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Plastic Debris in the World's Oceans

GREENPEACE

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Plastic Debris in the World's Oceans

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Executive Summary

Solid materials, typically waste, that has found its way to the marine environment is called marine debris.

It is probably a common conception that marine debris consists of just a few pieces of rubbish scattered along the strand line of beaches and is of no harm to anyone. Unfortunately this is not the case. Marine debris has become a pervasive pollution problem affecting all of the world's oceans. It is known to be the cause of injuries and deaths of numerous marine animals and birds, either because they become entangled in it or they mistake it for prey and eat it.

Plastic and synthetic materials are the most common types of marine debris and cause the most problems for marine animals and birds. At least 267 different species are known to have suffered from entanglement or ingestion of marine debris including seabirds, turtles, seals, sea lions, whales and fish.

The scale of contamination of the marine environment by plastic debris is vast. It is found floating in all the world's oceans, everywhere from polar regions to the equator. The seabed, especially near to coastal regions, is also contaminated – predominantly with plastic bags. Plastic is also ubiquitous on beaches everywhere from populous regions to the shores of very remote uninhabited islands.

Attempts to address the problem of marine debris range from international legislation to prevent shipping from dumping plastic at sea and campaigns to prevent losses due to poor industrial practice to beach and seabed clean-up operations and public awareness campaigns. Plastic debris originates from a wide and diverse range of sources. Estimates suggest that much of what is found at sea originates on the land. The effect of coastal littering and dumping is compounded by vectors such as rivers and storm drains discharging litter from inland urban areas. It is the very properties that make plastics so useful, their stability and resistance to degradation, that causes them to be so problematic after they have served their purpose. These materials persist in the environment and are not readily degraded or processed by natural biological mechanisms. However plastics in the ocean are weathered; broken up either mechanically or by the action of sunlight into smaller and smaller fragments. Eventually, fragments are reduced to into tiny pieces the size of grains of sand. These particles have been found suspended in seawater and on the seabed in sediments. Even such tiny particles may be causing harm to the marine environment since they have been shown to be ingested by small sea creatures and may concentrate persistent organic pollutants (POPs) present in the seas.

This report draws together scientific research on the distribution of marine debris in the world's oceans and its impacts on wildlife. The information is sourced largely from papers that have been published on this subject between 1990 and 2005. Finally it addresses workable solutions to help curb this threat to the marine environment.

Sources of Marine Debris

It has been estimated that around 80% of marine debris is from land-based sources and the remaining 20% is from ocean based sources. The sources can be categorised into four major groups:

- Tourism related litter at the coast: this includes litter left by beach goers such as food and beverage packaging, cigarettes and plastic beach toys.

- Sewage-related debris: this includes water from storm drains and combined sewer overflows which discharge waste water directly into the sea or rivers during heavy rainfall. These waste waters carry with them garbage such as street litter, condoms and syringes.

- Fishing related debris: this includes fishing lines and nets, fishing pots and strapping bands from bait boxes that are lost accidentally by commercial fishing boats or are deliberately dumped into the ocean

- Wastes from ships and boats: this includes garbage which is accidentally or deliberately dumped overboard.

Huge volumes of non-organic wastes, including plastics and synthetics, are produced in more developed, industrialised countries. Conversely, in less developed and more rural economies, generally a much smaller amount of these non-biodegradable persistent wastes are produced. However, in the future, as less developed countries become more industrialised, it is likely that they will also produce more plastic and synthetic wastes and this will increase further the threat of pollution of the marine environment.

Harm to Marine Wildlife

Countless marine animals and sea birds become entangled in marine debris or ingest it. This can cause them serious harm and often results in their death.

Entanglement in Marine Debris

Marine debris which is known to cause entanglement includes derelict fishing gear such as nets and mono-filament line and also six-pack rings and fishing bait box strapping bands. This debris can cause death by drowning, suffocation, strangulation, starvation through reduced feeding efficiency, and injuries. Particularly affected are seals and sea lions, probably due to their very inquisitive nature of investigating objects in their environment. Entanglement rates in these animals of up to 7.9% of a population have been recorded. Furthermore, in some instances entanglement is a threat to the recovery of already reduced population sizes. An estimated 58% of seal and sea lion species are known to have been affected by entanglement including the Hawaiian monk seal, Australian sea lions, New Zealand fur seals and species in the Southern Ocean.

Whales, dolphins, porpoises, turtles, manatees and seabirds have all been reported to have suffered from entanglement. Many different species of whale and turtle have been reported to have been tangled in plastic. Manatees have been found with scars or missing flippers due to entanglement. 51 species of seabirds are also known to have been affected . Derelict fishing gear also causes damage to coral reefs when nets or lines get snagged by the reef and break it off.

Finally, discarded or lost fishing nets and pots can continue to trap and catch fish even when they are no longer in use. This phenomenon is known as ghost fishing and it can result in the capture of large quantities of marine organisms. Consequently, it has become a concern with regard to conservation of fish stocks in some areas and has resulted in economic losses for fisheries.

Ingestion of Marine Debris

Ingestion of marine debris is known to particularly affect sea turtles and seabirds but is also a problem for marine mammals and fish. Ingestion is generally thought to occur because the marine debris is mistaken for prey. Most of that erroneously ingested is plastic. Different types of debris are ingested by marine animals including plastic bags, plastic pellets and fragments of plastic that have been broken up from larger items. The biggest threat from ingestion occurs when it blocks the digestive tract, or fills the stomach, resulting in malnutrition, starvation and potentially death.

Studies have shown that a high proportion (about 50 to 80%) of sea turtles found dead are known to have ingested marine debris. This can have a negative impact on turtle populations. In young turtles, a major problem is dietary dilution in which debris takes up some of the gut capacity and threatens their ability to take on necessary quantities of food.

For seabirds, 111 out of 312 species are known to have ingested debris and it can affect a large percentage of a population (up to 80%). Moreover, plastic debris is also known to be passed to the chicks in regurgitated food from their parents. One harmful effect from plastic ingestion in birds is weight loss due for example to a falsely sated appetite and failure to put on adequate fat stores for migration and reproduction.

Potential Invasion of Alien Species

Plastic debris which floats on the oceans can act as rafts for small sea creatures to grow and travel on. Plastic can travel for long distances and therefore there is a possibility that marine animals and plants may travel to areas where they are non-native. Plastic with different sorts of animals and plants have been found in the oceans in areas remote from their source. This represents a potential threat for the marine environment should an alien species become established. It is postulated that the slow speed at which plastic debris crosses oceans makes it an ideal vehicle for this. The organisms have plenty of time to adapt to different water and climatic conditions.

Marine Debris around the world

Many studies have been carried out in different countries and oceans estimating the quantity of plastic on beaches, the sea floor, in the water column, and on the sea surface. Most of these studies have focused, partially for reasons of practicality, on large (macro) debris. A limited body of literature also exists concerning small to microscopic particles (micro debris). The results show that marine debris is ubiquitous in the world's oceans and shorelines. Higher quantities are found in the tropics and in the mid-latitudes compared to areas towards the poles. It has been noted that high quantities are often found in shipping lanes, around fishing areas and in oceanic convergence zones.

- Floating marine debris: studies on different areas of the marine environment reported quantities of floating marine debris that were generally in the range of 0-10 items of debris per km^2. Higher values were reported in the English Channel (10-100+ items/km^2) and Indonesia (more than 4 items in every m^2). Floating micro debris has been measured at much higher levels: the North Pacific Gyre, a debris convergence zone, was found to contain maximum levels, that when extrapolated represent, near to a million items per square kilometre.

- Seafloor Debris: Research has shown that marine debris was present on the seafloor in several locations in European waters, and also in the USA, Caribbean and Indonesia. In European waters the highest quantity recorded was 101,000 items/km^2 and in Indonesia the equivalent of 690,000 items/km^2.

- Shoreline Debris: Surveys of shorelines around the world have recorded the quantity of marine debris either as the number of items per km of shoreline or the number of items per square meter of shoreline. The highest values reported were for Indonesia (up to 29.1 items per m) and Sicily (up to 231 items per m).

Solutions

There are a number of global, international and national initiatives in place that are aimed at protecting the oceans from marine debris. The most far reaching of these is the International Convention for the Prevention of Pollution from ships (MARPOL). Annex V of MARPOL was introduced in 1988 with the intention of banning the dumping of most garbage and all plastic materials from ships at sea. A total of 122 countries have ratified the treaty. There is some evidence that the implementation of MARPOL has reduced the marine debris problem but other research shows that it does not appear to have any positive impact. It must also be remembered that an estimated 80% of marine debris originates from sources on land. Even with total global compliance with MARPOL these sources would remain.

Other measures to address marine debris include manual clean-up operations of shorelines and the sea floor as well as school and public education programmes.

While the above measures are important at preventing or reducing the problem of marine debris, the ultimate solution to waste prevention is to implement a responsible waste strategy, namely the concept of "Zero Waste". Such a strategy encompasses waste reduction, reuse and recycling as well as producer responsibility and ecodesign. Ultimately, this would mean reduction of the use of plastics and synthetics such that they are only used where absolutely necessary and where they have been designed for ease of recycling within existing recovery infrastructure. It is possible that biodegradable plastics could be used where plastic was deemed necessary but could not be seen as an environmentally sound alternative unless they are known to break down rapidly to non-hazardous substances in natural environments.

1. Introduction

Industrialised human society generates vast quantities of materials, many of which, lacking recovery infrastructure, end up as waste. The nature of this waste has changed dramatically over the last 30 to 40 years due to the introduction of synthetic materials such as plastics (Sheavly 2005). Human garbage, including synthetics and plastics, have inevitably found their way into the world's oceans. This rubbish, which is present in the oceans and on beaches, is called marine debris. Astoundingly, it is now evident that marine debris is one of the world's most pervasive pollution problems affecting the oceans (Sheavly 2005). Synthetics like plastics are the most problematic debris because they resist natural degradation processes and are a danger to wildlife.

In 1997, it was estimated that a staggering 6.4 million tons of garbage reach the marine environment every year. Estimates suggesting that there are currently over 13,000 pieces of plastic litter floating on every square kilometre of ocean have been reported by UNEP (United Nations Environment Program) (UNEP 2005). Whilst another UNEP study reporting estimates of 46,000 pieces per square mile (18,000 per square kilometre) has also been produced (UNEP 2006). However, it must be noted that neither of these estimates are accredited to any particular source and must be treated with caution. The world's oceans are vast and varied. To get a handle on the estimated average level of plastic debris is a very difficult task. For, as this report illustrates, current understanding of problem is far from uniform across the globe. Plastic debris is nevertheless a ubiquitous global problem that requires attention.

There are numerous sources of man-made marine debris from activities both on land and at sea. Land-based sources include littering, losses from plastic manufacturing plants, landfills and storm drains. While sea-based sources include fishing gear, garbage from shipping and recreational boats, offshore drilling platforms and rigs.

Far from being just a litter problem, marine debris represents a significant threat to wildlife. Numerous marine animals and seabirds are killed or injured either because they become entangled or trapped by marine debris or because they ingest it.

Humans are also affected by marine debris. For instance, plastic bags can cause economic losses to recreational boats when they block water intakes and result in burned out water pumps. Boats and ships can also incur costly repairs when derelict fishing gear such as nets and ropes get entangled around propellers and rudders (Sheavly 2005). This can also be a safety concern should a propeller become clogged in a storm (Environment Canada 2003). Recently it was reported that an entire Russian submarine became entangled in discarded fishing net in 600 feet of water off the Kamchatka coast (TenBruggencate 2005).

In addition to being a safety concern for marine vessels, marine debris washing ashore can be also be an aesthetic problem on beaches and may cause economic losses to tourism because it discourages swimming, boating and fishing activities (Environment Canada 2003, Sheavly 2005). Communities may therefore need to spend money to clean up and look after the coastline (Sheavly 2005).

