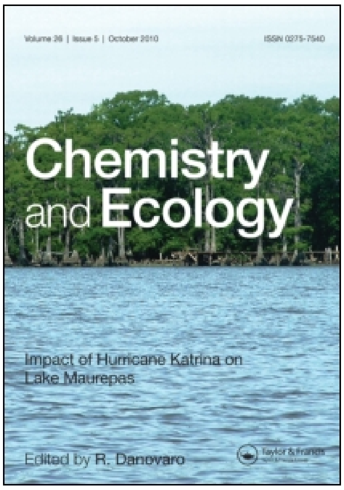

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PLASTICS IN THE MARINE ENVIRONMENT: PROBLEMS AND SOLUTIONS

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Plastics debris is known to be present in all of the world's oceans, and on most amenity beaches, although comparatively little data are available to provide reliable information on the extent of damage from this pollution, and on its spatial and temporal variations.

Marine pollution by plastics has been shown to be damaging to marine mammals, birds and reptiles. This is due to entanglement in packaging bands, synthetic ropes and lines, or drift nets; or by the ingestion of small items of plastics debris. More research is needed to quantify the extent of the problems.

Wider use of degradable plastics will not solve the problems of plastics pollution. Their lifetimes are relatively long and unpredictable, and they are not generally acceptable for recycling.

Marine plastics pollution may be alleviated by the judicious application of both economic incentives and legislation, designed to decrease their use, to increase the rate of recycling, and to restrict uncontrolled discards.

KEY WORDS: Plastics, pollution, marine fauna

INTRODUCTION

Over the past three or four decades, there has been an accelerating trend in many applications to replace glass, metals, wood, paper and board by synthetic polymers which are lighter, cheaper to convert into artefacts, and less susceptible to chemical attack. This paper reviews the recent evidence for marine pollution by plastics and measures needed to control it.

Thermoplastics such as polythylene, polypropylene, polystyrene and polyvinyl chloride (PVC) have revolutionised the packaging industry. While the undoubted advantages of strength, lightness and low permeability to gases and liquids have produced great benefits in, for example, the packaging of food and beverages, the very low environmental degradation rates for these materials have at the same time created serious waste disposal problems. Polymer chemists have expended enormous efforts over the past thirty years to produce plastics which are able to resist degradation by heat, oxygen, and ultraviolet light. In recent years, in an effort to alleviate the litter and waste disposal problems created by plastics, much research has been directed towards the production of plastics articles designed to degrade rapidly and predictably in the environment at the end of their useful lives. This approach has found little favour with environmentalists, for reasons which will be explained later.

Increasing concern is being shown by ecologists, fisherman, seafarers and tourists about the apparently increasing quantities of discarded plastics to be found both at sea and on beaches. Apart from being aesthetically detrimental on beaches, where plastics waste typically comprises 65 to 75% of all types of litter, there is growing evidence that sea birds and marine mammals and reptiles, are damaged in a number of different ways by various forms of plastics debris in the oceans.

The nature of the problems caused by discarded or lost nylon monofilament drift nets is well known, even if the true extent of the damage caused is difficult to estimate. The free drift nets can continue to capture or entangle fish, sea birds, and marine mammals and reptiles such as turtles, for some years after their loss. Such net debris may be particularly significant as a threat to endangered species of marine mammals.

EXTENT OF THE PLASTICS LITTER PROBLEM

By far the greatest application of plastics is in packaging, and in recent years this has been the subject of mounting criticism by environmental and consumer groups. The proportion of packaging produced from plastics materials is increasing. For example, between 1985 and 1989 the production of plastics for packaging in the UK increased by nearly 45%, while the production of packaging paper and board increased by only 4.4% and 15% respectively. The proportions of plastics used for various applications are given in Table 1.

