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The pollution of the marine environment by plastic debris: A Review

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Abstract

The deleterious effects of plastic debris on the marine environment were reviewed by bringing together most of the literature published so far on the topic. A large number of marine species is known to be harmed and/or killed by plastic debris and some other pollutants, which could jeopardize their survival, especially since many are already endangered by other forms of anthropogenic activities. Marine animals are mostly affected through entanglement in and ingestion of plastic litter. Other less known threats include the use of plastic debris by ‘‘invader’’ species and the absorption of polychlorinated biphenyls from ingested plastics. Less conspicuous forms, such as plastic pellets and ‘‘scrubbers’’ are also hazardous. To address the problem of plastic debris and some other pollutants in the oceans is a difficult task, and a variety of approaches are urgently required. Some of the ways to mitigate the problem are discussed.

Introduction

Marine plastics are known to undergo fragmentation into increasingly smaller pieces by photochemical, mechanical and biological processes (Andrady, 2011). Human activities are responsible for a major decline of the world’s biological diversity, and the problem is so critical that combined human impacts could have accelerated present extinction rates to 1000–10,000 times the natural rate (Lovejoy, 1997). In the oceans, the threat to marine life comes in various forms, such as over exploitation and harvesting, dumping of waste, pollution, alien species, land reclamation, dredging and global climate change (Beatley, 1991). One particular form of human impact constitutes a major threat to marine life, the pollution by plastic debris.

Plastic debris

Plastics are a diverse group of materials derived from petrochemicals (Thompson RC, 2009). Their global production has grown exponentially from 1,700,000 tonnes in 1950 to 280,000,000 tonnes in 2011 (Plastics Europe 2012). Plastics are synthetic organic polymers, and though they have only existed for just over a century (Gorman, 1993), by 1988 in the United States alone, 30 million tons of plastic were produced annually (O'Hara *et al*., 1988). The versatility of these materials has led to a Great increase in their use over the past three decades, and they have rapidly moved into all aspects of everyday life (Hansen, 1990). Plastics are lightweight, strong, durable and cheap (Laist, 1987), characteristics that make them suitable for the manufacture of a very wide range of products. These same properties happen to be the reasons why plastics are a serious Hazard to the environment (Pruter, 1987). Since they are also buoyant, an increasing load of plastic debris is being dispersed over long distances, and when they finally settle in sediments they may persist for centuries (Hansen, 1990). The threat of plastics to the marine environment has been ignored for a long time, and its seriousness has been only recently recognized (Stefatos, 1999). The member of the Council of the British Plastics Federation and a Fellow of the Plastics Institute, stated that ‘‘plastics litter is a very small proportion of all litter and causes no harm to the environment except as an eyesore’’.

The literature on marine debris leaves no doubt that plastics make-up most of the marine litter worldwide (Table 1). Though the methods were not assessed to ensure that the results were comparable, Table 1 clearly indicates the predominance of plastics amongst the marine litter, and its proportion consistently varies between 60% and 80% of the total marine debris (Gregory and Ryan, 1997). Horsman (1982) estimated that merchant ships dump 639,000 plastic containers each day around the world, and ships are therefore, a major source of plastic debris (Shaw, 1977; Shaw and Mapes, 1979). Recreational fishing and boats are also responsible for dumping a considerable amount of marine debris, and according to the US Coast Guard they dispose approximately 52% of all rubbish dumped in US waters (UNESCO, 1994). Plastic materials also end up in the marine environment when accidentally lost, carelessly handled (Wilber,1987) or left behind by beachgoers (Pruter, 1987). They also reach the sea as litter carried by rivers and municipal drainage systems (Pruter, 1987). The latter are found in large quantities on beaches (Gregory, 1978), and are the raw material for the manufacture of plastic products that end up in the marine environment through accidental spillage during transport and handling, not as litter or waste as other forms of plastics (Gregory, 1978). Since the use of plastics continues to increase, so does the amount of Plastics polluting the marine environment. Robards *et al*. (1995) examined the gut content of thousands of birds in two separate studies and found that the ingestion of plastics by seabirds had significantly increased during the 10–15 years interval between studies. A study done in the North Pacific (Blight and Burger, 1997) found plastic particles in the stomachs of 8 of the 11 seabird species caught as by catch. The list of affected species indicates that marine debris is affecting a significant number of species (Laist, 1997).