1.1 Plastic Marine Debris

The nature of wastes from human society has dramatically changed over the last 30 to 40 years due to the introduction of synthetics like plastics (Sheavly 2005). Many studies on marine debris have shown that plastics consistently make up 60 to 80% of all marine debris (Derraik 2002). In the fishing industry, plastic materials and synthetics have replaced natural fibres over the past 35 years and their widespread use has resulted in substantial amounts of derelict fishing debris in ocean waters and on beaches (Henderson et al. 2001). Plastic is routinely used for food and drink packaging and recreational users of beaches and coastal waters often leave behind this type of waste. Lightweight plastics also reach the ocean from inland urban areas via storm drain systems leading to rivers and the sea.

Once it reaches the ocean, about half of plastic debris floats and can therefore travel on currents for thousands of miles. Consequently plastic has become widely dispersed over the oceans (Derraik 2002, Sheavly 2005). Conversely, glass, metal, some types of plastic (such as PVC-, ABS, HDPE, PS-non expanded and nylon), and rubber debris tend to sink (US EPA 2002).

Plastic is generally a durable material which is resistant to natural biodegradation processes. Consequently, it does not readily break down in the marine environment. It is not clear just how long plastic items remain in their original form. However, some plastic items appear to be broken up into smaller and smaller fragments over time. At sea, this process is thought to occur due to wave action, oxidation and ultraviolet light. On the shore, it may break up into smaller pieces due to grinding from rocks and sand (Eriksson and Burton 2003). The resulting plastic fragments may be mistaken for prey and ingested by marine organisms (see section 2.4).

Plastic debris in the oceans may eventually be broken up so much that it becomes microscopic in size like grains of sand. These tiny fragments (about 20µm in diameter) have been identified in marine sediments and in ocean waters (Thompson et al. 2004). The consequences of this contamination are not yet known, but it potentially endangers wildlife. For example, plastic particles were found to be ingested by marine organisms (see section 2.4).

1.2 Marine Debris - A Global Problem

Marine debris, in particular plastics and synthetics, is a problem that pervades the entire globe. Plastic can be seen floating on all the world's oceans, even in extreme polar latitudes. Marine debris pollutes shorelines not only in industrialised nations but even on remote islands (see section 4).

High quantities of marine debris may be found on the shoreline close to urban areas. For example, in a highly populated area of eastern Indonesia litter has been found to cover up to 90% of the upper shore and strandline (Uneputty and Evans 1997). In more remote areas away from urbanised society, marine debris may consist mostly of fishing debris (Derraik 2002). Nevertheless, in some studies remote oceanic islands have been found to have similar levels of debris to those adjacent to heavily industrialised coasts in the Pacific and elsewhere (Barnes and Milner 2005). One study reported plastic debris stranded on shores in the far north at Spitsbergen in the Arctic. In addition to surveying different shorelines, this study also recorded the amounts of debris found floating in the Atlantic Ocean for almost its entire length. Floating marine debris, in particular plastics, was present from the far north (79°N) to the far south (68°S) of the Atlantic (Barnes and Milner 2005).

The dumping of plastics into the oceans is an increasing problem (Derraik 2002). As more plastic is being dumped, and that already present is slow to break down, plastic debris in the marine environment is accumulating (Environment Canada 2003). Research has shown, for instance, that the amount of debris around the coastline of the UK doubled between 1994 and 1998 and in parts of the Southern Ocean it increased 100-fold (Barnes 2002).

The type of waste that is produced by human society differs between industrialised and less industrialised regions. For example, in societies that are less developed and rural-agrarian in nature, wastes are minimal and tend to be organic. Conversely, in developed and more urbanised society, there is a colossal generation of non-organic wastes that are persistent in nature, such as plastic. It is therefore not surprising to find that much of the persistent waste, such as plastics, that enter the marine environment originate from coastal and upriver settlements in developed countries.

The problem of pollution of the oceans with plastic and other man-made debris from land-based sources could get worse in the future because it is likely that less developed countries will eventually become more urbanised, consumer-orientated societies that generate persistent wastes (Coe and Rogers1997). Presently, in some developing nations, marine debris may originate from uncontrolled dumping of wastes where sanitary disposal in landfills has not been implemented (Liffman and Boogaerts 1997).

1.3 Sources of Marine Debris

The United Nations Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) estimated that land-based sources are responsible for up to 80% of marine debris and the remainder was due to sea-based activities (Sheavly 2005). The main land and sea-based sources of marine debris are listed below.

1.3.1 Land-Based Sources

Marine debris from land-based sources is blown into the sea, washes into the sea or is discharged into the sea (Sheavly 2005). Land-based sources include the following:

- **Storm water discharges:**
  Storm drains collect runoff water which is generated during heavy rain events. The drains directly discharge this wastewater into nearby streams, rivers or the ocean. Rubbish from streets can be washed into storm drains and is then discharged straight into the ocean or to streams/rivers which, in turn, may carry the rubbish to the ocean (US EPA 2002c).

- **Combined Sewer Overflows:**
  Combined sewers carry sewage as well as storm water. Under normal weather conditions, sewage is carried to a wastewater treatment facility where non-sewage wastes are filtered out. However, during heavy rains the handling capacity of the wastewater treatment system may be exceeded and the sewage plus storm water is then not treated, but is directly discharged into nearby rivers or oceans. This waste can include rubbish such as condoms, tampon applicators, syringes and street litter (US EPA 2002c, Sheavly 2005). According to Nollkaemper (1994), waste from combined sewer overflows is one of the major land-based sources of plastic marine debris in the USA.

- **Littering:**
  Beachgoers may carelessly leave litter at the coast and this will become marine debris. The litter includes items such as food packaging and beverage containers, cigarette butts and plastic beach toys. Fishermen may leave behind fishing gear. Litter from inland areas can become marine debris if it gets into streams or rivers. In this way marine debris may result from rubbish left by workers in forestry, agriculture, construction and mining operations. (US EPA 2002c, Sheavly 2005).

- **Solid Waste Disposal and Landfills:**
  Run-off from landfills that are located in coastal areas or near to rivers may find its way into the marine environment. For example, in the USA many estuaries have been contaminated by garbage from nearby solid waste sites (Nollkaemper 1994). In addition to loss from landfills, garbage may be lost to the marine environment during its collection or transportation. Illegal dumping of domestic or industrial wastes into coastal and marine waters is another source of marine debris (US EPA 2002c, Sheavly 2005).

- **Industrial Activities:**
  Industrial products may become marine debris if they are improperly disposed of on land or if they are lost during transport or loading/unloading at port facilities (US EPA 2002c). A well known example is small plastic resin pellets, about 2-6 mm in diameter, which are the raw material for the manufacture of plastic products (Derraik 2002). These pellets have been released into the marine environment from accidental spillage during production and processing, transport and handling. Some are buoyant whilst others become suspended or sink (Redford et al. 1997). Their presence has been reported in most of the world's oceans (US EPA 1992b) and they are found even in more remote, non-industrialised areas in the Southwest Pacific such as Tonga, Rarotonga and Fiji (Derraik 2002). Although plastic pellets are one of the least visible forms of plastic pollution, it is apparent that they have become ubiquitous in ocean waters, sediments and on beaches (Redford et al. 1997) and are ingested by marine wildlife (see section 2.4).

1.3.2 Ocean-based Sources

All types of boats and ships and offshore industrial platforms are potential sources of marine debris. The debris may originate from accidental loss, indiscriminate littering or illegal disposal. It may also be the result of waste management disposal practices that were carried out in the past (Sheavly 2005). Ocean-based sources of marine debris include:

- **Commercial Fishing:**
  Commercial fishermen generate marine debris when they fail to retrieve fishing gear or when they discard fishing gear or other rubbish overboard. Debris resulting from commercial fishing includes nets, lines and ropes, strapping bands, bait boxes and bags, gillnet or trawl floats plus galley wastes and household trash (US EPA 1992c, Sheavly 2005).

- **Recreational Boaters:**
  Boaters may deposit garbage overboard such as bags, food packaging and fishing gear (Sheavly 2005).

- **Merchant, Military and Research Vessels:**
  Rubbish from vessels may be accidentally released or blown into the water or may be deliberately thrown overboard. Large vessels with many crew members may carry supplies for several months. They generate solid wastes daily which may end up as marine debris if it is not secured and stored properly (US EPA 1992c, Sheavly 2005).

- **Offshore Oil and Gas Platforms and Exploration:**
  Activities on oil and gas platforms may generate items which are deliberately or accidentally released into the marine environment including hard hats, gloves, 55-gallon storage drums, survey materials and personal waste. Undersea exploration and resource extraction also contribute to marine debris (US EPA 2002c, Sheavly 2005).

1.4 Trends of Marine Debris Over Time

The nature of rubbish ending up in the marine environment has changed in the last 30 to 40 years because of the increase in use of plastics and synthetics. Plastic only degrades slowly in the ocean (Moore et al. 2001). As a result of its ongoing use and longevity, it is likely that the quantity of plastics reaching the marine environment is increasing with time. Indeed, research has shown that there has been an increase in quantities of marine debris over recent decades in most of the regions that were studied.

Barnes and Milner (2005) list five studies which have shown increases in accumulation rates of debris on mid to high latitude coasts of the southern hemisphere. It was also noted that the densities of debris being found on remote shores has increased, for instance on remote Atlantic islands and Pacific atolls. An increase was also found in shore debris in two sites in the North Atlantic but no increase was found for a site in Alaska. At sea, no increase was found for large floating debris in the southern Atlantic and Southern Ocean (Barnes and Milner 2005). However, Derraik (2002) comments that one study showed that subantarctic islands are increasingly being affected by plastic debris, especially fishing lines.

Thompson et al (2004) investigated the quantity of microscopic plastic in plankton samples dating back to the 1960s on routes between Scotland and the Shetland Islands and from Scotland to Iceland. This study found there was a significant increase in abundance of microscopic plastic over the past 40 years.

2. Harm to Marine Life

Countless marine animals have been killed or harmed by marine debris primarily because they either become entangled in it, or, they mistake plastic debris for food and ingest it. A review of entanglement and ingestion of marine debris by marine organisms conducted in 1996, showed that these phenomena had been known to affect individuals of at least 267 species worldwide. This included 86% of all sea turtles, 44% of all seabird species, 43% of all marine mammal species and numerous fish and crustacean species. For most of the species concerned, significant numbers of individuals were affected (Laist 1997).

Table 2.1 lists the number of species that have been affected by entanglement or ingestion of marine debris. Since the publication of this list, other species have been found to be affected. For example, ingestion of marine debris by an additional five species of toothed whales was recorded (Baird and Hooker 2000). Furthermore, it is possible that the total number of species listed is an underestimate because most victims are likely to go undiscovered as they either sink or are eaten by predators (Derraik 2002).

An additional and potentially harmful aspect of marine debris is its possible impact on organisms living on the sea floor. Plastic debris is often buoyant but it eventually may break down and settle on the sea floor. An accumulation of this debris on the seabed may affect the organisms present. For example, a study on marine organisms in Indonesia where there was a high concentration of marine debris on the seafloor reported that the physical presence of the debris affected both the number and type of marine organisms that inhabited the area (Uneputty and Evans 1997). Furthermore, marine debris on the seabed can inhibit the gas exchange between overlying waters and the pore waters of the sediments, which can result in less oxygen in the sediments. This can interfere with organisms that live on the seafloor and potentially affect this ecosystem. In addition, organisms living on the seabed would also be at risk from entanglement or ingestion of marine debris (Derraik 2002).

