PLASTICS AND SHALLOW WATER CORAL REEFS

Synthesis of the science for policy-makers

UN environment

PLASTICS AND SHALLOW WATER CORAL REEFS

Synthesis of the science for policy-makers

PLASTICS AND SHALLOW WATER CORAL REEFS
Synthesis of the science for policy-makers

Michael Sweet[1], Martin Stelfox[1,2], Joleah Lamb[3],

1. Aquatic Research Facility, Environmental Sustainability Research Centre, University of Derby, Derby, DE22 2EY, UK
2. Olive Ridley Project 11 Dane Close, Bramhall, Stockport, SK73LF, UK
3. Department of Ecology and Evolutionary Biology, School of Biological Sciences, University of California, Irvine, CA 92697 USA

About

The overall purpose of this brief is to provide policy and management recommendations for addressing and reducing the impacts of plastics on shallow water coral reefs, based on current scientific knowledge. In doing so, the brief will contribute to achieving the related global, national and regional goals and targets, including the Sustainable Development Goals (SDGs).
The brief promotes integrated planning and management, awareness-raising, and other efforts to improve and standardise the monitoring of plastics on reefs.

It is primarily aimed at national and state policy-makers. The supporting scientific evidence provides rationale for recommendations and more detailed information for government officials with technical roles, as well as regional environmental organisations and conservation organizations.

Acknowledgements

The following reviewers: Gabriel Grimsditch, Jerker Tamelander, Heidi Savelli-Soderberg, Janna Hamilton, Ahmed Hussein (UN Environment); François Galgani (L'Institut Français de Recherche pour l'Exploitation de la Mer, France) and Perseveranda-Fe J. Otico (Environmental Management Bureau, Philippines) contributed to this document and are gratefully acknowledged. The financial support of Norway and the United States Department of State towards UN Environment's work on marine litter and coral reefs is gratefully acknowledged.

The brief should be cited as:

United Nations Environment Program (2019) Plastics and shallow water coral reefs. Synthesis of the science for policy-makers. Sweet, M; Stelfox, M. Lamb, J. (Authors)

UNIVERSITY OF DERBY

University of California, Irvine

EXECUTIVE SUMMARY

Hundreds of millions of people and industries worth billions of dollars depend on healthy shallow water reef ecosystems (UN Environment, 2018). Yet, anthropogenic stressors, including climate change and pollution, are threatening these fragile ecosystems. As a result, we are now seeing unprecedented levels of decline in reef health and coral cover across the globe.

Plastic, which makes up a sizable proportion of marine pollution, can now be found in all the world's oceans, but it is thought to be in highest concentration in coastal areas and reef environments where the vast majority of this litter originates from land-based sources.

Marine plastic litter pollution is already affecting more than 800 marine and coastal species through ingestion, entanglement and habitat change. With the additional impacts of climate change on coral reef ecosystems, the threat of plastics must be taken seriously. However, there remains a significant lack of knowledge on the true impacts of plastics on the reef environment. This research identifies a number of knowledge gaps that are necessary to address in order to strengthen the scientific evidence base for action on marine plastics that impact coral reefs, and towards achievement of targets set by the global community.

WHAT WE KNOW

The issue of plastics in the marine environment has been recognised by scientists, governmental organisations, non-governmental organisations, private institutions and charities alike. It is recognized as a global priority, including in the 2030 Sustainable Development Agenda, under Sustainability Development Goal (SDG) 14 on conserving and using the oceans, seas and marine resources for sustainable development. Specifically, Target 14.1 is to prevent and significantly reduce marine pollution of all kinds by 2025, with indicator 14.1.1 including an index on floating plastic debris density.

THE SCALE

A landmark study by Jambeck et al. (2015a) calculated that approximately 275 million metric tonnes (MT) of plastic waste was generated by 192 coastal countries, with 4.8 to 12.7 million MT entering the ocean. In the Asia-Pacific region alone, approximately 11.1 billion items of plastic are thought to be present in the shallow water reef environments and this is predicted to rise to more than 15.7 billion by 2025. In addition to the influx of plastics found around coastal areas, five major gyres (or aggregations of floating plastics) have now been identified across the world's oceans. However, a significant proportion of marine litter is unaccountable as estimates on the total amount of litter entering the marine ecosystem are one to three times the magnitude of that reported (Jambeck et al., 2015b).

THE SOURCE

Marine litter, due to its transboundary nature, is found in all the world's oceans and seas, threatening ecosystem health and causing substantial economic costs through its impacts on public health, tourism, shipping, fishing and aquaculture. The majority of marine litter is plastics (60-80%), predominantly from land-based sources through rivers and run-off. Tourism can be among the most significant sources of marine litter and unsurprisingly the most commonly encountered macroplastics in many reef environments are food and drink packages (Lamb et al., 2018). Other sources include direct dumping of solid waste into the ocean; abandoned, lost or discarded fishing gear, referred to as 'ghost gear'; and micro- or nano-plastics, which can include tyre dust, industrial pellets, paint chips, textile particles and cosmetic microbeads.

THE IMPACT

More than 800 species have had some form of encounter with marine litter, of which the majority is plastic. For example, every species of sea turtle has been documented to have been impacted, as well as 66% of marine mammals and 50% of seabirds. Trends over the past two decades have shown that instances of ingestion and entanglement of plastic debris has increased by 49% (Gall & Thompson, 2015). Recently, Lamb et al. (2018) demonstrated a link between macroplastic pollution and increased likelihood of coral disease, with the likelihood of disease rising from 4% to 89% when corals were in contact with plastics. However, across the current breadth of research globally, there remains major knowledge gaps as to the true scale and impact of plastic on reef organisms and the ecosystem as a whole.

WHAT WE NEED TO KNOW

Summary of knowledge gaps associated with reef ecosystems:

1. Understanding of the scale of mismanaged waste in relation to coral reef environments.
2. Understanding of the patterns of plastic pollution in and around coral reef environments.
3. Understanding of the impacts of leaching chemicals from plastics in coral reef environments.
4. Understanding of how, on a wider, more ecologically relevant scale plastics impact coral reef environments.
5. Understanding how macroplastics interact with and affect benthic invertebrates such as sponges and corals.
6. Quantification of the impact of ghost gear and its impact on coral reef communities
7. Understanding the role of macro- and micro-plastics in transporting invasive epibionts and possible pathogenic agents on a global scale.
8. Measuring concentrations of microplastics across coral reef ecoregions to understand the scale of the issue in a standardised manner.
9. Exploring the level of risk microplastics have on reef organisms.
10. Exploring issues with the detection of microplastics in organisms and the surrounding environment.
11. Assessing the quality of current assays used to assess microplastics and validate models for assessing the chance of false negatives and positives in plastic counts.

WHAT WE NEED TO DO

Closing the knowledge gaps highlighted above will allow us to understand the impacts of plastics on reef organisms and the ecosystem as a whole. However, even without this knowledge it remains clear that plastics are a major concern but one which can be addressed. Namely the restriction or elimination of single use plastics on a global scale would have a considerable and measurable impact on the amount of plastics which reach reefs.

This report identifies detrimental impacts of marine plastic litter on shallow water coral reef ecosystems and organisms. In response to these threats, the following recommendations are made in order to advance action on marine litter and SDG Target 14.1, especially in relation to the sustainable management of coral reef ecosystems:

1. ***Strengthen partnerships to eliminate marine litter and plastic pollution***
   Governments, civil society and private sector actors are encouraged to join the Global Partnership on Marine Litter and engage with the partnership to develop plans and targets for reduction of waste that may enter coral reef areas.

2. ***Strengthen national planning to address land-based sources of plastic litter on coral reefs***
   Countries with coral reefs should develop or revise national action plans and local mitigation measures, based on strategic assessments that identify key sources, pathways and impacts of plastics on reefs; identify and manage major local sources of plastic pollution; apply bans on harmful single-use plastics on beaches close to coral reefs; work with key plastic-producing industries to implement liability and compensation schemes based on polluter-pays mechanisms; and address consumer demand to ensure lasting impact.

3. ***Reduce the impact of marine litter from aquaculture, lost and abandoned fishing gear on coral reefs***
   Develop and apply regional regulations and guidelines on eliminating or reducing lost and abandoned fishing gear from entering the ocean on or around coral reefs,

through relevant regional organizations such as Regional Fisheries Management Organizations and Regional Seas Conventions and Action Plans, in close consultation with fishing industries and communities.

4. ***Invest in monitoring and research***

   Financial investment by governments and other entities, and efforts by academic and research institutions is required, in particular, to:

   I. Understand the status and magnitude of marine litter on coral reef ecosystems;
   II. Understand the impact of plastics on coral reef species and ecosystems;
   III. Understand the potential societal and economic impacts of plastics on coral reefs;
   IV. And improve data collection and information to address these knowledge gaps.

TABLE OF CONTENTS

Mismanaged plastic dump site on the coast

A GLOBAL PRIORITY

It has been estimated that over 500 million people, as well as industries worth billions of dollars (including tourism and fisheries) depend on healthy reef ecosystems (Cesar, 2000, Figure 1 A). As such, the continued decline in coral cover and shifts in community composition on a global scale are an extremely worrying trend from economic, social and ecological perspectives (Sweet and Brown, 2016; Hughes *et al.*, 2018). The overarching impacts of anthropogenic stresses, including those related to climate change and pollution, are unarguably responsible for the recent unprecedented declines. However, understanding how these may interact with natural stresses (with regard to their impact on coral reef organisms) remains a challenge, which in turn means management and mitigation of these threats are difficult.

Marine litter is a major anthropogenic stressor and one which is faced by all ecosystems in the marine biome. For this report, litter is defined as any persistent, manufactured or processed solid material discarded, disposed of, or abandoned in the marine and coastal environment (Coe and Rogers, 1997; GPA, 2006). Marine litter is, due to its transboundary nature, found in all the world's oceans and seas, even in remote areas far from human contact and obvious sources of the problem. It thereby constitutes an increasing risk to ecosystem health and biodiversity, while entailing substantial economic costs through its impacts on public health, tourism, shipping, fishing and aquaculture. Coming from both land-based as well as sea-based sources (abandoned, lost or discarded fishing gear, ship-based waste etc.), the majority of marine litter is plastics (60-80%). With regard to reefs, such litter can cause mechanical damage from fishing gear for example, direct uptake of micro- or nano-plastics via feeding, as well as smothering of reefs by certain types of macroplastics. This report aims to discuss these potential impacts and outline current state of knowledge as well as gaps therein with a specific focus on shallow water coral reefs.

Ghost fishing gear dislodging corals

SOURCES OF PLASTICS IN REEF ENVIRONMENTS

Plastics have become increasingly dominant in the consumer marketplace since their commercial development in the 1930s and 40s (Jambeck *et al.*, 2015). This has subsequently led to an increase in influx to the marine environment. The vast majority of plastics entering the marine ecosystem are from land-based sources (Table 1).

Table 1. Sources of plastic pollution reaching the marine ecosystem.