Table 1: Proportion of plastics among marine debris worldwide (per number of items)

Locality	Litter type	Percentage of debris items represented by plastics	Source
1992 International Coastal Cleanups	Shoreline	59	Anon (1990)
St. Lucia, Caribbean	Beach	51	Corbin and Singh (1993)
Dominica, Caribbean	Beach	36	Corbin and Singh (1993)
Curac_ao, Caribbean	Beach	40/64	Debrot et al. (1999)
Bay of Biscay, NE Atlantic	Seabed	92	Galgani et al. (1995a)
NW Mediterranean	Seabed	77	Galgani et al. (1995b)
French Mediterranean Coast	Deep sea floor	>70	Galgani et al. (1996)
European coasts	Sea floor	>70	Galgani et al. (2000)
Caribbean coast of Panama	Shoreline	82	Garrity and Levings(1993)
Georgia, USA	Beach	57	Gilligan et al. (1992)
5 Mediterranean beaches	Beach	60–80	Golik (1997)
50 South African beaches	Beach	>90	Gregory and Ryan (1997)
88 sites in Tasmania	Beach	65	Gregory and Ryan (1997)
Argentina	Beach	37–72	Gregory and Ryan (1997)
9 Sub-Antarctic Islands	Beach	51–88	Gregory and Ryan (1997)

South Australia	Beach	62	Gregory and Ryan (1997)
Kodiak Is, Alaska	Seabed	47–56	Hess et al. (1999)
Tokyo Bay, Japan	Seabed	80–85	Kanehiro et al. (1995)
North Pacific Ocean	Surface waters	86	Laist (1987)
Mexico	Beach	60	Lara-Dominguez et al. (1994)
Transkei, South Africa	Beach	83	Madzena and Lasiak (1997)
National Parks in USA	Beach	88	Manski et al. (1991)
Mediterranean Sea	Surface waters	60–70	Morris (1980)
Cape Cod, USA	Beach/harbor	90	Ribic et al. (1997)
4 North Atlantic harbors, USA	Harbour	73–9	Ribic et al. (1997)
Is. Beach State Park, New Jersey, USA	Beach	73	Ribic (1998)
Halifax Harbour, Canada	Beach	54	Ross et al. (1991)
Price Edward Is., Southern Ocean	Beach	88	Ryan (1987b)
Gough Is., Southern Ocean	Beach	84	Ryan (1987b)
Heard Is., Southern Ocean	Beach	51	Slip and Burton (1991)
Macquire Is., Southern Ocean	Beach	71	Slip and Burton (1991)
New Zealand	Beach	75	Smith and Tooker (1990)
Two gulfs in W. Greece	Seabed	79–83	Stefatos et al. (1999)
South German Bight	Beach	75	Vauk and Schrey (1987)
Bird Is., South Georgia, Southern Ocean	Beach	88	Walker et al. (1997)
FogBay, N. Australia	Beach	32	Whiting (1998)
South Wales, UK	Beach	63	Williams and Tudor (2001)

It affects at least 267 species worldwide, including 86% of all sea turtle species, 44% of all seabird species, and 43% of all marine mammal species (Laist, 1997). According to Kanehiro *et al*. (1995) plastics made up 80–85% of the seabed debris in Tokyo Bay, an impressive figure considering that most plastic debris is buoyant. The accumulation of such debris can inhibit the gas exchange between the overlying waters and the pore waters of the sediments, and the resulting hypoxia or anoxia in the benthos can interfere with the normal ecosystem functioning, and alter the make-up of life on the sea floor (Goldberg, 1994). Moreover, as for pelagic organisms, benthic biota is likewise subjected to entanglement and ingestion hazards (Hess *et al*., 1999).