Table 2.1
Number and Percentage of Marine Species Worldwide with Documented Entanglement and Ingestion Records

Species Group	Total number of species worldwide	Number and percentage of species with entanglement records	Number and percentage of species with ingestion records
Sea Turtles	7	6 (86%)	6 (86%)
Seabirds	312	51 (16%)	111 (36%)
Penguins (Sphenisciformses)	16	6 (38%)	1 (6%)
Grebes (Podicipediformes)	19	2 (10%)	0
Albatrosses, Petrels, and Shearwaters (Procellariiformes)	99	10 (10%)	62 (63%)
Pelicans, Boobies Gannets, Cormorants, Frigatebirds and Tropicbirds (Pelicaniformes)	51	11 (22%)	8 (16%)
Shorebirds, Skuas, Gulls, Terns, Auks (Charadriiformes)	122	22 (18%)	40 (33%)
Other birds	-	5	0
Marine Mammals	115	32 (28%)	26 (23%)
Baleen Whales (Mysticeti)	10	6 (60%)	2 (20%)
Toothed Whales (Odontoceti)	65	5 (8%)	21 (32%)
Fur Seals and Sea Lions (Otariidae)	14	11 (79%)	1 (7%)
True Seals (Phocidae)	19	8 (42%)	1 (5%)
Manatees and Dugongs (Sirenia)	4	1 (25%)	1 (25%)
Sea Otter (Mustellidae)	1	1 (100%)	0
Fish	-	34	33
Crustaceans	-	8	0
Squid	-	0	1
Species Total		136	177

Source: Laist (1997).

2.1 Entanglement

Marine debris is known to have either injured or killed marine mammals, sea turtles and seabirds due to their becoming entangled with it. The most problematic debris are fishing nets and ropes, monofilament lines, six-pack rings and packing strapping bands (Sheavly 2005). Many species are known to have suffered entanglement including 32 species of marine mammals, 51 species of seabirds and 6 species of sea turtles (see table 1.2). For some species, the number of victims involved is huge although the exact extent of the problem is difficult to quantify. For example, there are reported to be 130,000 small cetaceans (whales, dolphins and porpoises) caught in nets each year although the exact number may be much higher (Clark1992).

Once entangled in marine debris, an animal may suffer death by drowning or suffocation (US EPA 1992a). Entanglement may also cause death by strangulation. For instance, seal pups can get fishing net or plastic bands stuck around their necks and as they grow this plastic collar tightens and strangles the animal or severs its arteries (Derraik 2002). Entanglement can also result in lacerations from abrasive or cutting action of attached debris and these wounds can become infected (US EPA 1992a, Derraik 2002).

If not lethal, entanglement can impair an animal's ability to swim and therefore to find food or escape from predators (US EPA 1992a). Research has shown that entangled seals must increase metabolism to compensate for increased drag during swimming (Boland and Donohue 2003). For northern fur seals *(Callorhinus ursinus)*, it was reported that net fragments weighing over 200 grams could cause a 4-fold increase in the quantity of food an animal needed (Derraik 2002).

2.1.1 Seals and Sea Lions

Boland and Donohue (2003) reported that entanglement has been studied in 58% of all species of seals and sea lions. In these species it has caused detrimental effects for both individuals and populations. The rate of entanglement for these populations of seal and sea lion species is estimated to vary from 0.16 to 1.3% of the population, with the exception of one particularly high level of 3.9 to 7.9% for California sea lions in Mexico (Boland and Donohue 2003, Page et al. 2004). However, most entanglement rates are conservative because they rely on counting entangled animals on shores and do not account for those that die and remain at sea (Boland and Donohue 2003). The rates of entanglement that have been observed mean that many seals or sea lions of a population can be affected. For example, a study on northern fur seals in the Bering Sea estimated that 40,000 seals a year were being killed by plastic entanglement (Derraik 2002).

The Hawaiian monk seal *(Monachus schauinslandi)* is a critically endangered species and breeding colonies are limited to six small islands and atolls in the Northwestern Hawaiian Islands (Boland and Donohue 2003). Entanglement in marine debris, particularly derelict fishing gear, is causing injury and death to this species and represents a threat to the recovery of the population. Between 1982 and 1998, the mean entanglement rate for the population was 0.7%, a figure which is comparatively high. Research has shown that trawl net webbing is the biggest problem, the source of which is most likely the multinational trawl fisheries of the North Pacific Ocean. To help solve the problem of entanglement, a multi-agency effort was ensued between 1996 and 2000 to remove derelict fishing gear from the reefs of the Northwestern Hawaiian Islands. Reefs and areas close to breeding sites were cleaned (Boland and Donohue 2003). Up to 2003, a total of 195 tons of derelict fishing gear had been removed from this area.

A recent study was carried out on Australian sea lions *(Neophoca cinerea)* and New Zealand fur seals *(Arctocephalus forsteri)* that inhabit Kangeroo Island, South Australia (Page et al. 2004). Entanglement rates were found to increase in recent years and were high (1.3% of the population in 2002 for the Australian sea lion and 0.9% in 2002 for the New Zealand fur seal). Based on entanglement rates, it was estimated that 1478 entangled fur seals and sea lions die each year in southern Australia. It is likely that entanglement is slowing the recovery of these populations, particularly the Australian seal lions. The most common form of entanglement for Australian sea lions was monofilament gill nets which most likely originated from the shark fishery in the region. For New Zealand fur seals, the entanglement problem was caused by loops of packaging tape (from fishing bait) and trawl netting which was probably from regional rock lobster and trawl fisheries. The study suggested that by 2001-2 government and industry initiatives had not reduced the incidence of entanglement and further measures are needed.

Research at South Georgia in the Southern Ocean in 1988/9 reported that several thousand Antarctic fur seals were entangled, mainly in derelict fishing gear (Arnould and Croxall 1995). The rate of entanglement in the population was calculated to be 0.4%. In the following 6 years it was found that the rate of entanglement decreased by about a half. Even so, it was estimated that there could be up to 15,000 seals entangled per year of which 5700 would be expected to die as a consequence. Following the initial publication of the entanglement problem in 1988/9, there was campaigning for fishing vessels to comply with legislation on dumping garbage (MARPOL –see section 5.1.1) to try and help the situation. Although the rate of entanglement in the seals decreased in subsequent years, this was most likely due to a substantial reduction in fishing activity in the area. However, there was evidence that more packaging bands had been cut rather than left as loops as had been requested and the proportion of seals entangled in packaging bands was reduced. This suggested that there was a general improvement in standards of waste disposal in the Southern Ocean (Arnould and Croxall 1995).

2.1.2 Manatees

The endangered West Indian manatees in Florida, have been found to bear scars and have missing flippers as a consequence of entanglement. Research on 940 carcasses that were salvaged in the Southern US found that 1.7% had flippers that were scarred, missing or entangled in monofilament line, rope or crab trap lines. In 1.2% of the cases entanglement in line or netting was identified as the cause of death (Laist 1997).

2.1.3 Whales

Whales can become entangled in fishing gear. However, instead of drowning because they cannot get free, as occurs with smaller marine mammals, the larger size of whales means they are often capable of dragging fishing gear away with them. A serious entanglement can reduce a whale's feeding ability and can lead to death from starvation. The greatest problem is caused by gill nets (Clapham et al. 1999).

A number of species of baleen whales and toothed whales (which includes some species of dolphins and porpoises) have been reported to have suffered entanglement (Laist 1997, Baird and Hooker 2000, see Table 2.1). Those that are particularly vulnerable are coastal species that inhabit heavily fished areas. Of the large species of whales, those that have been affected the most are the Northern Right Whale and the Humpback Whale. For example, in the western North Atlantic, numerous deaths of Right Whales have occurred through entanglement in fishing gear. The Right Whale is a critically endangered species and entanglement in fishing gear has undoubtedly had negative impacts on population numbers and contributed to the population's apparent failure to recover. It is possible that other whale species with a low population numbers may also be significantly affected by entanglement mortalities but there is a lack of data on this subject (Clapham et al. 1999).

2.1.4 Sea Turtles

Entanglement has been recorded in six of the seven existing sea turtle species. It has been a widespread phenomenon occurring in many ocean areas. The majority of entanglements involve monofilament line, rope or commercial trawl nets and gillnets. Research suggests that entanglement rates can be high and possibly result in population declines for at least some species. Data collected between 1980 and 1992 on the US Atlantic and Gulf of Mexico coasts showed entangling debris was found on 0.8% (142 of 16,327) loggerhead turtles, 0.8% (18 of 2,140) Kemp's ridley turtles, 6.6% (123 of 1,874) green turtles, 6.8% (66 of 970) leatherback turtles and 14% (36 of 258) hawksbill turtles (Laist 1997). A study on 93 sea turtles that were stranded on the coasts of the Canary Islands between January 1998 and December 2001 reported that 24.78% died as a result of entanglement in derelict fishing nets (Orós et al. 2005).

2.1.5 Coastal and Marine Birds

Entanglement has been reported in 56 species of marine and coastal birds. Studies reported that entanglements appeared to be most common in pelicans and gannets and a few coastal gull species followed by albatrosses, petrels and shearwaters. Penguins and grebes were affected to a lesser extent (Laist 1997). The greatest cause of entanglements in seabirds was monofilament line and fishing net. Other commonly reported entanglements were due to fishing hooks, six-pack yokes, wire and string (Laist 1997).

A study on gannets *(Sula bassana)* reported that entanglement accounted for 13-29% of deaths in these birds at Helgoland, German Bight (Derraik 2002). Research on gannets also suggested that a small percentage of adults and chicks die from entanglement in debris woven into their nests (Laist 1997).

2.2 Damage to Coral Reefs

Derelict fishing gear can be destructive to coral reefs. Nets and lines become snagged on coral and subsequent wave action causes coral heads to break off at points where the debris was attached. Once freed, debris can again snag on more coral and the whole process is repeated. This cycle continues until the debris is removed or becomes weighted down with enough broken coral to sink (NOAA 2005a). Eventually, derelict fishing gear may become incorporated into the reef structure.

Efforts to remove derelict fishing gear from coral reefs of the Northwestern Hawaiian Islands reported that a proportion of the derelict nets that were recovered had about 20% of their weight attributable to broken coral fragments (Donohue et al. 2001).

A study on the biological impacts of marine debris on coral reefs in the Florida Keys reported that the most common debris in the area was hook and line gear and debris from lobster traps (Chiappone et al. 2002). It was predominantly these types of derelict fishing gear that caused damage to the reef. This debris was found to cause damage or mortality to many invertebrates including sponges and corals. As a consequence, it was suggested that the overall biological impacts from marine debris on the Florida Key reefs may be considerable.

2.3 Ghost Fishing

Derelict fishing gear which has been lost or discarded by fishermen may continue to function in the water as fishing apparatus on its own (Matsuoka et al. 2005). Both fishing nets and pots can continue to catch marine organisms such as fish and crustaceans and can cause their death if they cannot escape. The process is known as ghost fishing.

For both fishing nets and pots, a cycle is set up whereby marine organisms are captured and, in turn, these species may attract predator species which may then also become trapped. Organisms which die and decay in the nets and pots may subsequently attract scavengers such as crustaceans and again these species may then also become trapped (JNCC 2005). Indeed, ghost nets have been described as perpetual "killing machines" that never stop fishing (Sheavly 2005). Many organisms can be caught and trapped by ghost nets and pots. For example, one 1500-meter long section of net was found that contained 99 seabirds, 2 sharks and 75 salmon (US EPA 1992a). The net was estimated to have been adrift for about a month and to have travelled over 60 miles.

Fishing nets and pots are made of synthetic materials which do not biodegrade. Consequently, they can remain in the sea and continue to 'fish' for many years depending upon the environmental conditions they are in. For example, if nets become snagged on rocks that hold them in place or are lost in deep waters they may continue to fish for a more than a year. Nets lost in calm waters near oceanic convergence zones may continue to fish for decades, however, nets that are lost in areas of large swell and storm activity may be rapidly torn apart and destroyed. Lost pots are constructed of metal or thick netting attached to a rigid frame and are likely to continue fishing for even longer than nets. To overcome this problem, some fisheries fit their pots with escape gaps or escape panels that either biodegrade or fall out of the pot after a certain length of time (Bullimore et al. 2001). There is experimental evidence to show that these measures are successful such that organisms can escape. The use of these types of pots is now a requirement of fishery regulations in some countries (Matsukoka et al. 2005).

2.3.1 Impact of Ghost Fishing

Ghost fishing by gillnets was shown to be occurring by studies carried out with submersible in the USA. There is also evidence from experiments that lost nets (Tschernij and Larsson 2003) and pots (Bullimore et al. 2001) do continue to catch marine organisms. Ghost fishing by lost nets may continue for months and catch large quantities of marine organisms (Sancho et al. 2003) but catches in the nets can decrease substantially after some time (Santos et al. 2003). This is possibly due to the amount of fish already accumulated in the net and, in time, the growth of small organisms on the nets making them visible.