Table 1 Weight percentages of plastics used in various applications: world estimates for 1989 (British Plastics Federation, 1990)

Application	*Weight Percentage*
Packaging	30.0
Building	18.8
Housewares	7.2
Electrical	6.9
Automotive	5.3
Furniture	4.1
Agriculture	2.4
Mechanical Engineering	2.3
Others	23.0
Total	100.0

It is convenient to classify plastics debris found in the marine environment into three main groups (GESAMP, 1990):

(a) fishing gear and equipment (e.g. nets and lines)

(b) packing bands, straps and synthetic fibre ropes.

(c) plastics litter including bags, bottles, sheeting, crates, packaging foam, and feedstock pellets.

Plastics debris has been found in all of the world's oceans, including the polar regions, and from intertidal areas down to great depths.

Plastics debris reaches the oceans via rivers and municipal drainage systems, is discarded by visitors to beaches, is dumped overboard from ships, and lost accidently during loading operations at ports. Fishing gear may be lost accidentally or discarded by vessels when worn or damaged beyond use.

In a comprehensive paper, Pruter (1987) surveyed the available literature relating to the sources, amounts and distribution of various kinds of plastic debris in the oceans and on beaches. A few examples cited by Pruter are given here to provide some indication of the extent of plastics pollution.

Plastics Debris in the Oceans

Horsman (1985) estimated that a minimum of 450×10^3 plastics containers per day were discarded at sea from the world's shipping vessels, and that more than 23×10^3 tonnes per year of plastics packaging materials was discharged from commercial fishing vessels.

Merrell (1980) suggested that 135×10^3 tonnes per year of commercial fishing gear was lost or discarded, while the National Academy of Sciences (1975) proposed a figure of only 1% of this. These two estimates serve to illustrate the paucity of detailed knowledge about the extent of plastics pollution.

Plastics pellets, normally 1–5mm in size, appear to be present in all of the world's oceans, sometimes in high concentrations. These are the feedstock materials from which manufacturers produce all plastics artefacts, and probably find their way into the oceans via rivers, arising from spillages at factories and from accidental loading losses at ports. Published evidence is that, as would be expected, the highest concentrations of plastics pellets occur near industrial centres. For example, Colton *et al.* (1974) estimated an average of 8,300 pellets per km^2 off the east coast of the United States from Cape Cod to Cape Canaveral, Florida, but only 148 pellets per km^2 from south of Cape Canaveral to the Carribean.

Day and Shaw (1987) determined the distribution and abundance of pelagic plastics and tar in the subtropical and subarctic North Pacific and the Bering Sea in 1976, 1984 and 1985. The occurrence of large plastics objects (largest dimension greater than 2.5 cm) in subtropical waters was twice that in subarctic waters and 8 times that in the Bering Sea. The occurrence of small plastics objects in sub-tropical waters was 26 times that in subarctic waters and 400 times that in the Bering Sea. The occurrence of large plastics objects apparently increased significantly between 1976 and 1985, but not between 1984 and 1985.

Plastic Debris on Beaches

Gregory (1983) found typically 5000 polythene pellets per metre on Bermudan beaches, and occasionally over 10,000 pellets per metre.

A report by UNESCO and others (1990), giving the results of a 1990 study of beaches in Spain, Italy, Cyprus, Turkey and Israel, stated that 65–75% of litter items found on Mediterranean beaches was of plastics. Most appeared to be of terrestrial origin, and the concentration was greatest nearest areas of human activity.

Vauk and Schrey (1987) carried out a litter survey on 60 m of beach at Heligoland in the German Bight, over a year. 8539 items, weighing a total 1360 kg, were collected; 75% of items comprised plastics and foam rubber. 99.2% of all items were identified as ships' waste, and the objects found originated from 26 different countries.

Both at sea and on beaches, the relatively few quantitative studies carried out have produced information which allows tentative estimates to be made about the sources, concentrations and composition of plastics debris. More research is needed, in order to gain reliable data about plastics pollution in the marine environment, so that the true extent of the problem may be understood, and spatial and temporal variations studied.

