Centre: **Plymouth Marine Laboratory (PML)**

Title of case study: **Shaping policy and reducing marine plastic pollution**

1. Summary of the impact

Plastic debris is a widespread and persistent pollutant in the marine environment, which poses a considerable risk to marine organisms and has economic repercussions for society. PML was the first organisation to identify that microplastics are damaging zooplankton, the most numerous animals on Earth and a key link in oceanic food chains. This pioneering work underpinned UK legislation to ban microplastic beads from the manufacture of wash-off cosmetics; a landmark ruling which ensures 4,000 fewer tonnes of plastic enter our oceans every year. The research has also been used as evidence for bans in 4 other countries and is informing debate in Europe on an EU-wide restriction of intentionally added microplastics. PML's outreach activities have reached global audiences contributing to surging public awareness that is putting pressure on policymakers and manufacturers to reduce plastic waste.

2. Underpinning Centre activities

The potential environmental cost of marine plastic currently in the ocean has been valued by PML as at least GBP380,000,000,000 each year based on the effect it has on the oceans' ability to provide goods and services for humankind [3.1]. The most numerous plastic in the world's oceans are small pieces less than 5mm in size; these 'microplastics' are either manufactured to be microscopic in size, for use in cosmetic or industrial applications, or derive from the fragmentation of larger plastic debris following prolonged degradation.

PML's microplastics team comprises Dr Pennie Lindeque, Dr Matthew Cole and a cohort of students (4 PhD, 6 Masters and 4 placement students since 2014). Their unique area of expertise is the study of the effects of microplastics on zooplankton. Dr Lindeque (PML since 1995; Professor from 2019) has led this team since 2010, and in the past 5 years has overseen 10 microplastics research grants and 4 studentships, valued at more than GBP1,000,000 to PML, which has resulted in the publication of 31 research papers. Dr Cole undertook his PhD at PML (2010–2014), and continued as a postdoc on a joint NERC research grant between PML and the University of Exeter (2014–2017) before being employed by PML in 2017. PML collaborates with 4 UK Universities to host PhD students in the area of microplastics; these universities act as the awarding body and provide additional supervision and facilities. The microplastics team has worked with colleagues across PML to bring together expertise from different disciplines to broaden the research scope, including social scientists (Austen, Beaumont), ecologists (Fileman, Queiros) and environmental modellers (Clark, Artioli, Torres).

PML was the first to evidence that microplastics are ingested by small drifting animals called zooplankton that, with phytoplankton, make up the food supply upon which almost all marine organisms are ultimately dependent. In 2013 the research team used bioimaging techniques to document that microplastics could be consumed by a range of zooplankton species (Figure 1). Additionally, laboratory-based feeding rate studies were used to demonstrate that microplastic ingestion decreased food consumption in exposed zooplankton [3.2]. More recently, field studies conducted by PML have confirmed that zooplankton, such as fish larvae, are consuming microplastics in the natural environment [3.3].

