Marine Debris as a Global Environmental Problem

Introducing a solutions based framework focused on plastic

A STAP information document

November 2011

Scientific and Technical Advisory Panel

An independent group of scientists which advises the Global Environment Facility

GLOBAL ENVIRONMENT FACILITY 20 YEARS INVESTING IN OUR PLANET

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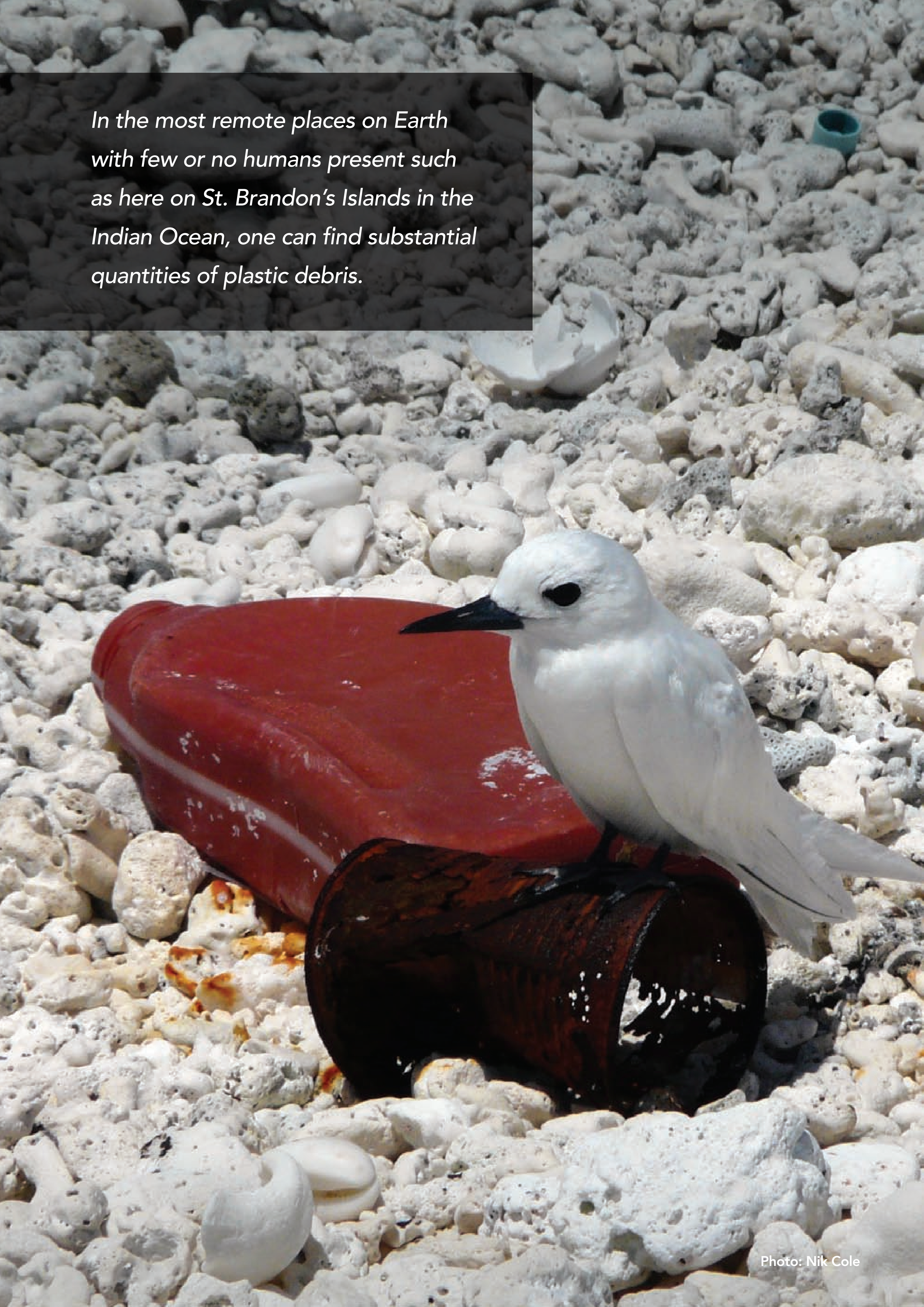

In the most remote places on Earth with few or no humans present such as here on St. Brandon's Islands in the Indian Ocean, one can find substantial quantities of plastic debris.

Photo: Nik Cole

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Marine Debris as a Global Environmental Problem:
Introducing a solutions based framework focused on plastic

Prepared on behalf of the Scientific and Technical Advisory Panel (STAP) of the Global Environment Facility (GEF) by:

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About STAP

The Scientific and Technical Advisory Panel comprises six expert advisers supported by a Secretariat, which are together responsible for connecting the Global Environment Facility to the most up to date, authoritative and globally representative science.

http://unep.org/stap

Foreword

Being confronted by the sight of debris littering the shores of otherwise beautiful and pristine isolated oceanic islands pushes home the cold realization that this world is both immensely rich in diversity, scenery, and sounds, as well as small when the visible products of mankind's industry are present far from their source, having travelled great distances on ocean currents. The worlds' oceans are vast, immensely powerful, but highly sensitive all at the same time. Having to cope with increasing uses from a variety of sources such as extractive industries, together with climate change, acidification, hypoxia, and chemical pollution, increasingly our oceans and seas are also absorbing an ever increasing volume of marine debris. The conflagration of threats and pressures are increasingly depleting the capacity of the world's oceans to absorb it all. Understanding that marine environments are responsible for many crucial global ecological services, together with other threats the presence of marine debris in the ocean is therefore a grave cause for concern. Given that individual materials found in marine debris may remain largely unchanged for hundreds of years, combined with the ever increasing production and use of such objects, it becomes increasingly obvious that continuing with present patterns of consumption and management of these materials and processes that produce them is unsustainable and needs urgent intervention.

> "Marine debris – trash in our oceans – is a symptom of our throw-away society and our approach to how we use our natural resources. It affects every country and every ocean, and shows us in highly visible terms the urgency of shifting towards a low carbon, resource efficient Green Economy as nations prepare for Rio+20 in 2012… However, one community or one country acting in isolation will not be the answer. We need to address marine debris collectively across national boundaries and with the private sector, which has a critical role to play both in reducing the kinds of wastes that can end up in the world's oceans, and through research into new materials. It is by bringing all these players together that we can truly make a difference"
>
> *United Nations Under-Secretary-General and UNEP Executive Director Achim Steiner in a message to the 5th International Marine Debris Conference.*

Addressing marine debris within this context, this STAP advisory is aimed at contextualizing the latest scientific knowledge about the causes of marine debris, and investigating and suggesting opportunities for catalytic activities to address this challenge within the GEF program. The GEF is well-placed to address marine debris in an integrative manner, as there is a strong intersection between three of its Focal Areas: Chemicals, Biodiversity, and International Waters. Moreover private sector involvement, such as those supported by corporate programs including the Earth Fund, are essential to success. As one of the most important custodians of mechanisms to achieve global environmental benefits through innovative action, this guidance is aimed towards exploring and supporting such intervention.

Thomas E. Lovejoy
Chair, Scientific and Technical Advisory Panel

Hindrik Bouwman
STAP member

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Abbreviations

ABNJ	Areas Beyond National Jurisdiction
ALDFG	Abandoned, Lost or Otherwise Discarded Fishing Gear
APEC	Asia-Pacific Economic Cooperation
BDE	Tetrabromodiphenyl Ethers and Penta-bromodiphenyl Ethers
BPA	Bisphenol A
CBD	Convention on Biological Diversity
CEIT	Countries with Economies in Transition
CMS	Convention on Migratory Species
COFI	The Committee on Fisheries
DOM	Dissolved Organic Matter
EPR	Extended Producer Responsibility
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GEF	Global Environment Facility
GPA	Global Programme of Action for the Protection of the Marine Environment from Land-based Activities
IMO	International Maritime Organization
ISO	International Organization for Standardization
IUCN	International Union for Conservation of Nature
LCA	Life Cycle Analysis
MARPOL	International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978
MPA	Marine Protected Area
NGO	Non-Governmental Organization
NOAA	The US National Oceanic and Atmospheric Administration
PBT	Persistent, Bioaccumulative and Toxic Substances
PET	Polyethylene Terephthalate
POPs	Persistent Organic Pollutants
STAP	Scientific and Technical Advisory Panel of the Global Environment Facility
UNCLOS	The United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Programme
UNGA	United Nations General Assembly

Photo: Hindrik Bouwman

Executive Summary

Marine habitats worldwide are contaminated with man-made debris. Plastic items consistently represent the major categories of marine debris by material type on a global basis. Plastic debris is unsightly; it damages fisheries and tourism, kills and injures a wide range of marine life, has the capacity to transport potentially harmful chemicals and invasive species and can represent a threat to human health. This document focuses on plastic debris and examines its sources, identifies impacts on ecosystems and economies, and by considering the life-cycle of plastic products that become marine litter proposes a framework for responding to marine debris issues in general. The evidence presented on global occurrence, including accumulation in the areas beyond national jurisdiction, on persistence, and transboundary sources, movements and impacts on marine biodiversity and ecosystems compounded by emerging data on potential impacts and fate makes a strong case for considering marine debris as a global environmental problem.

The focus of this document is on land-based sources and types of plastic debris which represent the major debris components in many regions. Measures to address sea-based sources such as pollution from ships and abandoned and lost or otherwise discarded fishing gear, while sector-specific, can also be treated using the framework developed in this document. The problems of marine debris are now recognized internationally alongside other major global challenges facing the marine environment such as loss of biodiversity, acidification and sea level rise. Marine debris problems and responses are often presented in isolation. However, there are considerable synergistic opportunities that will result from simultaneously tackling the issues of marine debris in terms of conserving habitats, biodiversity and fisheries, reducing our reliance on non-renewable resources, limiting global carbon emissions and reducing waste.

Current awareness and implementation of best practices in addressing the causes of marine debris are primarily centered on end-of-pipe solutions. However, a substantial, but relatively neglected, underlying cause that results in plastic debris entering the sea from the land lies within unsustainable production and consumption patterns. This includes the design and marketing of products internationally without appropriate regard for their environmental fate or ability to be recycled in the locations where sold, inadequate waste management infrastructure, and inappropriate disposal. Often there is geographical separation between production in relatively developed economies and consumption/disposal which is global. From a life-cycle perspective, the current linear use of most plastics from production, through a typically short-lived usage stage to disposal, is a major barrier as well as an major opportunity to tackling the challenge of marine debris.

This STAP information paper proposes the use of a regional approach oriented towards the needs and perspectives of the consumers and users of items that can become marine debris, and the nations and regions that suffer from its effects. Solutions should be identified through cooperation and dialogue between industry, government and consumers and should consider the five R's (Reduce, Reuse, Recycle, Redesign and Recover) in a regionally coherent context. Potential actions to consider should encompass any or all parts of the supply and value chain and assessment of the full life cycle of the product and extended producer responsibility. The framework requires a series of key stages in order to achieve a reduction in the quantity of waste material being produced and includes five steps: problem identification, stakeholder dialogue with supply chain entities, facilitation, identification of knowledge gaps, development of institutional mechanisms and strategic planning.

STAP recommendations for the GEF:

1. The Global Environment Facility (GEF), the largest multilateral fund supporting measures improving the state of the global environment in the context of sustainable development, could play a leading role in global efforts to tackle the problems associated with plastic which is by far the most common material in marine debris. As a cross-sectoral issue, most interventions aimed at marine plastic debris prevention, reduction and management fall under existing mandates of GEF focal areas including International Waters, Climate Change, Biodiversity and Chemicals, the Small Grants Program and the GEF Earth Fund and public-private partnership platforms, as well as new programmatic initiatives such as Management of Marine Areas Beyond National Jurisdiction (ABNJ).
2. STAP is encouraging GEF partners to consider *mainstreaming* interventions addressing marine debris into existing and planned GEF projects and programs, specifically projects supporting management of Marine Protected Areas and fish refuges, ecosystem-based management of ABNJ and Ecologically and Biologically Significant Areas or Vulnerable Marine Ecosystems, projects supporting activities aimed at the reduction of pollution sources from land-based activities, and projects and programs promoting material re-use and recycling. Participants in the Small Grants Program in relevant countries are also encouraged to consider interventions aimed at marine debris prevention, reduction and management.
3. Given limited resources available in the GEF and the global scale of the plastic debris problem in the marine environment, STAP is advising the GEF Council and GEF partners to focus support in GEF-5 on the following activities that may serve as catalysts for actions and generate global environmental benefits. These two types of activities are based on principles embedded in the framework on marine debris management introduced in this information paper:
    - I) A pilot project or program testing the life-cycle approach to plastic debris prevention, reduction, and management in one of the areas covered by the Regional Seas Conventions and Action Plans. Building on the existing baseline, institutions, and mechanisms in the selected region, GEF investments could play a catalytic role in mobilizing public and private sector dialogue and resources for specific market transformation in the production, consumption, and utilization of marine debris sources such as plastics.
    - II) By combining the existing efforts of plastic producers, packaging and retailer associations, civil society organizations, multilateral institutions, and utilizing opportunities provided by the Earth Fund platforms, the GEF could promote, facilitate or establish a global public-private partnership – a key focus of which would be to reduce the environmental impacts associated with single-use plastics packaging while at the same time ensuring products retain functionality and are fit-for-purpose. Through this initiative, the GEF could build a strong partnership with the private sector to encourage innovation and to expand assistance to developing countries and countries with economies in transition – seeking to transform their use and utilization of single-use plastics packaging to protect the global environment. This initiative would simultaneously help reduce reliance on non-renewable resources, reduce waste, improve waste management, and reduce carbon dioxide emissions.

