PS5 PILOT STUDY

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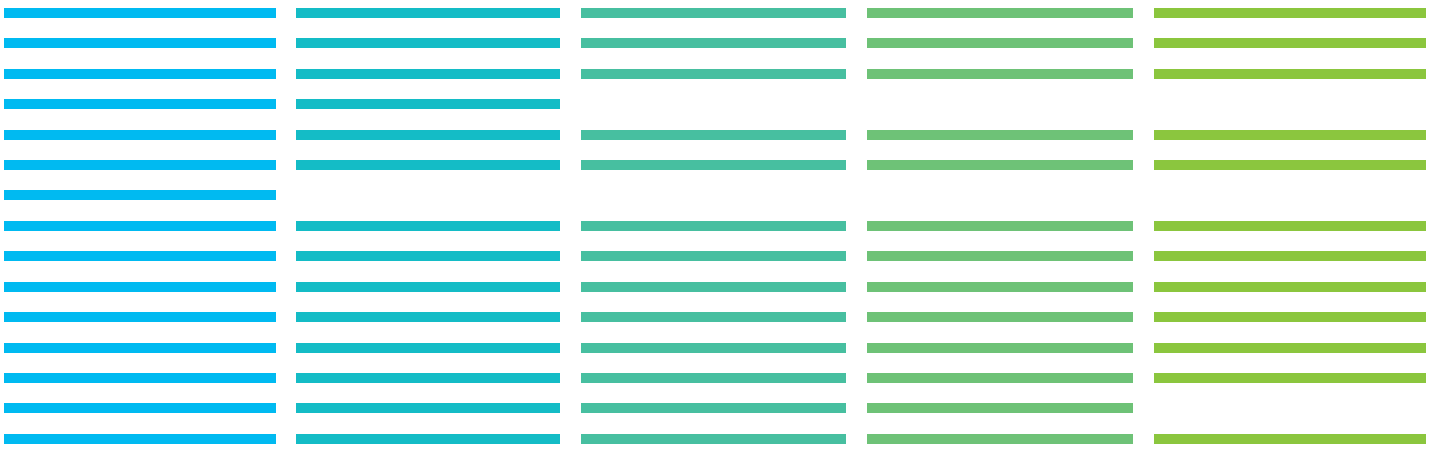
What are the effects of plastic particles on growth and mortality of marine organisms?

Ashraf Shehada
Magnus Land



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What are the effects of plastic particles on growth and mortality of marine organisms?

A Pilot Study

Magnus Land
Mistra EviEM
Royal Swedish Academy of Sciences
Box 50005, SE - 104 05 Stockholm, Sweden
Email: magnus.land@eviem.se

Ashraf Shehada

Abstract

As production of plastics has increased over the past 50 years, plastic pollution in marine environments has become a growing problem. A systematic review of how plastic particles in seawater affect marine biota has therefore been suggested by the Swedish Agency for Marine and Water Management (SWAM). Numerous studies report on the occurrence of plastic particles in the marine environment. A significant body of literature also reports on entanglement in plastic debris and ingestion of plastic particles by marine organisms. However, fewer studies have investigated the effects of these exposures, especially on a wider scale or at the population level. Moreover, the designs of the existing studies make it difficult to quantitatively synthesise the results using a systematic review approach. At present, a systematic review of this issue is not recommended.

Background

The first synthesised plastic, “Bakelite”, was introduced to the world in 1907, and ever since, the rush to use plastics has continued (PlasticsEurope, 2013). The material’s desirable characteristics, such as its light weight, durability and low lifetime costs, make it very resource-efficient (Andrady and Neal, 2009). Plastic is still one of the most used and versatile materials in the world. The global production in 2012 was 288 million tonnes (PlasticsEurope, 2013). The distribution between the major polymers in 2007 was polypropylene (PP), 24%, polyethylene (PE), 21%, and polyvinylchloride (PVC), 19% (Andrady, 2011).

Sources of plastic particles in the marine environment

As a direct consequence of the massive use of plastics in modern society, large amounts of plastic waste end up in seas and oceans. The sources of marine plastic pollution can be categorised into four major groups: tourism-related litter at the coast, sewage-related debris, fishing-related debris, and wastes from ships and boats (Allsopp et al., 2006). It is estimated that 20% of marine plastic debris comes from ocean-based sources, while around 80% derives from land-based sources.