Source	Tonnage of plastics estimated to be entering the marine ecosystem (thousand metric tonnes per annum)
Rivers/land run off – land based	9000
Direct dumping	1500
Fishing gear	640
Lost cargo	600
Vehicle tire dust	270
Industrial pellet spills	230
Road and building paint	210
Textiles	190
Cosmetics	35
Marine paint	16

In 2010 approximately 275 million metric tonnes of plastic waste was generated by 192 countries, with 4.8 to 12.7 million metric tonnes entering the ocean.

A landmark study by Jambeck *et al.* (2015) calculated that approximately 275 million metric tonnes (MT) of plastic waste was generated by 192 coastal countries, with 4.8 to 12.7 million MT entering the ocean. An abridged version of the Table – whereby mismanaged waste is mapped against countries with highest reef area is indicated below (Table 2). Here, Indonesia is ranked as having the highest percentage of the world's reefs and second highest levels of estimated mismanaged plastic waste.

Coastal areas (where the majority of shallow water reefs are found) are generally considered to be amongst the most highly impacted areas by

Table 2. Top 25 countries (from where data is available) in descending order (from highest to lowest) of area percentage of world total of reef within their jurisdiction. Data from World Atlas of Coral Reefs http://coral.unep.ch/atlaspr.htm. Along with the countries' percentage of total mismanaged plastic waste and therefore the plastic marine debris present – taken from (Jambeck *et al.*, 2015).

Country	Reef Area (km^2)	Percentage of World Total (%) – estimated total coverage of reefs = 284,300 km^2	% of total mismanaged plastic waste (as of 2010)	Plastic marine debris [million MT/year] as of 2010
Republic of Indonesia	51,020	17.95	10.10	0.48-1.29
Australia	48,960	17.22	0.01-0.25	
Republic of the Philippines	25,060	8.81	5.90	0.28-0.75
France	14,280	5.02	0.01-0.25	
Papua New Guinea	13,840	4.87	1-5	
Republic of Fiji	10,020	3.52	0.01-0.25	
Republic of Maldives	8,920	3.14	1-5	
Kingdom of Saudi Arabia	6,660	2.34	0.01-0.25	
Republic of the Marshall Islands	6,110	2.15	0.01-0.25	
Republic of India	5,790	2.04	1.90	0.09-0.24
Solomon Islands	5,750	2,02	0.01-0.25	
United Kingdom	5,500	2	0.01-0.25	
Federated States of Micronesia	4,340	1.53	0.01-0.25	
Republic of Vanuatu	4,110	1.45	0.01-0.25	
Arab Republic of Egypt	3,800	1.34	3	0.15-0.39
United States of America	3,770	1.33	0.90	0.04-0.11
Malaysia	3,600	1.27	2.90	0.14-0.37
United Republic of Tanzania	3,580	1.26	0.01-0.25	
Eritrea	3,260	1.15	0.01-0.25	
Commonwealth of the Bahamas	3,150	1.11	0.01-0.25	
Republic of Cuba	3,020	1.06	0.01-0.25	
Kiribati	2,940	1.03	0.01-0.25	
Japan	2,900	1.02	0.01-0.25	
Republic of the Sudan	2,720	0.96	0.01-0.25	
Republic of Madagascar	2,230	0.78	0.01-0.25	

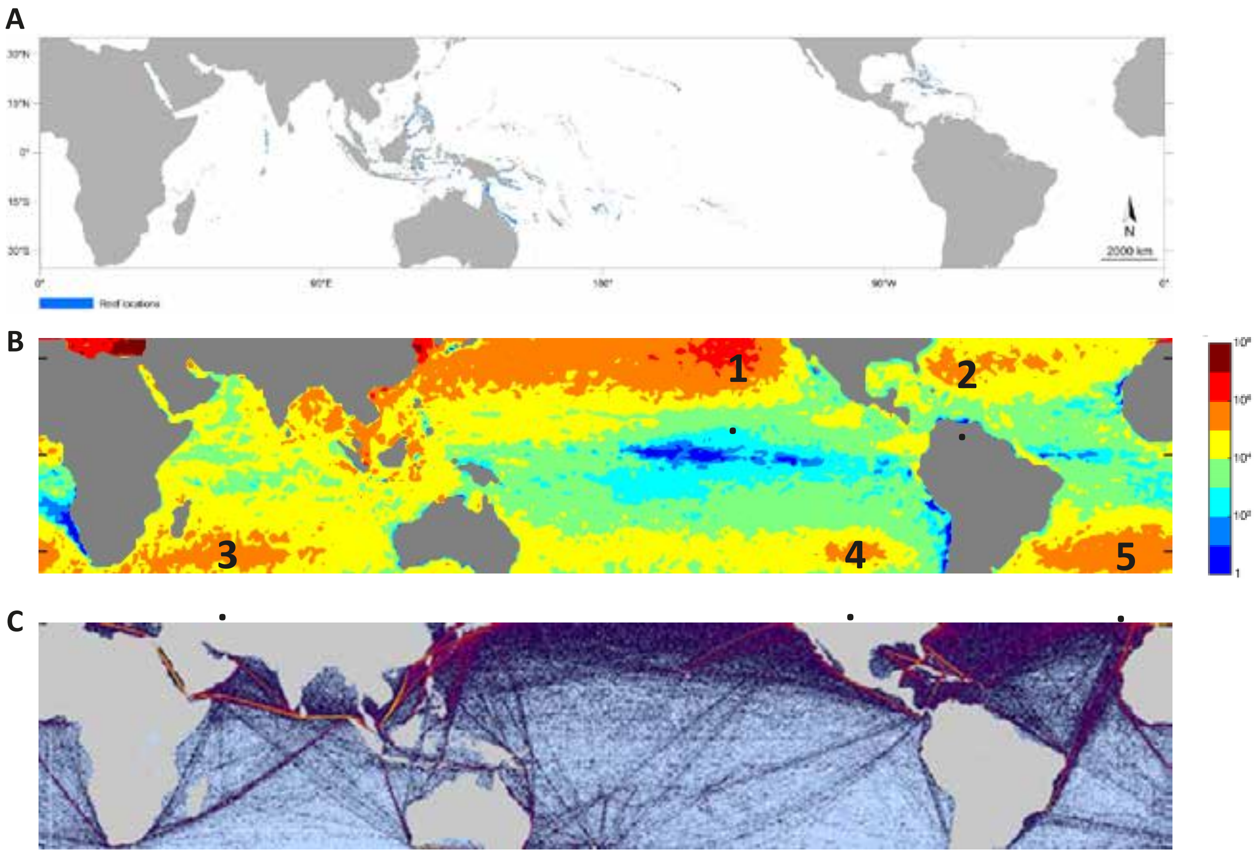

Figure 1 Highlighting reef location (A) against density of surface microplastics present # per km^2 (B) adapted from (Van Sebille *et al.*, 2015). (C) Shipping routes within the tropics. Numbers on B relate to major gyres 1. North Pacific Gyre, 2. North Atlantic Gyre, 3. Indian Ocean Gyre, 4. South Pacific Gyre and 5. South Atlantic Gyre.

plastic pollution. Indeed, recent research indicates that tourism can be among the most significant sources of marine litter such as in the southern Great Barrier Reef (Wilson and Verlis, 2017) and unsurprisingly, the most commonly encountered macroplastics in many reef environments are food and drink packages (Lamb *et al.*, 2018). In addition to the influx of plastics found around coastal areas, five major gyres (or aggregations of floating plastics) have now been identified across the world's oceans (Fig 1 B). However, estimates around the total amount of litter entering the marine ecosystem are in an order of one to three times the magnitude of that reported in any of the floating garbage patches or those found in coastal environments (Jambeck *et al.*, 2015). This suggests that a significant proportion of this litter is unaccountable.

The third major source of marine plastics has been linked to abandoned, lost or discarded fishing gear, also referred to as 'ghost gear', although this 'type' of plastic receives considerably less attention in main stream media than other macroplastics, like straws for example (Stelfox *et al.* 2015). A final 'type' of plastics includes the micro- or nano-plastics, which encompass; tyre dust, industrial pellets, paint chips, textile particles and cosmetic microbeads for example (Table 1).

Marine litter on the beach

Over 700 million metric tonnes of plastic fibres have been produced and washing a single garment releases more than 1900 individual fibres into our rivers and oceans

For these 'types', entry of plastics into the environment can occur at all stages of the life cycle of the product. For example, microplastics can be categorised as either primary or secondary (Thompson, 2015). A source of microplastics is considered primary when it enters the environment as a microplastic - such as synthetic textile fibres from washing machines, microbeads from personal care products or spillage of industrial pellets (Rochman *et al.*, 2016) (Table 1). A secondary, and likely more significant source results when a larger piece of plastic debris (i.e. macroplastics) break into micro-sized or nano-sized pieces via chemical, biological or physical degradation processes (Rochman *et al.*, 2016).

This makes understanding the scale of the issue difficult to quantify. If we look at the quantity of microplastics produced (i.e. the primary source) for only resins and fibres for example, production is thought to be in excess of 380 million MT a year (data for 2015) (Geyer *et al.*, 2017). However, as these microplastics are unlikely to decompose in their entirety, it is worth looking at the total tonnage of these plastics from their initial design in the 1950s. In this context, the amount of plastic fibres alone is predicted to be within the region of 700 million MT (Geyer *et al.*, 2017). Fibres have been documented to be the largest contributing microplastic in the effluent of wastewater-treatment plants. A single garment can produce more than 1900 individual fibres per wash (Browne *et al.*, 2011). Although, removal of a significant amount of this small anthropogenic litter (SAL) can occur in well-managed wastewater treatment (Michielssen *et al.*, 2016). This does vary with the type of treatment utilised. For example, many plants use either, secondary treatment (activated sludge), tertiary treatment (granular sand filtration), both as a final step, or a pilot membrane bioreactor system that finishes treatment with microfiltration. When secondary treatment is utilised, 95.6% of SAL are removed. This increases to 97.2% when tertiary treatment is applied and 99.4% with the membrane bioreactor treatment (Michielssen *et al.*, 2016). However, whilst plants that utilise one of these three methods are clearly reducing the impact of SAL downstream, out of the percentage which escapes, fibres make up the largest proportion. This equates to 79 and 83%, for plants using sand filtration or bioreactors respectively and 44% with the plants utilising activated sludge.

Another major contributor to plastics in the marine environment is that of microbeads. In 2009 alone, 263 tonnes of polyethylene microbeads were utilised in liquid soap products in the US (Gouin *et al.*, 2011). In the EU, 714 tonnes of microbeads were reported to be used in rinse-off personal care products per year, with a further 540-1120 tonnes associated with leave-on products (Scudo *et al.*, 2017). The raw plastic pellets associated with this industry have been shown to comprise approximately 11% by abundance and 7% of weight of the total measurable small plastic debris recorded in Hawaiian beaches (McDermid and McMullen, 2004). This brings us to our first Knowledge Gap.

1: Understanding of the scale of mismanaged waste in relation to coral reef environments

The few studies which have attempted to quantify the amount of plastics associated with reef environments show significant variation, with as little as 0.04×10^{-3} items per m^2 found on Hawaiian beaches, up to 6 items per m^2 in Jordan - the Gulf of Aqaba, Red Sea (Abu-Hilal and Al-Najjar, 2009; Donohue *et al.*, 2001).