Photo: Jim Patterson, Ocean Conservancy

1. Why focus on plastic debris as a global problem?

1.1. Global distribution and composition of marine debris categories

Man-made debris in the oceans is now found from the poles to the equator and from shorelines, estuaries and the sea surface to ocean floor. While the types and absolute quantities vary, it is clear that plastic materials represent the major constituents of this debris, and there is no doubt about the ubiquity of such debris on a truly global scale (Barnes *et al*. 2009; Ryan *et al*. 2009; Browne *et al*. 2011). Plastic debris can be harmful to wildlife and to human health (Derraik 2002; Gregory 2009), it has the potential to transport organic and inorganic contaminants (Mato *et al*. 2001; Teuten *et al*. 2009), can present a hazard to shipping, and can be aesthetically detrimental (Mouat *et al*. 2010). In addition to having consequences for biodiversity and potential indirect effects on ecosystem goods and services, marine debris has direct negative economic impacts on many coastal countries and small island states, of which many are developing countries and countries with economies in transition (Kershaw *et al*. 2011; UNEP 2009).

Marine debris includes any form of manufactured or processed material discarded, disposed of or abandoned in the marine environment. It consists of items made or used by humans that enter the sea, whether deliberately or unintentionally, including transport of these materials to the ocean by rivers, drainage, sewage systems or by wind (Galgani et al. 2010). While this definition encompasses a very wide range of materials, most items fall into a relatively small number of material types and usage categories. Integrating across the UNEP Regional Seas reports, scientific papers, and government reports (EA 2001; OSPAR 2007; Sutherland *et al*. 2010; Thompson *et al*. 2009a; UNEP-CAR/RCU 2008; UNEP 2005; UNEP 2009), it is readily apparent that plastic items consistently rank as being among the most abundant types of marine debris on a global scale and are typically followed by smaller quantities of other materials including metal and glass (see Figure 1 and Table 1 for illustration from South African and South American beaches, respectively and Figure 2 for Europe; (Coe & Rogers 1997; Ryan *et al*. 2009; Thompson *et al*. 2009c; UNEP 2009). The trend on shorelines is echoed by data from the seabed where items of plastic debris recovered by fishermen were more abundant (>58%) than those of metal (21%) (KIMO 2008). This report will therefore give much of its focus to considering plastic debris in terms of sources and causes, accumulation and consequences, potential solutions and associated recommendations, and a framework for dialogue to achieve solutions. It is hoped that the lessons learned in relation to plastic debris may subsequently be translated into good practice for other categories of marine debris.

Scope of the problem

Plastics are incredibly durable and represents a large portion of marine debris found throughout the world. Data on temporal trends vary between regions and are typically restricted to sampling at or near the sea surface in coastal waters or on the shoreline (Barnes *et al*. 2009; Derraik 2002; Gregory 2009). From these habitats there is evidence that despite efforts to remove debris from the marine environment and legislation to restrict dumping at sea, quantities of marine litter are stable in some locations and are increasing in others (Barnes *et al*. 2009; Thompson *et al*. 2004). For example data on the quantities of plastic bottle caps and lids show a 10 fold increase on shorelines in South Africa when comparing data over a 20 year period to 2005 (Figure 1) (Ryan *et al*. 2009). Since most plastic items will not biodegrade in the environment it seems inevitable that quantities of debris will increase over time (Andrady 2011) and that the lack of consistent trends in temporal data probably represent movement of debris into compartments that have not traditionally been monitored such as the deep sea and offshore regions or fragmentation of plastic debris into pieces so small that they are not routinely recorded.

In terms of larger debris of particular concern is the accumulation of Abandoned, Lost or Otherwise Discarded Fishing Gear (ALDFG) from at sea disposal, including fishing nets which continue to catch fish long after they have become marine debris. Plastics-based ALDFG can threaten marine habitats and fish stocks and is also a concern for human health (Macfadyen *et al*. 2009). Although ALDFG are not a specific focus of this report, the approach suggested here could be extended to address them.

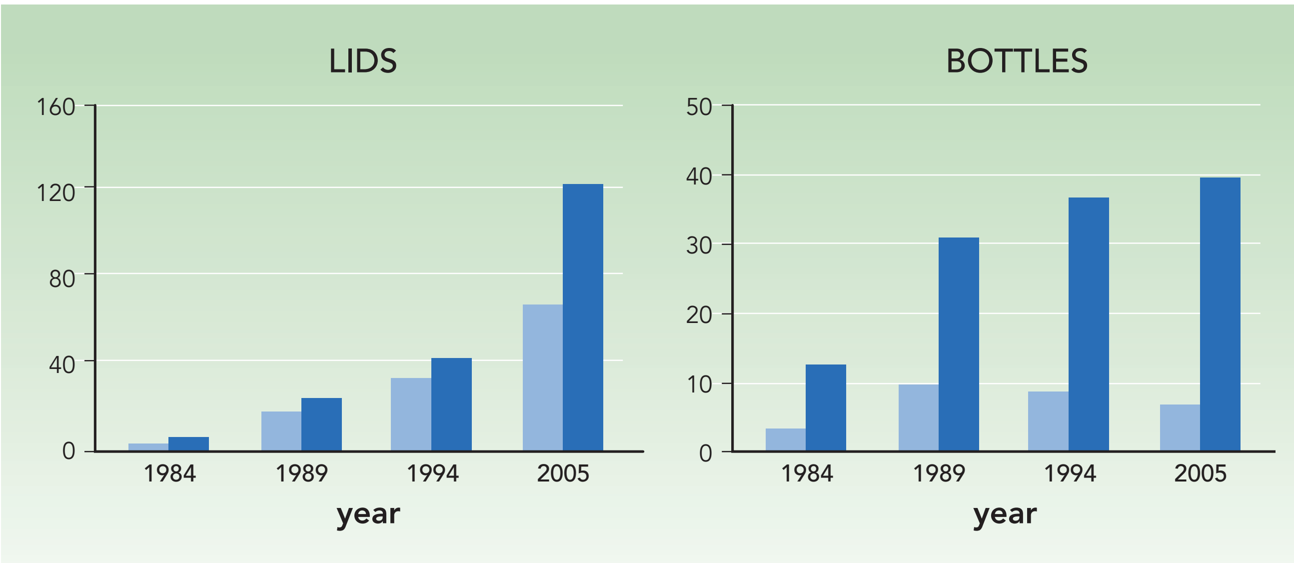

Figure 1. Trends in the abundance of plastic bottles and lids (bars show mean ± standard error) on South African beaches. Light grey bars – data from 36 beaches with regular municipal cleaning programs; dark grey bars – data from 14 beaches with no formal cleaning programs (Ryan *et al*. 2009).

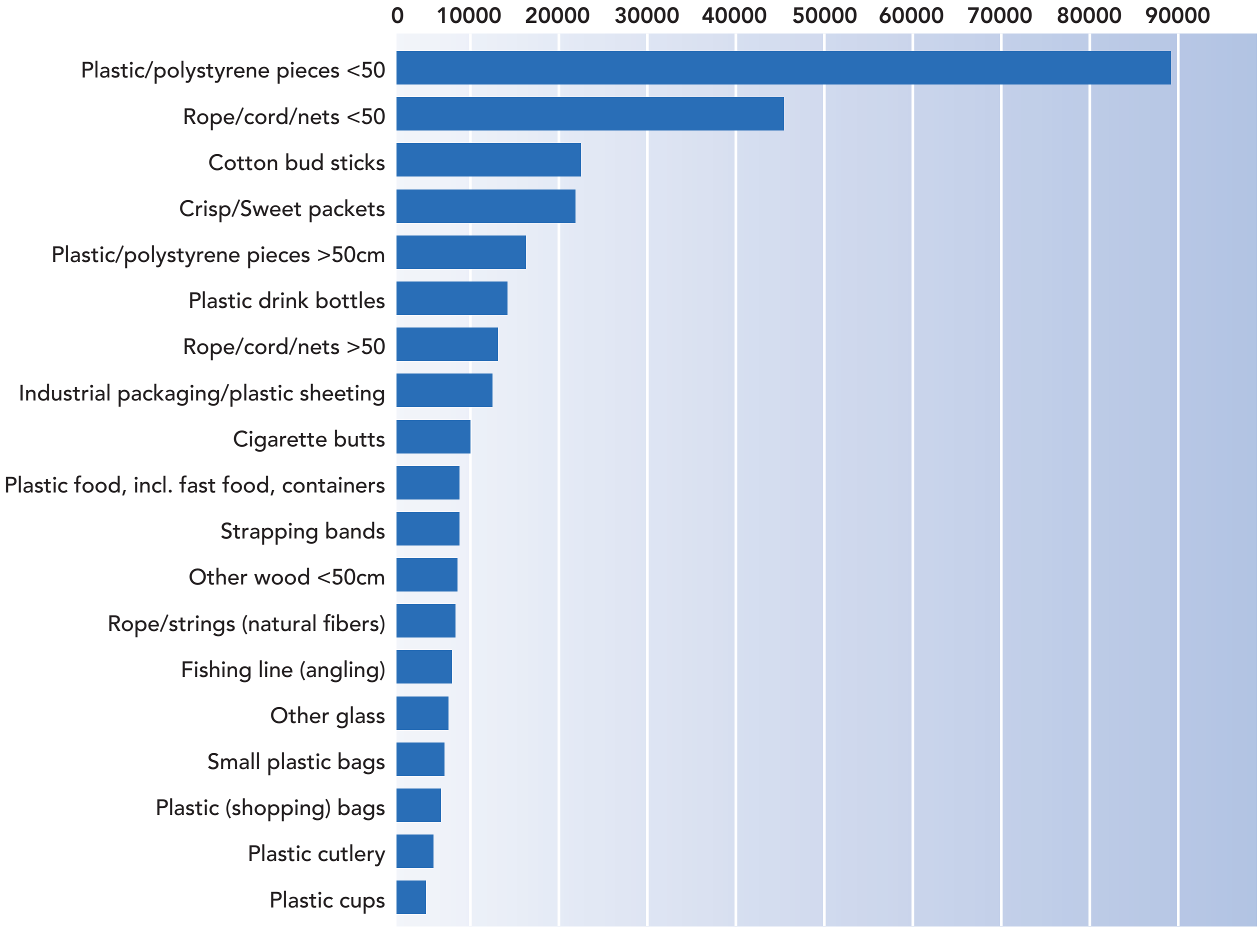

Figure 2. Combined data showing total number of items of marine debris from 100m sections of selected reference beaches in Europe examined between 2001 and 2006. Note the prevalence of plastic items as the major components of the debris recorded. These trends are broadly consistent across regions and at a global scale. The analysis was based on data from 609 surveys made in eight countries – Belgium, Denmark, Germany, The Netherlands, Portugal, Spain, Sweden and the United Kingdom (51 regular reference beaches altogether). (OSPAR 2007).

Because of their buoyancy and durability, plastic items can travel substantial distances. Plastics from cargo lost from ships have, for example, been reported over a decade later more than 10,000 km from the point of loss. Hence, in addition to shoreline or near-shore impacts, marine debris can have long-term impacts in the open ocean (Barnes *et al.* 2009). Ocean modeling indicates that floating marine debris originating from the western coast of South America, French Polynesia, New Caledonia, Fiji, Australia, and New Zealand not only fouls the coastlines of nations and archipelagos in the region where released, but much of it is pushed by wind and currents to the South Pacific subtropical gyre where it accumulates (Martinez, *et al.* 2009). A recent high profile publication in the journal *Science* presented over 20 years of data clearly demonstrating that some of the most substantial accumulations of debris are now in oceanic gyres far from land (Law *et al.* 2010; Figure 3). Therefore, marine debris, and in particular plastic debris, represents a growing transboundary global problem that recognizes no national borders and spreads from coasts to open ocean and Areas Beyond National Jurisdiction (ABNJ). While floating plastic marine debris is the most visible problem, and may most directly affect beaches, plastic items also pollute the ocean floor. A survey of marine debris on the sea floor along European coasts found that "In most stations sampled, plastic (mainly bags and bottles) accounted for a very high percentage (more than 70%) of total number of debris, and accumulation of specific debris, such as fishing gear, was also common (Galgani *et al.* 2000).