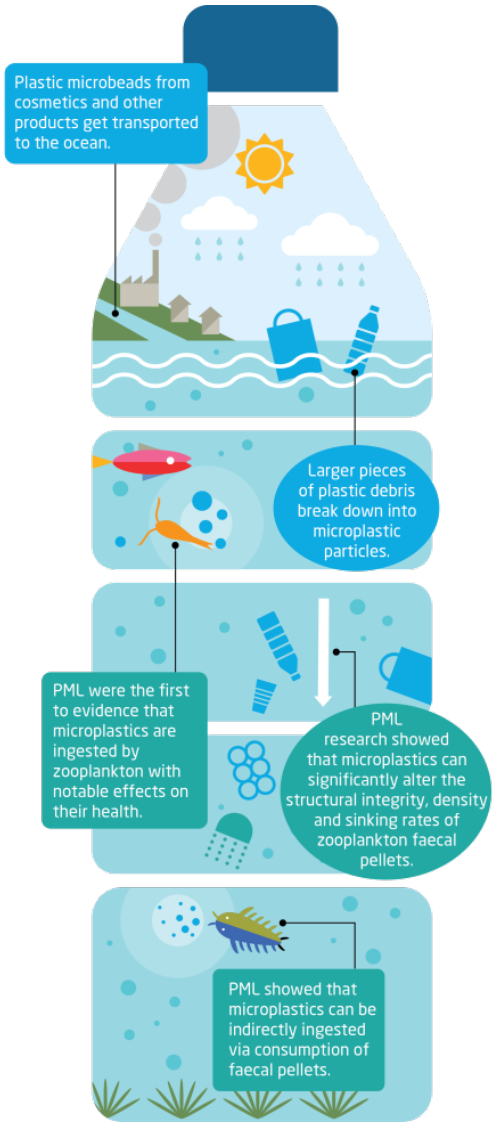
In 2015 PML demonstrated that microplastics can have a significant impact on how small crustaceans called copepods feed, with notable costs to the health of individual animals. Copepods are a globally abundant type of zooplankton that form a key nutritional link between primary producers and consumers further up the food chain. Dr Cole exposed a common copepod species to polystyrene beads representative of the size of microplastics used in personal care products. The exposure resulted in the copepods consuming smaller, less nutritious prey than usual, leading to a significant reduction in the amount of food ingested. Prolonged exposure to microplastics resulted in a 40% reduction in energy consumed by the copepods causing them to produce smaller eggs with reduced hatching success [3.4].

In 2016 the team explored the effects of microplastics egested by zooplankton in their faeces. Zooplankton faecal pellets are an important food source for marine organisms but they also play an instrumental role in the biological pump. This transports particulate organic matter, nutrients,

pollutants and carbon to deeper waters and the seafloor. The PML research team found microplastics can significantly alter the structural integrity, density, and sinking rates of faecal pellets. At average oceanic depths, it was calculated that pellets containing polystyrene microplastics would take 53 days longer to reach the seafloor. These pellets would therefore be more prone to consumption and degradation during their descent compared to faecal pellets devoid of plastic, leading to the reduced transport of organic matter to the seafloor. The research further illustrated that microplastics can be indirectly ingested via consumption of faecal pellets [3.5], highlighting them as a novel vector for incorporation of microplastics into the food web.

Research undertaken at PML has identified that plastic can be transferred through feeding from fish to marine mammals [3.6]. These findings have contributed to growing concern that humans may also be consuming microplastics through the food we eat and highlighted the need for further research on what the implications of microplastics on human health might be.

In 2019 PML's research team went on to reveal the impacts of microplastics of varying shape and size on copepods. Exposure to nylon fibres was shown to cause a 40% decrease in algal ingestion rates and triggered premature moulting in juvenile copepods. The results emphasized that the shape and chemical profile of a microplastic can influence its bioavailability and toxicity [3.7]. Furthermore, PhD student Rachel Coppock identified that different types of plastic can change the density of copepod faecal pellets, either increasing or decreasing their buoyancy and sinking rates. This has potential implications for the carbon cycle and the transport of microplastics and food through the ocean [3.8].



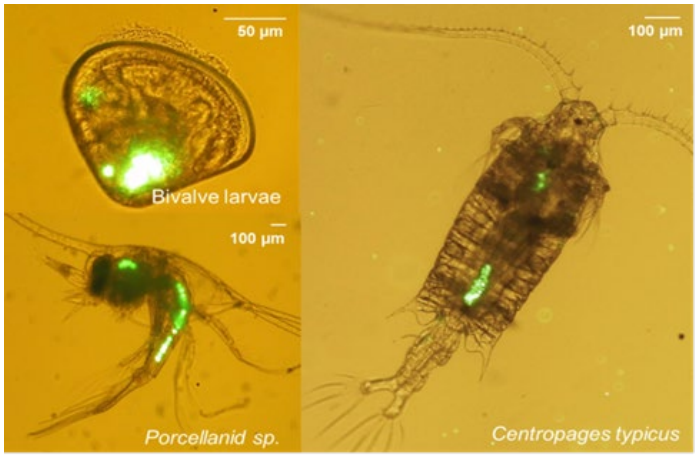


Figure 1. Left: Infographic showing PML's microplastic research (teal boxes) adapted from PML Annual Review 2016. Above right: Zooplankton showing ingested microplastics.