2.1. Ingestion of plastics

The bio-magnification process is more likely to happen when plastics are small enough to be ingested by organisms that are close to the bottom of the ocean food web, such as planktivorous fish and zooplankton (Boerger CM, 2010). A study done on 1033 birds collected off the coast of North Carolina in the USA found that individuals from 55% of the species recorded had plastic particles in their guts (Moser and Lee, 1992). The authors obtained evidence that some seabirds select specific plastic shapes and colors, mistaking them for potential prey items. Shaw and Day (1994) came to the same conclusions, as they studied the presence of floating plastic particles of different forms, colors and sizes in the North Pacific, finding that many are significantly under-represented. Carpenter et al. (1972) examined various species of fish with plastic debris in their guts and found that only white plastic spherules had been ingested, indicating that they feed selectively. A similar pattern of selective ingestion of white plastic debris was found for logger head sea turtles (Caretta caretta) in the Central Mediterranean (Gramentz, 1988). Amongseabir ds, the ingestion of plastics are directly correlated to foraging strategies and technique, For instance, planktivores are more likely to confuse plastic pellets with their prey than do piscivores, and therefore the former have a higher incidence of ingested plastics (Azzarello and Van-Vleet, 1987). Ryan (1988) performed an experiment with domestic chickens (Gallus domesticus) to establish the potential effects of ingested plastic particles on seabirds. They were fed with polyethylene pellets and the results indicated that ingested plastics reduce meal size by reducing the storage volume of the stomach and the feeding stimulus. He concluded that seabirds with large plastic loads have reduced food consumption, which limits their ability to lay down fat deposits, thus reducing fitness.

Connors and Smith (1982) had previously reached the same conclusion, as their study indicated that the ingestion of plastic particles hindered formation of fat deposits in migrating red phalaropes (Phalaropus fulicarius), adversely affecting long-distance migration and possibly their reproductive effort on breeding grounds. Even Antarctic and sub-Antarctic sea birds are subjected to this hazard (Slip *et al*., 1990). Wilson's storm-petrels (Oceanites oceanicus) for instance, pick up plastic debris while wintering in other areas (Van Franeker and Bell, 1988). A whitefaced storm-petrel (Pelagodroma marina) found dead at the isolated Chatham Islands (New Zealand) at a breeding site, had no food in its stomach while its gizzard was packed with plastic pellets (Bourne and Imber, 1982). The harm from ingestion of plastics is nevertheless not restricted to seabirds. Polythene bags drifting in ocean currents look much like the prey items targeted by turtles (Gramentz, 1988). Secchi and Zarzur (1999) blamed the fate of a dead Blainville's beaked whale (Mesoplodon densirostris) washed ashore in Brazil to a bundle of plastic threads found in the animals' stomach. Coleman and Wehle (1984) and cited other cetaceans that have been reported with ingested plastics, such as the killer whale (Orcinus orca).

2.2. Plastics ingestion and polychlorinated biphenyls

Over the past 20 years polychlorinated biphenyls (PCBs) have increasingly polluted marine food webs and are prevalent in seabirds (Ryan *et al*., 1988). Though their adverse effects may not always be apparent, PCBs lead to reproductive disorders or death; they increased risk of diseases and alter hormone levels (Ryan et al., 1988). These chemicals have a detrimental effect on marine organisms even at very low levels and plastic pellets could be a route for PCBs into marine food chains (Carpenter and Smith, 1972). Ryan *et al*. (1988) studying great shearwaters (Puffinusgravis), obtained evidence that PCBs in the birds' tissues were derived from ingested plastic particles. Their study presented the first indication that seabirds can assimilate chemicals from plastic particles in their stomachs, indicating a dangerous pathway for potentially harmful pollutants. Bjorndal *et al.* (1994) worked with sea turtles and came to a similar conclusion, that the absorption of toxins as sub lethal effects of debris ingestion has an unknown, but potentially great negative effect on their demography.