Many marine organisms can be caught in ghost nets and the amount of lost or discarded nets is vast. Consequently ghost fishing is having an impact on the viability of already stressed fisheries worldwide (Sheavly 2005). It is therefore of great concern both with regard to conservation of marine organisms and to economic loss in fisheries. An example of a conservation problem is a fishery in the NE Atlantic which fishes at depths between 200 and 1200 metres. Due to the fishing practices that are carried out, it has been suggested that it is likely that a large quantity of nets are lost, and additionally there is evidence of illegal dumping of nets. Anecdotal evidence suggests that up to 30 km of net are routinely discarded per vessel per trip. The number of deepwater sharks in the region has fallen to about 20% of their original population levels in less than ten years. Therefore, there is now concern about the impact of ghost fishing on the sharks because of the large losses of nets. The sharks are considered to be among the most vulnerable fish species known in the North Atlantic. It has been suggested that the introduction of retrieval surveys to remove the lost nets is urgently required (Hareide et al. 2005).

Ghost fishing can lead to economic losses for fisheries. For example, an experimental study on ghost fishing of monkfish from lost nets in the Cantabrian Sea, northern Spain, estimatated that 18.1 tonnes of monkfish are captured annually by abandoned nets. This represented 1.46% of the commercial landings of monkfish in the Cantabrian Sea (Sancho et al. 2003). A study on ghost fishing by lost pots off the coast of Wales, UK, noted that potential losses to the brown crab fishery caused by ghost fishing could be large (Bullimore et al. 2001). In the USA it was estimated that $250 million of marketable lobster is lost annually to ghost fishing (JNCC 2005).

2.3.2 Solutions

Prevention of fishing gear loss is the most fundamental solution to stop ghost fishing (Matsuoka et al. 2005). A strategy to prevent loss of fishing gear must include education to increase awareness of the problems of discarded nets together with enforcement of laws that prohibit the dumping of gear at sea (see further section 5.1.1 on MARPOL). The use of pots/traps with biodegradable parts to permit escape has already been implemented by legislation in some countries but this strategy is needed globally. Finally, retrieval of lost fishing gear can be undertaken to alleviate the problems of ghost fishing. For example, the Directorate of Fisheries in Norway has organised retrieval surveys in the Norwegian gillnet fisheries since 1980. Between 1983 and 2003, a total of 9689 gillnets of 30 metre standard length were removed from the fishing ground. The effort requires accurate positional information and the cooperation of fishermen (Hareide et al. 2005).

2.4 Ingestion

Many species of seabirds, marine mammals and sea turtles have been reported to eat marine debris, including plastics (see table 2.1). It is thought that this ingestion of marine debris occurs mainly because animals confuse debris for food but may also happen accidentally. Many sorts of plastic items have been ingested by marine organisms including plastic fragments derived from larger plastic items, plastic pellets, which are used as a feedstock material in the plastics industry, plastic bags and fishing line. In some instances the debris may pass through the gut without harming the animal, but in other cases it can become lodged in their throats or digestive tracts. This can lead to starvation or malnutrition if the digestive tract is blocked (US EPA 1992a). In addition, debris can accumulate in the gut and give a false sense of fullness, causing the animal to stop eating and slowly starve to death (Sheavly 2005). Ingestion of sharp objects can damage the gut and may result in infection, pain or death.

When plastics are ingested by animals, it is possible that hazardous chemicals in the plastics may leach out and be absorbed into the animal's body (US EPA 1992b). This could potentially cause toxic effects to the animal. A further threat to health from ingestion of plastic debris is from other hazardous chemicals in the environment which may adhere to the surface of the plastic debris. Research has shown that the hazardous pollutants DDE and PCBs become absorbed and concentrated onto the surface of plastic pellets (Mato et al. 2001). For example, a study on pellets from a beach in Tokyo, Japan, reported a mean concentration of PCBs in the plastic of 93 ppb (range <28 to 2300 ppb). The source of these chemicals on the pellets is likely to be from the surrounding seawater (Endo et al. 2005). Because contaminated pellets may be ingested by animals they could be a source of PCBs and DDE in the marine food chain. Such chemicals are resistant to natural breakdown processes, build up in body tissues and have serious detrimental effects on health (Allsopp et al. 1999). A study on great shearwaters *(Puffinus gravis)* cited by Derraik (2002) revealed that PCBs in the tissue of these seabirds were derived from ingested plastic debris.

Tiny plastic particles, or "scrubbers" from hand cleaners, cosmetic preparations and airblast cleaning media have contaminated ocean waters. Such particles could impact on the sea-surface microlayer ecosystems. The microlayer is an important nursery for numerous species and is sensitive to pollution (Gregory 1996). Those tiny plastic particles which are used in air blasting may present an additional hazard to marine life because they become contaminated with heavy metals when used for stripping paint from metallic surfaces and cleaning engine parts. When such contaminated particles reach the marine environment, heavy metals or other contaminants in these particles could potentially be taken in by filter feeding organisms and ultimately other passed onto organisms in the food chain (Gregory 1996, Derraik 2002).

The majority of studies on ingestion of marine debris have been carried out on sea turtles and seabirds. The impacts of ingestion on fish are less well studied (Moore et al. 2001). Other marine organisms may also be affected. Research has shown that there are both small (Moore et al. 2002) and microscopic plastic fragments (Thompson et al. 2004) in surface waters of the oceans and microscopic plastic particles in sediments (Thompson et al. 2004). The impact this has on marine organisms is unknown (Moore et al. 2002), but an experiment showed that microscopic plastic fragments were ingested by small marine organisms such as amphipods, lugworms and barnacles that were kept in aquaria. Furthermore the quantity of this microscopic plastic has been shown to have increased significantly over the past 40 years (Thompson et al. 2004).

In addition to being ingested by marine organisms, a study in Indonesia reported that there were differences in the number and type of marine organisms which inhabited a beach which had very high quantities of litter compared to an area which was litter free (Uneputty and Evans 1997). This physical impact of marine debris on populations of marine organisms was found to affect the numbers of very small organisms called diatoms as well as several other species.

2.4.1 Sea Turtles

Ingestion of marine debris represents a serious threat to sea turtle populations throughout the world. This was brought to light in a 1985 review of studies on ingestion of debris in sea turtles (see Bjorndal et al. 1994). Ingestion of marine debris, especially plastics, is of great concern because it can impact on turtle populations and the green turtle, leatherback turtle, hawksbill turtle, Kemp's ridley and olive ridley are listed as endangered species whilst the loggerhead turtle is listed as threatened (NOAA 2005b).

According to research, high numbers of sea turtles ingest marine debris and plastic is the most common sort of debris ingested (Tomás et al. 2002). For example, studies on dead turtles reported ingestion of marine debris in 79.6% of the turtles that were examined from the Western Mediterranean (Tomás et al. 2002), 60.5% of turtles in Southern Brazil (Bugoni et al. 2001) and 56% of turtles in Florida (Bjordal et al. 1994). Young turtles (in the pelagic stage) of all species of turtles have the highest incidence of marine debris ingestion (Tomás et al. 2002).

Plastic that is ingested by turtles may not result in their death or injury but instead pass straight through the gut. However, ingested plastic can cause mortality. Studies clearly show that just a small amount of ingested plastic can block the gut and result in death. Research on dead sea turtles has shown that in general, the amounts of plastic debris found in the guts is small but this can result in mortality. For example, a study on 38 dead juvenile green turtles in Southern Brazil found that 60.5% of them had ingested man-made debris and that the debris was a direct cause of death in 13.2% (Bugoni et al. 2001).

One of the most significant causes of death from plastic debris is obstruction of the digestive tract (Bugoni et al. 2001). The gut may also become perforated as a result of sharp-pointed objects such as hooks and this can result in death. Hooks from long-line fisheries have caused thousands of turtle deaths in the Western Mediterranean (Tomás et al. 2002). Another cause of death has been found to occur from ingestion of monofilament line where the gut gathers along the line so that food contents can no longer pass through the gut (Bjorndal et al. 1994). A potentially harmful side effect of ingested marine debris occurs when the debris takes up some of the gut capacity and reduces it and consequently less food can be digested. This is known as dietary dilution. It is especially a threat to young turtles because of their nutritional needs (Tomás et al. 2002). Other harm to sea turtles can occur from hard plastics which can cause internal damage to the gut including ulceration and tissue necrosis (death) (Barreiros and Barcelos 2001).

The reason that turtles ingest marine debris is not known with certainty. It has been suggested that debris, such as plastic bags, look similar to, and are mistaken for jellyfish. However, it is also possible that turtles have a low discrimination in their feeding habits. Young (pelagic stage) turtles are particularly vulnerable to plastic debris due to their close association with convergences where debris accumulates. Most turtle species are exposed to debris in near-shore habitats where they feed (US EPA 1992b, Tomás et al. 2002).

2.4.2 Seabirds

Plastic debris may be ingested by seabirds because it resembles prey, or, because it is present already in the gut of prey. Adult seabirds can pass on ingested plastic to their chicks by regurgitation. Marine debris ingested by seabirds includes mostly plastic pellets (see section 1.3.1) and plastic fragments broken down from larger items (Robards et al. 1997). There is evidence that seabirds may feed selectively of plastic debris, ingesting specific shapes or colours while mistaking them for prey (Derraik 2002).

It was first discovered that seabirds ingested plastic in the early 1960s (Spear et al. 1995). A review of data in 1997 revealed that 111 of the 312 species of seabirds had ingested marine debris. The prevalence of ingestion of debris among seabirds is, therefore, very high. For example, a study of seabirds from the Eastern North Pacific and tropical

Pacific reported that 73% of the species tested had ingested plastic (Blight and Burger 1997) whilst a study in the tropical Pacific found 57% of species had ingested plastic (Spear et al. 1995). Spear et al. (1995) noted that studies had shown that the number of species affected was particularly high in waters close to urbanised areas and, the number of individuals of a species that are affected in such areas can exceed 80%. Nevertheless, the problem is also apparent in remote areas. For example, plastic was found to be present in many carcasses of dead snow petrel chicks found in Antarctica Burton and Riddle 2002).

It has been shown that adult birds can pass plastic onto their chicks when they regurgitate food for them. A study of southern giant petrel chicks from the Patagonian coast in the Southern Atlantic Ocean examined the contents of the stomach of 73 chicks by gently making them regurgitate their last meal (Copello and Quintana 2003). Plastic was found in 66% of the food samples taken. It was suggested that the source of the plastic was mainly derived from fishing activities in the area. Chicks of the Laysan albatrosses have also been reported to ingest plastic in food from their parents and this can be a significant source of mortality. One study reported that 90% of chicks surveyed had some sort of plastic debris in their upper gastrointestinal tract (Derraik 2002). Mortality of chicks of Laysan albatrosses which nest on the Midway Atoll in the North Pacific Ocean has been found to occur due to their ingestion of plastic cigarette lighters (Tsukayama et al. 2003).

One study investigated the incorporation of plastics into nests of double-crested cormorants *(Phalacrocorax auritus)* in the Gulf of Maine (Podolsky and Kress 1989). Almost 500 nests were examined and plastic was found in 37% of them. The study commented that nestling and adult birds run the risk of becoming entangled or ingesting plastic from their nests.

One study suggested that once ingested by seabirds, degradation of plastic particles in the digestive tract may taken 6 months unless it was regurgitated, whilst another study suggested degradation of plastic took one to two years (Spear et al. 1995). There is evidence that ingested plastic may be detrimental or sometimes lethal to birds, for example, if it is ingested in sufficient quantity to obstruct the passage of food or cause stomach ulcers (Robards et al. 1997). In a study of birds from the Eastern North Pacific, it was reported that storm-petrels and stejnegers petrels that were examined had ingested enough plastic to reduce the volume of food in the gizzard or to affect food assimilation (Blight and Burger 1997).