Marine debris, and in particular the accumulation of plastic debris, has been identified as a global problem alongside other key issues of our time including climate change, ocean acidification and loss of biodiversity

(Ramirez-Llorda *et al.* 2011; Sutherland *et al.* 2010). This report sets out to indicate some of the solutions, and in doing so, aims to highlight the potential synergies and benefits that can be achieved by tackling the underlying causes of marine debris. These include potential economic benefits for industry, for developed and emerging economies, and for fisheries, as well as benefits for biodiversity together with the potential to reduce global carbon emissions.

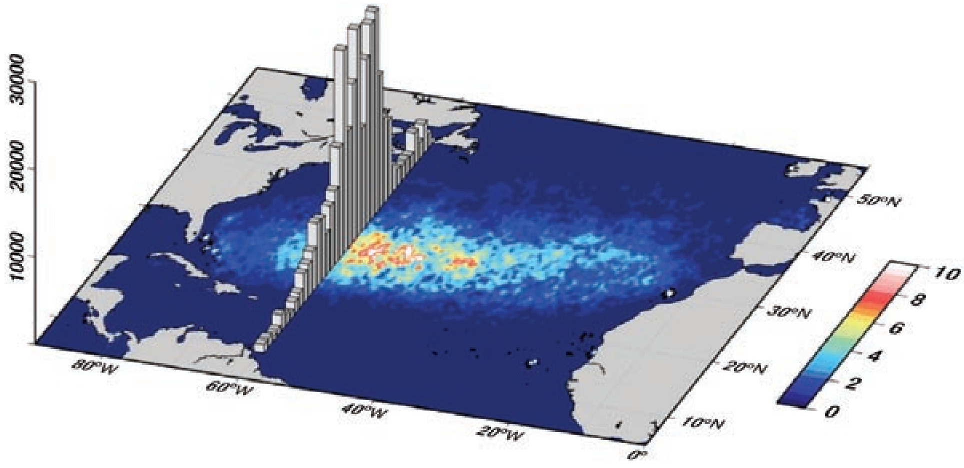

Figure 3. Average plastic concentration as a function of latitude (bars, units of pieces km^{-2}), and modeled concentration (color shading), of initially homogeneous surface tracer after 10-year model integration. The highest plastic concentrations were observed in subtropical latitudes (22-38°N) where model tracer concentration is also a maximum (see Law *et al.* 2010 for details).

Table 1. Ten most common items of marine debris collected in South America during the 2005 International Coastal clean-up. Each item is shown as a percentage of related sources of litter with the combined percentages for the top ten items shown by country at the base of the table (Source: UNEP 2009).

Panama		Columbia*		Ecuador		Perú		Chile	
Percentage of related sources of litter									
Beverage plastic bottles	11.8	Beverage plastic bottles	20.6	Cigarettes/ filters	55.5	Beverage plastic bottles	41.4	Bottle caps and other containers	38.7
Bags	10.6	Beverage glass bottles	16.6	Bottle caps and other containers	8.4	Bags	10.3	Beverage plastic bottles	30.9
Clothes	10.2	Bottle caps and other containers	12.8	Bottle caps and other containers	6.4	Bottle caps and other containers	7.1	Cigarette/filters	8.4
Cups, plates and utensils	8.6	Bags	12.2	Bags	4.8	Cups, plates and utensils	4.1	Food wrappings	4.4
Beverage glass bottles	7.4	Plastic joints	8.4	Food wrappings	3.9	Clothes	3.0	Bags	4.1
Beverage cans	6.5	Clothes	4.7	Rope	2.9	Toys	2.6	Plastic joints	2.8
Bottle caps and other containers	6.4	Cups, plates and utensils	4.2	Cups, plates and utensils	2.9	Cigarettes/ filters	2.5	Beverage glass bottles	1.4
Food wrappings	6.2	Food wrappings	3.7	Beverage glass bottles	2.3	Plastic straws and swizzle sticks for drinks	2.5	Chlorine bottles and other cleaning articles	1.1
Plastic joints	4.1	Beverage cans	3.1	Plastic joints	1.7	Diapers	2.3	Cigarette packs and wrappings	0.9
Oil bottles	2.9	Plastic straws and swizzle sticks for drinks	2.7	Plastic straws and swizzle sticks for drinks	1.6	Beverage cans	2.2	Building materials	0.9
Total	**74.7**	**Total**	**89.0**	**Total**	**89.2**	**Total**	**78.0**	**Total**	**93.6**

* *Data reference for San Andrés, Colombia (Caribbean island)*
Source: Ocean Conservancy

1.2. Plastic debris and global ecosystem impacts

More than 260 species are already known to be affected by plastic debris through entanglement or ingestion (Figure 4). Ingestion by birds, turtles, fish and marine mammals is well documented and can be fatal. A wide range of plastic types are involved and effects range from entanglement of cetaceans in rope and netting, suffocation of birds and turtles by plastic film to ingestion of microscopic fragments of plastic by fish and invertebrates (Boerger, 2010; Derraik 2002; Gregory 2009; Laist 1987; Murray and Cowie 2011). Small particles are of concern because they may be ingested by a wide range of organisms that form the base of the marine food web, and could have adverse physical effects, for example by disrupting feeding and digestion (Barnes *et al.* 2009; Boerger *et al.* 2010; GESAMP 2010; Murray & Cowie 2011).

Of the 120 marine mammal species listed on the IUCN Red List 54% are known to have been entangled in or have ingested plastic debris (Figure 4). A sample of all 34 green turtles and 14 of 35 seabirds found along the southern Brazilian seacoast had ingested debris, with plastic being the main ingested material. In addition to ingestion and entanglement, beach debris can affect behavior of intertidal organisms (Aloy *et al.* 2011) and adversely affect the ability of turtle hatchlings to reach the sea (Ozdilek *et al.* 2006). Plastic debris is fragmenting in the environment and pieces as small as 2μm have been detected (Ng & Obbard 2006). There is also the potential for plastic to break down into nano-sized particles which may still be too large to actually biodegrade (Andrady 2011).

Evidence of harmful effects of plastic on wildlife is mostly restricted to observations on individual specimens that have become entangled in or have ingested plastic debris. Concerns have been raised about potential consequences for ecosystem-wide impacts and ecosystem goods and services, however as yet little is known about larger-scale effects of plastic pollution. Some of the most comprehensive population level data are for Northern Fulmar, *Fulmarus glacialis*, and these have shown that over 95% of birds washed ashore dead contained plastic in their gut, with many individuals having substantial quantities of plastic (van Franeker *et al.* 2005). While it is not possible to attribute the cause of death of these birds it is clear that for some species a substantial proportion of the population are ingesting plastic debris and that some individuals contain substantial quantities of plastic (van Franeker *et al.* 2011).

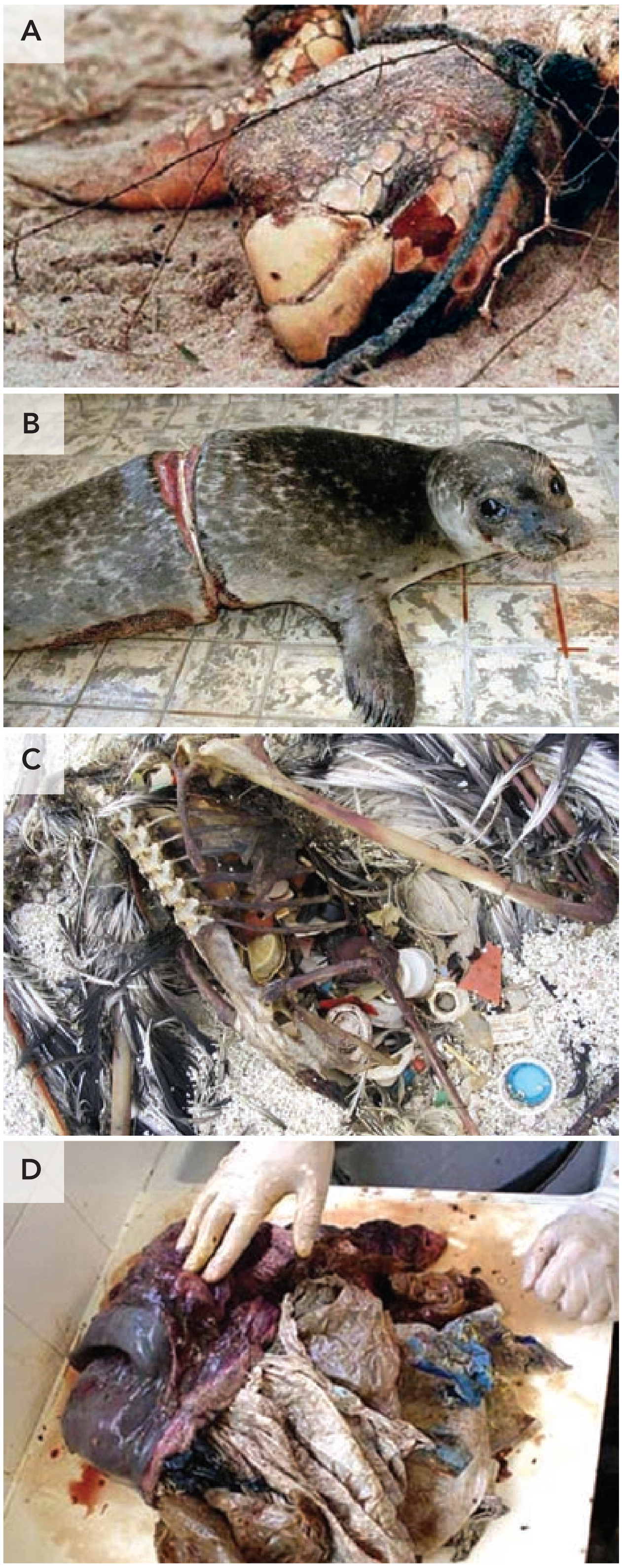

Figure 4. A) Turtle entangled in plastic rope in Caribbean (photo: UNEP-CAR/RCU, 2008); B) Entangled seal at Gweek Seal Sanctuary in Cornwall (photo by Caroline Curtis; source: OSPAR 2009); C) Plastic packaging from the carcass of a Laysan albatross at Kure Atoll, courtesy of Cynthia Vanderlip and Algalita Marine Research Institute; D) Plastic bags and film from stomach of young Minke whale that had been washed ashore dead in France (Courtesy for G. Mauger and F. Kerleau, Group d'Etudes de Cétacés du Cotentin (GECC)).

Floating marine debris has also been implicated in the transport of non-native invasive species which can ''raft'' considerable distances on such debris. Over 150 multi-cellular species have been reported associated with plastic debris, the majority being hard-shelled species including bivalve mollusks, barnacles, tube worms, bryozoans, hydroids and coralline algae. In addition, there is evidence that items of plastic washed ashore are often fouled by non-native species. Some species of *Vibrio* bacteria have been shown to grow preferentially on plastic particles in the ocean but it is unknown whether those found can cause disease. Rafting on plastic debris may facilitate transport of species across boundaries of water masses that might otherwise be relatively impenetrable (Barnes *et al.* 2010; Derraik 2002; Gregory 2009; Laist 1987). While it is clear that plastics are a vector for the transport of non-native species their relative contribution needs to be considered alongside other vectors, such as transport on wood and pumice, transport on the hulls of ships and release of ballast water (Bax *et al.* 2003).

The most visible types of plastic debris are large derelict fishing gears, bottles, bags, and other consumer products, however much of the debris collected during survey trawls consists of tiny particles or "microplastic" (Law *et al.* 2010 Thompson *et al.* 2004). This material has been defined as pieces or fragments less than 5*mm* in diameter (Arthur *et al.* 2009; Barnes *et al.* 2009). A horizon scan of global conservation issues recently identified microplastic as one of the top global emerging issues (Sutherland *et al.* 2010). Microplastic is formed by the physical, chemical and biological fragmentation of larger items, or from the direct release of small pieces of plastic such as industrial spillage of pre-production pellets and powders, together with microscopic plastic particles that are used as abrasive scrubbers in domestic cleaning products (e.g. Fendall and Sewell 2009; Gouin *et al.* 2011) and industrial cleaning applications such as shot blasting of ships and aircraft (Barnes *et al.* 2009). Plastic items fragment in the environment because of exposure to UV light and abrasion, such that smaller and smaller particles form. Some plastics are even designed to fragment into small particles, but the resulting material does not necessarily biodegrade (Roy *et al.* 2011). Microplastics have accumulated in the water column, on the shoreline and in subtidal sediments (Andrady 2011; Barnes *et al.* 2009; Thompson *et al.* 2004; Zarfl *et al.* 2011). Fragments as small as 2µm have been identified from marine habitats around Singapore (Ng and Obbard 2006), but due to limitations in sampling and analytical methods the extent to which this type of debris has fragmented into microscopic or nanoparticle-size pieces is unknown. As a consequence of fragmentation of larger items and direct release of small particles the quantity of fragments is therefore expected to increase in the seas and oceans (Andrady 2011; Thompson *et al.* 2009b). It is recognized therefore that there are important questions that should be investigated regarding the emissions, transport and fate, physical effects, and chemical effects of microplastics (Zarfl *et al.* 2011).

