.11158-11166.

Renner, S. (2004). Plant Dispersal across the Tropical Atlantic by Wind and Sea Currents. *International Journal of Plant Sciences*, 165(S4), pp.S23-S33.
Resource Magazine. (2016). *Adidas Launch Recycled Ocean Plastic Football Kits*. [online] Available at: <https://resource.co/article/adidas-launch-recycled-ocean-plastic-football-kits-11466> [Accessed 9 April 2020].

Rios, L., Jones, P., Moore, C. and Narayan, U. (2010). Quantitation of persistent organic pollutants adsorbed on plastic debris from the Northern

Pacific Gyre's “eastern garbage patch”. *Journal of Environmental Monitoring*. 12, pp.2226.

Rochman, C., Brookson, C., Bikker, J., Djuric, N., Earn, A., Bucci, K., Athey, S., Huntington, A., McIlwraith, H., Munno, K., De Frond, H., Kolomijeca, A., Erdle, L., Grbic, J., Bayoumi, M., Borrelle, S., Wu, T., Santoro, S., Werbowski, L., Zhu, X., Giles, R., Hamilton, B., Thaysen, C., Kaura, A., Klasios, N., Ead, L., Kim, J., Sherlock, C., Ho, A. and Hung, C. (2019). Rethinking microplastics as a diverse contaminant suite. *Environmental Toxicology and Chemistry*. 38, pp.703-711.

Rochman, C., Browne, M., Halpern, B., Hentschel, B., Hoh, E., Karapanagioti, H., Rios-Mendoza, L., Takada, H., Teh, S. and Thompson, R. (2013). Classify plastic waste as hazardous. *Nature*. 494, pp.169-171.

Rubin, B., 2011. Bisphenol A: An endocrine disruptor with widespread exposure and multiple effects. *The Journal of Steroid Biochemistry and Molecular Biology*. 127, pp.27-34.

Rujnićsokele, M. and Pilipović, A. (2017). Challenges and opportunities of biodegradable plastics: a mini review. *Waste Management Research*. 35, pp.132-140.

Samper, M., Bertomeu, D., Arrieta, M., Ferri, J. and López-Martínez, J. (2018). Interference of Biodegradable Plastics in the Polypropylene Recycling Process. *Materials*. 11, pp.1886.

SAPEA. (2019). *A Scientific Perspective on Micro-plastics in Nature and Society.* Science Advice for Policy by European Academies, Berlin.

SAS. (1990). *Surfers Against Sewage* | *Environmental Charity Tackling Plastic Pollution*. [online] Surfers Against Sewage. Available at: <https://www.sas.org.uk/> [Accessed 8 April 2020].

SAS. (2017). *SAS Warship Made From Plastic Waste Invades Cornish Coast*. [online] Available at: <https://www.recyclingwasteworld.co.uk/news/sas-warship-made-from-plastic-waste-invades-cornish-coast/157737/> [Accessed 8 April 2020].

Schmallenbach, K. and Pleiel, J. (2019). What can a Future "Treaty on Biodiversity in Areas Beyond National Jursidiction" Contribute to Solving a Global Problem. *Archiv des Völkerrechts.* 57, pp.1-25

Schmidt, C., Krauth, T. and Wagner, S. (2017). Export of plastic debris by rivers into the sea. *Environmental Science and Technology*. 51, pp.1246-1253.

Schmidt, N., Thibault, D., Galgani, F., Paluselli, A. and Sempéré, R. (2018). Occurrence of microplastics in surface waters of the Gulf of Lion (NW Mediterranean Sea). *Progress in Oceanography*. 163, pp.214-220.

Schmuck, D., Matthes, J. and Naderer, B. (2018). Misleading Consumers with Green Advertising? An Affect–Reason–Involvement Account of

Greenwashing Effects in Environmental Advertising. *Journal of Advertising*. 47, pp.127-145.