Plastic litter on the beach in Myanmar

MACROPLASTICS

There is a huge disparity between global estimates of plastic waste entering the oceans and the amount observed or recorded in any given marine biome. The levels of macroplastics observed on coral reefs (at least in the Asia-Pacific region - Figure 2) do appear to correspond to the estimated levels of plastic litter entering the ocean from the nearest coast (Lamb *et al.*, 2018). Throughout the Asia-Pacific region it was estimated that approximately 0.9 to 26.6 items of macroplastics were present in coastal areas per 100 m^2 in 2010. That equates to around 11.1 billion items in this region. Although staggering, this number is actually likely to be an underestimation, as China and Singapore fell outside of the studies model range and China in particular is a major source of mismanaged waste entering the oceans. Extrapolating the data, the researchers were able to illustrate that by as early as 2025, reefs and their organisms (in the same region) will have been exposed to 15.7 billion macroplastic items under 'business as usual' scenarios – a 40% rise from 2010 levels (Lamb *et al.*, 2018 - Figure 2). This value is not surprising as the same region encompasses 73% of the global population residing within 50 km of the coast (Jambeck *et al.*, 2015).

Accordingly, we utilized the same modeling parameters from Lamb *et al.* (2018) and the global levels of mismanaged plastic waste entering the ocean from Jambeck *et al.* (2015) to extrapolate levels of macroplastic debris on coral reefs to other global regions (Figure 2). Only relatively small changes are predicted to occur (from 2010 levels to 2025) outside of the Asia-Pacific region – with the exception of marked increases in macroplastic debris in Brazil and Egypt. Within the Asia-Pacific region, India by far shows the most worrying predicted changes, suggesting this country will be joining the ranks of Indonesia and China in the next 7 years or less.

As of 2010 an estimated 11.1 billion items of plastic are thought to be in the Asia-Pacific region alone and this is expected to increase to 15.7 billion by 2025.

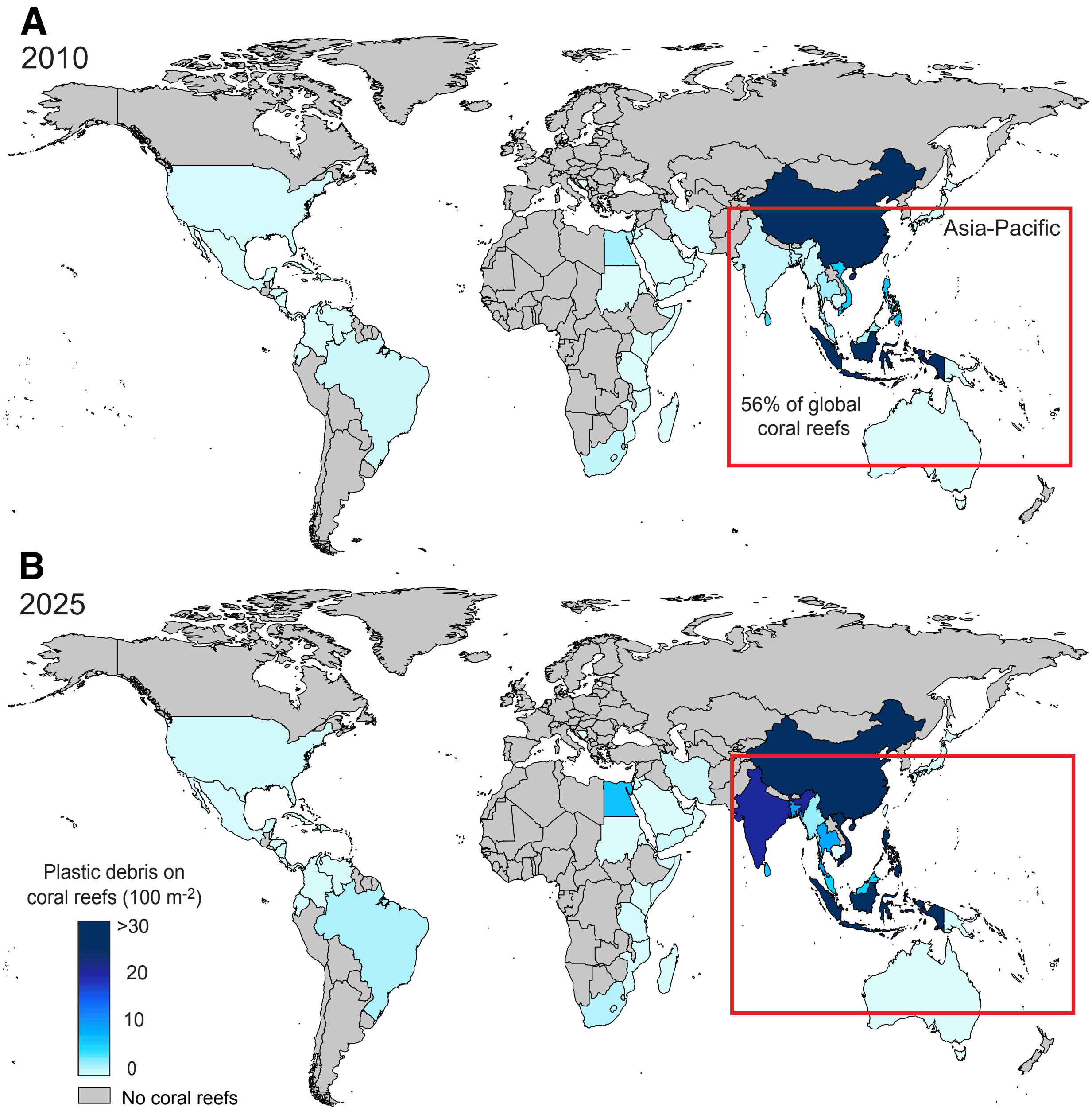

Figure 2. Estimated plastic debris levels estimated on coral reefs in 2010 and projected to 2025. Global dataset extrapolated from Lamb *et al.* 2018 (red square) and Jambeck *et al.* 2015 (global). Jambeck *et al.* (2015) assessed the mass of waste generated per capita annually, the percentage of waste that is plastic; and the percentage of plastic waste that is mismanaged and, therefore, has the potential to enter the ocean as marine debris. A range of conversion rates from mismanaged waste to marine debris was then applied, in order to estimate the mass of plastic waste entering the ocean from each country in 2010. Population growth data was then utilised to further predict growth in the percentage of waste that is plastic up to 2025. The colour scale represents the minima and maxima model estimates of mismanaged plastic waste on coral reefs from 2010. Areas without coral reefs are shown in grey.

Although plastic abundance on coral reefs is associated with the levels of mismanaged plastic in regions less than 50 km from the coast, the issue is certainly global. Levels of macroplastics found associated with an unpopulated island in the Maldives archipelago for example, were recorded at 35.8 particles per m^2 – compared to beaches in Mumbai, India (10-180 particles per m^2) and South Korea (976 particles per m^2) (Imhof *et al.*, 2017). Another study, which focused on one of the world's most remote and pristine islands, Henderson Island (in the South Pacific), estimated the level of macroplastics to be in excess of 37.7 million pieces - weighing 17.6 tonnes (Lavers and Bond, 2017). The authors went on to state that if historic records of plastic pollution were correct in this region, this is a 6.6-79.9% increase since the last time it was surveyed in 1991. Such large numbers in this instance are likely due to this particular study including naturally buried materials in their counts. Buried material is thought to encompass upwards of 68% of the total of plastics in

Buried material is thought to encompass upwards of 68% of the total plastics in a reef environment any given region, so this certainly needs to be taken into account in future studies (Lavers and Bond, 2017). It is therefore important to understand (or differentiate) that plastic loads recorded 'on' coral reefs (i.e. benthic plastic counts) is not necessarily the same as plastic that could 'end up' or 'floating above' a reef – and this is certainly not going to be a linear relationship (Lamb *et al.*, 2018). Indeed, the predicted increase of macroplastic debris on coral reefs is set to happen much faster in developing countries than industrialised ones. For example, between 2010 and 2025 the amount of macroplastic debris on U.S. coral reefs will increase by only about 1%, whereas for Myanmar it will almost double (Figure 2). This leads us to Knowledge Gap 2.

2: Understanding of the patterns of plastic pollution in and around coral reef environments

Impacts of macroplastics on reef organisms

More than 800 species are impacted directly by marine litter and plastics constitute 92% of the type of litter recorded (CBD technical report no. 83). For example, all sea turtles species have now been documented to have been impacted, 66% of marine mammals and 50% of seabirds and these figures appear to be increasing yearly (Kühn *et al.*, 2015). Trends over the last 2 decades have shown that instances of ingestion and entanglement (of plastic debris) has increased by 49% (Gall and Thompson, 2015).

At the time of writing over 700 different species have been documented to have had some form of negative interaction with marine litter (namely plastics).

Ingestion of macroplastics has been implicated in the mortality of a wide range of organisms Including seabirds and cetaceans, sirenians and sea turtles (Jacobsen *et al.*, 2010; Provencher *et al.*, 2014; Santos *et al.*, 2015). The impact of macroplastics on sea turtles in particular has been identified as a major concern as their visual feeding strategies select for structures analogous to jellyfish and soft floating plastics. Furthermore, their backward facing oesophageal papillae inhibit regurgitation and facilitate particle accumulation in the gut (Schuyler *et al.*, 2014; Vegter *et al.*, 2014). Indeed plastic bottle fragments, fishing lines and paint chips are commonly encountered in the guts of sea turtles (Clukey *et al.*, 2017; Wedemeyer-Strombel *et al.*, 2015). In Brazil for example, 70% of juvenile turtles analysed showed plastic ingestion with a mean of 47.5 items per turtle (Santos *et al.*, 2015). In the North-Pacific Ocean, 83% of turtles where shown to have ingested some form of debris (Wedemeyer-Strombel *et al.*, 2015).

Furthermore, in addition to causing blockages of the digestive tracts, many studies have highlighted the possibility of plastics acting as vectors for toxic chemicals and pathogenic agents (Moore, 2008; Von Moos *et al.*, 2012; Besseling *et al.*, 2013). Toxicity can occur via leaching plasticisers and UV stabilisers into the organisms' post ingestion, and/or adsorption of polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), metals and pesticides. Furthermore, accumulation of these toxins can also likely occur as further up the food chain (Caron *et al.*, 2018). However, a critical analysis of the available literature by Koelmans *et al.* (2016) suggested that this particular aspect of plastic pollution posed little concern and lacked any real tangible evidence. This highlights the need for further studies in this area to understand the impacts in more detail – Knowledge Gap 3.

3: Understanding of the impacts of leaching chemicals from plastics in coral reef environments

The majority of documented impacts that plastics have on any given organism are at the sub-organismal or organism level of biological organization and focus is usually on microplastics rather than macroplastics. This is not surprising as many of these studies have focused on laboratory exposure experiments – where the smaller size of microplastics allow for more manageable scaled experiments (Rochman *et al.*, 2016). Such studies have shown evidence of changes in gene expression (Rochman *et al.*, 2014), possible inflammation of tissues (Von Moos *et al.*, 2012) and changes in behaviour and mortality (Browne *et al.*, 2013) in various organisms under a diversity of exposure scenarios.