3. References to the underpinning work

PML authors are highlighted in bold type, citation numbers from Web of Science 7 January 2020.

3.1. **Beaumont, N.J.**, Aanesen, M., **Austen, M.C.**, Borger, T., **Clark, J.R.**, **Cole, M., Hooper, T., Lindeque, P. K.** *et al.* 2019. Global ecological, social and economic impacts of marine plastic. *Marine Pollution Bulletin*, 142, 189-195. doi:10.1016/j.marpolbul.2019.03.022 [9 citations].

3.2. **Cole, M.**, **Lindeque, P.**, **Fileman, E.**, Halsband, C., Goodhead, R., Moger, J. *et al.* 2013. Microplastic ingestion by zooplankton. *Environmental Science & Technology*, 47(12), 6646-6655. doi:10.1021/es400663f [534 citations].

3.3. **Steer, M.**, **Cole, M.**, Thompson, R.C., **Lindeque, P.K.** 2017. Microplastic ingestion in fish larvae in the western English Channel. *Environmental Pollution*, 226, 250-259. doi:10.1016/j.envpol.2017.03.062 [74 citations].

3.4. **Cole, M.**, **Lindeque, P.**, **Fileman, E.**, Halsband, C., Galloway, T.S. 2015. The impact of polystyrene microplastics on feeding, function and fecundity in the marine copepod *Calanus helgolandicus*. *Environmental Science & Technology*, 49(2), 1130-1137. doi:10.1021/es504525u [245 citations].

3.5. **Cole, M.**, **Lindeque, P.K.**, **Fileman, E.**, **Clark, J.**, Lewis, C., Halsband, C. *et al.* 2016. Microplastics alter the properties and sinking rates of zooplankton faecal pellets. *Environmental Science & Technology*, 50(6), 3239-3246. doi:10.1021/acs.est.5b05905 [98 citations].

3.6. **Nelms, S.E.**, Galloway, T.S., Godley, B.J., Jarvis, D.S., **Lindeque, P.K.** 2018. Investigating microplastic trophic transfer in marine top predators. *Environmental Pollution*, 238, 999-1007. doi:10.1016/j.envpol.2018.02.016. [78 citations].

3.7. **Cole, M.**, **Coppock, R.**, **Lindeque, P.K.**, Altin, D., Reed, S., Pond, D.W. *et al.* 2019. Effects of nylon microplastic on feeding, lipid accumulation, and moulting in a coldwater copepod. *Environmental Science & Technology*, 53(12), 7075-7082. doi:10.1021/acs.est.9b01853

3.8. **Coppock, R.L.**, Galloway, T.S., **Cole, M.**, **Fileman, E.S.**, **Queiros, A.M.**, **Lindeque, P.K.** 2019. Microplastics alter feeding selectivity and faecal density in the copepod, *Calanus helgolandicus*. *Science of the Total Environment*, 687, 780-789. doi:10.1016/j.scitotenv.2019.06.009 [1 citation].

4. Details of the impact

PML has significantly increased understanding of the impact of microplastics on zooplankton. The team's research has contributed evidence to underpin domestic and international legislation to reduce plastic entering our oceans. Through outreach activities PML has raised awareness of the scope of the plastic problem and helped to change public perceptions and behaviour.

Shaping national policy

Informed by PML research, the UK government passed legislation in 2016 to ban the manufacture of products containing microbeads, one of the world's most stringent bans. This ensures that manufacturers of cosmetics and personal care products sold in the UK are no longer able to add tiny pieces of plastic to rinse-off products such as face scrubs, toothpastes and shower gels.

PML contributed to the evidence base that underpinned the ban. Specific references were made to PML's research, with Dr Cole as the most cited researcher in the Parliamentary Office of Science Technology's POSTNote [5.1]. This research provided the only evidence relating to impacts on zooplankton. Dr Lindeque presented to members of the Houses of Commons and Lords, including Select Committee members and the Parliamentary and Scientific Committee, in the lead up to the ban. In addition, 6 PML scientists and students provided written evidence to the Environmental Audit Committee inquiry on the environmental impact of microplastics. The POSTNote and PML's written submission were used as evidence in the Committee's report that put forward the recommendation to ban the use of plastic microbeads, which was enacted by the UK government.