Schneider, F., Parsons, S., Clift, S., Stolte, A. and McManus, M. (2018). Collected marine litter – A growing waste challenge. *Marine Pollution Bulletin*. 128, pp.162-174

Schuyler, Q., Hardesty, B., Wilcox, C. and Townsend, K. (2013). Global Analysis of Anthropogenic Debris Ingestion by Sea Turtles. *Conservation Biology*. 28, pp.129-139.

Schuyler, Q., Townsend, K., Wilcox, C., Hardesty, B. and Marshall, J. (2014). Marine debris through a turtle-eyed view. *BMC Ecology*. 14, pp.14.

Schweitzer, J., Gionfra, S., Pantzar, M., Mottershead, D., Watkins, E., Petsinaris, F., ten Brink, P., Ptak, E., Lacey, C. and Janssens, C. (2018). *Unwrapped: How Throwaway Plastic Is Failing to Solve Europe's Food Waste Problem (and What We Need to Do Instead)*; Institute for European Environmental Policy AISBL: Brussels, Belgium.

Science. (2018). *Controversial Plastic Trash Collector Begins Maiden Ocean Voyage*. [online] Available at: <https://www.sciencemag.org/news/2018/09/still-controversial-plastic-trash-collector-ocean-begins-maiden-voyage> [Accessed 16 November 2020].

Sea Shepherd, (1971). *Sea Shepherd*. [online] Available at: <https://seashepherd.org/> [Accessed 18 December 2020].

Setälä, O., Fleming-Lehtinen, V. and Lehtiniemi, M. (2014). Ingestion and transfer of microplastics in the planktonic food web. *Environmental Pollution*. 185, pp.77-83.

Setälä, O., Norkko, J. and Lehtiniemi, M. (2016). Feeding type affects microplastic ingestion in a coastal invertebrate community. *Marine Pollution Bulletin*. 102, pp.95-101.

Sheridan, H., Johnson, K. and Capper, A. (2020). Analysis of international, European and Scot's law governing marine litter and integration of policy within regional marine plans. *Ocean & Coastal Management*. 187, pp.105119.

Sherrington, C. (2016). *Plastics In The Marine Environment*. [online] Eunomia. Available at: <https://www.eunomia.co.uk/reports-tools/plastics-in-the-marine-environment/> [Accessed 8 April 2020].

SHiFT, (2020). *Shift - Emily Penn*. [online] Available at: <http://www.emilypenn.co.uk/shift> [Accessed 18 December 2020].

Shortle, J. and Horan, R. (2017). Nutrient Pollution: A Wicked Challenge for Economic Instruments. *Water Economics and Policy*. 03, pp.1650033.

Simon, N. (2016). *We Need a Global Treaty on Plastics: Here's What it Should Look Like*. [online]. Available at <https://ensia.com/voices/we-need-a-global-treaty-on-plastics=heres-what-it-should-look-like> [Accessed 15 March 2020].

Sigler, M. (2014). The effects of plastic pollution on aquatic wildlife: current situations and future solutions, *Water Air Soil Pollution*. 225, pp.2184.

Silva, A., Basto, A., Justino, C., da Costa, J., Duarte, A. and Rocha-Santos, T. (2018). Microplastics in the environment: Challenges in analytical chemistry - A review. *Analytica Chimica Acta.* 1017, pp.1-19.

Simon, N. and Schulte, M. (2017). *Stopping Global Plastic Pollution: the Case for an International Convention.* Ecology Publication Series. Adelphi Berlin.

Simon, N., Knoblauch, D., Mederake, L., McGlade, K., Schulte, L. and Masali, S. (2018). *No More Plastics in the Ocean. Gaps in Global Plastic Governance and Options for a Legally Binding Agreement to Eliminate Marine Plastic Pollution*. Ecology Publication Series. Adelphi, Berlin

Smith, K. (2010). An examination of marketing techniques that influence Millennials' perceptions of whether a product is environmentally friendly. *Journal of Strategic Marketing*. 18, pp.437-450.

Smith, S. and Edgar, R. (2014). Documenting the density of sub-tidal marine debris across multiple marine and coastal habitats. *PLoS One*. 9, e94593.