There are, however, only relatively few studies which demonstrate how macroplastics may cause wider scale ecological impact in reef ecosystems – Knowledge Gap 4.

4: Understanding of how, on a wider, more ecologically relevant scale plastics impact coral reef environments

More field studies are urgently needed as they can highlight the impacts macroplastics have on a whole ecosystem level. For example, Lewis *et al.* (2009) highlighted the direct physical damage lost or abandoned lobster pots could have on the benthic reef communities and Lamb *et al.* (2018) demonstrated a link between macroplastic pollution and increased likelihood of coral disease. The likelihood of disease on corals rose from 4% to 89% when corals were in contact with plastics. However, why this is the case remains to be addressed – Knowledge Gap 5.

5: Understaing how macroplastics interact with and affect benthic invertebrates such as sponges and corals

Although the mechanisms are not yet clear, the influence of macroplastic debris on disease development may differ from organism to organism and from disease to disease. For example, macroplastic debris can likely cause direct damage to the tissue of coral, offering an opening to pathogenic agents like ciliates (Sweet and Bythell, 2015; Sweet and Séré, 2016). Plastic debris could also introduce pathogens directly. Polyvinyl chloride (PVC) (a very common plastic used in children's toys, building materials like pipes, and many other products) has been found carrying a family of bacteria called Rhodobacterales (Dang *et al.*, 2008). Rhodobacterales have been proposed as causal agents of some coral diseases (Soffer *et al.*, 2015). Similarly, polypropylene (used to make bottle caps and toothbrushes for example) can be colonised by members from the genus *Vibrio*, pathogenic bacteria which have been linked to a globally devastating group of coral diseases known as white syndromes and a multitude of other marine diseases that affect invertebrates, fishes and humans (Séré *et al.*, 2015; Sweet *et al.*, 2016; Lamb *et al.*, 2017). Yet, the virulence and disease dynamics of these pathogens 'hitching a ride' on plastics remains unknown (Bidegain and Paul-Pont, 2018). Finally, macroplastic debris overtopping corals can block out light and create low-oxygen conditions that favour the growth of microorganisms, for example those associated with another coral disease known as black band disease (Glas *et al.*, 2012). Furthermore, Lamb *et al.* (2018) highlighted that structurally complex corals (i.e. those accredited for the rugosity of reefs important to support the diversity of life) were eight times more likely to be affected by macroplastics. Such a result may have implications for the microhabitats of reef dwelling organisms. An economic impact of this finding can be linked to a reduction in the fishery productivity in these areas by a factor of 3 (Rogers *et al.*, 2014).

Macroplastics impact reefs by:

1. Direct physical, mechanical damage
2. The introduction of pathogenic agents 'hitch-hiking' on the plastics
3. 'Overtopping' phototrophic animals preventing light from reaching tissue and creating low oxygen levels
4. Direct ingestion and gut blockage
5. Entanglement and entrapment

Plastic packaging litter floating next to a canoe

ABANDONED, LOST OR DISCARDED FISHING GEAR

The vast majority of fishing gear in use today is made from plastics including nylon, polyethylene and polypropylene (Stelfox *et al.*, 2016). Fishing gear can be lost during storms but it can also be abandoned deliberately. The problem surrounding abandoned, lost or discarded fishing gear (more commonly referred to as 'ghost gear') has been well documented in recent years (Phillips, 2017; Richardson *et al.*, 2018; Stelfox *et al.*, 2016; Wilcox *et al.*, 2016). Out of 30,896 individual animals, counted entangled in ghost gear by one study, 79% of cases led to serious injury or death. Of the 13,110 reported to have ingested debris, 4% of cases led to injury and mortality (Gall and Thompson, 2015). For all cases, 92% of the time the marine debris was composed of plastics (Gall and Thompson, 2015; CBD technical report no. 83). Furthermore, the Coordinating Body on the Seas of East Asia (COBSEA) Regional Group on Marine Litter acknowledges significant marine litter generated from aquaculture e.g. loss of packaging, is released in the near shore environment and therefore in the immediate vicinity of coral reefs. A diverse range of materials are used to build and maintain the culture systems, and with the expansion of the aquaculture industry has also come an expansion in the use of synthetic polymers over the last 50 years (Lusher *et al.*, 2017).

Historically, it was estimated that less than 10% of the global marine debris could be attributed to ghost gear (Macfadyen *et al.*, 2009). However, more recent studies have shown contrasting results in this regard (Loulad *et al.*, 2017; Melli *et al.*, 2017; Pham *et al.*, 2014). For example, a study by Lebreton *et al.* (2017) highlighted 46% of the plastics associated with the Great Pacific Garbage Patch or gyre (Fig 1 B No. 1 and 4) were fishing nets, whilst in contrast only 8% were shown to be microplastics. There are however, still very few studies which attempt to quantify the impact on ghost gear globally and even fewer that focus on its impact on coral reefs – Knowledge Gap 6.

Ghost gear is likely to be one of the most significant threats in marine ecosystems and over 46% of plastics found in the 'floating garbage patches' (or gyres) are made up of this plastic type.

6: Quantification of the impact of ghost gear and its impact on coral reef communities

Evidence suggests that ghost gear can smother, entangle, occupy space and increase disease prevalence in coral reef environments (Angiolillo and Canese, 2018; Donohue *et al.*, 2001; Ferrigno *et al.*, 2017). For example, derelict monofilament fishing line has been shown to have a negative impact on the health of corals in Hawaii through entanglement and smothering (Asoh *et al.*, 2004). Moreover, derelict traps and pots can become wind driven during stormy, monsoonal or winter cold fronts and may travel a significant distance from where they were originally deployed. One study in the Florida Keys found this movement to cause significant damage to sponges, octocoral and stony coral in the area (Lewis *et al.*, 2009). Indeed remnant fishing traps and lost hook and line fishing gear accounted for 87% of all debris encountered in a 2001 survey on the Florida Keys and the authors accredited this gear to 84% of the recorded damage found on the adjacent reefs where the debris was located (Chiappone *et al.*, 2005). Such mechanical damage has also been linked with increased levels of disease associated with reef organisms, such as coral (Lamb *et al.*, 2015; 2016).

Damage from ghost gear may also have various indirect impacts on reef environments. For example, ghost nets that become snagged on a coral structure may have the capacity to entangle reef associated animals long after it is lost due to the structure of the mesh remaining intact. The efficiency of ghost gear to trap and kill marine organisms is partly dependent on environmental factors and habitat type (Kaiser *et al.*, 1996) and ghost nets that end up as a pile on the deep ocean floor loose efficiency because of loss in net structure (Stelfox *et al.*, 2016).
Further, ghost gear smothers reefs and block sunlight in a similar manner to that of macroplastics. Although this issue would be difficult to measure, it is reasonable to assume that ghost gear can disrupt productivity on sensitive habitats which may have a negative impact on heterotrophic levels. Disruption may also occur when fouling and encrusting epibionts are transported between regions by ocean currents – Knowledge Gap 7.

7: Exploring the role of macro- and microplastics in transporting invasive epibionts and possible pathogenic agents on a global scale

Invasive 'hitchhikers' clinging to, - or associated with, floating ghost gear could potentially 'jump ship' and invade sensitive reef habitats that may cause the spread of disease or the introduction of invasive species (Carlton *et al.*, 2017). For example, after the 2011 East Japanese earthquake and tsunami, nearly 300 (mainly invertebrate) species reached the shores of the US Pacific Northwest. Most of these 'hitchhikers' arrived attached to manmade structures (Carlton *et al.*, 2017).

Synthetic rope entangling branching coral

Plastic fibre smothering corals and causing death

MICROPLASTICS AND NANOPLASTICS

Microplastics and nanoplastics began accumulating in the oceans more than four decades ago (Allen *et al.*, 2017). In general it is often assumed that coastal ecosystems, such as inshore coral reefs will be particularly heavily impacted by microplastics as these contaminants often enter the marine environment through fragmentation of larger plastic items from terrestrial sources (Table 1, Hall *et al.*, 2015). Studies have indeed shown that a large percentage of the plastics coming from coastal areas remain in the vicinity of the source for a long time, while fragmenting into microplastics (Reisser *et al.*, 2013). Coral reefs are also popular sites for short and long term visits by tourists, as well as trawlers and recreational vessels (Fig 1 C), many of which carry components that are composed of various forms of plastics (Claessens *et al.*, 2011). Routine boating, fishing and other recreational activities can potentially introduce plastic debris into the marine environment through minor damage to boat hulls (releasing paint chips into the ocean) and/or inadvertent loss of ropes and rigging lines, fishing floats and marker buoys (Table 1). Indeed the most commonly encountered microplastics on the Great Barrier Reef have been shown to be made from polyurethane, polystyrene and polyester, - plastics which are commonly found in marine paints and fishing floats (Hall *et al.*, 2015).

8: Measuring concentrations of microplastics across coral reef ecoregions to understand the scale of the issue in a standardised manner

Of the few studies which have explored the concentrations of microplastics in reef environments, only relatively few particles are commonly reported within any given sample. For example in the waters off Mo'orea, microplastics are found at a concentration of 0.74 pieces per m^2 (Connors, 2017) and off the Great Barrier Reef levels are as low as 2 particles per 11,000 litres of seawater (Hall *et al.*, 2015). Closer to the coast however, particle levels do increase and in Australia 4.3 pieces per m^2 have been reported in certain areas (Reisser *et al.*, 2014).

Furthermore, in other (non-reef) environments, microplastic concentrations can be significantly higher. For example, in the North Atlantic, 14 particles per 100 litres of water have been reported (Wieczorek *et al.*, 2018) and record levels have been shown to occur in the sea ice off the Arctic (up to 12,000 microplastic particles per litre) (Obbard *et al.*, 2014). These levels are likely to illustrate a major historic global sink of particles, accumulated over many years. In a similar manner, where currents converge, concentrations in the ocean gyres are also reportedly high (Fig 1 B). For example, 334 pieces of microplastics have been found per m^2 in the North East Pacific (Moore *et al.*, 2001 - Fig 1 B), 324 pieces per m^2 in the Mediterranean (van der Hal *et al.*, 2017 – Fig 1 B) and 396 pieces per m^2 in the South Pacific gyres (Eriksen *et al.*, 2013 - Fig 1 B) or 26,898 particles per km^2 (Eriksen *et al.*, 2014).

Accumulation is also probable in reef sediments (Cheang *et al.*, 2018; Cordova *et al.*, 2018). Yet, from the few studies which have assessed this, concentrations range substantially, from 35 ± 13.98 items/kg to 221 ± 45 items/kg - (Indonesia and Hong Kong, China respectively) (Cheang *et al.*, 2018; Cordova *et al.*, 2018). The proportion of microplastics made from PE and PET in sediments is reportedly higher than that observed in local beach sediments (Cheang *et al.*, 2018).

It should be noted that concentration of microplastics recorded is directly influenced by the sampling approach used, this can and does vary significantly between studies, and makes comparison between studies difficult and almost impossible – hence the need for a standardised approach to measuring microplastic concentrations highlighted in knowledge gap 8 - above.