A potentially harmful side effect of plastic ingestion in seabirds is weight loss. A study on seabirds collected in the tropical Pacific found that ingested plastic had a negative impact on the body weight of birds (Spear et al. 1995). The more plastic particles ingested, the greater the reduction in body weight. It was proposed that the weight loss could be due to a number of impacts of ingested plastic including physical damage or blockage of the digestive tract, reduced digestive efficiency or possibly due to the introduction of toxins into the bird's body. Other research also concluded that ingestion of plastic limited a bird's ability to lay down fat deposits (Derraik 2002). Some other deleterious effects from plastic ingestion reported in seabirds include clogged gizzards, an increased risk of disease and alteration of hormone levels (Copello and Quintana 2003).

2.4.3 Marine Mammals

Thirty-one species of marine mammals have been reported to have ingested marine debris (see table 2.1) (Laist 1997, Baird and Hooker 2000). One study identified small plastic fragments in about 4% of scat samples from Antarctic fur seals *(Arctocephalus tropicalis)* (Eriksson and Burton 2003). It was suggested that the plastic had become incorporated into the food web such that fish had consumed the fragments and the seals had, in turn, fed on the fish and ingested the plastic.

The death of a young male pygmy sperm whale *(Kogi breviceps)* was found to be caused by plastic debris occluding its stomach. Deaths of a West Indian manatee *(Trichechus manatus)* and Florida manatees *(Trichechus manatus latirostris)* were reported to be due to plastic in their guts (Derraik 2002).

2.4.4 Fish

Studies published in the 1970s documented the presence polystyrene spherules in several species of fish. This debris was found in 21% of flounders *(Platichthyes flesus)* in the Bristol Channel in 1973 and 25% of sea snails *(Liparis liparis)*. The polystyrene was also found to contaminate 8 out of 14 species of fish from the New England coast, USA (Derraik 2002).

2.4.4 Zooplankton and other nonselective feeders

Microscopic fragments of plastic are known to be ingested by organisms. However the effect of this ingestion by zooplankton and other nonselective feeders is not known (Thompson et al 2005) and represents one of the current directions of marine debris research.

3. Spread of Alien Species by Marine Debris

Human activities have resulted in many species being moved from their native habitats to regions where they are not native. The introduction of a non-native species into another habitat is called a biological invasion. The impacts of biological invasions can be devastating for the ecosystem concerned. For example, a biological invasion of the American comb jellyfish *(Mnemiopsis leidyi)* into the Black Sea resulted in a huge population explosion of the jellyfish and a negative impact on the finfish fisheries of the area (GESAMP 1997). Indeed it has been stated that colonization by alien species poses one of the greatest threats to global biodiversity (Barnes 2002a), and introduction of native species is accepted to be one of the greatest causes of loss of species (Barnes and Milner 2005).

Natural debris floating in the oceans has always provided "rafts" which have offered a limited means of travel for certain marine species. Rafts include volcanic pumices, floating marine algae, seagrasses, plant trunks or seeds (Aliani and Molcard 2003, Barnes and Milner 2005). However, the introduction of vast quantities of plastic debris into the ocean environment over the past half century has massively increased the amount of raft material and consequently increased the opportunity for the dispersal of marine organisms. This represents an increased potential for alien invasions of new habitats (Barnes 2002a, Barnes and Milner 2005). Plastic debris is long lasting, highly abundant and travels slower than boats, factors which could all favour the survival of rafting organisms (Barnes 2002a).

Organisms ranging from algae to iguanas have been observed to raft on rubbish in the marine environment (Barnes and Milner 2005). However, the most commonly found organisms living on plastic waste in the oceans include barnacles, polychaete worms, bryozoans, hydroids and molluscs (Barnes 2002a). Plastic encrusted with marine organisms has been found in the Pacific, the Atlantic, the Caribbean (Winston et al. 1997) and the Mediterranean Sea (Aliani and Molchard 2003).

It is evident that organisms colonize marine debris most frequently and prevalently in the tropics, (Barnes 2002b), although colonised debris has also been found towards polar regions (Barnes and Fraser 2003, Barnes and Milner 2005). In warm regions, for example, Florida, an exotic bryozoan species *(Thalmoporella species)* was found which was not from the region (Winston et al. 1997). In colder regions, a species of barnacle and bryozoan were found on plastic at extreme northerly latitudes whilst an invasive and exotic barnacle, *Elminius modestus*, was found on plastic debris in the Shetland Islands (Barnes and Milner 2005). These examples demonstrate the potential of drifting plastic to aid an alien species invasion. It has been estimated that man-made marine debris has approximately doubled the opportunities for marine organisms to travel at tropical latitudes and more than tripled it at high (>50°) latitudes and, thereby increased the potential for alien species invasion (Barnes 2002a and 2002b).

One study identified the presence of marine species on plastic debris which cause harmful algal blooms (Masó et al. 2003). These species were found on plastic debris in an area where harmful algal blooms had occurred. It was suggested that plastic debris may act as a vector for the transport of these species and possibly could favour success of their dispersal in the oceans.

4. Marine Debris around the world

Many studies undertaken in different areas of the world have investigated the quantity of debris in the marine environment. Research has focused on debris that is floating on the ocean surface, in the water column (Lattin et al. 2004), debris that is stranded on the shoreline or debris that is present on the seafloor.

Such studies show that debris is ubiquitous throughout the world's oceans and shores. Generally, there is a trend of a tropics to poles decrease, so that that the lowest quantities are found towards the poles (Barnes and Milner 2005). High concentrations of debris are often found in shipping lanes, around fishing areas and in oceanic convergence zones (Galgini et al. 1995). Other factors that influence the type and amount of debris present include proximity to urban centres, industrial and recreational areas (Sheavly 2005).

One study investigated trends in the movement of floating debris in the world's oceans using satellite data to analyse ocean currents and winds (Kubota et al. 2005). The research predicted that most debris is moved towards the mid-latitudes. This is in agreement with observations from other studies which showed higher concentrations of debris in such areas compared to nearer the poles. It also identified areas where ocean movements results in particularly high concentrations of debris such as north of Hawaii.

A large proportion of marine debris consists of plastics or synthetics that generally do not biodegrade. Continual input of such materials into the world's oceans has therefore resulted in a constant increase of marine debris. Despite efforts to alleviate the problem of marine debris over the past 20 years or so, there are no clear indications that the quantity of marine debris is decreasing either globally or regionally (UNEP 2005).

To compose this section on quantities of debris in the marine environment, a search of the scientific literature was made for years spanning 1990 to 2005. Data from the studies are reviewed by region and subdivided under the categories of floating marine debris, debris on the seafloor and debris on shorelines. Within each category, it is not always possible to compare results between global regions because different methods have been used to collect the debris and present the data. Nevertheless, many of the studies did use similar methodology and some comparisons can therefore be made. These data are presented in table form for ease of comparison of the quantities of debris between different areas. Table 4.1 gives quantities of floating debris analysed using visual surveys from ships, table 4.2 gives seafloor debris analysed using trawl nets, tables 4.3 and 4.4 give shore debris that is presented as the quantity of debris along a given length of shore or in a given area.

4.1 Northern Atlantic Ocean and Europe

4.1.1 Floating Debris:

A survey of floating debris in the Northern Atlantic was conducted in 2002 which used visual sighting of debris on the ocean surface from a ship (Barnes and Milner 2005). It revealed that the density of debris ranged from 0 to 20 items/km2 at latitudes between 0 and 50°N. The highest density of floating debris was located around the UK and North-West Europe. For instance, figures given for the English Channel were 10 to 100+ items/km^2. Further north at West Spitsbergen in the Arctic, the density was at the lower end of the range (0 to 3 items/km^2). The study noted that levels of floating debris in the North Atlantic were generally lower than levels in the North Pacific and Caribbean Atlantic. However, figures for the North Pacific from a study reviewed by Thiel et al. (2003), (<1 to 1.8 items/km^2), were at the lower end of the range of levels given for the Northern Atlantic by Barnes and Milner (2005).

4.1.2 Seafloor Debris:

One study was undertaken between 1992 and 1998 to determine the density of marine debris on the seafloor along European Coasts (Galgani et al. 2000). The study used trawl nets to collect the debris and found that overall there was considerable variation between the regions surveyed. Values ranged from 0 to 101000 items/km^2. The mean density of debris was 126 items/km^2 for the Baltic Sea, 156 items/km^2 for the North Sea, 528 items/km^2 for the Celtic Sea, 142 items/km^2 for the Bay of Biscay, 143 items/km^2 for the Gulf of Lion, 1935 items/km^2 in the North-Western Mediterranean (see also below), 229 items/km^2 for East-Corsica and 378 items/km^2 for the Adriatic Sea. Clearly, the highest quantities of debris were located in the Mediterranean.

4.1.3 Shore Debris:

A study on beach litter off the coast of Edinburgh, UK, in 1994 reported the density of litter was 0.8 items/m^2 (Velander and Mocogni 1998). This was more than double the density given by a study in the same area 10 years before (density 0.35 items/m^2).

A review of the scientific literature on beach debris on different shores of the North Atlantic which were undertaken between 1984 and 2001 at latitudes between 9.5 to 57° N, showed the densities of debris varied from 0.15 to 12.5 items/m^2 (Barnes and Milner 2005). Notably higher levels (70.9 items/m^2) were found at Padre.

4.2 Mediterranean

Semi-enclosed seas that are surrounded by developed areas, such as the Mediterranean Sea, are likely to have particularly high concentrations of marine debris (Barnes and Milner 2005).

4.2.1 Floating Debris

A survey of large debris which was floating in the North-Western Mediterranean was conducted using visual inspection of the ocean surface (Aliani et al. 2003). In 1997, a density of 15 to 25 items/km^2 was observed and in 2000, a lower range of 1.5 to 3 items/km^2 was recorded. It was suggested that the difference could be due to meteorological conditions, variability in marine currents of a change in debris input.

4.2.2 Seafloor Debris:

A visual survey of the seafloor by scuba divers around coastal sites of Greece (Eastern Mediterranean) in 2003 reported a mean of 15 items of debris per 1000m^2 (range 0 to 251 items/1000m^2) (Katsanevakis and Katsarou 2004). Greater concentrations of debris were found in bays compared to open areas and in areas where fishing boats anchor. Another study of two coastal areas of Greece used trawl nets to survey the seafloor in 1997/8 and reported concentrations of debris within the same range (89 and 240 items/km^2) (Stefatos et al. 1999).

A study of the seafloor using trawl nets in the North-Western Mediterranean around the coasts of Spain, France and Italy in 1993/4 reported a particularly high mean concentration of debris (1935 items/km^2 or 19.35 items/hectare) (Galgani et al. 1995). 77% of the debris was plastics and of this, 92.8% were plastic bags.

4.2.3 Shore Debris

A comprehensive review of marine debris in the Mediterranean which was published in 1991 concluded that close to 75% of beach litter consisted of plastic items (UNEP 2005). Another review of data on the density of stranded debris on shorelines in five Mediterranean countries gave values of 6.4 to 231 items/m (Barnes and Milner 2005). It was calculated that values for stranded debris in the Mediterranean were significantly higher for their latitude compared to other regions.

4.3 Middle East

4.3.1 Shore Debris:

A study of beaches along the Omani coast in the Gulf of Oman in 2002 reported densities of marine debris ranging from 0.43 to 6.01 items/m, mean 1.79 items/m (Claereboudt 2004). The plastic debris appeared to be mainly of local origin or discarded fishing gear.

A study of beaches along the Jordanian coast of the Gulf of Aqaba recorded debris densities of 5 and 3 items/m^2 in 1994 and 1995 respectively (Abu-Hilal and Al-Najjar 2004). When wood was excluded from the debris, the most abundant items were plastic which appeared to be largely of local origin. Fishing-related debris on average accounted for 25% of the debris.

4.4 Southern Atlantic

4.4.1 Floating Debris

A study investigated floating debris concentrations between latitudes of 50°S to 0°S in 2002 by means of visual inspection of the ocean surface (Barnes and Milner 2005). The density of debris recorded ranged from 0 to 10 items/km^2.