NYLON MONOFILAMENT DRIFT NETS

Nylon monofilament drift nets, which may be up to 60 km long and 15 m deep, with a mesh size of, say, 17 cm, are claimed to cause widespread loss of life among marine animals and sea birds. They are acoustically and visually undetectable by most marine animals, and since the late 1960s, evidence of damage to non-target species has been accumulating.

Marine Mammals and Reptiles

The earliest studies referring to the entanglement of northern fur seals were described and analysed by Fiscus and Kosloff (1972), and Sanger (1974). Fowler (1987) points out that the incidence of entanglements in this species increased from the mid-1960s when plastics began to be used extensively in making trawl netting, coinciding with the increase in commercial fishing in the North Pacific and Bering Sea. The incidence of entanglement on one of the Pribilof Islands was estimated to be at least two orders of magnitude greater than that observed in the 1940s. Entanglement occurs with both sexes, and predominantly with young, which may occasionally be entangled in groups. Fowler concluded that the mortality of fur seals due to entanglement in marine debris, including packing bands, was contributing significantly to their declining population on the Pribilof Islands.

Piatt and Nettleship (1987) carried out summer surveys around the east coast of Newfoundland to investigate the capture of marine birds and mammals by fishing nets. They estimated that more than 3,600 seals and porpoises were killed in nets over the four-year period 1981–1984. It was claimed that this mortality was already having a negative impact in some populations.

Sea turtles appear to be specially prone to injury by entanglement in stray netting. Balazs (1985) recorded 60 cases of entanglement involving not only netting, but monofilament fishing lines, synthetic ropes and other debris. However, the main cause of injury to turtles by plastic debris seems to be due to ingestion of the materials, which they may mistake for jellyfish (Gramentz, 1988).

Sea Birds

Piatt and Nettleship (1987) recorded the numbers of 17 species of sea birds caught in fishing nets off eastern Newfoundland between 1981 and 1984. The species composition of the catches seemed to depend on three main factors: regional abundance, foraging behaviour and diving ability, and the degree of aggregation at which different species forage. From a total catch of over 30,000 birds, nearly 27,000 were common guillemots, and it was estimated that the average catch of sea birds per year in fishing nets off eastern Newfoundland is over 27,000. Most birds were trapped in salmon gill nets.

Many authors have described the capture of sea birds in fishing nets since the early 1970s. These include Bibby (1972), King *et al.*, (1979), De Gange and Newby (1980), Ainley *et al.* (1981), King (1984), and Olden *et al.* (1985): all cited by Piatt and Nettleship (1987).

INGESTION OF PLASTICS BY MARINE ANIMALS

Sea Birds

Ingestion of plastics by sea birds, first reported by Kenyon and Kridler (1969), is a worldwide phenomenon, and 50 species have been implicated (Day *et al.*, 1985). Feedstock pellets, the raw material from which plastics artefacts are manufactured, appear to pose the greatest threat. These pellets are typicaly 1–5 mm in size, and it has been suggested that they may be confused with food items such as fish eggs or larvae, which may be of similar size and appearance (Laist, 1987).

There is a general absence of plastics pellets from the droppings and examined intestines of sea birds, suggesting that ingested plastics are able to reach only as far as the stomach (Laist, 1987).

Larger items of pelagic plastics debris, including items or fragments up to 20×80 mm, are ingested by large birds such as albatrosses, and Fry *et al.* (1987) found a high proportion of Laysan albatross and wedge-tailed shearwaters on certain Hawaiian islands with plastics debris in the upper gastrointestinal tract. These materials are regurgitated by parents during the feeding of chicks, and a correspondingly high proportion of pre-fledgling albatross chicks were found to have ingested plastics. The chicks also pick up from the breeding ground, and ingest, plastics fragments directly (Fry *et al.*, 1987). Fry *et al.* (1987) state that adult birds are not necessarily at risk from plastics ingestion since the basic polymers, and most additives (excepting certain colourants) are not particularly toxic. However, plastics adsorb organochlorine pollutants from sea water. Carpenter *et al.* (1972), cited in Fry *et al.* (1987), reported adsorption of PCBs and DDT on plastics pellets found in the Atlantic Ocean. However, although persistent organochlorines have been detected in Laysan albatross (Fisher, 1975, cited in Fry *et al.*, 1987), the food chain may be the source, rather than ingested plastics.