Consumption of microplastics by organisms at the base of food webs such as mussels (Farrell and Nelson, 2013) and plankton (Cole *et al.*, 2013) have raised concerns about the potential for transfer of plastics and their associated toxins throughout marine food webs (Thompson *et al.*, 2009). Ingestion of plastics has indeed been shown by some studies to result in gut blockage, false saturation and reduced energy reserves in various organisms stemming from laboratory based trials (Allen *et al.*, 2017). Fibres for example, have been shown to form tangled balls in the guts of reef dwelling organisms such as crabs (Watts *et al.*, 2015).

Athough microplastics (and potentially nanoplastics) are commonly found within organisms – there is a substantial contrasting body of evidence which highlights little to no significant impact of plastic exposure (and ingestion) on growth, body condition or behaviour for a number of organisms including reef fish and urchins for example (Kaposi *et al.*, 2014; Critchell and Hoogenboom, 2018).

In fact many organisms have been shown to be able to detect and actively avoid ingestion of the microplastics when the plastics in question were of similar size to their food items (i.e. 2mm in the fish study mentioned here) (Critchell and Hoogenboom, 2018). However, it was also highlighted that when the size of the microplastics available were reduced, the amount of plastic ingestion increased and after 1 week of exposure, upwards of 2102 microplastics (<300μm diameter) were found within the guts of the test subjects (Critchell and Hoogenboom, 2018). As plastics continue to break down (and will therefore naturally get smaller and smaller within the ocean environment), this study highlights that ingestion will undoubtedly be occurring at large scales, though the level of risk still remains undetermined – Knowledge Gap 9.

9: Exploring the level of risk microplastics have on reef organisms

Critchell and Hoogenboom (2018), went on to further conclude that given the additive impacts of climate change on plankton diversity and concentrations, ingestion of microplastics may well increase in the absence of normal fish prey items. Furthermore, the species of fish and the life stage have also been suggested to be factors worthy of consideration when exploring the impact of microplastics on fish assemblages. In a recent study, Garnier *et al*. (2019) assessed the presence of microplastics across four common reef fish genera; *Myripristis, Siganus, Epinephelus* and *Cheilopogon* – representing four different trophic guilds. Only 21% of the fish surveyed showed particles within the digestive tract of the fish (28/133) and this was independent of the trophic guild. Furthermore, many reef fish exhibit ontogenetic changes in diet as they grow, with smaller fish generally eating smaller prey. For instance, some (like damselfish) increase their reliance on consumption of benthic algae as they mature, meaning that juvenile fish may be at more risk of harm from microplastic consumption than adults (Critchell and Hoogenboom, 2018). The colour of the microplastics also appears to be important with regard to likelihood of ingestion by many coastal dwelling fish species, with white often being preferred (Carpenter *et al.*, 1972). As reefs are well known nurseries of many fish species (including larger commercially important pelagic species) further work should be undertaken in this regard to ascertain the level of threat. That said, the majority of studies which have explored microplastic ingestion, illustrate that excretion occurs after relative short time periods (2-3 hours for copepods/plankton, 2-3 days for mussels and oysters and 2-3 weeks for top predators such as turtles (Duis and Coors, 2016) and so some argue ingestion of microplastics may not be a major threat to reef organisms.

'The additive effects of climate change and other stressors (like plastic pollution) are unknown'.

Direct ingestion, however is not the only way higher trophic level organisms can be exposed to microplastics – and the impact of movement of plastics through the food chain is gaining increasing attention. Indeed, organisms at the lower end of many food chains such as zooplankton and phytoplankton have been shown to uptake microplastics in experimental trials (Cole *et al.*, 2013; Besseling *et al.*, 2014; Sun *et al.*, 2017). Furthermore, when exposed to microplastics, such organisms express reduced levels of feeding rates (in the case of copepods) growth and photosynthesis (for algae) (Cole *et al.*, 2013; Besseling *et al.*, 2014). Further, Duncan *et al.* (2019) indicated the presence of microplastics in seven turtle species occupying different trophic levels, indicating that multiple ingestion pathways are likely. These may include, for example - exposure from polluted seawater and sediments (direct ingestion) and/or additional trophic transfer from contaminated prey or forage items.

Corals have also been shown to directly uptake microplastics. For example, 21% of coral polyps analysed in an ex situ exposure trial of microplastics were shown to have ingested at least one particle (Hall *et al.*, 2015). Corals appeared to be able to ingest fragments from a wide variety of shapes and sizes (ranging from 100μm to 2mm) and they are able to trap the particles in their mucus

Debris lining the beach in Sulawesi, Indonesia

(Hall *et al.*, 2015; Allen *et al.*, 2017; Hankins *et al.*, 2018; Reichert *et al.*, 2018) - the coral mucus is used to clear the surface from settling debris as well as for feeding. Feeding rates of microplastics by the corals have been shown to be variable between individual colonies and species but they can still ingest upwards of 660 µg cm-2 per day (Hall *et al.*, 2015). However, the majority of ingested particles are again highlighted as being expelled relatively quickly i.e. within 48 hrs in this instance (Hankins *et al.*, 2018). When expulsion does not occur, corals have been shown to be able to overgrow the microplastic particles (Reichert *et al.*, 2018), again providing further evidence that microplastics may not be a major threat. Overgrowth particularly occurs in areas where cleaning mechanisms were ineffective and where tissue or skeletal morphology, colony orientation and water movement hindered passive removal of the particles.

It is now clear that reef organisms can and do ingest plastics from their environment, however, there is limited documented evidence to illustrate the impact this ingestion has on the health of the individual - Knowledge Gap 9.

The few studies, which have explored this issue, highlight that the impacts of microplastic ingestion are likely to be species specific. For example, the coral species *Pocillopora verrucosa* and *P. damicornis* were reported to show varying levels of tissue necrosis when exposed to microplastics. *Acropora humilis, A. millepora* and *Porites cylindrica* bleached under the same conditions, whilst Porites lutea showed no adverse effects (Reichert *et al.*, 2018). Hankins *et al.* (2018) used calcification rates as a proxy for the impact of microplastics in their study and focused on two Caribbean coral species, *Montastrea cavernosa* and *Orbicella faveolata*, however they were unable to show any impact of the presence of plastics. Although polyethylene (a common polymer found in marine sediment and surface waters) was utilised in both studies, the sizes and densities (per litre of sea water) varied and could possibly explain the differences in host response. Hankins *et al.* (2018) for example, reported that an undetermined number of microplastics in the range of 90-106 µm per L^{-1} were used in their experiments, 215 particles per L^{-1} for the 425-500 µm size class and 24 particles per L^{-1} for the 850-100 µm size class. In contrast, Reichert *et al.* (2018) used only one size class (37 to 163 µm) and reported 4000 particles per L^{-1}.

Unlike that of macroplastics, the levels of microplastics in higher organisms like sea turtles, sirenians, cetaceans and sea birds is less well understood. Caron *et al.* (2018) attempted to tackle this issue and designed a novel method to explore levels of microplastics in these higher organisms and used green sea turtles (Chelonia mydas) as an example. From a combined approach (visual inspection, nitric acid digestion, emulsification of residual fat, density separation and chemical identification by Fourier transform infrared spectrometry), microplastics were indeed located in the turtles and were identified as paint chips and synthetic fibres. As mentioned earlier, Duncan *et al.* (2019) has now highlighted that microplastic ingestion is ubiquitous in marine turtles and found in all seven species sampled, across three ocean basins (the Mediterranean, Pacific and Atlantic). These results hint the levels of plastics found in these organisms may well be underreported at the current time – leading us to Knowledge Gap 10 and issues with the detection of plastics.

10: Exploring issues with the detection of microplastics in organisms and the surrounding environment

Finally, it should be noted that caution needs to be taken in all microplastic experiments and surveys due to the high possibility of contamination occurring from other sources including natural fibres (Hermsen *et al.*, 2017, GESAMP 2016). Indeed, one study which used particularly strict quality assurance criteria, illustrated substantially low numbers of microplastics in fish surveyed from wild habitats, compared to studies which may not have been so stringent (Hermsen *et al.*, 2017). This particular study focused on the North Sea.

Challenges with detecting plastics

As with all sciences, the interpretation of the findings is limited by the quality of the data utilised. Identifying larger pieces of plastics is not difficult and should result in little error. Microplastics and nanoplastics in contrast are often much harder to count reliably and need a little more attention. Further, the methods utilised to record the abundance of plastics vary from publication to publication and can make compiling meta-analysis difficult or impossible.

There is an urgent need to agree upon a standardised method for surveying plastics in a reef environment in order to allow for direct comparisons between studies and different regions and facilitate effective management and mitigation solutions.

For example, assessing the number of plastic items collected by an observer (along a certain stretch of beach), then comparing these numbers across space and time, rests on the assumption that a constant proportion of plastic pieces are detected and recorded. Below, we suggest that standardisation of surveying for plastics is one way to help with this issue. Although we acknowledge that there are some (quite significant) hurdles which need to be overcome (or at least understood) before reliable interpretation of any data can be undertaken.

As with any count data, the importance of detection probability is paramount. For plastics this has been shown to range from 60-100% and varies considerably by observer, observer experience and biological material present on the beach which can be confused with plastics (Lavers *et al.*, 2016). Blue microplastics have been shown to have the highest detection probability, while white microplastics had the lowest. Such information could be adapted into survey design for long term monitoring or utilisation of statistical models in order to reliably predict the level of missed plastics in any given environment. Imperfect detection of plastic debris can potentially be accounted for using repeat surveys and modelling the data. For this to occur at least 3-10 independent repeat counts need to be conducted from at least 25-50 distinct sites (Lavers *et al.*, 2016). Whilst it is acknowledged that such effort is expensive and time consuming, the use of citizen scientists could overcome certain costs associated with more detailed surveying. Alternatively, corrections in counts could be utilised to adjust for the missed plastic items. For example, in the surface sediments on beaches it has been suggested that multiplying the actual count of white microplastic particles by 1.3-9.5 will give a more realistic account (Lavers *et al.*, 2016).

One could argue, however, that we have enough knowledge to understand the issue and so as long as a standardised protocol can be decided and is consistent, any underestimates are not going to be vastly important as long as the underestimate is consistent between repeat surveys. Therefore focusing on one 'type' or candidate of microplastic (as an indicator) could be a way round this. Before such application is undertaken in wide spread survey methods, a study needs to be undertaken that estimates the correlation between the abundance of white or blue plastics for example and other plastic debris. A more pressing issue however, is the quality of assays used for detection of microplastics and the detection of false positives. Indeed, false positives are often routine in any count data and attempts should always be undertaken to minimise this issue where possible. In the case of microplastics again, false positives have been shown to be highly likely and often confused with natural debris for example clam shell fragments, charcoal or coral (Imhof *et al.*, 2017). When strict quality assurance criteria are put in place, much lower numbers of microplastics are usually reported, compared to other studies, which may not pay attention to as much detail (Hermsen *et al.*, 2017). Whilst the use of certain statistical models (binomial mixed) can account for 'undetected' microplastics, they cannot deal with false positives as well. Further research is needed in this area – Knowledge Gap 11.