2.3. Entanglement in plastic debris

Entanglement in plastic debris, especially in discarded fishing gear, is a very serious threat to marine animals. According to Schrey and Vauk (1987) entanglement accounts for 13–29% of the observed mortality of gannets (Sula bassana) at Helgoland, German Bight. Entanglement also affects the survival of the endangered sea turtles (Carr, 1987), but it is a particular problem for marine mammals, such as fur seals, which are both curious and playful (Mattlin and Cawthorn, 1986). Youngfur seals are attracted to floating debris and dive and roll abo ut in its (Mattlin and Cawthorn, 1986).They will approach objects in the water and often poke their heads into loops and holes (Laist, 1987). Though the plastic loops can easily slip onto their necks, the lie of the long guard hairs prevents the strapping from slipping off (Mattlin and Cawthorn, 1986). Many seal pups grow into the plastic collars, and in time as it tightens, the plastic severs the seal's arteries or strangles it (Weisskopf, 1988). Ironically, once the entangled seal dies and decomposes, the plastic band is free to be picked up by another victim (Mattlin and Cawthorn, 1986). The decline in the populations of the northern sea lion (Eumetopias jubatus), endangered Hawaiian monk seal (Monachus schauinslandi) (Henderson, 2001) and northern fur seal seems at least aggravated by entanglement of young animals in lost or discarded nets and packing bands. In the Pribil off Islands alone, in the Bering Sea west of Alaska, the percentage of northern fur seals returning to rookeries entangled in plastic bands rose from nil in 1969 to 38%in 1973 (Mattlin and Cawthorn, 1986). The population in 1976 was declining gate rate of 4–6% a year, and scientists estimated that up to 40,000 fur seals a year were being killed by plastic entanglement (Weisskopf, 1988). A decline due to entanglement also seems to be occurring with Antarctic fur seals (Arctocephalus gazella). Pemberton *et al*. (1992) reported similar concern for Australian fur seals (Arctocephalus pusillus doriferus). In a survey done in 1983/84 off the coast of Japan, it was estimated that 533 fur seals were entangled and drowned in nets lost in the area (Laist, 1987).Whales are also victims, as ''they sometimes lunge for schools of fish and surface with netting caught in their mouths or wrapped around their heads and tails''(Weisskopf, 1988).

2.4. Plastic ''scrubbers''

Studies (Gregory, 1996) have drawn attention to an inconspicuous and previously overlooked form of plastics pollution: small fragments of plastic (usually up to 0.5 mm across) derived from hand cleaners, cosmetic preparations and air blast cleaning media. The environmental impact of these particles, as well as similar sized flakes from degradation of larger plastic litter, has not been properly established yet. In New Zealand and Canada, polyethylene and polystyrene scrubber grains respectively were identified in the cleansing preparations available in those markets, sometimes in substantial quantities (Gregory, 1996). In air blasting technology, polyethylene particles are used for stripping paint from metallic surfaces and cleaning engine parts, and can be recycled up to 10 times before they have to be discarded, sometimes significantly contaminated by heavy metals (Gregory, 1996). The impacts of plastics on marine vertebrates, such as turtles, mammals and birds, have been well recognized since the 80's (De

Stephanis, 2013). However, only recently has concern about the effects of small plastic particles on food webs and marine ecosystems been raised. More than half of modern plastics contain at least one hazardous ingredient and those that end up in aquatic systems can become increasingly toxic by adsorbing persistent organic pollutants on their surface (Rochman, 2013).

2.5. Drift plastic debris: possible pathway for the invasion of alien species

The introduction of alien species can have major consequences for marine ecosystems (Grassle *et al*., 1991). This biotic mixing is becoming a widespread problem due to human activities, and it is a potential threat to native marine biodiversity (McKinney, 1998). Plastics floating at sea may acquire a fauna of various encrusting organisms such as bacteria, diatoms, algae, barnacles, hydroids and tunicates (Carpenter and Smith, 1972). Minchin (1996) also describes barnacles that crossed the North Atlantic Ocean attached to plastic debris. Drift plastics can therefore increase the range of certain marine organisms or introduce species into an environment where they were previously absent (Winston, 1982). Gregory (1991, 1999) pointed out that the arrival of unwanted and aggressive alien taxa could be detrimental to littoral, intertidal and shoreline ecosystems. He emphasized the risk to the flora and fauna of conservation islands, for instance, as alien species could arrive rafted on drifting plastics.