4.4.2 Shore Debris:

A review of literature on beach debris in the Southern Atlantic reported densities of 0.319 to 0.813 items/m (or 319-813 items/km) for Tristan da Cunha in 1984 (37.2°S) and 0.019 items/m (or 19 items/km) for Gough in 1984 (41.2°S) (Barnes and Milner 2005).

A study on the Falkland Islands in 2001/2 studied the monthly rate of accumulation of marine debris along a 1.8 km stretch of beach (Otley and Ingham 2003). The mean accumulation rate was 77 items/km/month and 42% of the items were fishing debris. This study also noted that other research in the Southern Hemisphere showed a general trend of upwards of 200 items/km at sites less than 50° S and less than 100 items/km on beaches greater than 60° S (i.e. further towards the south pole)

4.5 Southern Ocean and Antarctica

4.5.1 Floating Debris

Floating debris in the Southern Ocean was analysed by visual sightings from a ship (Barnes and Milner 2005). Debris near to the Antarctic Peninsula was present at a density of 0 to 1 items/km^2. At Drakes Passage in the Southern Ocean the density ranged from 0 to 3 items/km^2.

Other studies also noted the presence of low quantities of plastic debris in the Southern Ocean south of New Zealand (Grace 1997a), near the Antarctic Peninsula and north and north west of the Ross Sea (Grace 1995a). These studies tested for the abundance of mesolitter, that is, material of less than 5-10mm across by trawling the ocean surface with nets. South of New Zealand a mean density of mesolitter of 1.2 particles/hectare was found (Grace 1997a). Near to, and to the west of the Antarctic Peninsula, and north and northwest of the Ross Sea, mesolitter was usually absent. However, in a convergence zone midway between the Antarctic Peninsula and the Ross Sea it reached 8.7 particles/hectare (Grace 1995a).

4.5.2 Shore Debris

Oceanic Islands of the Southern Ocean are generally uninhabited by humans and can be considered to be among the remotest shores in the world (Convey et al. 2002). Yet surveys of their shores report the presence of plastic debris. It is evident from a review of studies on shore debris in the Southern Ocean (latitude 54 to 63°S) that the density of debris present is generally an order of magnitude lower than the density of debris found on shores in the Northern Atlantic (9.5 to 57° N) (Barnes and Milner 2005).

The density of debris for different shores surveyed in the Southern Ocean listed by Barnes and Milner (2005) was as follows: Bird Island (0.017-2.49 items/m) in 1990-2001, South Georgia (0.36 items/m) in 1993, Candlemas Island (0.008-0.026 items/m) in 1997, Saunders Island (0.285 items/m) in 1997, Bouvet (0.077 items/m) in 1997, Signy Island (0.012-0.224 items/m) in 1990-2001, Livingstone (0.019-0.304 items/m) in 1984-1998 and Ardley (0.006 items/m) in 1996. The figures given here for Candlemas, Saunders and Signy Islands were from a study by Convey et al. (2002), which commented that the two most common forms of debris apparent were plastic bottles or containers and fishing floats or polystyrene fragments thought to be derived from net floats. On Bird Island, the most common form of debris present was discarded fishing gear (Walker et al. 1997).

4.6 Sea of Japan

4.6.1 Shore Debris

A study surveyed debris on beaches along the Sea of Japan both in Japan and Russia (Kusui and Noda 2003). This study did not monitor the number of items/m^2 as many studies on shore litter have done, but instead investigated the weight of debris in a given area. The result was a mean concentration of 2144 g/100 m^2 for Japan and 1344 g/100 m^2 for Russia. One unusual observation was that no plastic resin pellets were found on the Russian beaches. This was surprising given that such pellets even occur in non-industrialised regions of the South Pacific (Kusui and Noda 2003).

4.7 Indonesia

4.7.1 Floating Debris

A survey of floating debris in Ambon Bay, Eastern Indonesia was carried out in 1994/5 (Uneputty and Evans 1997). In the worst affected areas densities of debris were extremely high (> 4 items/m^2).

4.7.2 Seafloor Debris

A study of Ambon Bay, Eastern Indonesia, in 1994/5 investigated the concentrations of submerged debris in the area. Nets were used to collect submerged debris from the waters edge at low tide (Uneputty and Evans 1997). The mean density of debris recorded at five different locations ranged from 0.05 to 0.69 items/m^2.

4.7.3 Shore Debris

Two studies on several islands off Jarkarta Bay and islands further to the northwest in the Java Sea, reported that debris pollution on shorelines had substantially increased between 1985 and 1995 (Uneputty and Evans 1997b, Willoughby et al. 1997). Both studies noted that results implicated Jakarta as a major source of the debris. On 23 of the islands, it was reported that the mean total litter at the strandline ranged from not detectable to 29.1 items/m (Willoughby et al. 1997). Plastic bags, polystyrene blocks and discarded footwear accounted for 80% of the items found.

A survey of strandlines at different locations along Ambon Bay, Eastern Indonesia, in 1994/5 reported mean densities of debris up to 8.6 items/m^2 (Uneputty and Evans 1997).

4.8 Indian Ocean and Red Sea

4.8.1 Floating Debris

A series of studies of floating debris in the Indian Ocean were carried out by Greenpeace between 1993 and 2000 (Grace 1994, Grace 1995b, Grace 1997b, Grace and Frizell 1998, Grace and Frizell 2000). Visual inspection of floating debris showed that levels were very low in the central and western Indian Ocean but moderate in the eastern Indian Ocean. Man-made litter was commonly observed in the Red Sea.

The studies also tested for quantities of mesolitter, that is, material of less than 5-10mm across by trawling the ocean surface with nets. In 1993, the mean density of mesolitter in the eastern Indian Ocean was 22.1 particles per hectare, and in the central and western Indian Ocean was 1.8 particles per hectare (Grace 1994). In 1995, results consistent with 1993 were obtained, for example, the mean density of mesolitter between Australia and the Seychelles was 4.4 particles/hectare (Grace 1997b) and in 1997 a value of 4.4 particles/hectare was obtained off the west coast of Australia (Grace and Frizell 1998).

4.9 Australia

4.9.1 Shore Debris

Studies on debris on Australian beaches have revealed that near urban areas such as Brisbane, Sydney and Melbourne, the general public was the main source of shoreline litter (Frost and Cullen 1997). Debris from commercial fishing was found to occur in Tasmania, parts of Western Australia (Jones 1995) and in the remote Great Australian Bight, South Australia (Edyvane et al. 2004). Another report published in 2003 found up to 90% of beach debris was fishing gear in a region of Northern Australia (UNEP 2005). In Fog Bay, Northern Australia, research in 1996/7 suggested that 85% of the debris originated from commercial fishing, merchant shipping and recreational boaters (Whiting 1998).

Surveys of the coastline of Tasmania (1990/1) showed there was an average of 300 items/km and in the Marmion Marine Park, Western Australia (1992) there was 3660 items/km (Jones 1995).

4.10 South America

4.10.1 Floating Debris

A study was conducted on floating debris in coastal waters of Chile in 2002 from latitude 18°S to 50°S (Thiel et al. 2003). The quantity of debris was assessed by visual sighting from a ship. Debris was found to often be present in patches both in coastal and in offshore regions. Between latitudes of 20°S and 40°S, which corresponded to the main concentrations of human populations, debris densities of 1-36 items/km^2 were recorded.

The highest concentrations (>20 items/km^2) were generally found in coastal waters, particularly near to large ports, although high densities were also found in some offshore regions. The lowest densities (<1 item/km^2) were evident at latitudes between 40°S and 50° S which correspond to areas of Chile with low population densities.

In the survey of Southeast Pacific waters off Chile, plastic bags were the most predominant items of debris (Thiel et al. 2003). Based on evidence from other studies, it was suggested that plastic bags may not stay afloat for long periods and so do not often get washed ashore, but instead sink to the seafloor. Results also suggested that commercial shipping activities in the Southeast Pacific were responsible for a large part of the floating marine debris although only a small fraction was derelict fishing gear.

4.10.2 Shore Debris

A study was undertaken to survey litter on beaches in the Costa dos Conqueiros region of North-Eastern Brazil between 2002 and 2004 (Santos et al. 2005). The highest litter densities averaged 14.6 items/km, which was about twice the density found in most other beach areas. In comparison with studies in other countries (table 4.3) the density was low. This is almost certainly due to the low population of the Costa dos Conqueiros region. It was noted that plastic bottles made up a high proportion of the debris (nearly 35%) and that debris from overseas countries was present. Results of the study suggested that garbage originating from ships was an important source of debris on beaches in this region.

4.11 Pacific Ocean

4.11.1 Floating Debris

In a review of data on floating debris in the world's oceans it was noted that the density of debris in coastal waters of the North East Pacific was 1.8 items/km^2 at < 20°N latitude and 1.0 items/km^2 at latitudes of 20°N to 40°N (Thiel et al. 2003) Slightly lower values were given for coastal North West Pacific waters, for example, 0.25 items/km^2 at <20°N and 0.8 items/km^2 at 20° to 40°N. These values were obtained by visual sighting surveys of debris from ships.

The North Pacific central gyre is an area of convergence where clockwise ocean currents act as a retention mechanism and prevent plastic debris from moving towards mainland coasts. A study in this region (within 30°N and 40°N) in 1999, reported exceptionally high densities of plastic debris (Moore et al. 2001). Using nets to collect debris, the abundance of floating plastic averaged 334,271 pieces/km^2, (range 31,982 to 969,777 pieces/km^2). Most of the debris consisted of thin plastic films, fishing line and unidentified plastic which was mainly plastic fragments. Surveying at a depth of 10 metres gave a density of plastic less than half of that found on the surface and consisted largely of monofilament line. The results of floating plastic debris from this study cannot be directly compared with most other studies on floating debris in which debris is quantified by a different method, namely visual inspection of the ocean surface. The visual method of quantification only can only detect and count large visible pieces of debris and cannot detect smaller items such as plastic fragments and monofilament line. Such items can only be accounted for using a net as in the North Pacific central gyre study.

4.12 Caribbean

4.12.1 Shore Debris

A study of stranded debris on beaches along the Caribbean coast of Panama reported an average density of 3.6 items/m^2 (Garrity and Levings 1993). Plastic and styrofoam were the most common sorts of debris and many items related to fast-food operations were found.

Contamination of beaches by debris was studied on two Caribbean islands between 1991 and 1992 (Corbin and Singh (1993). On St. Lucia, the mean debris density ranged from 4.5 to 11.2 items/m. Similar levels ranging from 1.9 to 6.2 items/m were found on Dominica. Another study on beaches of the island of Curaçao in the Southern Caribbean in 1992/3 reported somewhat higher debris concentrations on the windward north-east coast ranging from 19 to 253 items/m (Debrot et al. 1999).

4.12.2 Seafloor Debris

One study investigated the quantity of submerged debris in the shallow marine environment off recreational beaches on Curaçao (Nagelkerken et al. 2001). On the 5 recreational beaches that were surveyed, the mean number of items per 100m2 ranged from 19.8 to 66. Another two beaches that were closed to recreational use had much lower levels of debris ranging from means of 0.9 to 1.1 item/100m^2. On the recreational beaches, the majority of debris items were food related.

4.13 USA

4.13.1 Floating Debris

An aerial survey of the Gulf of Mexico investigated plastic debris (larger than a cup in size) (Lecke-Mitchell and Mullin 1997). Plastic debris was reported to be abundant and widely distributed throughout the Gulf of Mexico. A density of approximately 1 item/km^2 was given. Results from this study are not directly comparable with studies on floating marine debris which use visual sighting of debris from ships.

4.13.2 Seafloor Debris

A study on submerged debris in shallow-water coral reefs and hard-bottom habitats around the Florida Keys was conducted in 2000 (Chiappone et al. 2002). Nearly 90% of all the debris encountered was derelict fishing gear. Of this, monofilament line accounted for 38%, fishing weights, leaders and hooks 16%, wood from lobster pots 20% and rope from lobster traps 13%.

A study of seafloor debris in the Southern California Bight in 1994 found that the most common forms of man-made debris were plastic, fishing gear, metal and cans (Moore and Allen 2000). Results of the study suggested that the main source of the seafloor debris was marine vessel and fishing activity.