11: Assessing the quality of current assays used to assess microplastics and validate models for assessing the chance of false negatives and positives in plastic counts

Only 61% of particles identified as microplastics were indeed plastic.

One method aimed at tackling false positives is the use of 'polymer identification techniques' such as Fourier Transform Infrared Spectroscopy (FTIR). For example, in a study exploring the levels of microplastics in the Maldives archipelago, FTIR highlighted that only 61% of the particles visually identified as microplastics were indeed plastic (Imhof *et al.*, 2017).

The final two knowledge gaps (10 and 11) are designed in order to address the issues around measuring and monitoring plastics in reef ecosystems. There are many methods employed in assessing the levels of plastics (both macro and micro) and there appears to be no clear consensus over which can, or should be utilised over others. Before any mitigation strategy is undertaken there is an urgent need to develop a standardised approach to measuring environmental levels of plastic contaminants in reef ecosystems. This will enable before-after-control-impact designs to be implemented to measure the impact of any management activity.

Discarded fishing gear on a rocky shore

POLICY AND MANAGEMENT RECOMMENDATIONS

The issue of plastics in the marine environment has been recognised by scientists, governmental organisations, non-governmental organisations, private institutions and charities alike. It is recognized as a global priority, including in the 2030 Sustainable Development Agenda, under Sustainability Development Goal (SDG) 14 on conserving and using the oceans, seas and marine resources for sustainable development. Specifically, Target 14.1 is to prevent and significantly reduce marine pollution of all kinds by 2025, with indicator 14.1.1 including an index on floating plastic debris density.

This report identifies detrimental impacts of marine plastic litter on shallow water coral reef ecosystems and organisms. In response to these threats, the following recommendations are made in order to advance action on marine litter and SDG Target 14.1, especially in relation to the sustainable management of coral reef ecosystems.

1. Strengthen partnerships to eliminate marine litter and plastic pollution at source

Governments, civil society and private sector actors are encouraged to join the Global Partnership on Marine Litter, and engage with the partnership to develop plans and targets for reduction of waste that may enter coral reef areas.

The Global Partnership on Marine Litter, hosted by UN Environment, is a multistakeholder partnership that gathers international agencies, governments, non-governmental organizations, academia, private sector, civil society and individuals with the common goal of protecting human health and the global environment through the reduction and management of marine litter. The Global Partnership on Marine Litter has several specific objectives including:

- to reduce the impacts of marine litter worldwide on economies, ecosystems, animal welfare and human health;

- to enhance international cooperation and coordination through the promotion and implementation of the Honolulu Strategy - a global framework for the prevention and management of marine litter, as well as the Honolulu Commitment – a multi-stakeholder pledge;

- to promote knowledge management, information sharing and monitoring of progress on the implementation of the Honolulu Strategy;

- to promote resource efficiency and economic development through waste prevention e.g. 4Rs (reduce, re-use, recycle and re-design) and by recovering valuable material and/or energy from waste;

- to increase awareness on sources of marine litter, its fate and impacts, and

- to assess emerging issues related to the fate and potential influence of marine litter, including (micro) plastics uptake in the food web and associated transfer of pollutants as well as impacts on the conservation and welfare of marine fauna.

2. Strengthen national planning to address land-based sources of plastic litter on coral reefs

1. Countries with coral reefs should develop or revise national action plans and local mitigation measures, based on strategic assessments that identify key sources, pathways and impacts of plastics on reefs. It is important to engage the full range of stakeholders in the development of plans and implementation of mitigation measures.

2. Identify and manage major local sources of plastic pollution to coral reefs, for example through appropriate and low-cost technology such as litter traps in river mouths close to coral reefs, or through improved waste management in nearshore dumpsites and waste management facilities close to coral reefs.

3. Apply bans on harmful single-use plastics on beaches close to coral reefs, for example banning smoking on public beaches to reduce littering of cigarette butts, and banning the use of plastic straws, bottles and bags.

4. Work with key plastic-producing industries to implement liability and compensation schemes based on polluter-pays mechanisms.

5. Consumer demand should also be addressed in tandem in order to ensure lasting impact.

3. Reduce the impact of aquaculture, lost and abandoned fishing gear on coral reefs

Develop and apply regional regulations and guidelines on eliminating or reducing lost and abandoned fishing gear from entering the ocean on or around coral reefs, through relevant regional organizations such as Regional Fisheries Management Organizations and Regional Seas Conventions and Action Plans, in close consultation with fishing industries and communities.

1. Invest in education of fishers to implement preventative measures or interventions before the fishing gear reaches sensitive coral reef habitats.

2. Develop incentives for the retrieval or safe deposit of used gear, including innovative financial mechanisms to incentivize gear retrieval such as https://www.aquafil.com/ or http://net-works.com/.

3. Implement programmes to mark fishing gear, so that lost and abandoned fishing gear can be traced back to owners. The Food and Agriculture Organization Committee on Fisheries has developed voluntary guidelines on marking fishing gear, which should be implemented globally.

4. Reduce or eliminate harmful fishing subsidies which exacerbate overfishing, with special attention to industrialized fishing.

5. Reduce fishing demand from wild stocks by investing in closed system, environmentally-sustainable, aquaculture practices, which do not allow macro-plastics to enter the marine environment.

6. Enforce the reporting of accidental or discharge of fishing gear as specified in regulation 10.6 of the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex V (MEPC, 2017).

4. Invest in monitoring and research

This report identifies a number of knowledge gaps that are necessary to address in order to strengthen the scientific evidence base for action on marine plastics that impact coral reefs, and towards achievement of targets set by the global community. Addressing these knowledge gaps requires financial investment by governments and other entities, and efforts by academic and research institutions. The knowledge gaps include:

1. The status and magnitude of marine litter on coral reef ecosystems:
- Understand the scale of mismanaged waste entering coral reef environments.
- Understand the patterns of plastic pollution in and around coral reef environments, e.g. identify hot spots of plastic pollution accumulation on coral reefs.
- Ascertain concentrations of microplastics across coral reef ecoregions to understand the scale of the issue in a standardised manner.
- Assess the quality of current assays used to assess microplastics and validate models for assessing the chance of false negatives and positives in plastic counts.

2. The impact of plastics on coral reef species and ecosystems:
- Understand the impacts of leaching chemicals from plastics in coral reef environments.
- Understand how, on a wider, ecologically relevant scale plastics impact coral reef environments.
- Explore how macroplastics interact with and affect benthic invertebrates such as sponges and corals.
- Quantify the amount of ghost gear and its impact on coral reef communities.
- Explore the level of risk microplastics have on reef organisms, e.g. by cross mapping microplastic quantities and the distribution of sensitive reef organisms.
- Explore issues with the detection of microplastics in organisms and the surrounding environments.
- Explore the role of macro- and micro-plastics in transporting invasive epibionts and possible pathogenic agents on a global scale.

3. The potential societal and economic impacts of plastics on coral reefs:
- Understand reef mediated human exposure to microplastics, chemicals leeched by plastics as well as entanglement of or injuries to swimmers.
- Understand the health impacts on humans of consuming microplastics in coral reef organisms.
- Understand current and projected economic impacts of marine plastic litter and microplastics on reef dependent industries and communities.

4. Improving data collection and information to address these knowledge gaps:
- Include coral reef environments in marine litter monitoring programmes.
- Incorporate marine plastic litter indicators in regular national coral reef monitoring programmes, for example occurrence of macro-plastics on coral reefs as well as its effects on coral reef organisms (e.g. mortality, injury or competitive interactions with other biota). This may be advanced through the Global Coral Reef Monitoring Network.
- Engage citizen scientists to collect data on macro-plastics and ghost gear on coral reefs, for example through the marinelitternetwork.org.

REFERENCES

Abu-Hilal, A., Al-Najjar, T., 2009. Marine litter in coral reef areas along the Jordan Gulf of Aqaba, Red Sea. J. Environ. Manage. 90, 1043–1049. https://doi.org/10.1016/j.jenvman.2008.03.014

Allen, A.S., Seymour, A.C., Rittschof, D., 2017. Chemoreception drives plastic consumption in a hard coral. Mar. Pollut. Bull. 124, 198–205. https://doi.org/10.1016/j.marpolbul.2017.07.030

Angiolillo, M., Canese, S., 2018. Deep Gorgonians and Corals of the Mediterranean Sea, in: Corals in a Changing World. https://doi.org/10.5772/intechopen.69686

Asoh, K., Yoshikawa, T., Kosaki, R., Marschall, E.A., 2004. Damage to cauliflower coral by monofilament fishing lines in Hawaii. Conserv. Biol. 18, 1645–1650. https://doi.org/10.1111/j.1523-1739.2004.00122.x

Besseling, E., Wang, B., Lürling, M., Koelmans, A.A., 2014. Nanoplastic affects growth of S. obliquus and reproduction of D. magna. Environ. Sci. Technol. 48, 12336–12343. https://doi.org/10.1021/es503001d

Besseling, E., Wegner, A., Foekema, E.M., Van Den Heuvel-Greve, M.J., Koelmans, A.A., 2013. Effects of microplastic on fitness and PCB bioaccumulation by the lugworm Arenicola marina (L.). Environ. Sci. Technol. 47, 593–600. https://doi.org/10.1021/es302763x

Bidegain, G., Paul-Pont, I., 2018. Commentary: Plastic waste associated with disease on coral reefs. Front. Mar. Sci. 5, 1–2. https://doi.org/10.3389/fmars.2018.00237

Browne, M.A., Crump, P., Niven, S.J., Teuten, E., Tonkin, A., Galloway, T., Thompson, R., 2011. Accumulation of microplastic on shorelines woldwide: Sources and sinks. Environ. Sci. Technol. 45, 9175–9179. https://doi.org/10.1021/es201811s

Browne, M.A., Niven, S.J., Galloway, T.S., Rowland, S.J., Thompson, R.C., 2013. Microplastic moves pollutants and additives to worms, reducing functions linked to health and biodiversity. Curr. Biol. 23, 2388–2392. https://doi.org/10.1016/j.cub.2013.10.012

Carlton, J.T., Chapman, J.W., Geller, J.B., Miller, J.A., Carlton, D.A., McCuller, M.I., Treneman, N.C., Steves, B.P., Ruiz, G.M., 2017. Tsunami-driven rafting: Transoceanic species dispersal and implications for marine biogeography. Science (80-.). 357, 1402–1406. https://doi.org/10.1126/science.aao1498

Caron, A.G.M., Thomas, C.R., Berry, K.L.E., Motti, C.A., Ariel, E., Brodie, J.E., 2018. Ingestion of microplastic debris by green sea turtles (Chelonia mydas) in the Great Barrier Reef: Validation of a sequential extraction protocol. Mar. Pollut. Bull. 127, 743–751. https://doi.org/10.1016/j.marpolbul.2017.12.062

Carpenter, E.J., Anderson, S.J., Harvey, G.R., Miklas, H.P., Peck, B.B., 1972. Polystyrene Spherules in Coastal Waters. Science (80-.). 178, 749–750. https://doi.org/10.1126/science.178.4062.749

Cesar, H., 2000. The Biodiversity Benefits of Coral Reef Ecosystems : Values and Markets 2000, 1–27.