As colloidal size particles, nanoplastic particles could be subject to different transport mechanisms than larger fragments and more work is needed to understand the potential movement and sinks where this material will accumulate (Hansell *et al.* 2009). Small plastic fragments are the most common size fraction reported in oceanic gyres in the Pacific and Atlantic, with some of the highest densities being reported in the open ocean rather than in coastal waters adjacent to population centers (Law *et al.* 2010). In some locations the abundance of small fragments in the water column is increasing (Thompson *et al.* 2004). Small particles such as these may impact the bottom of the food web (Teuten *et al.* 2007) and it has been reported in a laboratory studies, for example, that plastic particles in the size range 3-10µm are ingested and then retained by bivalve mollusks (Browne *et al.* 2008), while in a laboratory study nanopolystyrene beads were shown to inhibit photosynthesis and cause oxidative stress in algae (Bhattacharya *et al.* 2010). However, our knowledge about the effects of very small plastic particles lags behind that of larger debris items. More work is needed to understand the implications of ingestion of micro and nano-plastics by marine organisms (Figure 5).

There is also concern that small plastic fragments might present a toxicological challenge. Plastics contain a variety of potentially toxic chemicals that are incorporated during manufacture (monomers and oligomers, bisphenol-A (BPA), phthalate plasticizers, flame retardants and antimicrobials) (Lithner *et al.* 2011). There is evidence regarding the potential for these chemicals to be released to humans from plastic containers used for food and drink, plastic in medical applications, and in toys (Koch and Calafat 2009; Lang *et al.* 2008; Meeker *et al.* 2009; Talsness *et al.* 2009), and this has led to introduction of legislation on human usage of plastic items containing additives in some countries. Hence there is the potential that these substances might also be released if plastics containing them are ingested by marine organisms (Oehlmann *et al.* 2009; Teuten *et al.* 2009). More work is required, however, to understand the relative importance of this pathway compared to other sources of contaminant uptake. While exposure pathways have not been determined, chemicals used in plastics such as phthalates and flame retardants have been found in fish, sea mammals, mollusks and other forms of marine life. This raises concerns about a potential for toxic effects. For example BPA, for which there is evidence from laboratory studies of adverse effects on a variety of aquatic organisms (Oehlmann *et al.* 2009; Talsness *et al.* 2009), may enter the marine benthic environment through a variety of pathways including marine debris. Phthalates have also been shown in laboratory studies to have adverse effects on aquatic organisms (Oehlmann *et al.* 2009). While a direct link between plastic debris and adverse effects on populations of marine organisms would be very difficult to demonstrate experimentally, if such effects were to occur there would be no way of reversing or remediating them due to the nature of debris accumulation in the environment (GESAMP 2010; Thompson *et al.* 2009b).

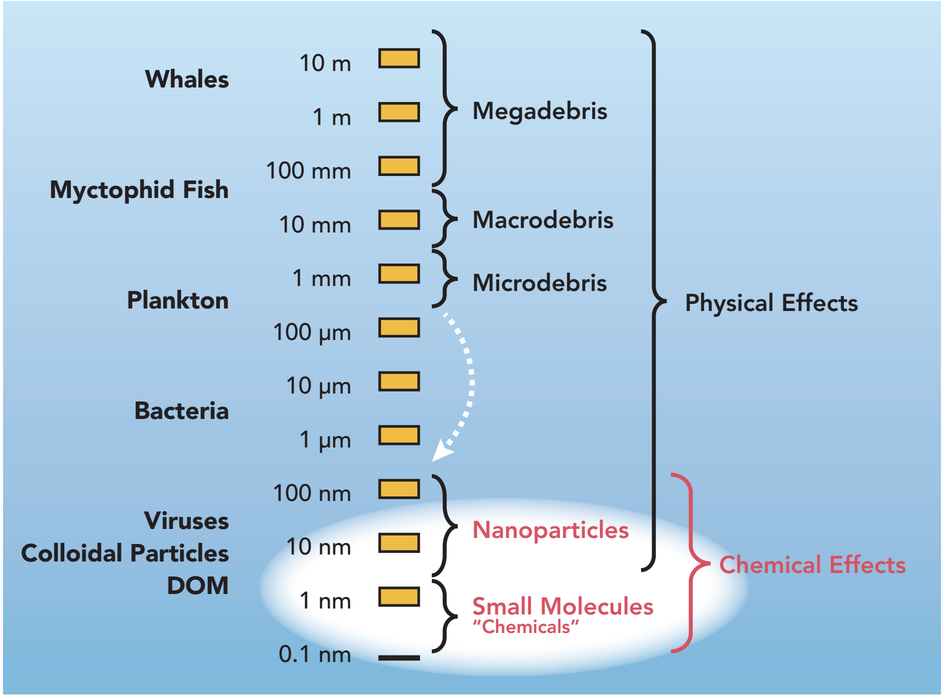

Figure 5. Schematic diagram illustrating various sizes of plastic debris and marine organisms together with the potential impacts both physical and chemical. It should be noted that our understanding of impacts of microscopic and nano-sized particles is at present very limited.

In addition to the potential for release of additive chemicals, studies in Japan, the USA and Europe have demonstrated that plastic debris can absorb persistent, bioaccumulative and toxic (PBT) substances including persistent organic pollutants (POPs), that are present in the oceans from other sources, and that within a few weeks these substances can become orders of magnitude more concentrated on the surface of plastic debris than in the surrounding water column (Mato *et al.* 2001; Teuten *et al.* 2009, Hirai *et al.* 2011; Rios *et al.* 2010). At present our understanding about the potential for plastics to adsorb, transport and release chemical contaminants is limited. Basic thermodynamic equilibrium calculations indicate that over large ocean areas (e.g., between the tropics and the Arctic) transport of POPs adsorbed to plastics is insignificant compared with long-range transboundary fluxes with air and ocean waters (Gouin *et al.* 2011; Zarfl and Matthies 2010). Hence at a global scale plastic particles are unlikely to be an important reservoir of POPs (Arthur *et al.* 2009). On local scales over shorter distances and/or timeframes, however, plastics may short-circuit the long-term equilibrium processes resulting in increased exposure (Hirai *et al.* 2011; Yang *et al.* 2011). (Hirai et al. 2011; Yang et al. 2011). When plastic particles are therefore re-distributed in the water column and sediments they have the potential to carry adsorbed chemicals with them, and if subsequently ingested there is evidence that these adsorbed POPs will be released in the gut (Teuten *et al.* 2007; Teuten *et al.* 2009). The extent to which plastic particles act as a vector in the transport of contaminants is uncertain and more work is required to establish the relative importance compared to other pathways.

It is difficult to isolate the impacts of marine debris from a range of other anthropogenic factors influencing marine ecosystems, but it is important to acknowledge marine debris as a major additional degrading agent. Addressing the impacts of marine debris on biodiversity will likely be impractical using approaches adopted to reduce other human impacts such as over-exploitation and disturbance. The latter can be regulated to some extent through the use of marine reserves, protected areas and integrated coastal zone management, but the potential for plastic debris to persist in the marine environment for long periods, to travel considerable distances, and to accumulate in habitats far from its point of origin presents a distinct challenge that is difficult (if not impossible) to resolve once the debris is adrift. Conservation tools based on spatial planning will therefore be ineffective to deal with plastics debris in many settings. Prevention at source is key to mitigating increases in marine debris.

1.3. Social-economic impacts of marine debris

This chapter considers data on marine debris in general. Fishing, transportation and tourism sectors, as well as governments and local communities, suffer from the negative economic and financial impacts of marine debris (Brink *et al*. 2009; Mouat *et al*. 2010) and the costs associated with plastic and other marine debris are often borne by those affected by, rather than those causing, the problem. It is important to note that the true costs from marine debris are likely to be greater than those quantified so far because of the distinct paucity of available data.

The most obvious economic impacts are loss of fishing opportunities due to time spent cleaning debris from nets, propellers and blocked water intakes and multiple impacts on subsistence livelihoods. For instance, fouling of the nets of subsistence fishermen in Indonesia, with plastic bags reduced catch rates and resulted in lost revenues. It has been estimated that the damage from marine debris on fishing, shipping, and tourism industries in the APEC region is US$1.265 million annually and a recent report has also shown that marine debris costs the Scottish fishing industry around US$16 million per year, the equivalent of 5% of the total revenue of the affected fisheries. There are additional negative consequences for aquaculture (Brink *et al.* 2009; Mouat *et al*. 2010).

Marine debris is also a significant ongoing navigational hazard for shipping, as reflected in the increasing number of coast guard rescues to vessels with fouled propellers. In the United Kingdom, for example, there were 286 such rescues in 2008, at a cost of up to US$2.8 million (Mouat *et al.* 2010). Cleanups of beaches and waterways can be expensive. In the Netherlands and Belgium, approximately US$13.65 million per year is spent on removing beach litter. Cleanup costs for municipalities in the United Kingdom have increased by 38% over the last ten years, to approximately US$23.62 million annually and it is estimated that removing litter from South Africa's wastewater streams would cost about US$279 million per year (Brink *et al.* 2009). A further consideration is aesthetic damage caused by marine debris. Litter affects the public's perception of the quality of the environment and in turn, can lead to loss of income to tourism, and in some cases by national economies dependent on tourism. A model of the value of beach quality in Dalian, China, for example, gives an estimation of coastal beach quality improvement of about US$26 per person (Brink *et al*. 2009; Kershaw *et al*. 2011; Mouat et al. 2010).

Major companies that make and use packaging have recognized that while modern packaging can have significant benefits to communities, "its detrimental impacts exist because: 1) packaging production is resource intensive; 2) toxicants and other environmentally relevant chemicals used during the growth, harvest or extraction and processing of raw materials, processing of recycled materials and the production of packaging materials, packaging components and units of packaging can release harmful emissions into natural eco-systems and have direct or indirect effects on human health; and 3) packaging has end-of-life implications that add stress to both human and natural systems" (Sustainable Packaging Coalition, 2009). These companies recognize that the design, production, and use of their products can have social as well as economic effects on local communities, and have committed to taking this into account in their business sustainability practices.

There are environmental and economic benefits associated with waste minimization achieved through material reduction, re-use and recycling. For example, where plastics are recycled to produce goods that would otherwise have been made from new (virgin) polymers, this will directly reduce oil usage and can also reduce emissions of greenhouse gases associated with plastics production. One of the key benefits of recycling plastics is to reduce the requirement for plastics production (Hopewell *et al.* 2009; Thompson *et al.* 2009b; WRAP 2006; WRAP 2008). In terms of energy use, recycling has also been shown to save more energy than that produced by energy recovery, even including the energy used to collect, transport and re-process the plastic.

Life-cycle analyses (LCA) have also been used to evaluate net environmental impacts, and these find greater positive environmental benefits for mechanical recycling over landfill and incineration with energy recovery. For example, it has been estimated that polyethylene terephthalate (PET) bottle recycling gives a net benefit in greenhouse gas emissions of 1.5 tonnes of CO_2 per tonne of recycled PET as well as reduction in landfill and net energy consumption. A recent LCA showed that using 100% recyclable PET bottles instead of virgin materials will reduce the full life-cycle emissions from 446 to 327 g CO_2 per bottle or 27% relative reduction in carbon emissions (Hopewell *et al.* 2009; Thompson *et al.* 2009b). The conclusions of academic publications are supported by reports form industry highlighting the importance of recycling as an approach to reduce carbon emissions (Franklin-Associates 2010). In the context of this report recycling represents a key strategy to reduce the quantity of plastic in landfill and accumulation in the natural environment.

Photo: Tony Oquias Photography

2. How to address the plastic debris problem?

2.1. Knowledge gaps

There is a considerable volume of scientific literature, together with publications from governments, non-governmental organizations (NGOs), academia and industry, outlining our understanding of issues relating to plastics in the environment and human health (Thompson *et al*. 2009a). It is clear from this literature that there are unresolved knowledge gaps, uncertainties and areas of disagreement and debate. A summary of existing knowledge and current uncertainty is given in Thompson *et al.* 2009b, Table 1 and in (Zarfl, 2011). Some key knowledge gaps are also outlined below. While resolving these will clearly help us refine solutions and prioritize, the authors consider there to be broad agreement from industry, governments, academia, and civil society that a reduction in marine debris, and in particular plastic debris, is a priority that requires urgent action. The objective of this document is to provide a framework to facilitate productive dialogue among relevant parties with a view to supporting consensus building and tangible progress on this challenging issue. The authors believe that sufficient empirical knowledge exists to support progress on this issue now. The knowledge gaps outlined below should be considered as means of refining actions, rather than defining or delaying them.

Knowledge gaps

Production and use

- Is there sufficient arable land available for effective and wide scale use of bioplastics as a renewable alternative to hydrocarbons as a source of plastic?
- To what extent can green chemistry be applied to provide more sustainable material for single use packaging?
- How can labeling of "degradable," "biodegradable" and "compostable" plastics be clarified so it is accurate, easy for retailers and consumers to understand and reflect real-world, end-of-life scenarios such as fate in the marine environment?
- What are the major global, regional, and local sources and practices that result in marine debris?