Kodiak Island in Alaska has a low human population but is an area where there are commercial and subsistence fisheries. One study used trawls of the seafloor to analyse and quantify the type of debris present (Hess et al. 1999). Between 1994 and 1996, fishery related debris made up 38 to 46% of the total debris. In sea inlets around Kodiak Island, the density of plastic debris measured in 1994, 1995 and 1996 ranged from 22 – 31.5 items/km^2. In areas outside of the inlets the density of plastic debris ranged from 7.8 – 18.8 items/km^2.

4.13.3 Shore Debris

Plastic debris is the predominant form of litter in almost all studies of shore debris around the world. A study of beaches in Orange County, California reported an exceptionally high proportion (99%) of the shore debris was plastic (Moore et al. 2001). Plastic pellets were the most abundant form of litter and hard plastics and foamed plastics were also present. Johnson and Eiler (1999) noted that in Alaska, derelict trawl web is commonly found on beaches. Such stranded trawl web can be washed back into the sea where is poses a threat to marine life.

Jones (1995) listed densities of beach debris given by studies in or near to the USA. In Hawaii in 1989 the average debris was 262 items/km, in California 814 items/km, in Texas 1712 items/km and in Mexico 8000 items/km.

4.14 Canada

4.14.1 Shore Debris

A beach debris monitoring program in Canada undertaken in 1995/6, and again in 1999, reported that the most of the debris originated from land-based sources (Topping 2000). The most prevalent type of debris was food and alcoholic beverage related rubbish and this is associated with shore-side recreational activities.

4.15 Tables Giving Quantities of Marine Debris in the World's Oceans

Table 4.1
Levels of Floating Debris in the World's Oceans. Data collected by visual sighting from ships.

Location and Date	Mean Number of Items of Debris per km²	Reference
West Spitsbergen, Arctic (2002)	0 - 3	Barnes and Milner 2005
North Atlantic, latitude 0° to 50°N (2002)	0 – 20	Barnes and Milner 2005
English Channel (2002)	10 – 100+	Barnes and Milner 2005
Mediterranean (1997) (2000)	Density of the order of: 1.5 – 25 1.5 - 3	Aliani et al. 2003
NE Pacific, latitude < 20°N (1986-91)	1.8	Thiel et al. 2003
NE Pacific, latitude 20°N to 40°N (1986-91)	1	Thiel et al. 2003
NE Pacific, latitude >40°N (1986-91)	1	Thiel et al. 2003
NW Pacific, latitude <20°N (1986-91)	0.25	Thiel et al. 2003
NW Pacific, latitude 20°N to 40°N (1986-91)	0.8	Thiel et al. 2003
NW Pacific, latitude >40°N (1986-91)	0.2	Thiel et al. 2003
Southern Atlantic, latitude 50°S to 0°S (2002)	0 - 10	Barnes and Milner 2005
Indonesia (Ambon Bay) Figure is for worst affect areas (1994/5)	> 4 per m²	Uneputty and Evans 1997
Chile, coastal waters, latitude 20°S to 40°S (2002)	1 - 36	Thiel et al. 2003
Chile, coastal waters, latitude 40°S to 50°S (2002)	< 1	Thiel et al. 2003
Southern Ocean, near Antarctic Peninsula	0 - 1	Barnes and Milner 2005
Southern Ocean, Drakes Passage	0 - 3	Barnes and Milner 2005

Table 4.2.
Levels of Debris on the Seafloor of the World's Oceans. Data are from studies that used trawl nets to collect the debris

Location and Date	Mean Number of Items of Debris per km^2	Reference
Alaska, Kodiak Island (1994-6) Debris in coastal inlets Debris outside inlets	Plastic debris only, given as the range not the mean 22 – 31.5 7.8 – 18.8	Hess et al. 1999
Baltic Sea (1992-8)	126	Galgani et al. 2000
North Sea (1992-8)	156	Galgani et al. 2000
Celtic Sea (1992-8)	528	Galgani et al. 2000
Bay of Biscaye (1992-8)	142	Galgani et al. 2000
Gulf of Lion (1992-8)	143	Galgani et al. 2000
NW Mediterranean (1992-8)	1935	Galgani et al. 2000
Mediterranean, coastal Greece, 2 sites 1997/8	89 and 240	Stefatos et al. 1999
Indonesia, Ambon Bay, 5 sites (1994/5)	0.05 to 0.69 per m^2	Uneputty and Evans 1997
Caribbean, Curacao 5 recreational beaches 2 non-recreational beaches	19.8 - 66.0 per 100m^2 0.9-1.1 per 100m^2	Nagelkerken et al. 2001

Table 4.3
Levels of Stranded Debris on Shorelines Throughout the World (number of items/km)

Location and Date	Mean Number of Items of Debris per km	Reference
USA Hawaii (1989) California Texas Mexico	 262 814 1712 8000	 Jones 1995
NE Brazil, Costa dos Conqueiros (2002-4)	14.6	Santos et al. 2005
Caribbean St. Lucia (1991/2)	4500 – 11,200	Corbin and Singh 1993
Caribbean Dominica (1991/2)	1900 - 6200	Corbin and Singh 1993
Indonesia (23 Islands)	Range 0 – 29,100	Willoughby et al. 1997
Tasmania (1990/1)	300	Jones 1995
Western Australia (1992)	3660	Jones 1995

Table 4.4
Levels of Stranded Debris on Shorelines Throughout the World (number of items/m2)

Location and Date	Mean or Range of Number of Items	Reference
Northern Atlantic shores, latitude 9.5°N to 57°N (1984-2001)	0.15 – 70.9 per m	Barnes and Milner 1995
UK, Edinburgh (1994)	0.8 per m^2	Velander and Mocogni 1998
Mediterranean		Barnes and Milner 2005
Croatia (2000) Sicily (1988) Spain (1991) Cyprus (1988) Israel (1988/9)	6.4 per m 9 – 231 per m 33.2 per m 10.4 per m 7.3 – 8.7 per m	
Gulf of Oman, Omani coast (2002)	1.79 per m	Claereboudt 2004
Gulf of Aqaba, Jordanian coast (1995)	3 per m^2	Abu-Hilal and AlNajjar 2004
Southern Atlantic		Barnes and Milner 2005
Tristan da Cunha (1984)	0.3 – 0.8 per m	
Gough (1984)	0.019 per m	

5. Prevention and clean-up of Marine Debris

Many different measures have been adopted to try to prevent garbage from entering the marine environment or to clean up existing marine debris. These measures can be categorised into global, international and national initiatives, clean-up operations of beaches and the ocean waters and education programs. For example, an important international initiative that was taken many years ago to help prevent ships from discarding their garbage at sea was the International Convention for the Prevention of Pollution from Ships (MARPOL, see below).

The continuation, ongoing improvement and increased use of the types of measures outlined above are important to help prevent more wastes from entering the marine environment. In addition to such measures, however, further action is needed "upstream" if the marine debris problem is to be properly addressed, particularly with regard to the production, use and disposal of plastics and other synthetic materials. This will require the adoption of more responsible waste strategies, at local, national and/or international levels, which aim to prevent the production of waste at source, i.e. so-called "Zero Waste" strategies. The concept of Zero Waste encompasses various elements including waste minimisation, re-use and recycling together with ecodesign.

It is important that strategies to achieve Zero Waste are adopted throughout the world, in industrialised countries and in less developed countries. Presently, products and packaging used primarily in richer western countries are dispersed throughout the world and it is of concern that there is a growing lack of capacity for dealing with waste from such products, especially in less developed countries (Nollkaemper 1994).

Zero Waste strategies are urgently needed because other measures alone cannot cope with the increasing marine debris problem. Many positive actions have been undertaken globally and regionally to reduce marine debris both at source and to clean up marine debris (see below), but despite these efforts the marine debris situation does not appear to be improving (UNEP 2005). It is, therefore, very important not only that these measures continue but also that attention is urgently focused on implementing Zero Waste strategy measures.

5.1 Conventions and Agreements

A number of conventions and agreements have been made which specifically address the problem of marine debris.

5.1.1 MARPOL

A convention known as the International Convention for the Prevention of Pollution from Ships (MARPOL) brought legislation into force in 1988 which had the aim of preventing ships from disposing of their garbage overboard. Annex V of MARPOL is specifically concerned with controlling garbage disposal from ships. It imposes a complete ban on the dumping at sea of all forms of plastic (IMO 2002) and restricts dumping of other synthetic materials such as ropes and fishing nets (Derraik 2002). Annex V also requires ports and terminals to provide garbage reception facilities for boats and ships.

Up to April 2005, a total of 122 countries had ratified Annex V of MARPOL (Sheavly 2005). These signatory countries are required to take steps to fully implement it (Derraik 2002). Ships of signatory nations have to abide by Annex V at all times in all waters, while ships from non-signatory nations must follow Annex V when in waters of signatory countries (Sheavly 2005).

MARPOL has also designated "Special Areas" where all overboard discharges are forbidden except for ground food waste. The Special Areas include the Mediterranean Sea, Baltic Sea, Black Sea Red Sea, Persian Gulf, Gulf of Aden, North Sea, Antarctic area and the wider Caribbean. However, not all these areas have adequate port facilities to handle the increased amount of garbage from ships and this is a prerequisite before designation can take effect. Consequently, many of the designated Special Areas are not yet treated as a Special Area (Sheavly 2005).

Impacts of MARPOL on Marine Debris

The greatest problem with legislation is its enforcement. Derraik (2002) noted that MARPOL is still widely ignored and that ships are estimated to dump 6.5 million tons of plastic a year. However, Sheavly (2005) suggested that MARPOL has led to a reduction of debris in the oceans and on beaches. Research on the effects of MARPOL on marine debris has given mixed results. For instance, in some areas a reduction in marine debris has been suggested but in other areas there appears to be no decline in debris at all (see discussion below). Barnes and Milner (2005) suggested that evaluation of the impacts of MARPOL may prove difficult because the number of sites surveyed is so small and from a restricted geographical area. However, results from their extensive survey of the Southern Atlantic in 1993, and then again in 2003, did not indicate any change in the amounts of marine debris in the Southern Atlantic and Southern Ocean. Other research has found an increasing trend of marine debris in recent decades (see section 1.4).

Some studies have also found no positive effects of MARPOL Annex V. For example, Henderson (2001) made an inventory of beach debris in the Northwestern Hawaiian Islands between 1987 and 1996 and concluded that the accumulation of debris had not decreased since the introduction of Annex V in 1989. Furthermore, at the same time and in the same area, the number of entanglements of the Hawaiian monk seal *(Monachus schauinslandi)* did not change (Henderson 2001). In South Australia, a study of entanglement of Australian sea lions and the New Zealand fur seals found that by 2002, there was no evidence of a reduction in the number of entanglements (Page et al. 2004).

In Brazil, research showed that ships continued to dump trash into the ocean (Santos et al. 2005). This study noted that in Brazil, and in other developing countries, there can be a lack of facilities to receive garbage at ports and that this fact, together with a lack of inspection and fines for non-compliance, is the reason for continued ocean dumping from ships.

A few studies have suggested that MARPOL Annex V may have resulted in a reduction of marine debris in specific areas. A reduction in the amount of derelict trawl webbing washed ashore in Alaska after the implementation of MARPOL Annex V was reported. Another possible positive impact of MARPOL Annex V was a reduction in the rate of entanglement recorded for northern fur seals *(Callorhinus ursinus)* (see Henderson 2001). Spear (1995) noted that an increase of plastic debris found in seabirds was apparent for the North and South Pacific from the 1960s to 1980s but a decline may have occurred after 1990.

5.1.2 Other Conventions and Agreements

In the Caribbean, the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region known as the Cartagena Convention came into force in 1987. It includes measures to prevent or reduce pollution from both ships and land-based activities (Sheavly 2005). Although the Caribbean has been designated as a Special Area by MARPOL, it has not yet entered into force because many countries in the region lack the port facilities necessary for receiving Annex V wastes from ships (UNEP 2005).