Ryan *et al.* (1988) showed that the mass of plastics ingested by great shearwaters was correlated positively with the concentration of PCBs found in the birds, and considered that sea birds may assimilate PCBs and other toxic chemicals partly from ingested plastics. However, there is no published evidence to support this hypothesis. The mass of plastics found in Wilson's storm petrel chicks suggest that in adults returning from wintering areas, not only the gizzard contains high levels of plastics, but also the proventriculus, since plastics can only be regurgitated from this (van Franekar and Bell, 1988). The authors suggest that harmful effects may occur during incubation shifts, when starvation periods must be compensated by short periods of high intensity foraging at sea. A reduction in foraging capacity, due to ingested plastics, could reduce the energy stored in order to manage adequate lengths of incubation shifts.

Turtles

Plastics debris is ingested by turtles and fish, probably due to an inability to distinguish between prey and small plastics pellets or sheeting fragements (Laist, 1987). However, this appears to be less of a problem than entanglement in drift netting or packing bands. Laist (1987) mentions the death in 1985 of a West Indian manatee, an endangered species, attributed to the ingestion of a piece of plastic (sheeting?) blocking the digestive tract.

Balazs (1985) argues that blockage of the alimentary canal by plastics in sea turtles presents a significant threat to their survival; 79 cases are reported where the guts of sea turtles contained substantial quantities of plastics debris, including net and line fragments, bags, pellets, bottles and films. One dead turtle contained a heavy plastics sheet measuring about 3 m×4 m.

The ingestion of plastics sheets and bags by leatherback turtles may be due to an inability to distinguish such debris from jellyfish, a normal prey item (Carr, 1987; Gramentz, 1988). In one investigation, only transparent, translucent, or white pieces of polystyrene (solid or foam) and PVC were observed in turtles' alimentary canals or faeces, supporting the hypothesis of prey mis-identification (Gramentz, 1988).

DEGRADABLE PLASTICS: ENVIRONMENTAL LIMITATIONS

Most degradable plastics have been developed for use in specific applications or, more importantly, to be disposed of under specified conditions. Current applications of degradable plastics are for six-pack rings, grocery bags, refuse bags, compost bags, mulch films and disposable diapers. These items were selected because they were seen as causing litter pollution and entanglement in marine environments, persisting for long periods of time in landfills, or were useful in agriculture. In the USA, a federal law (1987) to forbid use of six-pack rings unless degradable, was due to take effect in October 1990, unless a negative environmental impact of the degraded material was identified. 29 States have now enacted laws to ensure the degradability of six-pack rings, bags or diapers. However, there is no certainty that degradation will occur noticeably quicker given that there are about thirty variables which determine whether a given material will degrade within a given time period. In general, packaging analysts do not now envisage degradable plastics as important in the long term, and they may only reach 1 to 2% of the total plastics production in the USA.

It is possible that toxic by-products may be released by degradable plastics. Further, they are a positive discouragement to attempts to recycle plastics. Mixed degradable and non-degradable waste streams must lead to recycled products with unpredictable lifetimes, and degradable plastics are not accepted by most plastics recyclers for this reason.

Since the creation of litter is a behavioural problem, and even plastics designed to be degradable are generally slow to degrade, built-in degradability cannot solve the problems of plastics litter. The threat to marine life will still exist if degradation rates are insufficiently fast to save trapped animals. Also, as plastics artefacts disintegrate into small pieces, they become more and more available for ingestion.