Sonam, C., Prasad, Y., Anwar, S. and Kumar, C. (2019). Mathematical modelling and analysis of plastic waste pollution and its impact on the ocean surface. *Journal of Ocean Engineering and Science*.

Stachowitsch, M. (2019). *The Beachcomber's Guide to Marine Debris*. Springer: Amsterdam.

Steer, M., Cole, M., Thompson, R. and Lindeque, P. (2017). Microplastic ingestion in fish larvae in the western English Channel. *Environmental Pollution*. 226, pp.250-259.

Steffen, W., Crutzen, P. and McNeill, J. (2007). The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature. *AMBIO: A Journal of the Human Environment*. 36, pp.614-621.

Stoett, P. (2016). *People and plastic: The oceans plastic crisis, global governance, and development norms*. Paper presented to the 2016 ACUNS annual meeting, New York.

Storrier, K. and McGlashan, D. (2006). Development and management of a coastal litter campaign: the voluntary coastal partnership approach. *Marine Policy*. 30, pp.189-196.

Sunstein, C. (2007). Of Montreal and Kyoto: a tale of two protocols. *Harvard Environmental Law Review*. 31, pp.1-65

Sunstein, C. and Thaler, R. (2008). Nudge: improving decisions about health, wealth, and happiness. *Choice Reviews Online*. 46, pp.46-0977-46-0977.

Sussarellu, R., Suquet, M., Thomas, Y., Lambert, C., Fabioux, C., Pernet, M., Le Goïc, N., Quillien, V., Mingant, C., Epelboin, Y., Corporeau, C., Guyomarch, J., Robbens, J., Paul-Pont, I., Soudant, P. and Huvet, A. (2016). Oyster reproduction is affected by exposure to polystyrene microplastics. *Proceedings of the National Academy of Sciences*. 113, pp.2430-2435.

Syberg, K., Hansen, S., Christensen, T. and Khan, F. (2018). Risk Perception of Plastic Pollution: Importance of Stakeholder Involvement and Citizen Science. In Wagner, M. and Lambert, S. (Eds.), *Freshwater Microplastics,* 58, pp. 203-223.

Talvitie, J., Heinonen, M., Pääkkönen, J., Vahtera, E., Mikola, A., Setälä, O. and Vahala, R. (2015). Do wastewater treatment plants act as a potential point source of microplastics? Preliminary study in the coastal Gulf of Finland, Baltic Sea. *Water Science and Technology*. 72, pp.1495-1504.

Tanaka, K. and Takada, H. (2016). Microplastic fragments and microbeads in digestive tracts of planktivorous fish from urban coastal waters. *Scientific Reports*. 6, pp.34351-34359.

Taylor, M., Gwinnett, C., Robinson, L. and Woodall, L. (2016). Plastic microfibre ingestion by deep-sea organisms. *Scientific Reports*. 6, pp.33997.

Tekman, M., Krumpen, T. and Bergmann, M. (2017). Marine litter on deep Arctic seafloor continues to increase and spreads to the North at the HAUSGARTEN observatory. *Deep Sea Research Part I: Oceanographic Research Papers*. 120, pp.88-99.

ten Brink, P., Lutchman, I., Bassi, S., Speck, S., Sheavly, S., Register, K. and Woolaway, C. (2009). *Guidelines on the Use of Market-based Instruments to Address the Problem of Marine Litter*. Institute for European Environmental policy (IEEP).

ten Brink, P., Schweitzer, J., Watkins, E. and M. Howe. (2016). *Plastics Marine Litter and the Circular Economy*: A Briefing by IEEP for the MAVA Foundation. Institute for European Environmental Policy (IEEP).

ten Brink, P., Schweitzer, J., Watkins, E., De Smet, M., Leslie, H. and Galgani, F. (2017). *T20 Task Force Circular Economy: Circular economy measures to keep plastics and their value in the economy, avoid waste and reduce marine litter: Policy Brief for the G20, The 2030 Agenda Climate & Finance Trade & Investment*.

ten Brink, P., Schweitzer, J., Watkins, E., Janssens, C., De Smet, M., Leslie, H. and Galgani, F. (2018). Circular economy measures to keep plastics and their value in the economy, avoid waste and reduce marine litter. *Economics Discussion Papers*. 3.