The ban came into effect in January 2018, which has led to a reduction of 4,000 tonnes of plastic entering the ocean every year [5.2]. This equates to the protection of marine natural capital of at least USD13,200,000 (05-2019) each year, based on conservative calculations of the cost each tonne of marine plastic debris can have on marine ecosystem goods and services [3.1].

The ban is a key first step in making sure UK government policy is tackling plastic pollution in the marine environment. Defra are continuing to address and expand on this issue on behalf of the government through a Marine Plastic Pollution Evidence Review. PML has been integral to this process: the microplastics team co-authored 3 of 6 rapid-reviews requested by Defra; Drs Lindeque, Beaumont and Cole presented at the review workshop in March 2019; and Dr Lindeque was the co-scientific lead on the final report that she presented to DEFRA in October 2019. The results of the evidence review and workshop will be used in Defra policy work to help direct future funding and to identify the most harmful types of litter [5.3].

"*As the first researchers to identify the impact of plastic on zooplankton, PML have been instrumental in raising awareness of the breadth of this issue and bringing it to the fore of political awareness. PML produced 3 comprehensive reports for the government's Marine Plastic Pollution Evidence Review that provided important information for our approach to addressing marine plastic pollution*" Department for Environment Food and Rural Affairs [5.4].

Global influence

Leading on from the UK microbead ban, PML's research has been used as evidence for legislation to ban microbeads in Canada [5.5], New Zealand [5.6], South Africa [5.7] and Sweden [5.8]. For example, PML's research is referenced in the Canadian Environment Agency's, *Microbeads, a science summary* which called for microbeads to be classified as a toxin under environmental protection law [5.5] and ultimately led to a ban that came into effect on 1 January 2018.

The EU is considering the restriction of microplastics in products which are intentionally added during manufacture and are likely to be released to the environment. In 2018 it commissioned the European Chemicals Agency to review the available scientific evidence and to produce a proposal for the restriction. Three of Dr Cole's papers on the impact of microplastics on zooplankton are cited in the proposal. The restriction report features a table of the 25 most influential articles on the (eco)toxicity of microplastics [5.9] in which Dr Cole's papers feature 2nd and 9th.

The proposed EU-wide ban will be voted on in 2020 and, if adopted, will mean restrictions on microplastic use from 2022 for all 28 member states. The report states that only Union-wide measures will curb microplastic emissions effectively and ensure the free movement of goods within the Union. The European ban aims to cut 90% of microplastic pollution, amounting to 400,000 tonnes of microplastics over the 20 year period following its entry into force [5.9].

PML's research has also featured in reports from intergovernmental organisations that aim to address this global problem. These include the United Nations and the World Health Organisation. The UN's Environment Programme produced the report *Marine plastic debris and microplastics – Global lessons and research to inspire action and guide policy change,* which drew upon and made reference to PML's papers. The report is the supporting evidence for 3 UN resolutions on marine litter and microplastics [5.10] that call for Member States to create action plans to tackle plastic pollution.

Raising awareness and changing behaviour

The first ever footage of zooplankton eating microplastic was filmed at PML in 2014, which featured in a short film that won the Atkins CIWEM Environmental Film of the Year. The footage received global media attention featuring on websites including the New Scientist and Mail Online. It was aired on prime-time programmes including BBC and ITV local and national news and BBC's The OneShow and Inside Out, with a potential combined reach of over 20,000,000 people [5.11].

In 2017 the BBC filmed zooplankton eating plastic at PML, which featured in the final episode of Blue Planet II and the accompanying book. The episode was watched by 12,000,000 viewers in the UK, broadcast internationally on BBC Earth channel and sold to more than 30 countries. The episode informed a global audience of the dangers of plastic waste, which helped to trigger global debate and a shift in attitudes. *"The 'Blue Planet effect' has been cited in many actions by government and businesses"* [5.2].