Waste management and end-of-life

- To what extent do chemicals leach from plastics in landfills?
- What are the rates of deterioration and consequences of products formed from deterioration of fragmentable and biodegradable plastics especially in the natural environment?
- How much debris has accumulated, and how much is continuing to accumulate, in the deep sea or become buried in sediments?
- Do ingestion and/or entanglement with plastic debris result in population level consequences for marine organisms?
- To what extent can ingestion of plastics result in release of chemicals to organisms?
- What are the main sources and sinks of microplastics?
- What are the consequences of wide scale accumulation of small plastic particles (microplastics and nanoplastics) in the environment / organisms?

2.2. Major causes (=sources and processes) of marine debris

Some of the major sources of marine debris are well described, and include sewage and run-off related debris, materials from recreational/beach users, and materials lost or disposed of at sea from fishing activities (such as ALDFG) or shipping (Derraik 2002; OSPAR 2007; Thompson *et al.* 2009b; UNEP 2009). Debris originating from the land is either transported by storm water, via drains and rivers toward the sea, or is blown into the sea (Macfadyen *et al.* 2009; Ryan *et al.* 2009). Extreme weather events such as hurricanes and floods are important point sources of marine debris from/to the sea (Thompson *et al.* 2005). Sea-based sources of debris represent additional, and in some regions, substantial sources of debris. The dumping of waste at sea is regulated by many agreements and conventions, and while there are problems with enforcement reduction in the amount of debris from ship-based activities have been reported in some regions. Two commonly used tools in reducing ship-based sources of marine debris are the availability of appropriate and convenient port reception facilities for waste from ships (Mouat *et al.* 2010; Thompson *et al.* 2009b) and educational materials (e.g., multi-language posters and video footage).

Abandonded, lost, or otherwise discarded fishing gear (ALDFG) represents a problematic aspect of sea-based sources of the marine debris. It undermines fisheries management and threatens marine life, and can have significant negative economic, ecological and public health effects including habitat destruction through abrasion or smothering, macrofaunal entanglement, ingestion, and prolonged ghost fishing. Increases in the scale of fishing operations, universal use of synthetic materials and expansion of fishing into the deep-seas and ABNJ have increased these impacts (Macfadyen et al. 2009). ALDFG has been recognized internationally as a major problem and proposals for addressing the problem have been made at the level of the United Nations General Assembly (UNGA) and its specialized agencies and programmes including the Food and Agriculture Organization of the United Nations (FAO), the

United Nations Environment Programme (UNEP), and the International Maritime Organization (IMO). There have also been regional calls to address ALDFG. Initiatives to reduce ADLFG are crucial and implementation principles are generally similar to measures addressing land-based sources of marine debris such as discarded consumer goods and packaging (prevention, mitigation, removal and awareness raising), but there are many important sector-specific issues[1].

This document seeks to highlight much broader causes and responsibility, spanning production, use and disposal of the items that become marine debris. The authors consider the problems and the solutions have origins not only in coastal communities, but also far inland. They are rooted in production and consumption patterns, including the design and marketing of products internationally without appropriate consideration for their environmental persistence or ability to be recycled in the locations where sold. In addition, there can be considerable geographical separation between production, which is typically centered in relatively developed economies, and consumption/disposal which is global. As such it expands significantly the widely accepted proposition that the problem of marine debris is predominantly associated with poor management practices on land (Andrady and Neal 2009; Leous and Parry 2005; PlasticsEurope 2010; UNEP 2005; 2009). A broader approach such as that proposed in this document is now gaining momentum among governments, NGO's and some industries (DG-Environement 2011; Kershaw *et al*. 2011; US Commission on Ocean Policy 2004; Honolulu Commitment, 2011). The Honolulu Commitment, a document adopted by a range of stakeholders including governments, industries and NGOs at the 5th International Marine Debris Conference, is an example for a more encompassing approach. Endorsees of the Commitment expressed concern at the growing presence of plastic debris in the marine environment and acknowledged the plastic associations' Global Declaration on Marine Litter, while recognizing other materials also constitute marine debris.

An essential part of this discussion is to consider the benefits that plastic products bring to society and to the environment. Plastics are lightweight, durable and inexpensive; plastic products bring benefits in medical, educational, and transport applications. Plastics also play an important role in helping reduce mankind's footprint on the environment (PlasticsEurope 2008). Use of plastic components in automobiles and aircraft results in significant weight savings compared to metals. The new Boeing 787 aircraft will, for example, have an exterior skin that is 100% composite and an interior which is 50% plastic, resulting in combined fuel savings of around 20% (Andrady & Neal 2009). Plastic packaging has a key role in reducing food wastage, through extending the shelf life of perishable products and hence contributing to food safety. Since plastic packaging is light weight it can also achieve significant reductions in fuel usage (packaging in PET can achieve a 52% saving over glass for example) during transportation of packaged items (Andrady & Neal 2009). These and other advantages has led to global production of plastics now accounting for approximately 4% of world oil production in the products themselves, and a further 4% in the energy required for this production. However, this success also results in growing accumulation of end-of-life plastics which are being examined here. Hence, while this document considers issues relating to plastic debris, it focuses on a holistic framework to generate solutions – a framework which aspires to optimize benefits and reduce impacts in order to harness the greatest potential that plastic products can offer at minimum cost to the environment.

Plastic production continues to grow at about 9% annually (Figure 6) and developed countries in Europe, Northern America and Japan account for about 60% of global production and have the highest plastics consumption per capita rates of about 100-130 kg/yr (PlasticsEurope 2008). The demand and consumption of plastics in developing countries is also growing rapidly, and driving a shift in production and conversion of plastics from developed to developing countries. The highest potential for growth is in the rapidly developing countries of Asia, along with CEITs in Europe (Figure 7). Current consumption of plastic, similar to production, shows an exponential increase with more plastics being produced in the first decade of the present century than in the entire preceding century (Thompson *et al.* 2009c).

1 For more information and measures to reduce ADLFG, please refer to the document UNEP/FAO (2009). Abandoned, lost or otherwise discarded fishing gear available at: http://www.fao.org/docrep/011/i0620e/i0620e00.htm

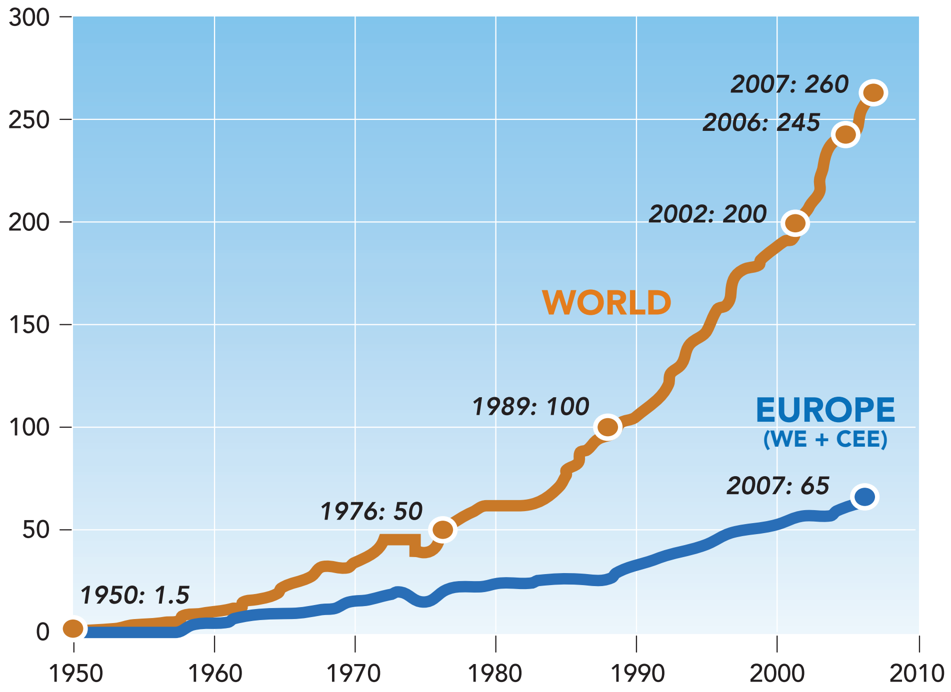

Figure 6. Global and European production of plastics (millions tonnes per annum) from 1950 to 2007. Data include thermoplastics, polyurethanes, thermosets, elastomers, adhesives, coatings and sealants and polypropylene fibers. Not included are polyethylene terephthalate-, polyacrylate- and polyacrylic-fibers (Source: PlasticsEurope, 2008).

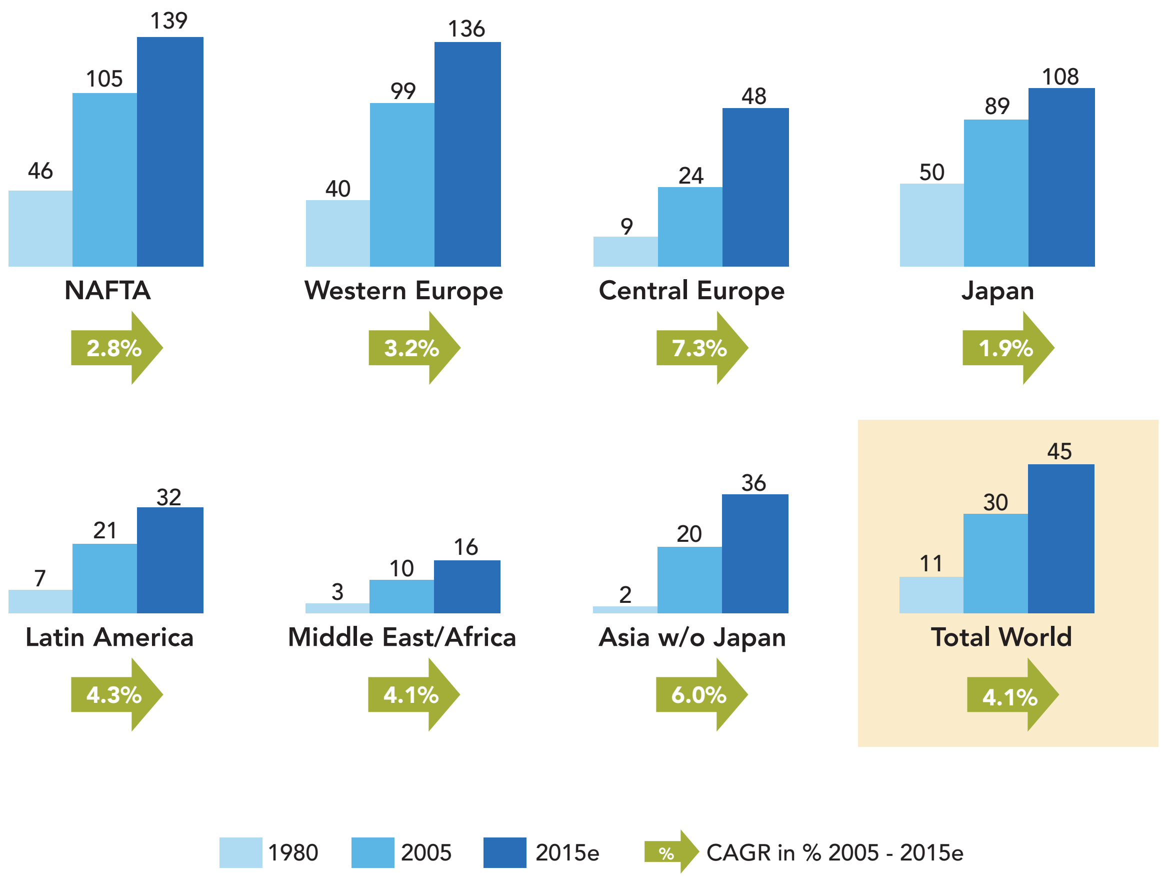

Figure 7. Plastic demand by converters shown by region expressed as values in kg/yr per capita, together with predicted increase by 2015. Most significant growth is anticipated in Asia and Eastern Europe. (Source: PlasticsEurope 2008).

2.3. Key challenge: how to reduce the quantity of plastic debris entering marine and freshwater environments?

A key challenge in addressing the problems associated with plastic debris in the ocean is in broadening the range of available management measures beyond improvement in waste management practices (DG-Environment 2011; UNEP 2009). At present these are predominantly 'end of pipe' responses, rather than preventative. The most commonly used approaches vary regionally, but include educational notices about the problems of dumping and littering, improved reuse, recycling and recovery (under strictly controlled conditions) provision of litter bins on beaches, port reception for waste from ships, and extensive clean-up campaigns on shorelines and at sea (Figure 8). The plastics industry has supported end-of-life consumer education and recycling programs as a solution, see for example http://marinedebrissolutions.com/, but such measures are more relevant to highly developed nations with economic resources and economies of scale to make the programs cost-effective. In relation to ever increasing global and regional trends in the quantity of plastics waste being produced, it is becoming increasingly clear that a paradigm shift is required in the way we address this global problem.