Teuten, E., Rowland, S., Galloway, T. and Thompson, R. (2007). Potential for Plastics to Transport Hydrophobic Contaminants. *Environmental Science & Technology*. 41, pp.7759-7764.

The Cigarette Surfboard. (2017). *The Film — The Cigarette Surfboard*. [online] Available at: <https://www.thecigarettesurfboard.com/the-film/> [Accessed 9 April 2020].

The Flipflopi. (2018). *The Plasticrevolution — The Flipflopi*. [online] Available at: <http://www.theflipflopi.com/our-mission> [Accessed 9 April 2020].

The Inertia. (2017). *Here'S Why Critics Of Boyan Slat'S Ocean Cleanup Project Are Calling Bullshit*. [online] Available at: <https://www.theinertia.com/environment/heres-why-critics-of-boyan-slats-ocean-cleanup-project-are-calling-bullshit/> [Accessed 16 November 2020].

The Ocean Cleanup. (2013). *The Ocean Cleanup*. [online] Available at: <https://theoceancleanup.com/> [Accessed 9 April 2020].

The Ocean Cleanup. (2018). *How we will rid the Oceans of Plastic*. [video] Available at: <https://youtu.be/du5d5PUrH0I> [Accessed 9 April 2020].

The Verge. (2016). *Adidas' limited edition sneakers are made from recycled ocean waste.* [online] Available at: <http://www.theverge.com/2016/6/8/11881670/adidas-3d-printed-sneaker-competition.> [Accessed 4 April 2020].

Thompson, R. (2004). Lost at Sea: Where Is All the Plastic?. *Science*. 304, pp.838-838.

Trucost. (2016). Plastics and sustainability: a valuation of environmental benefits, costs and opportunities for continuous improvement. [online] Available at: https://plastics.americanchemistry.com/Plasticsand-Sustainability.pdf. [Accessed 4 April 2020].

Tudor, D. and Williams, A. (2008). Important aspects of beach pollution to managers: Wales and the Bristol Channel, UK. *Journal of Coastal Research*. 24, pp.735-745.

U.S. EPA. (2016). Bisphenol A (BPA) action plan. [online] Available at: <https://www.epa.gov/assessing-and-man aging-chemicals-under-tsca/bisphenol-bpa-action-plan.> [Accessed 6 April 2020].

UN Environment. (1987). The Montreal Protocol on Substances that Deplete the Ozone Layer. United Nations Environment Programmed (UNEP) and Ozone Secretariat, Montreal.

UN Environment. (2017). *Clean Seas*. [online] Available at: https://www.cleanseas.org> [Accessed 31 March 2020].

UN Environment. (2017). *Cleanseas*. [online] Available at: <https://www.cleanseas.org> [Accessed 31 March 2020].

UN Environment. (2019). *Marine Litter*. [online] Available at: <https://www.unenvironment.org/explore-topics/oceans-seas/what-we-do/working-regional-seas/marine-litter> [Accessed 31 March 2020].

UNCLOS. (1982). *United Nations Convention on the Law of the Sea*. United Nations.

UNEP. (2009). *Abandoned, Lost or Otherwise Discarded Fishing Gear – Marine Litter : A Global Challenge*. United Nations Environment Programme (UNEP), Food and Agriculture Organization of the United Nations (FAO), Rome.

UNEP. (2014). *Valuing Plastic: The Business Case for Measuring, Managing and Disclosing Plastic Use in the Consumer Goods Industry.* United Nations Environment Programme (UNEP).

UNEP. (2015). *Massive Online Open Course On Marine Litter*. [online] Available at: <https://www.unenvironment.org/explore-topics/oceans-seas/what-we-do/addressing-land-based-pollution/global-partnership-marine-2> [Accessed 10 December 2020].