PML's work on marine plastics has featured in over 20 print and online newspaper articles, with a total readership in excess of 100,000,000 people [5.11]. Dr Lindeque and Dr Cole have been interviewed for several documentaries including *Eating our way to extinction* and Al Jazeera's *Earthwise* programme. Dr Lindeque was recently an expert panellist on the Royal Institution debate on *Marine plastics: is it too late to save our oceans?*

PML has contributed to educational programmes such as EncounterEdu.com, creating a resource pack for teaching 14–16 year olds. PML was the Science Partner for the educational unit, *Plankton, Plastics and Poo,* which has been downloaded 6,387 times by teachers, educating at least 236,000 students.

At the grass roots level PML is active in the community; visiting schools and universities, presenting at exhibitions and collaborating in art projects. This has directly led to changes in behaviour with schools feeding back that they have implemented plastic reduction policies and targets. *"Dr Lindeque's visit inspired our students to launch a recycling scheme, raise awareness within the school and local community and find ways to reduce plastic use."* Kingsbridge Community College [5.12].

PML's microplastic research, alongside work from the Universities of Exeter and Plymouth, won the prestigious NERC societal impact award and the overall winners award in December 2018. The accolades recognised the efforts of the 3 organisations to bring the causes and effects of plastic pollution to the attention of policy makers, industry and the general public globally. In November 2019 Dr Lindeque received the Highly Cited Researcher award from Web of Science for her work in the field of Environment and Ecology [5.13].

5. Sources to corroborate the impact

5.1. Parliamentary Office of Science and Technology (POST). 2016. *Marine microplastic pollution*. POSTNote. No.528. Parliamentary Office of Science and Technology, London. 5pp. http://researchbriefings.files.parliament.uk/documents/POST-PN-0528/POST-PN-0528.pdf

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5.6. Ministry for the Environment, N.Z. 2017. Feedback on the proposal to ban the sale and manufacture of plastic microbeads in personal care products in New Zealand. *PML research referenced in evidence submitted by Our Seas our Future and Friends of Taputeranga Marine Reserve* [online] [Cited 3 December 2019]. https://www.mfe.govt.nz/waste/waste-strategy-and-legislation/plastic-microbeads-ban/submissions-proposal

5.7. Bouwman, H., Minnaar, K., Bezuidenhout, C., Verster, C. 2018. *Microplastics in freshwater water environments: a scoping study. Report to the Water Research Commission.* Gezina, South Africa, 62pp. http://www.wrc.org.za/wp-content/uploads/mdocs/2610-1-18.pdf

5.8. KEMI. Swedish Chemicals Agency. 2016. *Proposal for a national ban on microbeads in cosmetic products (report in Swedish with English summary)* Stockholm, Sweden, 47pp. https://www.kemi.se/en/global/rapporter/2016/rapport-2-16-forslag-till-nationellt-forbud-mot-mikrokorn-av-plast-i-kosmetiska-produkter.pdf

5.9. European Chemicals Agency. 2019. *Annex XV restriction report. Intentionally added microplastics. Version 1.2. See p.55 for most influential papers on (eco)toxicology* Helsinki. 145pp. https://echa.europa.eu/documents/10162/12414bc7-6bb2-17e7-c9ec-652a20fa43fc

5.10. United Nations Environment Assembly. 2018. *Compilation of United Nations Environment Assembly resolutions on marine litter and microplastics*. Ad hoc open-ended expert group on marine litter and microplastics. UNEP/AHEG/2018/1/INF/2. 10pp. https://papersmart.unon.org/resolution/adhoc-oeeg-information-documents

5.11. Plymouth Marine Laboratory. 2019. Microplastics media coverage. [online] [Cited 6 December 2019]. https://www.pml.ac.uk/Research/Projects/Microplastics_media_coverage.pdf

5.12. 16 October 2019. School quote for microplastic impact study [email]. *Kingsbridge Community College*.

5.13. Web of Science. 2019. Penelope Lindeque - highly cited researcher. [online] [Cited 3 December 2019]. https://publons.com/researcher/3229882/penelope-lindeque/