The scientific community is currently focusing on microplastics (plastic particles smaller than 5 mm) more than macroplastics (Ivar do Sul et al., 2013). Hidalgo-Ruz et al. (2012) classified the origin of microplastics according to primary sources, including manufactured plastics of microscopic size (e.g. scrubbers in cosmetics and soaps or precursors for manufactured plastic products), and secondary sources, such as plastics debris derived from the breakdown of larger plastic products. Most plastic fragments are poly¬ethylene and polypropylene polymers.

Occurrence in the marine environment

Plastics have been found in most marine habitats. Microplastics are present even in the top sediment layer of the deep-sea floor (Van Cauwenberghe et al., 2013); some of these deep-sea sediments are situated at depths of 5000 m (Wright et al., 2013b).

Generally, the highest plastic concentrations in the North Atlantic are observed in subtropical latitudes (22-38°N) (STAP, 2011). However, Norén (2007) found abundant microplastic particles on the Swedish coast (150–2400 particles per m3 of seawater), and one of the highest microplastics concentrations, 102 000 particles per m3, was reported in the harbour outside a polyethylene production plant.

Microplastic debris has been detected in many marine organisms. Carson (2013) reviewed the documentation of plastic ingestion in seabirds, sea turtles, marine mammals, filter-feeding organisms, deposit-feeding organisms and various kinds of fish, such as sharks, tuna and catfish. Laist (1987), cited in GEF (2012), has identified 247 marine species known to be impacted by plastic debris.

Effects in the marine environment

Entanglement in and ingestion of plastic debris are the main threats of plastic pollution to marine life (Carson, 2013). Freely floating (i.e. pelagic) marine debris may also facilitate dispersal of “hitchhiking” invasive species (Gregory, 2009).

Effects of plastic particles on marine organisms may be caused by the particles themselves as physical entities, or by chemicals released from the particles. The chemicals can either be part of the plastics, or they can be contaminants adsorbed to the plastic particles. Mato et al. (2000) found that plastic resin pellets play a role in transporting pollutants in marine environments. Teuten et al. (2007) showed that chemicals adsorbed and transported by plastic debris may include high concentrations of organochlorines (PCBs, DDT, and PAHs). Rochman et al. (2013) showed that plastic particles act as vectors transferring persistent, bioaccumulative and toxic substances, or PBTs, from the water to the food web. In a review article, Engler (2012) concluded that while there is significant uncertainty and complexity in the kinetics and thermodynamics of the interactions, plastic debris may in this way cause adverse effects throughout the marine food web, which includes humans. Because of the extremely long lifetime of plastic and PBTs in the ocean, prevention strategies are vital to minimising these risks.

The problem of plastic pollution has been recognised in the European Union's Marine Strategy Framework Directive (MSFD), which was adopted in 2008 (European Commission, 2008).

Identification of topic and stakeholders

At a general stakeholder meeting arranged by Mistra EviEM, a systematic review of the effects of plastic particles in seawater was suggested by the Swedish Agency for Marine and Water Management (SWAM).

Other stakeholders concerned by this topic may include fisheries and conservation organisations and the plastics industry.

Formulation of review question

The original review question suggested at the EviEM stakeholder meeting was “What are the effects of plastic particles in water?” If written more specifically -- “What are the effects of plastic particles on growth and mortality of marine organisms?” -- the question can be seen to contain the following elements:

Population/Subject: Marine organisms (needs to be better defined)

Exposure: Plastic particles in seawater

Comparator: No exposure

Outcomes: Changes of growth rate and mortality

Elements of all four of these kinds have to be specified clearly for any question that is considered for systematic review.

Scientific basis

Literature searches
Searches for literature relevant to the proposed topic have been performed using the Web of Knowledge and Google. The search string shown below returned 874 articles from the Web of Knowledge:

(microplastic$ OR plastic$) **AND** (ingest* OR entangle* OR suffocat* OR debilitat* OR mortality OR growth) **AND** (marine OR sea OR ocean)

Review articles
Two recent reports have reviewed the effects of plastic debris on biodiversity (GEF, 2012) and animal welfare (Butterworth et al., 2012). In GEF (2012), 319 publications on marine debris were analysed (76.5% of the publications were about plastic debris). Together, these publications reported on 663 species of marine mammals, birds, fish, sea turtles, sea snakes, crustaceans, cephalopods, bivalves, gastropods, echinoderms, and cnidaria. More than 50% of the reports documented entanglement in or ingestion of marine debris that had caused direct harm or even death. The literature reviewed by Butterworth et al. (2012) reflects a tendency of current research to focus on the more charismatic marine species: most of the reports are concerned with entanglement of mammals, birds and turtles in marine debris. The review reported the mortality due to entanglement as percentages for pinnipeds and cetaceans and as numbers for sharks, turtles, manatees and birds. It also reviewed the literature on ingestion of plastics by the same species.