UNEP. (2016). *Marine Plastic Debris and Microplastics – Global Lessons and Research to Inspire Action and Guide Policy Change*. United Nations Environment Programme (UNEP), Nairobi.

UNEP. (2017). *Global Program of Action for the Protection of the Marine Environment from Land-based Activities.* United Nations Environment Programme (UNEP).

UNEP. (2018) *Single-use plastics: a roadmap for sustainability.* United Nations Environment Programme (UNEP). 72, pp.46-48.

UNEP. (2018). *Report on possible options available under the Basel Convention to further address marine plastic litter and microplastics.* United Nations Environment Assembly (UNEA) of the United Nations Environment Programme (UNEP), Nairobi.

UNEP. (2019). *Sustainable Coastal Tourism – an Integrated Planning Management Approach.* United Nations Environment Programme (UNEP), Milan.

UNEP. and NOAA. (2012). *The Honolulu Strategy: A Global Framework for Prevention and Management of Marine Debris.* United Nations Environment Programme (UNEP) and National Oceanic and Atmospheric Association (NOAA).

UNESCO. (2017). *Policy Monitoring Platform*. [online] Available at: <https://en.unesco.org/creativity/policy-monitoring-platform> [Accessed 8 April 2020].

Unger, A. and Harrison, N. (2016). Fisheries as a source of marine debris on beaches in the United Kingdom. *Marine Pollution Bulletin*. 107, pp.52-58.

United Nations. (2015). Transforming our World: the 2030 Agenda for Sustainable Development, Resolution adopted by the General Assembly on 25 September 2015. [online] Available at: <http://www.un.org/ga/search/view_doc.asp?Symbol=A/ RES/70/1&Lang=E>

UTas. (2018). University of Tasmania. [Interview by Lead Author, Name Withheld]

Van Assche, K., Beunen, R. and Duineveld, M. (2014). *Evolutionary Governance Theory: An Introduction*. 95. Springer: Heidelberg.

Van Cauwenberghe, L. and Janssen, C. (2014). Microplastics in bivalves cultured for human consumption. *Environmental Pollution*. 193, pp.65-70.

van der Velde, T., Milton, D., Lawson, T., Wilcox, C., Lansdell, M., Davis, G., Perkins, G. and Hardesty, B. (2016). Comparison of marine debris data collected by researchers and citizen scientists: is citizen science data worth the effort? *Biological Conservation*. 208, pp.127-138.

van Franeker, J. and Law, K. (2015). Seabirds, gyres and global trends in plastic pollution. *Environmental Pollution*. 203, pp.89-96.

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

VanderZwaag, D. and Powers, A. (2008). The Protection of the Marine Environment from Land-Based Pollution and Activities: Gauging the Tides of Global and Regional Governance. *The International Journal of Marine and Coastal Law*. 23, pp.423-452.

Veiga, J., Vlachogianni, T., Pahl, S., Thompson, R., Kopke, K., Doyle, T., Hartley, B, Maes, T., Orthodoxou, D., Loizidou, X. and Alampei, I. (2016). Enhancing public awareness and promoting coresponsibility for marine litter in Europe: the challenge of MARLISCO. *Marine Pollution Bulletin.* 102, pp.309-315.

Villarrubia-Gómez, P., Cornell, S. and Fabres, J. (2018). Marine plastic pollution as a planetary boundary threat – The drifting piece in the sustainability puzzle. *Marine Policy*. 96, pp.213-220.

Vince, J. and Hardesty, B. (2018). Governance solutions to the tragedy of the commons that marine plastics have become. *Frontiers in Marine Science*. 5, pp.1-10.

Vince, J. and Stoett, P. (2018). From problem to crisis to interdisciplinary solutions: Plastic marine debris. *Marine Policy*. 96, pp.200-203.

von Friesen, L., Granberg, M., Pavlova, O., Magnusson, K., Hassellöv, M. and Gabrielsen, G. (2020). Summer sea ice melt and wastewater are important local sources of microlitter to Svalbard waters. *Environment International*. 139, pp.105511.