Figure 8. Illustrative examples of coastal clean-up activities across UNEP Regional Seas: A, India; B. Japan; C. Greece; D. Yemen; E. Djibouti and F. Australia. (A. Marine litter in the South Asian Seas Region, South Asia Co-operative Environment Programme 2007; B-E. UNEP 2009; F., Macfadyen and Huntingdon, 2009).

2.4. Introducing a need for paradigm shift: Plastic debris in a broader context of sustainability and green economy

From a life-cycle perspective, the linear use of resources from production to a short-lived single-use stage to disposal is a central underlying cause of the accumulation of waste (Thompson *et al*. 2009b; WRAP 2006). Hence, despite the durability of plastics and the very broad range of applications and benefits, a recent life-cycle analysis of different materials used in industrial production highlighted plastics together with fossil fuels and biotic materials as those representing large contributions to environmental issues (Figure 9). .

The quantity of plastic debris generated will be related to economic productivity, since this will be paralleled by the quantity of end-of-life material generated. This in turn is likely to become either waste disposed via landfill, incineration, or released as debris to the natural environment. Much of our current production and consumption patterns do not reflect principles of long-term sustainability, as access to raw materials and our capacity to deal with wastes are finite (Barnes *et al*. 2009; Thompson *et al*. 2009b). If there are manufactured products and associated packaging there is a potential source of debris. Putting it simply, if we can reduce the quantity of plastic waste we produce while at the same time improving waste management options, we maximize our potential to tackle the problems associated with accumulation of waste products in the environment. While the trends in quantity of debris parallel with economic growth, the pathways which cause plastic debris to enter the environment are transboundary and global in nature – and it is this disconnect which necessitates new approaches.

Recognition that marine debris is not merely a waste management issue is fundamental to addressing the underlying causes of this debris. As such, addressing the marine plastic debris problem through a complete life-cycle approach is one of the potential testing grounds for the green economy concept – which promotes approaches using fewer resources per unit of economic output, and reducing environmental impact of any resources that are used or economic activities that are undertaken without compromising growth. Applied to plastics, this means promoting structural economic changes that would reduce plastics consumption, increase production of environmentally friendlier materials, increase recycling and reuse, promote investments in alternative conversion technologies and new materials and products, and support an enabling environment including capacity building, new regulations and standards (Thompson *et al.* 2009b). Such benefits can only be realized working in partnership with industry. The benefits of collaboration with the private sector are recognized by both the Congressionally mandated US Commission on Ocean Policy (US Commission on Ocean Policy 2004), and industry (APR 2011) and acknowledged within the European Union (DG-Environement 2011). The framework presented

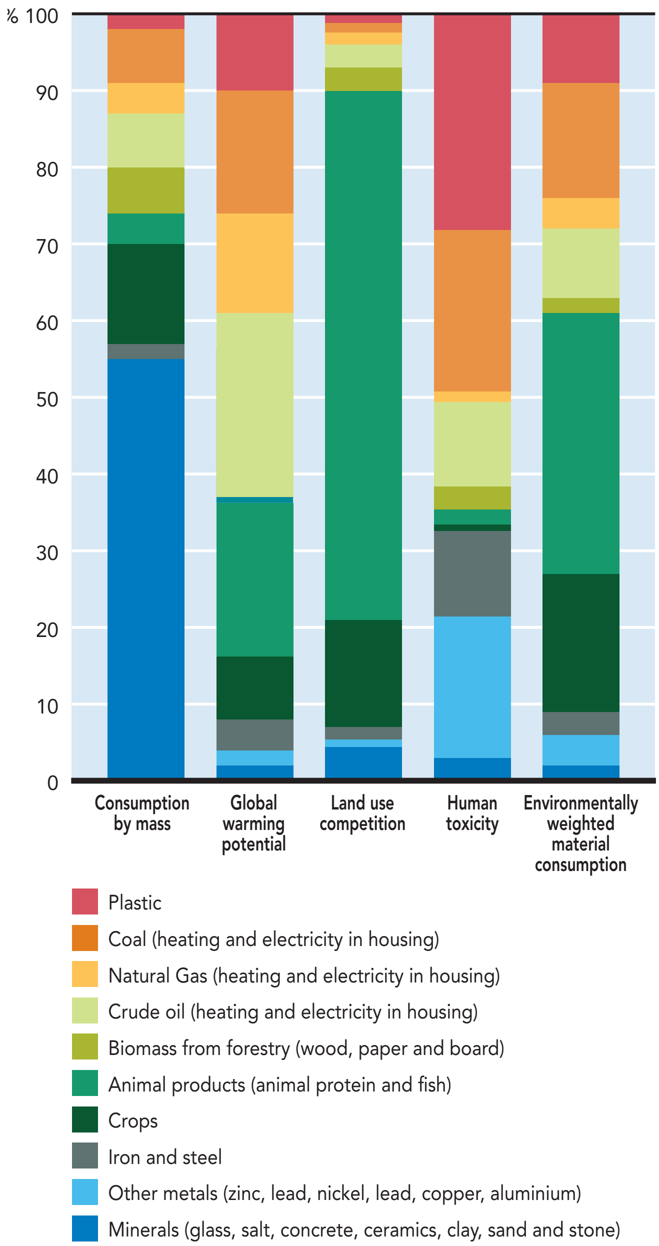

Figure 9. Relative contribution of material groups to environmental problems (EU27+Turkey) (Source: UNEP, 2010).

here provides a mechanism for productive dialogue on a regional basis appropriate to addressing the key issues.

Working in partnership to help realize the benefits that plastic products can offer, including for example those associated with reduced environmental impacts, and at the same time reducing the quantity of plastics present in marine debris is the key challenge presented in this document. Significant progress in tackling the problems of plastic debris can be made by simultaneously focusing on *direct* causes, such as littering and inappropriate waste management, together with *ultimate* causes which are more closely linked to the quantities and types of materials that are produced and marketed. This is especially the case for single-use items which have short lived utility, but potentially long lasting environmental impacts. For example, plastic items are often designed in developed countries for single-use with little consideration for the impacts of the associated debris on marine ecosystems and coastal tourism. Such impacts may have a disproportionate effect on less developed nations or regions that often lack the funding, infrastructure, or space for integrated materials and waste management. Consideration of the sustainability of production and end-of-life disposal of the items produced is most appropriate at the product design phase, rather than when an item becomes a waste product. In essence, consideration of material reduction, re-use and recycling from product design through to the end of its life would not only contribute towards sustainability, but would also directly reduce the quantity of waste that requires disposal and hence the potential for this waste to become marine debris.

Given the increasing demand for domestic production and import of plastics packaging with increasing economic development, it is not surprising that plastics often constitutes a majority of the marine debris reported. Yet plastics can be designed to be inherently recyclable, and there is considerable potential to turn waste items into new products. There is now strong evidence that significant potential lies in increasing our capacity to recycle end-of-life plastics; recycling can be economically attractive and can reduce carbon dioxide emissions compared to the use of new polymers (Defra 2007; WRAP 2006; WRAP 2008). However, it may be advantageous to introduce further economic incentives to encourage the redesign of plastic items to be both more reusable and recyclable, and to increase local and regional opportunities for recycling in order to achieve broader geographic impact. Recognizing the potential value of end-of-life plastics as a raw material for new production not only reduces waste in the environment, it incentivizes careful disposal, reduces reliance on non-renewable oil and gas resources, and supports global environmental and economic benefits (Thompson *et al*. 2009b).

2.5. Introducing a conceptual framework to reduce the quantity of plastic debris entering the ocean

While marine plastic debris has a variety of global sources and causes, the types and quantities of this debris and their impacts have strong regional components. Numerous relatively generic approaches have been identified to reduce the amount of debris produced, to better manage the waste that is produced, and to remove from aquatic habitats the waste that has accumulated. Since packaging comprises a substantial proportion of the plastic items produced and also comprises one of the major categories of plastics within marine debris, much of the following discussion will focus on examples relating to production use and disposal of single-use packaging. This discussion and the framework we propose acknowledges that such packaging brings benefits to society. What is considered here is a framework to examine a range of alternative ways to obtain the benefits that plastics and packaging can provide in order to identify options which will help reduce environmental consequences to the marine environment.

The three R's – *reduce, reuse, recycle* are widely advocated to reduce the quantities of waste and especially plastics packaging waste we generate (Figure 10 a-c). To be effective, we need to consider the interconnectivity between these approaches together with a fourth 'R', *redesign*. This includes both molecular redesign via green chemistry approaches, as well as product redesign with greater resource efficiency and environmental sustainability in mind as an emerging and potentially very important strategy. For items that cannot be designed for re-use or recycling, a fifth R *energy recovery* can be considered. Hence, the three R's become five: 'reduce, reuse, recycle, redesign and recover'.

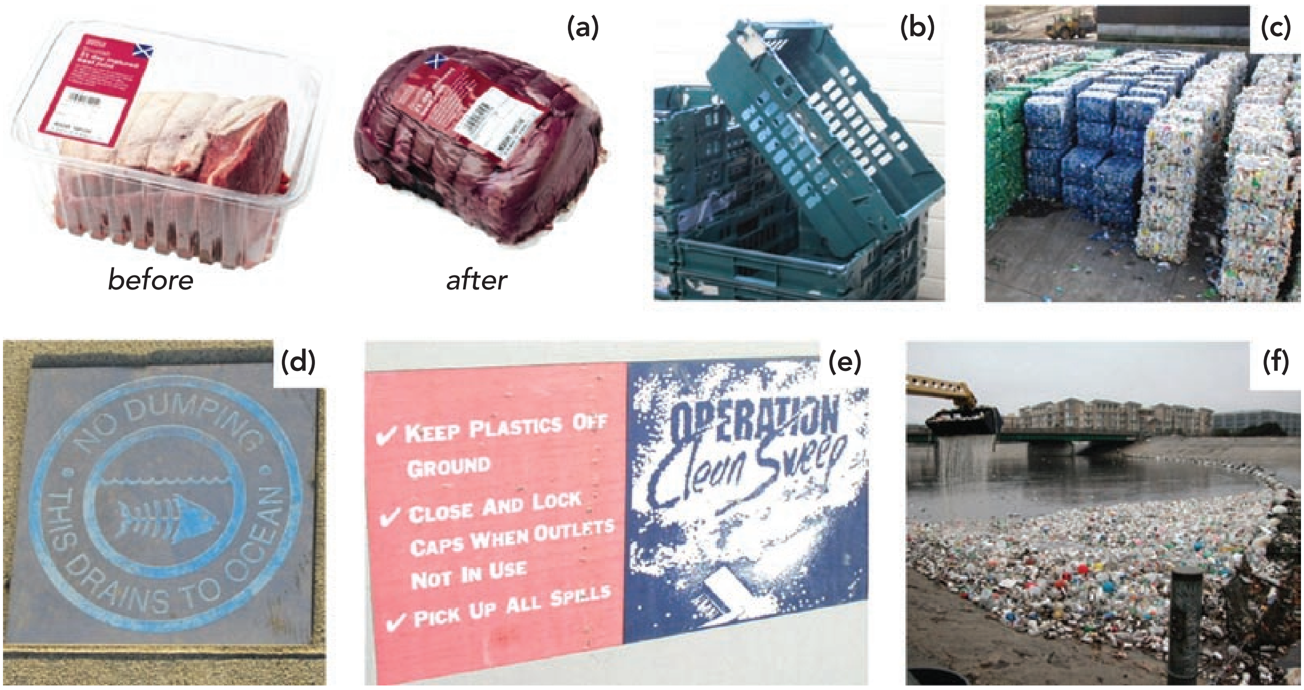

Figure 10. Solutions to marine debris include: (a) measures to reduce the production of new plastics from oil, here an example showing how small changes in product packing reduced the weight of packaging required by 70% while (b) re-useable plastic packing crates have reduced the packaging consumption of the same retailer by an estimated 30,000 tonnes per annum; (c) recycling, here bales of used plastic bottles have been sorted prior to recycling into new items, such as plastic packaging or textiles. Measures to reduce the quantity of plastic debris in the natural environment include: (d) educational signage to reduce contamination via storm drains and (e) via industrial spillage together with (f) booms to intercept and facilitate the removal of riverine debris (photographs a and b, and associated usage statistics) courtesy of Marks and Spencer PLC; (c) courtesy of P. Davidson, WRAP; (d and e and f) courtesy of C. Moore, Algalita Marine Research Foundation) (Source: Thompson *et al.* 2009a)

There are numerous opportunities to '*reduce*' usage of raw material by product redesign (Figure 10, a) along with opportunities to '*reuse*' plastics, for example in the transport of goods at an industrial (e.g. pallets, crates; Figure 10, b) and a domestic scale (e.g. reusable carrier bags). However, there is often limited potential for wide-scale reuse of packaging because of the substantial back-haul distances and logistics involved in returning empty cartons to suppliers, especially in communities or regions with an underdeveloped infrastructure. Perhaps most importantly, there is now a strong evidence base to indicate the significant potential that lies in increasing our ability to effectively '*recycle*' end-of-life plastic products. Although thermoplastics have been recycled since the 1970's, the proportion of material recycled has increased substantially in some countries in recent years (APR 2011; PlasticsEurope 2008; WRAP 2006). While this indicates the potential which exists, there is still much more that can be done to increase the spatial extent and increase the proportion of plastic items that are recycled. Greatest energy-efficiency is achieved where recycling diverts the need for use of fossil fuels as raw materials (Figure 10 c); good examples being the recycling of PET bottles into new ones (closed-loop recycling) (Hopewell *et al.* 2009).