The International Council of Cruise Lines brought in mandatory standards for cruise ships in 2001 which committed them to a policy goal of zero discharges of MARPOL Annex V solid waste products. This is to be achieved by using comprehensive waste minimisation practices, and re-use and recycling waste strategies (UNEP 2005).

There are a number of other global, international and national initiatives which have some connection with the problems of marine debris. For example, the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities is a UNEP programme. It was adopted in 1995 and has the goal of addressing negative effects of land-based activities on the marine and coastal environment. It has named marine litter as one of the nine pollution categories it acts upon (UNEP 2005).

The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) is a group of independent experts who give advice to major international bodies. It has recommended improvement of land-based waste recycling, improvement of port facilities, development of more degradable packaging materials and improvement of education (UNEP 2005).

In the Mediterranean region, the Convention for the Protection of the Mediterranean Sea against Pollution (the Barcelona Convention) is a UNEP programme that was adopted in 1976. Since 1980 it has dealt with pollution of the Mediterranean Sea coming from land-based sources. Guidelines have been prepared for the management of coastal litter and these will be used to prepare action plans for the region (UNEP 2005).

Within the European Union (EU), one of the proposed objectives of the European Marine Strategy is to "eliminate marine litter arising from illegal disposal at sea by 2010". In addition, the EU Directive on Port Reception Facilities for Ship-generated Waste and Cargo Residues has the objective of reducing discharges of waste from ships at sea and improving the availability of port facilities for handling waste (UNEP 2005).

Marine debris is a problem in the Northwest Pacific region (NOWOPAP). The NOWPAP programme of work for 2004/5 plans to develop a joint initiative to address marine debris. When brought into practice, it is expected that China, Japan, Korea and Russia will work to improve the problem (UNEP 2005).

A report published by UNEP (2005) reviewed the above global and regional conventions and initiatives and offered some suggestions on possible future work they could perform to help the marine debris problem.

5.2 Clean-Up of Marine Debris

Local authorities, non-government organisations and volunteers have all contributed towards coastal clean-up operations throughout the world. The cost of clean-ups can be high. For example, in 1998, 64 local communities in the North Sea region were reported to spend six million US dollars on beach clean up (UNEP 2005).

The Ocean Conservancy began a beach clean-up program in Texas in 1986 which has since grown into the International Coastal Cleanup (ICC). All 55 US States are now involved with the program together with 127 countries. All consolidate in a local effort for one day each year to carry out a beach clean-up day in their area. This is undertaken by numerous volunteers. The ICC also gathers information on the types of debris collected for its global database (Sheavly 2005). In 2002, almost 58% of the marine debris collected appeared to be sourced from shore-line and recreational activities, such as beach-picknicking and general littering (UNEP 2005).

Another global clean-up program is the "Clean-Up the World" program which is run in conjunction with UNEP. It engages more than 40 million people from 120 different countries in clean up operations, and has a special initiative on marine debris (UNEP 2005). Clean-up the World was originally started as an outreach program from "Clean-Up Australia Day", a programme that has been very successful in helping to clean up beaches of Australia (UNEP 2005). In the UK, a non-government organisation called the Marine Conservation Society has set up programmes to clean-up beaches as well as to raise awareness of the problems of marine debris (UNEP 2005).

The coral reef ecosystems of the Northwestern Hawaiian Islands suffer from contamination by considerable amounts of derelict fishing gear from North Pacific Ocean fisheries washed in by ocean currents. This is a threat to the marine ecology of the area, particularly to the endangered Hawaiian monk seal. Efforts have been made to remove the derelict fishing gear since the 1980s, but in 1998, several organisations came together from federal, state, local, industry and NGO sources to address the problem by adopting a multi-agency approach. Research published in 2003 reported that up to that time, 195 tons of derelict fishing gear had been removed from the Northwestern Hawaiian Islands (Donohue (2003).

In Greece, a non-government organisation (HELMEPA) has organised local annual public voluntary beach clean-ups and education material for schools (UNEP 2005).

The National Oceanic and Atmospheric Administration (NOAA) of the US government have been pioneering a method to locate marine debris at sea. Ocean convergence zones, where debris is likely to accumulate, are identified by satellite. Aircraft with special sensors are then deployed to the convergence zones to pinpoint the location of debris. This has been performed experimentally and the idea is to then send ships to areas with high quantities of debris so it could be cleared up (NOAA 2005c).

In addition to clean-up programs of marine debris, it is essential that sufficient waste recycling or disposal facilities are provided. This includes facilities at ports for shipping and facilities at marinas/harbours and in coastal areas for residents and visitors. The implementation of port, marina/harbour facilities would be helped by regional and global regulations to ensure that waste is properly taken care of (UNEP 2005).

5.3 Education

Land-based sources of rubbish often represent a large proportion of marine debris. Therefore, education of a community about the problems of marine debris may help to prevent some of the problem, and education in schools can help not only the children to learn good habits but also can spread the knowledge to their families (Derrraik 2002). In 2004, the Australian government launched a campaign called "keep the sea plastic free" in which it attempted to educate the public to dispose of plastic waste properly (Australian Government 2004).

With regard to sea-based sources of marine debris, education is needed for ship owners and operators and users of pleasure craft (UNEP 2005).

5.4 Zero Waste Strategy

We live in a world in which our resources are not always given the precious status they deserve. In industrialised society, this has contributed to the creation of a "disposable" society in which enormous quantities of waste, including much that is "avoidable waste" are generated. This situation needs urgently to be changed, so that the amount of waste produced, both domestically and by industry, is reduced and that, as par as possible, generation of persistent and hazardous wastes is eliminated (Allsopp et al. 2000). The solution to waste minimisation and responsible waste management is enshrined in the concept of 'Zero Waste', such as that outlined by Robin Murray for the independent UK group DEMOS at the close of the last millennium (Murray 1999).

In simple terms, Zero Waste encompasses programmes of waste reduction, reuse and recycling as well as producer responsibility and ecodesign, supported by government commitments and dedicated agency oversight, development of new academic and technical infrastructure and expertise and revised approaches and responsibilities with respect to management and taxation of waste (Murray 1999). In practical terms, it means progressive reduction in all waste streams directed to disposal, with the ultimate aim that no material should be discarded as useless if it can be re-used or recycled. Widespread adoption of such a Zero Waste strategy would inevitably contribute, in turn, to ongoing reductions in the quantities of human garbage reaching the marine environment.

As noted above, plastics and synthetics constitute the major problems of marine debris, being the most prevalent (and among the most persistent) type of debris and the most harmful for wildlife. Prevention of such waste is therefore a key factor to aid in the reduction of plastic waste entering the marine environment. The use of plastics and synthetics should therefore be avoided wherever possible, and supported by highly efficient separation, collection and re-use/recycling schemes for any essential uses which remain.

It has been suggested that a move towards using biodegradable plastics (frequently derived from plant material) as an alternative to using plastics derived from petrochemicals would help combat the growing marine debris problem (Kubota et al. 2005). Certainly biodegradable plastics can be used for numerous applications including food packaging, fishing lines and fishing nets. According to the Biodegradable Plastics Society (2005), when such plastics are composted they break down to carbon dioxide and water. However, further independent research is necessary to confirm whether this is the case under a wide range of environmental conditions. For example, it is possible that biodegradable plastics do not break down fully, especially under environmental conditions which are not ideal for composting, and leave non-degradable constituents, some of which may be equally, if not more, hazardous.

With regard to the marine environment, in particular, it is not clear how quickly biodegradable plastics would break down and what would be formed as interim and final degradation products. In any case, biodegradable plastics could well persist long enough to cause harm to wildlife through their physical presence and mechanical properties once they have entered the marine environment. Finally, on a cautionary note, there is a danger that biodegradable plastics will be seen as "litter friendly" materials, conveying the wrong message to the public and potentially leading to less responsible and more wasteful practices than those extended to conventional plastics (UNEP 2005). Clearly, education is also needed to bring insight on a responsible attitude to dealing with such waste.

In summary, the key to solving the marine litter problem in terms of waste management is action at source, including the widespread adoption and implementation of Zero Waste strategies entailing waste prevention, minimisation, re-use and recycling. Until such initiatives are widely and effectively implemented, measures available to address the problem of marine litter and debris will inevitably remain extremely limited.

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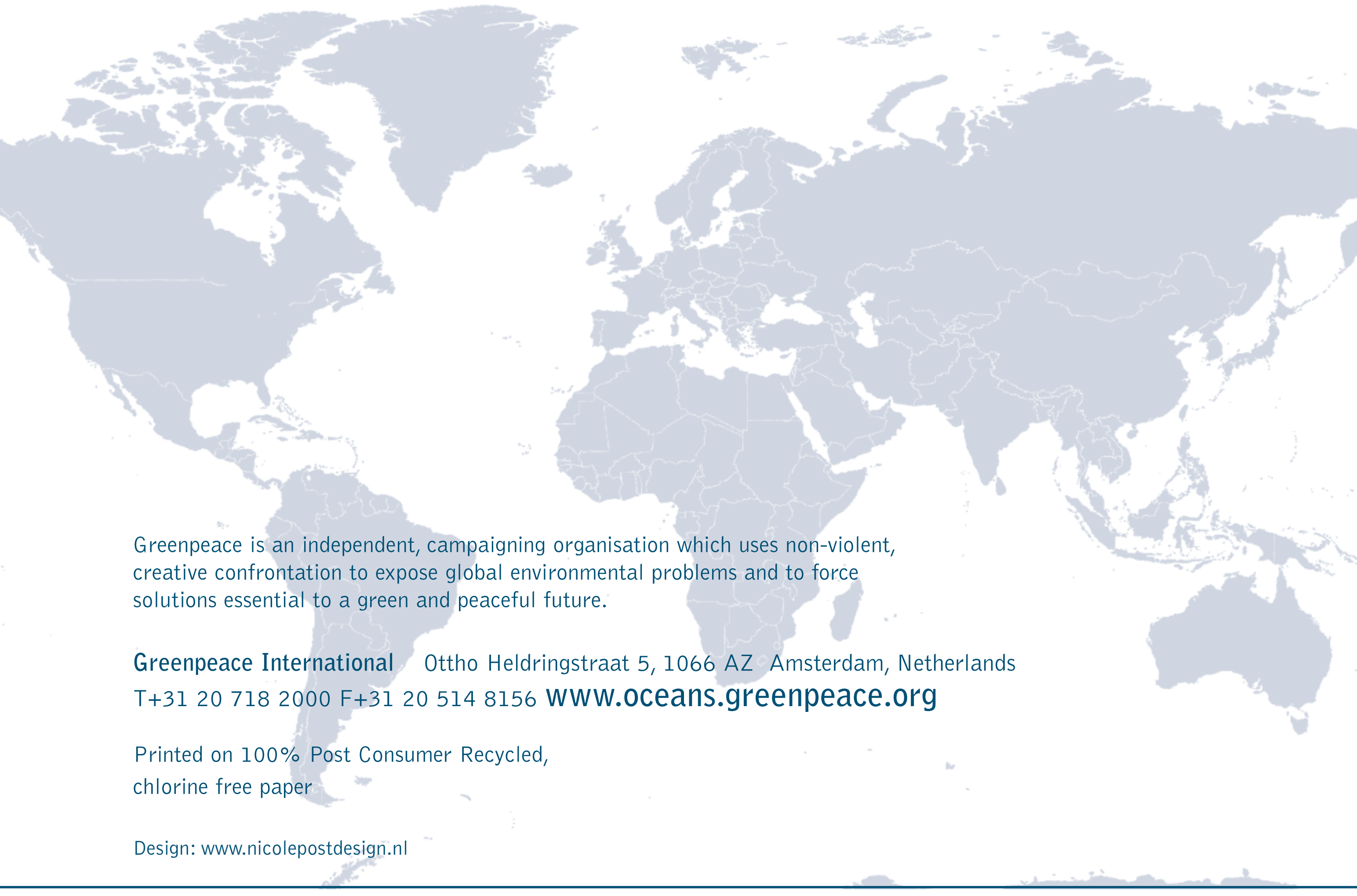

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