Waller, C., Griffiths, H., Waluda, C., Thorpe, S., Loaiza, I., Moreno, B., Pacherres, C. and Hughes, K. (2017). Microplastics in the Antarctic marine system: An emerging area of research. *Science of The Total Environment*. 598, pp.220-227.

Watkins, E., Gionfra, S., Schweitzer, J., Pantzar, M., Janssens, C. and ten Brink, P. (2017). *EPR in the EU Plastics Strategy and the Circular Economy: A focus on plastic packaging.* Institute for European Environmental Policy (IEEP).

Watts, A., Urbina, M., Corr, S., Lewis, C. and Galloway, T. (2015). Ingestion of Plastic Microfibers by the Crab Carcinus maenas and Its Effect on Food Consumption and Energy Balance. *Environmental Science & Technology*. 49, pp.14597-14604.

Welsh Government. (2012). Welsh Government announces ban on single-use plastic in bid to tackle ocean waste. [online] Available at: <https://www.independent.co.uk/life-style/welsh-government-plastic-ban-ocean-waste-a9408166.html> [Accessed 8 April 2020].

Wieczorek, A., Morrison, L., Croot, P., Allcock, A., MacLoughlin, E., Savard, O., Brownlow, H. and Doyle, T. (2018). Frequency of Microplastics in Mesopelagic Fishes from the Northwest Atlantic. *Frontiers in Marine Science*. 5.

Wierckx, N., Narancic, T., Eberlein, C., Wei, R., Drzyzga, O., Magnin, A., Ballerstedt, H., Kenny, S., Pollet, E., Avérous, L., O'Connor, K., Zimmermann, W., Heipieper, H., Prieto, A., Jiménez, J. and Blank, L. (2018). Plastic Biodegradation: Challenges and Opportunities. In: Steffan, R. (eds) *Consequences of Microbial Interactions with Hydrocarbons, Oils, and Lipids: Biodegradation and Bioremediation. Handbook of Hydrocarbon and Lipid Microbiology.* pp.1-29

Williams, A. and Rangel-Buitrago, N. (2019). Marine Litter: solutions for a major environmental problem. *Journal of Coastal Research.* 35, pp.648-663.

Williams, A., Rangel-Buitrago, N., Anfuso, G., Cervantes, O. and Botero, C. (2016). Litter impacts on scenery and tourism on the Colombian north Caribbean coast. *Tourism Management*. 55, pp.209-224.

Willis, K., Maureaud, C., Wilcox, C. and Hardesty, B. (2018). How successful are waste abatement campaigns and government policies at reducing plastic waste into the marine environment?. *Marine Policy*. 96, pp.243-249.

Wilson, S. and Verlis, K. (2017). The ugly face of tourism: marine debris pollution linked to visitation in the southern Great Barrier Reef, Australia. *Marine Pollution Bulletin*. 117, pp.239-246.

Wise, R., Fazey, I., Stafford Smith, M., Park, S., Eakin, H., Archer Van Garderen, E. and Campbell, B. (2014). Reconceptualising adaptation to climate change as part of pathways of change and response. *Global Environmental Change*. 28, pp.325-336.

World Wildlife Fund, (1961). *WWF - Endangered Species Conservation | World Wildlife Fund*. [online] Available at: <https://www.worldwildlife.org/> [Accessed 18 December 2020].

Worm, B., Lotze, H., Jubinville, I., Wilcox, C. and Jambeck, J. (2017). Plastic as a persistent marine pollutant*. Annual Review of Environment and Resources*. 42, pp.1-26.

WRAP. (2014). *UK Voluntary Carrier Bag Monitoring - 2013 Data*. [ebook] Available at: <http://www.wrap.org.uk/sites/files/wrap/Carrier%20Bag%20results%202013.pdf> [Accessed 9 April 2020].

WRAP. (2020). *WRAP - Circular Economy & Resource Efficiency Experts*. [online] Available at: <http://www.wrap.org.uk/> [Accessed 9 April 2020].