Historically, the main considerations for the design of plastic packaging have been getting goods safely to market and product marketing. These are of course important for food safety and for industry; however there is an increasing urgency to also design plastic products, especially packaging, for material reduction, reuse, and high end-of-life recyclability. Public support for recycling is high in some countries (57% in the UK and 80% in Australia), and consumers are keen to recycle (Hopewell *et al.* 2009); but the small size, the diversity of different symbols to describe a product's potential recyclability, together with uncertainties as to whether a product will actually be recycled if collected, has the potential to hinder engagement (Hopewell *et al.* 2009; Thompson *et al.* 2009b). In addition, recycling requires significant investment infrastructure for collection, transport, sorting, and management of the recyclable items. While such infrastructure can be economically feasible in developed nations, it may not be feasible or cost-effective for developing countries at this time – adding substance to the notion of a regionally centered framework as outlined here. From an industry perspective, molecular *redesign* of plastics (the 4th R) has become an emerging issue in the domain of "green" chemistry. In this context, the design of products ensures they are (i) fully effective; (ii) have little or no toxicity or endocrine disrupting activity; (iii) break down into innocuous substances if released into the environment after use; and/or (iv) are based upon renewable feedstock, such as agricultural wastes. It has been proposed that such approaches should be considered within the design and lifecycle analysis of plastics (DG-Environment 2011).

One of the fundamental factors limiting progress on the three R's (reduce, re-use and recycle), is that the design criteria used to develop new polymers and products seldom include specifications to enhance reusability, recyclability or recovery of plastic once it has been used. Typically, such assessments have only been made after products have entered the marketplace and been recognized as having unintended consequences. Such sentiments are echoed by the recycling sector whose trade association considers

> *''the guiding principle of any packaging design must be fitness of purpose. Beyond this, designing to enhance recyclability should be in the forefront of design considerations'' (APR 2011).*

These statements are aspirational for innovation by leading producers; for example, *DuPont* states that they have

> *"the experience and expertise to put our science to work in ways that can design in - at the early stages of product development - attributes that can deliver solutions that help protect or enhance human health, safety and the environment."*

Dow has committed that

> *"There's only one planet earth, with limited resources. So everything we do, and how we do it, has an impact. As the world's population rises and new economies emerge, society requires novel solutions to meet its most basic needs, including energy, water, housing, food, health and transportation. Those solutions simply can't happen without the right chemistry. So we put some of the world's best scientists and engineers to work solving global challenges. We focus our innovation engine on delivering new technologies that enable our customers to meet society's greatest needs, while at the same time, responsibly reducing our own footprint. That commitment to protecting the planet unlocks opportunities that are good for business and good for the world."*

While both industry and policy makers concur on the necessity to seek innovative solutions that go beyond end-of-pipe recycling (e.g. DG Environment 2011; PlasticsEurope 2008), it is essential that this is achieved in collaboration and this documents sets out a framework for such. The dangers of working in isolation are already apparent from industry-centered responses such as development of 'oxo-degradable' plastic products which merely fragment at the end of their life time into numerous small but essentially non-degradable pieces, the environmental impact of which is not yet known (Roy *et al.* 2011). Degradable materials such as these also compromise recycling efforts and there are concerns about their efficacy (Defra 2010). From a different perspective, working in isolation can also lead to sectorally centered policy responses, such as a blanket ban plastic bags, rather than promoting the use of re-usable bags including those made of plastic.

For plastic products that cannot be redesigned and plastic waste that cannot be re-used or recycled, some of the energy content can be 'recovered' by incineration and through approaches such as co-fuelling of kilns. This can be reasonably energy-efficient but multiple trade-offs have to be accounted for before such decisions are made (Thompson et al. 2009b). However, unless appropriate regulations are in place, combustion of plastics may result in significant releases of chlorinated dioxins and furans and other persistent toxic compounds such as brominated dioxins. Due to these negative impacts, combustion of plastics debris could be a very serious environmental issue in developing countries if end-of-life energy recovery is not considered by the plastic manufacturer when designing the plastic or product, or if the energy recovery system is inadequately regulated. While the exemption continues under the Stockholm Convention for POPs, which allows the recycling of POP tetra-bromodiphenyl ethers and penta-bromodiphenyl ethers (BDEs), the plastic production chain continues to be contaminated with brominated POPs much of which results in plastic marine debris. Many of the resultant PBT by-products of plastic incineration already contaminate and damage the marine environment and food chain. While energy recovery for certain types of plastic waste have benefits compared to disposal to potentially inadequately designed landfills, energy recovery does not reduce the demand for raw material used in production. Hence, it is considered much less desirable and less energy efficient than re-use or product recovery via recycling.

Application of the R's, such as those illustrated in Figure 10, will only succeed if they are based on regional priorities, and oriented towards the needs and perspectives of the consumers/users in the affected regions and nations. Solutions should then be identified through cooperation between industry, government and users and consider all five R's in a regionally relevant context. Potential actions to consider in this context encompass any or all parts of the supply and value chain, and the full life cycle of the product including: (i) educating users (Figure 10 d and e); (ii) collecting and removing debris from the environment (Figure 10 f); (iii) measures to reduce the production of waste or improve the design of the product itself; and (iv) considering Extended Producer Responsibility (EPR) to achieve these goals. EPR may be well suited to some developing nations, because it helps redistribute the burden of handling end-of-life plastic from governments and individuals who may be impacted by the waste, to producers whose interests would then be aligned with those of the region. Under an EPR approach, producers have the responsibility to bear the costs of managing their waste products. This in turn incentivizes innovation to find ways to reduce the amount of plastic packaging used, as well as to ensure it is properly recovered when the product has reached the end of its useful life. In an EPR oriented system, the costs of running programs and building new infrastructure, including recycling and other waste management facilities, are redistributed away from national governments. EPR allows for design flexibility—bounded by clear performance standards—so innovative companies rather than those that push costs off onto regional governments can succeed in the marketplace, and programs can be tailored to the governance, capacity, and institutional realities of any given nation.

The framework suggested in this paper (Figure 11) indicates a series of key steps to achieve a reduction in the quantity of waste material being produced and should be applied at the regional level:

1) Identify key, regionally-specific, aspects of marine debris that are particularly problematic, and recognize the needs and perspectives of the consumers/users in the affected regions and nations, as the basis for selecting priorities for action (e.g., plastic bottles, fishing gear, fast food packaging, etc.).

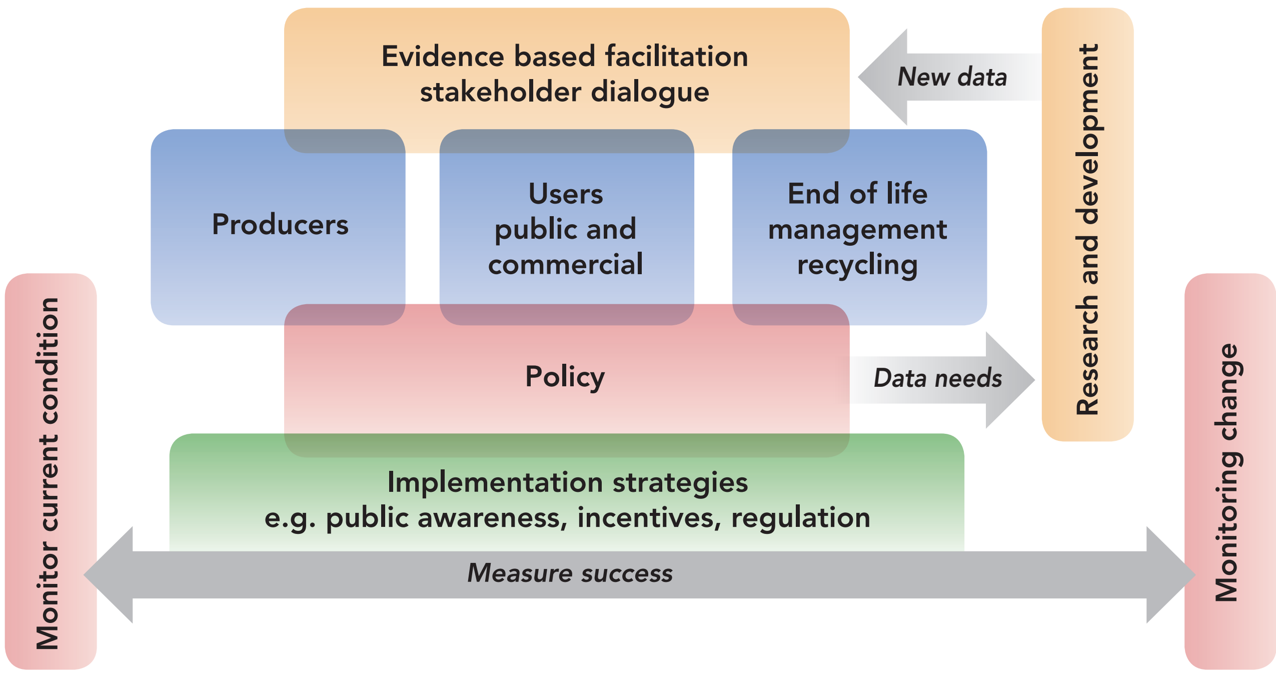

Figure 11. A framework describing key stages to tackle specific marine debris priorities on a regional basis.

2) Organize a dialogue among key stakeholders, including the supply chain (from chemical/material producers, to product designers, importers, distributors, and retailers), product users (be they members of the public or commercial sector), those responsible for end-of-life handling of waste products, government representatives, experts, and civil society.
3) Provide facilitators for the dialogue who can bring the stakeholders together in a goal-oriented process, and who understand the evidence base related the problem, the various steps in the supply/value chain, and potential solutions (for example based on the discussion on material reduction, re-use and recycling, etc. above).
4) Identify and prioritize actions that can be taken now together with any research / information gaps that may need to be addressed in order to establish and/or move toward more comprehensive solutions.
5) Establish institutional mechanisms and devise appropriate strategies and action plans together with policy-makers in the affected nations.
6) Monitor the changes that have been implemented, and measure the effectiveness of the results, as the basis for decisions about further actions.

By way of illustration it is evident from the UNEP Regional Seas reports that problems of marine debris vary on a regional basis, as do the potential solutions.

1) An appropriate starting point is to identify a specific problem in terms of the types of marine debris of concern (e.g., consumer waste, industrial waste, and packaging), including volumes and flows. It is essential that this evidence base considers all stages in the supply chain relating to the item(s) of debris: e.g. where and in what quantities are they made, for what purpose, how best to achieve their primary purpose, what is the lifespan and what are the local options at the end-of-life. This effort should be based on the perspectives and priorities of those in the affected region.
2) The next step is to bring together the key players in the supply chain, and organize an evidence-based dialogue aiming at the identification of ways to reduce the accumulation of debris. This could be a reduction in production of the waste, a reduction in the need for the material that becomes waste, and/or a better approach to dealing with end-of-life material in order to prevent it from accumulating. It is worthwhile establishing what can be done *straight away* together with any potential gaps in the evidence base requiring research and development and time needed to address such gaps.
3) The next step would be to facilitate the most desirable immediate and long-term options via a range of implementation strategies such as public awareness, development incentives and regulation.
4) Finally, it is crucial to measure success via monitoring of both changes in the scale of the marine debris problem identified at the outset, and assessment of the effectiveness of the individual implementation strategies and action plans. Raising *awareness* is a cross-cutting activity that will facilitate the development and implementation of all elements of the framework.

By way of example, if plastic bottles represent a key marine debris problem the solutions may differ between regions. Taking appropriate account of all relevant drivers such as food safety, carbon emissions, etc., governments within a region may place an emphasis on market forces (inherent recycling value of end-of-life material), market incentives (recycling incentives, extended producer responsibility), rethinking the product/market (reusable bottles, light-weighting of bottles), or some combination of these approaches depending on the region's needs and capabilities. If capacity for recycling is readily available then the following might be appropriate a) producers design for end-of-life recyclability for example under an EPR framework, b) suppliers identify material using recycled content and with high end-of-life recyclability and inform consumer choice, (c) educators inform consumers about good practice, and (d) recycling infrastructure is established. Conversely, in regions where recycling is less feasible, the focus might be toward material reduction, material re-use, and development of a cost-effective strategy for waste management. Hence effective prevention methods must be tailored to the varied institutional capacity and infrastructure of particular nations.

For debris in the open ocean in ABNJs it will be harder to reach back up the supply chain, and in this case it may be that responses are initially focused on 'end of pipe' approaches such as removal of debris together with education campaigns as the most realistic options. In the longer term, reductions in inputs of debris achieved in inshore waters on a regional basis should also reduce the quantity of debris entering the open ocean. As modeling and sampling data continue to clarify how materials from different on-shore sources contribute to marine debris in the ocean proper, the regional approach provides a useful framework for identifying priority locations for action and potential solutions to this problem.