Chiappone, M., Dienes, H., Swanson, D.W., Miller, S.L., 2005. Impacts of lost fishing gear on coral reef sessile invertebrates in the Florida Keys National Marine Sanctuary. Biol. Conserv. 121, 221–230. https://doi.org/10.1016/j.biocon.2004.04.023

Claessens, M., Meester, S. De, Landuyt, L. Van, Clerck, K. De, Janssen, C.R., 2011. Occurrence and distribution of microplastics in marine sediments along the Belgian coast. Mar. Pollut. Bull. 62, 2199–2204. https://doi.org/10.1016/j.marpolbul.2011.06.030

Clukey, K.E., Lepczyk, C.A., Balazs, G.H., Work, T.M., Lynch, J.M., 2017. Investigation of plastic debris ingestion by four species of sea turtles collected as bycatch in pelagic Pacific longline fisheries. Mar. Pollut. Bull. 120, 117–125. https://doi.org/10.1016/j.marpolbul.2017.04.064

Coe, J.M., Rogers, D.B., 1997. Marine Debris: Sources, Impacts and Solutions. Springer. https://doi.org/10.1007/978-1-4613-8488-5

Cole, M., Lindeque, P., Fileman, E., Halsband, C., Goodhead, R., Moger, J., Galloway, T.S., 2013. Microplastic ingestion by zooplankton. Environ. Sci. Technol. 47, 6646–6655. https://doi.org/10.1021/es400663f

Connors, E.J., 2017. Distribution and biological implications of plastic pollution on the fringing reef of Mo'orea, French Polynesia. PeerJ 5, e3733. https://doi.org/10.7717/peerj.3733

Critchell, K., Hoogenboom, M.O., 2018. Effects of microplastic exposure on the body condition and behaviour of planktivorous reef fish (Acanthochromis polyacanthus). PLoS One 13, e0193308. https://doi.org/10.1371/journal.pone.0193308

Dang, H., Li, T., Chen, M., Huang, G., 2008. Cross-ocean distribution of Rhodobacterales bacteria as primary surface colonizers in temperate coastal marine waters. Appl. Environ. Microbiol. 74, 52–60. https://doi.org/10.1128/AEM.01400-07

Donohue, M.J., Boland, R.C., Sramek, C.M., Antonelis, G.A., 2001. Derelict fishing gear in the Northwestern Hawaiian Islands: Diving surveys and debris removal in 1999 confirm threat to Coral Reef ecosystems. Mar. Pollut. Bull. 42, 1301–1312. https://doi.org/10.1016/S0025-326X(01)00139-4

Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, J.C., Galgani, F., Ryan, P.G., 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. https://doi.org/10.1371/journal.pone.0111913

Eriksen, M., Maximenko, N., Thiel, M., Cummins, A., Lattin, G., Wilson, S., Hafner, J., Zellers, A., Rifman, S., 2013. Plastic pollution in the South Pacific subtropical gyre. Mar. Pollut. Bull. 68, 71–76. https://doi.org/10.1016/j.marpolbul.2012.12.021

Farrell, P., Nelson, K., 2013. Trophic level transfer of microplastic: Mytilus edulis (L.) to Carcinus maenas (L.). Environ. Pollut. 177, 1–3. https://doi.org/10.1016/j.envpol.2013.01.046

Ferrigno, F., Appolloni, L., Russo, G.F., Sandulli, R., 2017. Impact of fishing activities on different coralligenous assemblages of Gulf of Naples (Italy). J. Mar. Biol. Assoc. United Kingdom 98, 1–10. https://doi.org/10.1017/S0025315417001096

Gall, S.C., Thompson, R.C., 2015. The impact of debris on marine life. Mar. Pollut. Bull. 92, 170–179. https://doi.org/10.1016/j.marpolbul.2014.12.041

Geyer, R., Jambeck, J.R., Law, K.L., 2017. Production, use, and fate of all plastics ever made. Sci. Adv. 3, e1700782. https://doi.org/10.1126/sciadv.1700782

Glas, M.S., Sato, Y., Ulstrup, K.E., Bourne, D.G., 2012. Biogeochemical conditions determine virulence of black band disease in corals. ISME J. 6, 1526–1534. https://doi.org/10.1038/ismej.2012.2

Gouin, T., Roche, N., Lohmann, R., Hodges, G., 2011. A thermodynamic approach for assessing the environmental exposure of chemicals absorbed to microplastic. Environ. Sci. Technol. 45, 1466–1472. https://doi.org/10.1021/es1032025

GPA, 2006. Global Programme of Action for the Protection of the Marine Environment from Landbased Activities. UNEP Fact Sheet.

Hall, N.M., Berry, K.L.E., Rintoul, L., Hoogenboom, M.O., 2015. Microplastic ingestion by scleractinian corals. Mar. Biol. 162, 725–732. https://doi.org/10.1007/s00227-015-2619-7

Hankins, C., Duffy, A., Drisco, K., 2018. Scleractinian coral microplastic ingestion: Potential calcification effects, size limits, and retention. Mar. Pollut. Bull. 135, 587–593. https://doi.org/10.1016/j.marpolbul.2018.07.067

Hermsen, E., Pompe, R., Besseling, E., Koelmans, A.A., 2017. Detection of low numbers of microplastics in North Sea fish using strict quality assurance criteria. Mar. Pollut. Bull. 122, 253–258. https://doi.org/10.1016/j.marpolbul.2017.06.051

Hughes, T.P., Kerry, J.T., Baird, A.H., Connolly, S.R., Dietzel, A., Eakin, C.M., Heron, S.F., Hoey, A.S., Hoogenboom, M.O., Liu, G., McWilliam, M.J., Pears, R.J., Pratchett, M.S., Skirving, W.J., Stella, J.S., Torda, G., 2018. Global warming transforms coral reef assemblages. Nature 556, 492–496. https://doi.org/10.1038/s41586-018-0041-2

Imhof, H.K., Sigl, R., Brauer, E., Feyl, S., Giesemann, P., Klink, S., Leupolz, K., Lï¿½der, M.G.J., Lï¿½schel, L.A., Missun, J., Muszynski, S., Ramsperger, A.F.R.M., Schrank, I., Speck, S., Steibl, S., Trotter, B., Winter, I., Laforsch, C., 2017. Spatial and temporal variation of macro-, meso- and microplastic abundance on a remote coral island of the Maldives, Indian Ocean. Mar. Pollut. Bull. 116, 340–347. https://doi.org/10.1016/j.marpolbul.2017.01.010

Jacobsen, J.K., Massey, L., Gulland, F., 2010. Fatal ingestion of floating net debris by two sperm whales (Physeter macrocephalus). Mar. Pollut. Bull. 60, 765–767. https://doi.org/10.1016/j.marpolbul.2010.03.008

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Plastic waste inputs from land into the ocean. Science (80-.). 347, 768–771. https://doi.org/10.1126/science.1260352

Kaiser, M.J., Bullimore, B., Newman, P., Lock, K., Gilbert, S., 1996. Catches in "ghost fishing" set nets. Mar. Ecol. Prog. Ser. 145, 11–16. https://doi.org/10.3354/meps145011

Kaposi, K.L., Mos, B., Kelaher, B.P., Dworjanyn, S.A., 2014. Ingestion of microplastic has limited impact on a marine larva. Environ. Sci. Technol. 48, 1638–1645. https://doi.org/10.1021/es404295e

Koelmans, A.A., Bakir, A., Burton, G.A., Janssen, C.R., 2016. Microplastic as a Vector for Chemicals in the Aquatic Environment: Critical Review and Model-Supported Reinterpretation of Empirical Studies. Environ. Sci. Technol. https://doi.org/10.1021/acs.est.5b06069

Kühn, S., Bravo Rebolledo, E.L., Van Franeker, J.A., 2015. Deleterious effects of litter on marine life, in: Marine Anthropogenic Litter. Springer International Publishing, Cham, pp. 75–116. https://doi.org/10.1007/978-3-319-16510-3_4

Lamb, J.B., Van De Water, J.A.J.M., Bourne, D.G., Altier, C., Hein, M.Y., Fiorenza, E.A., Abu, N., Jompa, J., Harvell, C.D., 2017. Seagrass ecosystems reduce exposure to bacterial pathogens of humans, fishes, and invertebrates. Science (80-.). 355, 731–733. https://doi.org/10.1126/science.aal1956

Lamb, J.B., Wenger, A.S., Devlin, M.J., Ceccarelli, D.M., Williamson, D.H., Willis, B.L., 2016. Reserves as tools for alleviating impacts of marine disease. Philos. Trans. R. Soc. B Biol. Sci. 371, 20150210. https://doi.org/10.1098/rstb.2015.0210

Lamb, J.B., Willis, B.L., Fiorenza, E.A., Couch, C.S., Howard, R., Rader, D.N., True, J.D., Kelly, L.A., Ahmad, A., Jompa, J., Harvell, C.D., 2018. Plastic waste associated with disease on coral reefs. Science (80-.). 359, 460–462. https://doi.org/10.1126/science.aar3320

Lavers, J.L., Bond, A.L., 2017. Exceptional and rapid accumulation of anthropogenic debris on one of the world's most remote and pristine islands. Proc. Natl. Acad. Sci. 114, 6052–6055. https://doi.org/10.1073/pnas.1619818114

Lavers, J.L., Oppel, S., Bond, A.L., 2016. Factors influencing the detection of beach plastic debris. Mar. Environ. Res. 119, 245–251. https://doi.org/10.1016/j.marenvres.2016.06.009

Lewis, C.F., Slade, S.L., Maxwell, K.E., Matthews, T.R., 2009. Lobster trap impact on coral reefs: Effects of wind-driven trap movement, in: New Zealand Journal of Marine and Freshwater Research. Taylor & Francis Group, pp. 271–282. https://doi.org/10.1080/00288330909510000

Loulad, S., Houssa, R., Rhinane, H., Boumaaz, A., Benazzouz, A., 2017. Spatial distribution of marine debris on the seafloor of Moroccan waters. Mar. Pollut. Bull. 124, 303–313. https://doi.org/10.1016/j.marpolbul.2017.07.022

Lusher, A., Hollman, P., Mandoza-Hill, J.. J., 2017. Microplastics in fisheries and aquaculture, FAO Fisheries and Aquaculture Technical Paper. https://doi.org/dmd.105.006999 [pii]\r10.1124/dmd.105.006999

Macfadyen, Graeme;Huntington, Tim;Cappell, R., 2009. Abandoned, lost or otherwise discarded fishing gear, FAO Fisheries and Aquaculture Technical Paper 523. United Nations Environment Programme.