Wyles, K., Pahl, S., Thomas, K. and Thompson, R. (2016). Factors That Can Undermine the Psychological Benefits of Coastal Environments. *Environment and Behaviour*. 48, pp.1095-1126.

Wyles, K., Pahl, S., Holland, M. and Thompson, R. (2016). Can Beach Cleans Do More Than Clean-Up Litter? Comparing Beach Cleans to Other Coastal Activities. *Environment & Behaviour*. 49, pp.509-535.

Xanthos, D. and Walker, T. (2017). International policies to reduce plastic marine pollution from single-use plastics (plastic bags and microbeads): a review. *Marine Pollution Bulletin*. 118, pp.17-26.

Yoshida, S., Hiraga, K., Takehana, T., Taniguchi, I., Yamaji, H., Maeda, Y., Toyohara, K., Miyamoto, K., Kimura, Y. and Oda, K. (2016). A bacterium that degrades and assimilates poly(ethylene terephthalate). *Science*. 351, pp.1196-1199.

Young, O. (2011). The Effectiveness of International Environmental Regimes: Existing Know-ledge, Cutting-edge Themes, and Research Strategies. *Proceedings of the National Academy of Sciences*. 108, pp.19853.

Yuhui, M. (2018). Problems and Resolutions in Dealing with Waste Disposable Paper Cups. *Science Progress*. 101, pp.1-7.

Zhao, S., Zhu, L., Wang, T. and Li, D. (2014). Suspended microplastics in the surface water of the Yangtze Estuary System, China: First observations on occurrence, distribution. *Marine Pollution Bulletin*. 86, pp.562-568.

Zielinski, S., Botero, C. and Yanes, A. (2019). To clean or not to clean? A critical review of beach cleaning methods and impacts. *Marine Pollution Bulletin*. 139, pp.390-401.

Zink, T. and Geyer, R. (2017). Circular economy rebound. *Journal of Industrial Ecology*. 21, pp.593-602.

APPENDICES

Appendix 1: *Concentration calculations*

Distance (nautical miles) = *average boat speed* (knots) x *sampling time* (hour)

e.g. 2.6 x 0.5 = 1.3

Distance (metres) = *distance* (nm) x *1852* (length of nautical mile)

e.g. 1.3 x 1852 = 2408

Surface area (m^2) = *distance* (m) x *trawl diameter* (ARC, ATL:0.7; PAC:0.57)

e.g. 2408 x 0.57 = 1372

Concentration (m^{-2}) = *number of SPP's* / *Surface area* (m^2)

e.g. 197 / 1182.2 = 0.167

Concentration (km^{-2}) = *concentration* (m^2) x *1,000,000*

e.g. 0.167 x 1000000 = 167,000

Net aperture = *trawl height* (m) x *trawl diameter* (m)

e.g. ARC and ATL samples: 0.70 x 0.40 = 0.28

e.g. PAC samples: 0.57 x 0.23 = 0.13

Volume (m^3) = (*net aperture* x *distance* (m)) / *2* (assuming 50% efficiency)

e.g. (0.28 x 3871) / 2 = 541.9

Concentration (m^{-3}) = *number of suspected plastic particle* / *Volume* (m3)

e.g. 197 / 135.9 = 1.449

Appendix 2: *Laboratory analysis*

Physical categorisation of SPPs involved identification of type, colour and size in the laboratory (Figure 1.3). The dominant colour of each individual piece noted as was type, classified into five forms commonly found in the marine environment: fibre, film, foam, fragment and pellet (see Eriksen *et al*., 2013; Eriksen *et al.*, 2014; Hartmann *et al*., 2019). Utilising its greatest diameter, every SPP was classified into the following size ranges; microplastic: <1mm, 1.1-2mm, 2.1-3mm, 3.1-4mm, 4.1-5mm; mesoplastic: 5.1-20mm; microplastic: >20mm. It should be noted that based on mesh size, the minimum detection limit of particles collected in each trawl is 330 µm.