Discussion and Recommendations

Plastics are also directly manufactured in small sizes (.5mm), which may find their way into the oceans. These include virgin plastic pellets (pelletwatch.org).Though the seas cover the majority of our planet’s surface, far less is known about the biodiversity of marine environments then that of terrestrial systems (Ormond *et al*., 1997). Irish and Norse (1996) examined all 742 papers published in the journal Conservation Biology and found that only 5% focused on marine ecosystems and species, compared with 67% on terrestrial and 6% on freshwater. As a result of this disparity, marine conservation biology severely lags behind the terrestrial counterpart (Murphy and Duffus, 1996), and this gap of knowledge poses major problems for conservation of marine biodiversity and must be addressed. This study shows that there is overwhelming evidence that plastic pollution is a threat to marine biodiversity, already at risk from overfishing, climate change and other forms of anthropogenic disturbance. Plastics are transported from populated areas to the marine environment by rivers, wind, tides, rainwater, storm drains sewage disposal, and even flood events. It can also reach the sea from vessels (e.g. fishing gear) and offshore installations (Ryan, *et al*., 2009). The research information would provide input for conservation management, strengthen the basis for educational campaigns, and also provide marine scientists with better evidence that could be used to demand from the authorities more effort to mitigate the problem. Due to the long life of plastics on marine ecosystems, it is imperative that severe measures are taken to address the problem at both international and national levels, since even if the production and disposal of plastics suddenly stopped, the existing debris would continue to harm marine life for many decades. The concentrated toxins might then be delivered to animals via plastic ingestion and/or endocytosis (Von Moos, 2012).

Plastics pollution and legislation

The most important legislation addressing the increasing problem of marine pollution is probably the 1978 Protocol to the International Convention for the Prevention of Pollution from Ships (MARPOL), which recognized that vessels present significant and controllable source of pollution into the marine environment (Lentz, 1987).The Annex V of MARPOL is the key international authority for controlling ship sources of marine debris (Ninaber, 1997), and came into effect in 1988 (Clark, 1997). It ‘‘restricts at sea discharge of garbage and bans at sea disposal of plastics and other synthetic materials such as ropes, fishing nets, and plastic garbage bags with limited exceptions’’ (Pearce, 1992). More importantly, the Annex V applies to all watercraft, including small recreational vessels (Nee, 1990). Seventy-nine countries have so far ratified the Annex V (CMC, 2002), and the signatory countries are required to take steps to fully implement it. Annex V also refers to ‘‘special areas’’ ,including the Mediterranean Sea, the Baltic Sea, the Black Sea, the Red Sea and the ‘‘Gulfs’’ areas, where discharge regulations are far more strict (Lentz,1987).Nevertheless, the legislation is still widely ignored, and ships are estimated to discard 6.5 million tons per year of plastics (Clark, 1997). Observers on board foreign fishing vessels within Australian waters, for instance, found that at least one-third of the vessels did not comply with the MARPOL regulations on the disposal of plastics (Jones, 1995). As Kirkley and McConnell (1997) pointed out, the compliance of individuals with laws is partly a question of economics. They believe most people (or companies) would not change their attitude if stopping the dumping of plastics into the ocean were economically costly. Henderson (2001) assessed the impact of Annex V and found reduction neither in the accumulation of marine debris nor in the entanglement rate of Hawaiian monk seals in the Northwestern Hawaiian Islands. Johnson (1994) however, found that it has been of some effect in reducing plastic litter in the oceans. Legislation at the national level also plays an important role. Individual countries can be effective through their own legislation, such as laws that require degradability standards or that encourage recycling (Bean, 1987).

Other issues and ways to prevent marine pollution

Education is also a very powerful tool to address the issue, especially if it is discussed in schools. Youngsters not only can change habits with relative ease, but also be able to take their awareness into their families and the wider community, working as catalysts for change. Since land-based sources provide major inputs of plastic debris into the oceans, if a community becomes aware of the problem, and obviously willing to act upon it, it can actually make a significant difference. The power of education should not be underestimated, and it can be more effective than strict laws, such as the Suffolk County Plastics Law (in New York, USA) that banned some retail food packaging and was unsuccessful in reducing beach and roadside litter (Ross and Swanson, 1995).

Final remarks

Ultimately, all sectors of the community should take their individual steps. Thinking globally and acting locally is a fundamental attitude to reduce such an environmental threat. A combination of legislation and the enhancement of ecological consciousness through education are likely to be the best way to solve such environmental problems. The general public and the scientific community have also the responsibility of ensuring that governments and businesses change their attitudes towards the problem. It is nevertheless certain that the environmental hazards that threaten the oceans' biodiversity, such as the pollution by plastic debris, must be urgently addressed. ''The last fallen mahogany would lie perceptibly on the landscape, and the last black rhino would be obvious in its loneliness, but a marine species may disappear beneath the waves unobserved and the sea would seem to roll on the same as always''.

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