GOVERNMENTAL PLASTICS WASTE STRATEGIES

Most governments of the developed countries are moving towards plastics waste strategies based on three principles:

(a) elimination or reduction of waste at source

(b) increase in recycling of waste

(c) safe disposal of unavoidable waste.

Strategies will be pursued by making use of both financial incentives and legislation.

Principle (a) embodies the concept that plastics artefacts must be designed and manufactured so as to reduce waste and energy consumption, facilitate recycling, and minimise pollution. Principle (b) is based on a recognition that an increase in the recycling of plastics waste is both possible and desirable, and that a higher proportion of waste from competitive materials is currently recycled.

The European Community's environmental policy is to set targets, requiring a minimum percentage of plastics waste to be recyled. Targets will depend on existing levels of recycling in member states. Assistance will be given to encourage plastics recycling and to develop markets for recycled plastics. Possible measures include: tax reductions for recycled plastics products; reservation of public procurement contracts for recycled plastics products; financial support for research into selective collection and automatic sorting of post-user plastics waste; the establishment of Information Centres, doubling as plastics waste exchanges.

A system of codes for plastics identification is planned. A symbol may be moulded into packaging products, but for bulky items some form of electronic recognition may be needed.

RECYCLING OF PLASTICS

While plastics processors recycle virtually 100% of the waste generated in-house, a low proportion of post-user waste is recycled. All thermoplastics in the waste stream are technically recyclable, and the reasons for the low recycling rate are largely economic. While some mixed and slightly contaminated waste is recycled to produce products such as fencing posts, pallets and industrial shelving, generally plastics waste for recycling must be clean, and separated by type. Different plastics do not mix well together.

Major successes have been achieved for some products. For example, PET beverage bottles are recycled to produce polyester fibre. In Germany, the government imposes a levy of 50 pf deposit on these, a sum greater than the value of the bottles. In the Netherlands, reverse vending machines have been installed in large stores, and in smaller outlets there is manual collection.

In the USA, 20% of plastics drinks containers are recycled; 70,000 tonnes of PET bottles are currently processed each year, and 24,000 tonnes of high density polythene milk jugs.

LEGISLATION RELATING TO PLASTICS USAGE AND DISPOSAL

Although difficult to quantify, the source of much of the plastics debris found at sea is terrestrial. In the first 10 months of 1988, 21 USA State legislations State legislatures considered more than 1300 proposals to restrict or ban the sale and use of a variety of plastic products. In the following legislative session, 30 States and several municipal bodies considered even more bills proposing punitive action involving plastics products.

The German government has confirmed regulations aimed at reducing annual household waste from 39×10^6 tonnes to 10– 11×10^6 tonnes. By December 1991, consumers will have the right to leave film wraps and cartons in the store, and by January 1992 stores will be obliged to take back used containers. At the same time, a tax on one-trip containers will be introduced.

These examples serve to indicate the increasing pressure which is being brought to bear on suppliers and users of plastics, particularly packaging.

The International Convention for the Prevention of Pollution from Ships (1973), as modified by the Protocol of 1978 (MARPOL 73/78), in Annex V, contains regulations for the prohibition of the discharge to sea of all plastics, including fishing net, synthetic ropes, bottles and garbage bags.[1] In addition, governments are asked to consider a series of measures including reporting systems, record books on board ships, compliance incentive schemes and educational programmes (GESAMP, 1990). Contracting parties to the Convention are obliged to provide facilities in ports for the reception of garbage. While it is too early to estimate the impact of MARPOL 73/78 Annex V, some problems have been reported, due to the lack of garbage reception facilities at some ports (Okamura, 1991).

Environmental groups have expressed scepticism about the enforcement of MARPOL 73/78. The Dutch environmental organisation, Werkgroep Noordzee, has investigated the extent to which flag states take their duties under the Convention seriously, in relation to Annex I which refers to oil discharges at sea. Of 300 reports of alleged violation of rules sent to flag states by the International Maritime Organisation's Marine Environment Protection Committee (MEPEC), only 17% resulted in a report back to MEPEC. Of these 51 cases, only 18 resulted in convictions, and fines were said to be very low (Ijlstra, 1989). However, IMO claims that enforcement is now becoming more effective (Okamura, 1991).