A sub-sample of no less than 10% of all SPP's (n=548) were subjected to further analysis using attenuated total reflection-Fourier Transform Infra-red (FT-IR) Spectroscopy (ATR-FTIR; PerkinElmer Spotlight 400 FT-IR Imaging System). Commonly used to identify polymer type, confirming its identification as a true plastic following visual identification as a suspected plastic particle (SPP). Particles were scanned individually operating in reflectance mode, at wavelength 4000-650cm-1, with a resolution of 4cm for optimum efficiency. Spectral comparisons were analysed using PerkinElmer Spectrum software (version 10.5.4.738), incorporating eight commercially available libraries of polymer, polymer additives and adhesive spectra; (adhes.dlb, Atrpolym.dlb, ATRSPE~1.DLB, fibres.dlb, IntPoly.spl, poly1.dlb, polyadd1.dlb and POLYMER.DLB), in addition to a library compiled at the Greenpeace Research Laboratory to identify and exclude common laboratory contaminants (*i.e*. fibre from tissues or clothing, glove fragments, airborne contaminants *etc*). The Spectrum software allows for comparison of obtained particle spectra with the nine built-in libraries, reporting the ten most likely as a spectral match certainty out of 1. The most robust method for acceptance for further analysis was to include spectral results that generated a search score of 0.70 or greater (Lusher *et al*., 2013), and those confirmed upon further detailed microscopic visual inspection (LJ, DS). In all cases, spectral matches were checked by the analyst, to verify the quality of the match and reliability in its identification.

All particles were categorised, counted and concentration calculated (supplementary material) into three reporting units (number of particles m^{-2} / km^{-2} / m^{-3}) (Table 1.1) to facilitate overall comparison to the wider literature (Table 1.3).

Appendix 3*: Contamination Control*

Strict sampling procedures were maintained throughout, minimising possible contamination of samples during at-sea sampling and laboratory analysis. 1. Keeping samples covered and stored appropriately when not in use, handling them only in rooms with limited access and controlled circulation; 2. Samples stored consistently in foil and 200 micron mesh where possible, only using glass or metal equipment rather than plastic; 3. Laboratory surfaces cleaned using 70% ethanol and tissue, with all sampling equipment in the field rinsed with de-ionised water prior to and following use; 4. A 100% cotton lab coat was worn at all times during laboratory analysis, avoiding the use of synthetic textile clothing during sampling; 5. Procedural blanks and contamination samples taken where possible, no particle analysis carried out on-board the vessel, with all samples transported to the lab to be analysed; 6. A library of laboratory contaminants were present in the Perkin Elmer Software library system, highlighting any spectral matches of concern, to control for possible airborne contamination. It should be noted that whilst the vast proportion of sampling and research carried out on large commercial vessels through citizen science programmes boasts significant risk of contamination (through lack of space or appropriate equipment), the vast majority of analysis within this methodology is completed by trained professionals in a laboratory environment, following extensive procedures to minimise contaminants.

A single black fibre (n=1), was identified in all procedural blanks (n=5), thought to originate from synthetic clothing or rope. A number of fragments (n=7), with spectra results matching that of anti-foul paint (multi-component system, with a base of Polyurethane) were identified in ATL samples during FT-IR analysis, however given difference in colour (grey) from control samples and colour of the vessel (blue), visual presence of fouling and degradation in addition to a spectral match of previous library polymer ‘Grey Paint 036 Arctic Sunrise’, it was concluded that these particles were obtained during sea-surface trawls, hence included in analysis. This successfully demonstrates that measures used and implemented during sampling and laboratory analysis were highly effective in preventing contamination.

Appendix 4: *Detailed attribute table of all individually isolated suspected plastic particles*

Table lists; Ocean basin (ARC; ATL; PAC), Date of trawl, sample number and particle number in addition to identified type (Fibre; Film; Foam; Fragment; Pellet), primary colour and size (sub-categories in mm: Microplastic: 0.1-1, 1.1-2, 2.1-3, 3.1-4, 4.1-5; Mesoplastic: 5.1-20; Macroplastic: 20+). Due to the size, the database can be downloaded **here.**