3. Existing global frameworks and initiatives

The global importance afforded by states to the marine debris problem is reflected in resolutions by the UN General Assembly on oceans and the law of the sea. At the 65th session, the UN General Assembly urged states to support measures aimed at prevention, reduction, and pollution control of any source of marine debris. A resolution called on states to cooperate regionally and sub-regionally to implement joint prevention and recovery programs for marine debris (A/65/L.20).

There are multiple global legal instruments and voluntary agreements aimed at the prevention and management of marine debris, both on land and sea. Currently, the most applicable overarching legal framework addressing marine debris is provided by the United Nations Convention on the Law of the Sea (UNCLOS). It entered into force in 1994 calling for the protection of the entire marine environment from all sources and types of marine pollution, including marine debris. UNCLOS does not directly addresses the issue of terrestrial waste reduction, except for Article 207 calling on states to pass national legislation combating pollution from rivers, estuaries, and pipelines. Among more specific agreements regulating different sources of marine debris are:

- The International Convention for the Prevention of Marine Pollution from Ships (MARPOL) and its Annex V prohibiting at-sea pollution by various materials including all plastics and restrictions on at-sea discharge of garbage from ships.
- The London Convention for the Prevention of Marine Pollution by Dumping of Wastes and other Matter and its 1996 Protocol.

- Current IMO efforts are underway on the revision of MARPOL Annex V provisions aimed at prohibiting almost any garbage discharges from ships at sea, on tackling the inadequacy and upgrade of port reception facilities and development of a port reception facilities database as a module of the Global Integrated Shipping Information System.
- Two new standards relevant to marine debris are expected to be introduced soon by the International Organization for Standardization (ISO): ISO 21070: Shipboard Waste Management Standard and ISO 16304: Port Reception Facility Standard.
- Certain provisions (Annex IX wastes containing Annex I materials) of the Basel Convention on the trans-boundary movements of hazardous wastes and their disposal are applied to marine debris wastes.
- While the Convention on Biological Diversity (CBD) has not yet adopted specific guidance addressing the impacts of debris on marine biodiversity, the Convention does have an overarching framework for addressing threats to marine biodiversity. Decision X/29 on marine and coastal biodiversity adopted at CBD COP-10 calls on states and other relevant entities to assess and monitor the impacts and risks of human activities on marine and coastal biodiversity, mitigate the negative impacts and risk of human activities to marine and coastal biodiversity, and adopt complementary measures to prevent significant adverse effects by unsustainable human activities to marine and coastal areas, especially those identified as ecologically or biologically significant. Targets 7 and 11 of the CBD Aichi Strategic Plan are generally applicable in the context of marine debris impacts on coastal and open ocean biodiversity.
- The Convention on the Conservation of Migratory Species of Wild Animals (CMS) will consider for adoption a specific resolution on marine debris submitted by Australia at the next COP meeting (CMS/StC37/21).

Among prominent global soft legal instruments with specific provisions for marine debris are:

- The Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA) created by the Washington Declaration in 1995 and putting priority, *inter alia*, on addressing land-based sources of marine debris emphasizing implementation at the regional level.
- The UNEP Global Initiative on Marine Litter provides a platform for the management of this problem. Regional Seas Conventions and Action Plans are the main partners in implementing this Initiative. This is achieved through a range of activities aimed at the assessment on distribution and sources of marine debris, preparation of Regional Action Plans and management initiatives, twelve Regional Seas programmes (Conventions and Action Plans) took part in the Global Initiative including Baltic Sea, Black Sea, Caspian Sea, East Asian Seas, Eastern Africa/West Indian Ocean, Mediterranean, Northeast Atlantic/OSPAR, Northwest Pacific/NOWPAP, Red Sea and Gulf of Aden, South Asian Seas, Southeast Pacific/SPREP, and the Wider Caribbean/CEP.
- Marine debris is a specific thematic focus of the Global Partnership on Waste Management currently under development by UNEP (http://www.unep.or.jp/ietc/SPC/activities/GPWM/Framework.asp).
- The FAO Code of Conduct for Responsible Fisheries encourages states to tackle issues addressing requirements of the MARPOL. The FAO Committee on Fisheries (COFI), the only intergovernmental forum on fisheries, regularly considers marine debris issues associated with fisheries activities, specifically ALDFG.
- The ALDFG issue is also considered by the UN Fish Stocks Agreement in force since 2001, and by a number of soft law agreements such as 1991 Voluntary Guidelines for the marking of fishing gear, and 2011 International Guidelines for bycatch management and reduction of discards.

The above review presents several applicable instruments and frameworks at the global level. There are hundreds of legal, regulatory and management initiatives at regional, national, sub-national and community levels. Notably, but not exhaustively:

- The development of marine debris indicators for the European Commission Marine Strategy Framework Directive. The EU is currently discussing a pilot project in the Mediterranean that would provide alternative income to local fishermen through buy-back of collected marine debris.
- For more than 10 years a Practical Integrated System for Marine Debris in South Korea is a successful national example of the integrated and highly sophisticated infrastructure project addressing the marine debris issue using a life-cycle approach from identification, waste prevention, removal, and marine debris treatment and recycling.
- Other notable examples include marine debris work done by the NOAA and its partners in the United States; Waste and Resources Action Programme of the UK and others.

- Dozens of initiatives on marine debris including plastics are implemented by industries such as Operation Clean Sweep reducing losses of resin pellets by American and British plastics industries, Waste Fishing Gear Buy-Back Project in Korea.
- Expand-Away-from-Home Access initiative promoting recycling in the State of California and Keep America Beautiful Initiative in the USA.
- Collection of discarded fishing gear on some South African coasts, and many others.

The recently concluded 5th International Marine Debris Conference in Honolulu, Hawaii, (attended by more than 400 participants from 38 countries) reflected and manifested the global importance and the increasing awareness of the global community on the impacts of marine debris on the environment and response measures (http://www.5imdc.org/). The meeting culminated in the adoption of the Honolulu Commitment and launching of the Global Declaration on Marine Debris Solutions by the American Chemistry Council and PlasticsEurope, representing 47 world plastics organizations from 29 countries. A Honolulu Strategy: A strategic framework for the prevention, reduction, and management of marine debris is currently being developed to be the first integrated global framework document dedicated entirely to the issue of marine debris.

A wide range of NGOs are focusing efforts on marine debris prevention, reduction, and clean-up including Algalita Marine Research Foundation, 5 Gyres Initiative, International Coastal Cleanup by Ocean Conservancy, Project Kaisei, Plastic Pollution Coalition, Surfriders, Dyer Island Conservation Trust, Marine Conservation Society, World Wildlife Fund, Project Aware Dyer Island Conservation Trust, and many others. The International Coastal Cleanup by Ocean Conservancy is the largest global volunteer effort to clean-up beaches, but also to address the sources and distribution of marine debris globally.

While there is a broad range of global instruments addressing the issue from sectoral, land-based or sea-based perspectives, they are not enough. Marine debris remains an increasing global environmental concern. The issue is complex and extends beyond the jurisdictional authority or ability of any one institution or global entity to address. The fundamental problem is a disconnect which often exists between responses aimed at addressing the causes of marine debris and efforts addressing the impacts of marine debris. While a major cause of many common items of plastic debris is a result of unsustainable design and production, this situation may be exacerbated by poor waste management practices.

The global regulatory frameworks described above and relevant national obligations are almost entirely applied to maritime issues when discarded items have already become debris or waste. The lack of overarching jurisdictional responsibility in any single agreement for the entire life-cycle chain from production to disposal to clean-up is compounded by the lack of appropriate infrastructure, enforcement in existing regulations and lack of standards for more sustainable plastics production and consumption activities. This may partially be explained by the lack of economic and financial incentives, or even perverse incentives for large upstream producers to pass costs on to individuals or nations that are disproportionately impacted by marine debris in comparison to any economic benefits they may receive. In contrast, more efficient production processes can actually lead to economic savings for companies that recognize opportunities, and economic incentives for recycling plastic waste can be instituted by governments. Reducing raw materials usage through green design alternatives, more sustainable consumption patterns, and improved options for re-use, re-cycling and zero waste management - all support efforts to reduce marine debris and ultimately promote green economy goals. The economic and environmental benefits of recycling, development of waste-to-energy markets and technologies, reductions in GHG emissions, job creation, and others will also offer multiple opportunities.

Photo: Julie Stowell

4. STAP recommendations for the GEF

This document was prepared by STAP as an information paper to explore the problem of marine debris and plastics debris in the ocean, inform the Council, and explore possible solutions relevant to GEF programs. This document specifically is intended to address needs of GEF recipient countries (developing countries and CEITs). In addition, this document evaluates marine debris from multiple perspectives and suggests that plastic debris should be recognized as a global environmental issue. This finding is based on largely on the global occurrence of the problem including in ABNJ, the transboundary nature of sources and impacts, significant impacts on marine organisms and biodiversity, and social and economic impacts especially on developing countries and CEITs.

The authors of this paper did not intend to cover all possible options and solutions in dealing with plastics debris, but to outline and provide justification for a consideration of this issue in future GEF programs and outlining a common framework that could be generally applicable in the context of developing countries and CEITs eligible for GEF support. The GEF has a special opportunity and is well placed to play a leading role in global efforts to tackle the marine debris problem. As a cross-sectoral issue, most interventions aimed at marine plastic debris prevention, reduction and management fall under the mandate of several GEF focal areas including International Waters, Climate Change, Biodiversity and Chemicals, as well as the public-private partnership based Earth Fund and the Small Grants Program. For example:

- In the Biodiversity Focal Area, marine debris measures will contribute to more effective management of coastal and near-shore protected area networks and interventions that address the issue of marine species conservation and impacts of invasive alien species.
- In the International Waters Focal Area, measures addressing marine debris fall under several strategic objectives supporting multi-state cooperation to rebuild marine fisheries and reduce pollution of coasts and Large Marine Ecosystems and promotion of learning and targeted research needs for ecosystem-based, joint management of transboundary water systems.
- An emerging program area for the GEF, effective management of ABNJ could also address marine debris, particularly through AFDLG and activities supporting Regional Fisheries Management Organizations to protect deep-sea species, marine biodiversity, and seamount habitats through the application of ecosystem-based approaches and use of conservation tools such as marine protected areas (MPAs) and spatial management tools.
- At least two strategic objectives of the Climate Change Focal Area supporting (i) demonstration, deployment, and transfer of innovative low-carbon innovative technologies and (ii) promotion of energy efficient, low-carbon transport and urban systems, could explore multiple opportunities that could assist in addressing this issue.
- The Chemicals Focal Area provides an opportunity to support the demonstration of "zero waste" concepts. Where feasible and synergies with the POPs focal area can be demonstrated, GEF support for economic incentives aimed at prevention and collection of solid waste will have positive impacts on the issue of marine debris. Targeted investments at the source of plastics and other important types of debris will also address the reduction in the long range transport of inherent and acquired pollutants, including POPs and heavy metals.
- Finally, the Earth Fund platform could be used for testing, demonstration and deployment of new technologies and practices in support of recycling or other technologies, as well as approaches for removal of plastic debris from pelagic environments and the sea floor.

STAP is encouraging GEF partners to mainstream interventions addressing marine debris in existing and planned GEF projects, specifically, *inter alia*, (i) projects supporting management of Marine Protected Areas and fish refuges, (ii) ecosystem-based management of areas beyond national jurisdiction, and Ecologically and Biologically Significant Areas or Vulnerable Marine Ecosystems, where activities are aimed at the reduction of pollution sources from land-based activities, and (iii) projects and programs promoting material reduction, re-use and recycling. Participants in the Small Grants Program are also encouraged to consider interventions which support marine debris prevention, reduction and management.

Recognizing the limited resources available in the GEF and the global scale of the plastic debris problem in the marine environment, STAP proposes that the GEF Council and GEF partners consider support in GEF-5 to the following catalytic activities responding to the global problem of plastic marine debris that would demonstrate potentially wide reaching global environmental benefits, based on the principles of marine debris management introduced in this document:

A) A project or program testing the life cycle approach to marine debris prevention, reduction, and management in one of the areas covered by Regional Seas Conventions and Action Plans. Building on the existing baseline and institutions and mechanisms in the selected region, GEF investments could play a catalytic role in mobilizing public and private sector resources for specific market transformation in the production, consumption, and utilization of marine debris sources such as plastics.

B) By combining the efforts of the plastics production manufacturers, packaging and retailer associations, civil society organizations, multilateral institutions, and utilizing opportunities provided by the Earth Fund platforms, GEF could promote, facilitate and establish a global public-private partnership to transform single-use plastics packaging markets to reduce the environmental footprint of packaging on a global scale. Through this initiative, the GEF could build a strong partnership with the private sector to encourage innovation, to ensure they are part of the solution, and to expand assistance to developing countries and CEITs seeking to transform their use and utilization of single-use plastics packaging to protect the global environment.

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