General reviews on the effects of plastic particles on marine organisms have also been published by Derraik (2002), Gregory (2009), Thompson et al. (2009), and Wright et al. (2013b). The latter concentrated on physical impacts. Andrady (2011) discussed the mechanisms of generation and potential impacts of microplastics and their fate in the ocean environment. Cole et al. (2011) reviewed the abundance of microplastics in the marine environment and discussed some environmental impacts. They also noted that there are uncertainties regarding the mechanisms behind health effects such as mortality, morbidity and impaired reproductive success, and whether such effects are caused by the particles themselves or by external pollutants adhered to them.

A review article on marine birds concluded that microplastics may cause blockage of gastric enzyme secretion, lowered steroid hormone levels, and delayed ovulation and reproduction (Azzarello and Vanvleet, 1987).

Examples of effect studies

Based on laboratory studies, Cole et al. (2013) reported that exposure of the copepod Centropages typicus to natural assemblages of algae with and without 7.3-µm microplastics significantly decreased algal feeding, which could imply that marine microplastic debris may impair zooplankton function and health. Lee et al. (2013) showed that nano- or micro-sized polystyrene beads may have negative effects on marine copepods through decreasing survival and retardation of development, and especially through decreasing fecundity.

Ingestion of microplastics also causes depletion of energy reserves by up to 50% in marine worms due to reduction in feeding activity, longer gut residence times of ingested material, and inflammation (Wright et al., 2013a).

Toxicity caused by microplastics has also been shown in Japanese medaka (Oryzias latipes), a widely accepted model fish species; toxicity resulted in hepatic stress for that fish (Rochman et al., 2013). However, according to Possatto et al. (2011), reports of ingestion of plastic marine debris by fish the natural environment are rare and lack temporal or spatial trends; there is little indication of systematic or analytical data in the literature. Also, according to GEF (2012), there is an underreporting of ingestion impacts.

Fossi et al. (2012) studied baleen whales which potentially are exposed to micro-litter ingestion as a result of their filter-feeding activity. The authors detected high concentrations of phthalates (DEHP and MEHP) in neustonic/planktonic samples. Based on the concentrations of MEHP found in the blubber of stranded fin whales (Balaenoptera physalus), they suggested that phthalates could serve as a tracer of the intake of microplastics. There are very few similar studies, but according to the authors, the results of this study could represent the first warning of an emerging threat to baleen whales.

In a before-after control-impact (BACI) study, Katsanevakis et al. (2007) investigated the effects of debris at the sea floor on soft-bottom epibenthic megafauna. Both the number of species and their total abundance increased on the plastic-impacted surfaces. The authors hypothesised that the litter provided refuge or reproduction sites for mobile species, and for sessile species a hard substratum on which to settle. They observed a marked yet gradual shift in the community structure where litter was present, compared to control patches on the sea floor.

A report issued by the Scientific and Technical Advisory Panel (STAP, 2011) concluded that evidence of harmful effects of plastic on wildlife is mostly restricted to observations of individual specimens that have become entangled in or have ingested plastic debris. Little is known about larger-scale effects and ecosystem-wide impacts of plastic pollution, and this conclusion was corroborated by Butterworth et al. (2012) in a discussion of the uncertainties in estimating overall numbers of animals affected.

In summary, numerous studies report on the occurrence of plastic particles in the marine environment. A significant body of literature also reports on entanglement in plastic debris and ingestion of plastic particles by marine organisms. However, fewer studies have investigated the effects of these exposures, especially on a wider scale or at the population level.

Fulfilment of selection criteria

As a summary of the preceding sections, this section presents tables showing the extent to which the suggested primary review question fulfils the criteria for selection of systematic review topics that have been approved by the EviEM Executive Committee. Table 1 shows the mandatory criteria, and table 2 shows the optional criteria.

Table 1.