AGREEMENTS TO CONTROL DRIFT NET FISHING

In 1988, the USA introduced legislation to control damage to the marine environment caused by drift net fishing. In addition to USA vessels, the legislation applied to other countries fishing in the USA Exclusive Economic Zone, including Japan, Taiwan and South Korea (Anon, 1988).

Australia, New Zealand, and 15 other smaller South Pacific countries have adopted a convention to ban drift net fishing in the South Pacific region. The signatories also sought the co-operation of distant water fishing nations in upholding the ban. The convention requires signatories to prohibit the use of drift nets within the area under their jurisdiction and prevent the use of such nets by vessels registered under their laws (Anon. 1990a). Japan has recently agreed to reduce its drift net fleet to 20 ships, although will not impose a ban. Taiwan, with 130 vessels, has refused to impose a ban or place a moratorium on drift net fishing (Anon. 1990a).

The South Pacific Convention was followed by a proposal by the European Commissioner for Fisheries for a ban on drift net fishing in EC waters. Italy and Spain already operate a ban in their own waters, although drift nets are still used extensively by the French in the Bay of Biscay. The European proposal would cover fishing in all EC waters except the Mediterranean, where fisheries policy has yet to be agreed. The principle of the ban was supported by the fisheries sub-committee of the European Parliament. However, EC Commission members have opposed the ban, claiming lack of scientific evidence of the damaging effects of drift nets (Anon., 1990b; Anon., 1990c).

The UN has proposed a moratorium to ban all drift net fishing in the whole of the South Pacific from July 1991, and in all international waters from July 1992.

[1] Annex V did not come into effect until December 31st 1988.

CONCLUSIONS

Marine pollution by plastic debris is recognised to cause damage to marine mammals, reptiles, fish and birds. This damage may result from entanglement in packing bands, fishing lines, monofilament drift nets, synthetic ropes and other debris, or the ingestion of plastics fragments. However, more research is needed to quantify the degree of damage caused. Apart from damage to marine animals, plastics debris is aesthetically detrimental both at sea and on amenity beaches. There is no single solution to the problem of marine pollution by plastics, and alleviation will occur only by a combination of economic incentives, legislation and education.

One of the most important means by which plastics pollution may be significantly reduced, is by reduction at source. Packaging accounts for about 30% of the plastics produced worldwide. Not only are many products over-packaged (i.e. unnecessary packaging material is used), but paper and board (much of it recycled) could be used to replace plastics. These materials are naturally biodegradable within resonable times, and are far less likely to damage marine life. Glass could replace plastics bottles for most purposes, and it is easily recyclable.

By judicious use of tax incentives, manufacturers could be encouraged to switch to the least environmentally damaging packaging materials. When there are advantages to the continued use of plastics, recycling of post-user waste should be encouraged. Tax and other incentives could be used to encourage increased use of recycled plastics in the manufacture of a wide range of products.

The further development and use of degradable plastics will not solve the problems of marine and terrestrial plastics pollution, and large-scale use of such materials is unlikely in the future. Also, built-in degradability is a positive discouragement to attempts to recycle post-user plastics waste.

Legislation to restrict, ban, or otherwise control the sale and use of plastics products is gathering momentum in the developed countries.

The implementation of MARPOL 73/78, Annex V, was a positive move to try to prohibit the discharge of plastics from ships. However, the regulations must be enforced effectively if they are to have an impact. Financial incentives to sort and compact ship-generated wastes, and for their reception at ports, could be introduced.

The problems created by the use, loss and discarding of monofilament nylon drift nets must be countered by pursuing further national and international agreements to ban or control their use.

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