MARINE, E.P.C., 2017. 2017 GUIDELINES FOR THE IMPLEMENTATION OF MARPOL ANNEX V [WWW Document]. URL http://www.imo.org/en/OurWork/Environment/PollutionPrevention/Garbage/Documents/MEPC.295%2871%29.pdf

McDermid, K.J., McMullen, T.L., 2004. Quantitative analysis of small-plastic debris on beaches in the Hawaiian archipelago. Mar. Pollut. Bull. 48, 790–794. https://doi.org/10.1016/j.marpolbul.2003.10.017

Melli, V., Angiolillo, M., Ronchi, F., Canese, S., Giovanardi, O., Querin, S., Fortibuoni, T., 2017. The first assessment of marine debris in a Site of Community Importance in the north-western Adriatic Sea (Mediterranean Sea). Mar. Pollut. Bull. 114, 821–830. https://doi.org/10.1016/j.marpolbul.2016.11.012

Moore, C.J., 2008. Synthetic polymers in the marine environment: A rapidly increasing, long-term threat. Environ. Res. 108, 131–139. https://doi.org/10.1016/j.envres.2008.07.025

Moore, C.J., Moore, S.L., Leecaster, M.K., Weisberg, S.B., 2001. A comparison of plastic and plankton in the North Pacific Central Gyre. Mar. Pollut. Bull. 42, 1297–1300. https://doi.org/10.1016/S0025-326X(01)00114-X

Obbard, R.W., Sadri, S., Wong, Y.Q., Khitun, A.A., Baker, I., Thompson, R.C., 2014. Global warming releases microplastic legacy frozen in Arctic Sea ice. Earth's Futur. 2, 315–320. https://doi.org/10.1002/2014EF000240

Pham, C.K., Ramirez-Llodra, E., Alt, C.H.S., Amaro, T., Bergmann, M., Canals, M., Company, J.B., Davies, J., Duineveld, G., Galgani, F., Howell, K.L., Huvenne, V.A.I., Isidro, E., Jones, D.O.B., Lastras, G., Morato, T., Gomes-Pereira, J.N., Purser, A., Stewart, H., Tojeira, I., Tubau, X., Van Rooij, D., Tyler, P.A., 2014. Marine litter distribution and density in European seas, from the shelves to deep basins. PLoS One 9, e95839. https://doi.org/10.1371/journal.pone.0095839

Phillips, C., 2017. Ghostly encounters: Dealing with ghost gear in the Gulf of Carpentaria. Geoforum 78, 33–42. https://doi.org/10.1016/j.geoforum.2016.11.010

Provencher, J.F., Bond, A.L., Hedd, A., Montevecchi, W.A., Muzaffar, S. Bin, Courchesne, S.J., Gilchrist, H.G., Jamieson, S.E., Merkel, F.R., Falk, K., Durinck, J., Mallory, M.L., 2014. Prevalence of marine debris in marine birds from the North Atlantic. Mar. Pollut. Bull. 84, 411–417. https://doi.org/10.1016/j.marpolbul.2014.04.044

Reichert, J., Schellenberg, J., Schubert, P., Wilke, T., 2018. Responses of reef building corals to microplastic exposure. Environ. Pollut. 237, 955–960. https://doi.org/10.1016/j.envpol.2017.11.006

Reisser, J., Shaw, J., Hallegraeff, G., Proietti, M., Barnes, D.K.A., Thums, M., Wilcox, C., Hardesty, B.D., Pattiaratchi, C., 2014. Millimeter-sized marine plastics: A new pelagic habitat for microorganisms and invertebrates. PLoS One 9, e100289. https://doi.org/10.1371/journal.pone.0100289

Reisser, J., Shaw, J., Wilcox, C., Hardesty, B.D., Proietti, M., Thums, M., Pattiaratchi, C., 2013. Marine plastic pollution in waters around Australia: Characteristics, concentrations, and pathways. PLoS One 8, e80466. https://doi.org/10.1371/journal.pone.0080466

Richardson, K., Gunn, R., Wilcox, C., Hardesty, B.D., 2018. Understanding causes of gear loss provides a sound basis for fisheries management. Mar. Policy. https://doi.org/10.1016/j.marpol.2018.02.021

Rochman, C.M., Cook, A.-M., Koelmans, A.A., 2016. Plastic debris and policy: Using current scientific understanding to invoke positive change. Environ. Toxicol. Chem. 35, 1617–1626. https://doi.org/10.1002/etc.3408

Rochman, C.M., Kurobe, T., Flores, I., Teh, S.J., 2014. Early warning signs of endocrine disruption in adult fish from the ingestion of polyethylene with and without sorbed chemical pollutants from the marine environment. Sci. Total Environ. 493, 656–661. https://doi.org/10.1016/j.scitotenv.2014.06.051

Rogers, A., Blanchard, J.L., Mumby, P.J., 2014. Vulnerability of coral reef fisheries to a loss of structural complexity. Curr. Biol. 24, 1000–1005. https://doi.org/10.1016/j.cub.2014.03.026

Santos, R.G., Andrades, R., Boldrini, M.A., Martins, A.S., 2015. Debris ingestion by juvenile marine turtles: An underestimated problem. Mar. Pollut. Bull. 93, 37–43. https://doi.org/10.1016/j.marpolbul.2015.02.022

Schuyler, Q.A., Wilcox, C., Townsend, K., Hardesty, B.D., Marshall, N.J., 2014. Mistaken identity? Visual similarities of marine debris to natural prey items of sea turtles. BMC Ecol. 14, 14. https://doi.org/10.1186/1472-6785-14-14

Scudo, Alexandra; Liebmann, Bettina; Corden,, Casper; Tyrer, David; Kreissig, Juilus; Warwick, O., 2017. Intentonally added microplastics in products. Eur. Comm. (DG Environ.

Séré, M.G., Tortosa, P., Chabanet, P., Quod, J.-P., Sweet, M.J., Schleyer, M.H., 2015. Identification of a bacterial pathogen associated with Porites white patch syndrome in the Western Indian Ocean. Mol. Ecol. 24. https://doi.org/10.1111/mec.13326

Soffer, N., Zaneveld, J., Vega Thurber, R., 2015. Phage-bacteria network analysis and its implication for the understanding of coral disease. Environ. Microbiol. 17, 1203–1218. https://doi.org/10.1111/1462-2920.12553

Stelfox, M., Hudgins, J., Sweet, M., 2016. A review of ghost gear entanglement amongst marine mammals, reptiles and elasmobranchs. Mar. Pollut. Bull. https://doi.org/10.1016/j.marpolbul.2016.06.034

Sweet, M., Bulling, M., Williamson, J.E., 2016. New disease outbreak affects two dominant sea urchin species associated with Australian temperate reefs. Mar. Ecol. Prog. Ser. 551. https://doi.org/10.3354/meps11750

Sweet, M., Bythell, J., 2015. White Syndrome in Acropora muricata: Nonspecific bacterial infection and ciliate histophagy. Mol. Ecol. 24. https://doi.org/10.1111/mec.13097

Sweet, M.J., Brown, B.E., 2016. Coral responses to anthropogenic stress in the twenty-first century: an ecophysiological perspective. Oceanogr. Mar. Biol. An Annu. Rev. 54, 271–314. https://doi.org/10.1111/gcb.12011

Sweet, M.J., Séré, M.G., 2016. Ciliate communities consistently associated with coral diseases. J. Sea Res. 113, 119–131. https://doi.org/10.1016/j.seares.2015.06.008

Thompson, R.C., 2015. Microplastics in the marine environment: Sources, consequences and solutions, in: Marine Anthropogenic Litter. Springer International Publishing, Cham, pp. 185–200. https://doi.org/10.1007/978-3-319-16510-3_7

Thompson, R.C., Moore, C.J., vom Saal, F.S., Swan, S.H., 2009. Plastics, the environment and human health: current consensus and future trends. Philos. Trans. R. Soc. B Biol. Sci. 364, 2153–2166. https://doi.org/10.1098/rstb.2009.0053

UN Environmemt, ISU, ICRI, and TRUCOST. (2018). The Coral Reef Economy: The business case for investment in the protection, preservation and enhancement of coral reef health. 36pp

Van Sebille, E., Wilcox, C., Lebreton, L., Maximenko, N., Hardesty, B.D., Van Franeker, J.A., Eriksen, M., Siegel, D., Galgani, F., Law, K.L., 2015. A global inventory of small floating plastic debris. Environ. Res. Lett. 10, 124006. https://doi.org/10.1088/1748-9326/10/12/124006

Vegter, A.C., Barletta, M., Beck, C., Borrero, J., Burton, H., Campbell, M.L., Costa, M.F., Eriksen, M., Eriksson, C., Estrades, A., Gilardi, K.V.K., Hardesty, B.D., Ivar do Sul, J.A., Lavers, J.L., Lazar, B., Lebreton, L., Nichols, W.J., Ribic, C.A., Ryan, P.G., Schuyler, Q.A., Smith, S.D.A., Takada, H., Townsend, K.A., Wabnitz, C.C.C., Wilcox, C., Young, L.C., Hamann, M., 2014. Global research priorities to mitigate plastic pollution impacts on marine wildlife. Endanger. Species Res. 25, 225–247. https://doi.org/10.3354/esr00623

Von Moos, N., Burkhardt-Holm, P., Köhler, A., 2012. Uptake and effects of microplastics on cells and tissue of the blue mussel Mytilus edulis L. after an experimental exposure. Environ. Sci. Technol. 46, 11327–11335. https://doi.org/10.1021/es302332w

Watts, A.J.R., Urbina, M.A., Corr, S., Lewis, C., Galloway, T.S., 2015. Ingestion of Plastic Microfibers by the Crab Carcinus maenas and Its Effect on Food Consumption and Energy Balance. Environ. Sci. Technol. 49, 14597–14604. https://doi.org/10.1021/acs.est.5b04026

Wedemeyer-Strombel, K.R., Balazs, G.H., Johnson, J.B., Peterson, T.D., Wicksten, M.K., Plotkin, P.T., 2015. High frequency of occurrence of anthropogenic debris ingestion by sea turtles in the North Pacific Ocean. Mar. Biol. 162, 2079–2091. https://doi.org/10.1007/s00227-015-2738-1

Wieczorek, A.M., Morrison, L., Croot, P.L., Allcock, A.L., MacLoughlin, E., Savard, O., Brownlow, H., Doyle, T.K., 2018. Frequency of Microplastics in Mesopelagic Fishes from the Northwest Atlantic. Front. Mar. Sci. 5, 39. https://doi.org/10.3389/fmars.2018.00039

Wilcox, C., Mallos, N.J., Leonard, G.H., Rodriguez, A., Hardesty, B.D., 2016. Using expert elicitation to estimate the impacts of plastic pollution on marine wildlife. Mar. Policy 65, 107–114. https://doi.org/10.1016/j.marpol.2015.10.014

Wilson, S.P., Verlis, K.M., 2017. The ugly face of tourism: Marine debris pollution linked to visitation in the southern Great Barrier Reef, Australia. Mar. Pollut. Bull. 117, 239–246. https://doi.org/10.1016/j.marpolbul.2017.01.036

PHOTO CREDITS

Cover | J. Tamelander
Page 03 | Dr. Kathryn Berry
Page 06 | Prof. Bette Willis
Page 08 | Tane Sinclair Taylor
Page 09 | Prof. Bette Willis
Page 10 | J. Tamelander
Page 12 | J. Tamelander
Page 14 | Dr. Kathryn Berry
Page 18 | Dr. Joleah Lamb
Page 19 | J. Tamelander
Page 20 | Prof. Bette Willis
Page 22-23 | Dr. Joleah Lamb
Page 25 | J. Tamelander
Back cover | Tane Sinclair Taylor