Mandatory criterion	Y/N	Comments
Deals with conditions in the natural environment	Y	
Relevant to the situation in Sweden	Y	See Norén (2007)
Well-defined, conceptually clear and reasonably limited in scope	N	The elements of the review question need to be better defined, especially Population and Outcome.
Deals with problem descriptions or countermeasures whose scientific support is insufficient, disputed or incompletely known	Y	
Covered in the scientific literature (or by other investigations) to such an extent that a systematic assessment can be implemented	N	There are many gaps and uncertainties.

Table 2.

Optional criterion	Y/N	Comments
Controversial and/or the subject of great public attention	N?	Does not get a lot of public attention in the Swedish-language media.
Seen as environmental policy issues of high concern	Y	The EU Marine Strategy Framework Directive (MSFD, 2008/56/EC) addresses marine litter and aims at achieving that "Properties and quantities of marine litter do not cause harm to the coastal and marine environment".
Deals with new forms of environmental pressures, changes or actions	N	Synthetic plastics were introduced in 1907 and mass production began in the 1940s.
Deals with environmental disturbances or mitigation efforts that affect great natural values and/or extensive parts of the country	Y	Plastic pollution occurs in marine environments worldwide.
Deals with measures that are particularly costly or resource-demanding in some other respect	?	
Deals with actions that in some respects are beneficial to the environment but may be unfavourable in other respects	N	
Deals with environmental problems currently treated by a variety of alternative measures.	N	

Conclusion

Most of the published studies of plastic debris (especially microplastics) in the marine environment are dedicated to investigating the occurrence of such pollution rather than its effects on marine biota. A significant number of review articles cover the topic quite well, and the designs of the existing studies make it difficult to quantitatively synthesise the results using a systematic review approach. At present, a systematic review of this issue is not recommended.

References

Allsopp, M., Walters, A., Santillo, D., Johnston, P., 2006. **Plastic Debris in the World's Oceans**. Greenpeace, Amsterdam, The Netherlands.

Andrady, A.L., 2011. **Microplastics in the marine environment**. Marine Pollution Bulletin 62, 1596-1605.

Andrady, A.L., Neal, M.A., 2009. **Applications and societal benefits of plastics**. Philosophical Transactions of the Royal Society B-Biological Sciences 364, 1977-1984.

Azzarello, M.Y., Vanvleet, E.S., 1987. **Marine birds and plastic pollution**. Marine Ecology Progress Series 37, 295-303.

Butterworth, A., Clegg, I., Bass, C., 2012. **Untangled – Marine debris: a global picture of the impact on animal welfare and of animal-focused solutions**. World Society for the Protection of Animals, London.

Carson, H.S., 2013. **The incidence of plastic ingestion by fishes: From the prey's perspective**. Marine Pollution Bulletin 74, 170-174.

Cole, M., Lindeque, P., Fileman, E., Halsband, C., Goodhead, R., Moger, J., Galloway, T.S., 2013. **Microplastic Ingestion by Zooplankton**. Environmental Science & Technology 47, 6646-6655.

Cole, M., Lindeque, P., Halsband, C., Galloway, T.S., 2011. **Microplastics as contaminants in the marine environment: A review**. Marine Pollution Bulletin 62, 2588-2597.

Derraik, J.G.B., 2002. **The pollution of the marine environment by plastic debris: a review**. Marine Pollution Bulletin 44, 842-852.

Engler, R.E., 2012. **The Complex Interaction between Marine Debris and Toxic Chemicals in the Ocean**. Environmental Science & Technology 46, 12302-12315.

Fossi, M.C., Panti, C., Guerranti, C., Coppola, D., Giannetti, M., Marsili, L., Minutoli, R., 2012. **Are baleen whales exposed to the threat of microplastics? A case study of the Mediterranean fin whale (Balaenoptera physalus)**. Marine Pollution Bulletin 64, 2374-2379.

GEF, 2012. **Impacts of Marine Debris on Biodiversity: Current Status and Potential Solutuions**. Secretariat of the Convention on Biological Diversity and Scientific and Technical Advisory Panel -GEF, Technical Series No. 67, 61 pages, Monterial.

Gregory, M.R., 2009. **Environmental implications of plastic debris in marine settings-entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions**. Philosophical Transactions of the Royal Society B-Biological Sciences 364, 2013-2025.

Hidalgo-Ruz, V., Gutow, L., Thompson, R.C., Thiel, M., 2012. **Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification**. Environmental Science & Technology 46, 3060-3075.

Ivar do Sul, J.A., Costa, M.F., Barletta, M., Cysneiros, F.J.A., 2013. **Pelagic microplastics around an archipelago of the Equatorial Atlantic**. Marine Pollution Bulletin 75, 305-309.

Katsanevakis, S., Verriopoulos, G., Nicolaidou, A., Thessalou-Legaki, M., 2007. **Effect of marine litter on the benthic megafauna of coastal soft bottoms: A manipulative field experiment**. Marine Pollution Bulletin 54, 771-778.

Laist, D.W., 1987. **Overview of the biological effects of lost and discarded plastic debris in the marine-environment**. Marine Pollution Bulletin 18, 319-326.

Lee, K.-W., Shim, W.J., Kwon, O.Y., Kang, J.-H., 2013. **Size-Dependent Effects of Micro Polystyrene Particles in the Marine Copepod Tigriopus japonicus**. Environmental Science & Technology 47, 11278-11283.

Mato, Y., Isobe, T., Takada, H., Kanehiro, H., Ohtake, C., Kaminuma, T., 2000. **Plastic Resin Pellets as a Transport Medium for Toxic Chemicals in the Marine Environment**. Environmental Science & Technology 35, 318-324.

Norén, F., 2007. **Small plastic particles in Coastal Swedish waters**. KIMO Sweden, N-Research, Lysekil, Sweden., http://www.google.se/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&ved=0CDwQFjAA&url=http%3A%2F%2Fwww.kimointernational.org%2FWebData%2FFiles%2FSmall%2520plastic%2520particles%2520in%2520Swedish%2520West%2520Coast%2520Waters.pdf&ei=wjXdUrTLEOaLyQPanYHwAQ&usg=AFQjCNHORHRscEmf7Qff45w5Q0eCRYcICQ&bvm=bv.59568121,d.bGQ.

PlasticsEurope, 2013. **Plastics – the Facts 2013**. Plastics Europe, Brussels , Belgium http://www.plasticseurope.org/cust/documentrequest.aspx?DocID=59108.

Possatto, F.E., Barletta, M., Costa, M.F., Ivar do Sul, J.A., Dantas, D.V., 2011. **Plastic debris ingestion by marine catfish: An unexpected fisheries impact**. Marine Pollution Bulletin 62, 1098-1102.

Rochman, C.M., Hoh, E., Kurobe, T., Teh, S.J., 2013. **Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress**. Scientific Reports 3.

STAP, 2011. **Marine Debris as a Global Environmental Problem: Introducing a solutions based framework focused on plastic. A STAP Information Document**. Global Environment Facility, Washington, DC.

Teuten, E.L., Rowland, S.J., Galloway, T.S., Thompson, R.C., 2007. **Potential for plastics to transport hydrophobic contaminants**. Environmental Science & Technology 41, 7759-7764.

Thompson, R.C., Moore, C.J., vom Saal, F.S., Swan, S.H., 2009. **Plastics, the environment and human health: current consensus and future trends**. Philosophical Transactions of the Royal Society B-Biological Sciences 364, 2153-2166.

Van Cauwenberghe, L., Vanreusel, A., Mees, J., Janssen, C.R., 2013. **Microplastic pollution in deep-sea sediments**. Environmental Pollution 182, 495-499.

Wright, S.L., Rowe, D., Thompson, R.C., Galloway, T.S., 2013a. **Microplastic ingestion decreases energy reserves in marine worms**. Current Biology 23, R1031-R1033.

Wright, S.L., Thompson, R.C., Galloway, T.S., 2013b. **The physical impacts of microplastics on marine organisms: A review**. Environmental Pollution 178, 483-492.

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Mistra EviEM conducts systematic reviews of environmental issues identified as important by public agencies and other stakeholders. These provide an overall assessment of the state of scientific knowledge and help to improve the basis for environmental decision-making in Sweden.

All systematic reviews are preceded by a pilot study. If such a study indicates that the topic is not suitable for systematic review, the process ends with the pilot study being published in this series instead.

EviEM
Mistra Council for Evidence-based Environmental Management

Address:
Royal Swedish Academy of Sciences
Box 50005, SE-104 05 Stockholm, Sweden

Visit/Deliveries:
Lilla Frescativägen 4A, SE-114 18 Stockholm, Sweden

Phone: 08-673 95 00 | Email: info@eviem.se | **www.eviem.se**