Institution: Plymouth University

Unit of Assessment: Earth Systems and Environmental Sciences B7

Title of case study: Discovery of microplastics as key anthropogenic contaminants in the marine environment

1. Summary of the impact (indicative maximum 100 words)

Researchers at Plymouth University were the first to demonstrate the occurrence of microscopic plastic debris in the environment. Professor Thompson's team showed that '*microplastic'* particles had accumulated since the 1960s and are present in oceans worldwide. This case study describes the impacts from these findings and the subsequent research by the team which demonstrated that marine organisms could ingest and retain this material and that, upon ingestion, microplastics had the potential to release chemical contaminants. The research impacted on UK, European and American policy and contributed to a body of evidence which influenced companies to phase-out microplastics from their products.

2. Underpinning research (Citations in parentheses are listed in Section 3)

Richard Thompson moved to Plymouth to take up his first permanent academic position as lecturer in Benthic Ecology in January 2001. Previously, during postdoctoral positions (at Newcastle and Southampton) he had become intrigued by the quantities of small plastic debris accumulating in some of his experiments on the shoreline. As a consequence of voluntary work co-ordinating beach-cleans for the UK Marine Conservation Society he had also realised that substantial quantities of small plastic fragments were being overlooked by standard marine litter surveys. Shortly after arriving at Plymouth he secured funding to describe and quantify these fragments (Leverhulme Trust Pilot Grant, Principal Investigator Thompson, 2001-2002) and with colleagues at Plymouth he quickly established that sub-millimetre sized fragments of plastic were widespread in sediments and in the water column in the north-east Atlantic. Using archived plankton samples his team went on to show that the abundance of this material had more than doubled over the previous 40 years, mirroring trends in plastic production, and that a range of marine organisms could ingest these fragments. In 2004 he published a paper in the journal *Science*, which summarised the findings and described the fragments using, for the first time, the name '*microplastic',* (Thompson *et al.* 2004; 90% of this work was done at Plymouth University).

Having described this new form of contamination, Thompson, then a Senior Lecturer in Marine Ecology, together with Prof. Rowland and Dr Galloway (all Plymouth University) secured further funding from the Leverhulme Trust (principal investigator Thompson, 2003-2007) to quantify microplastic contamination and examine the potential environmental consequences. They supervised PhD student Browne and Research Assistants Niven and Teuten at Plymouth University. Teuten used radio-labelled contaminants and an *in-vitro* modelling approach to show that minute quantities of microplastics (parts per million) had the potential to increase uptake of a persistent organic pollutant to deposit feeding worms (Teuten *et al.* 2007; 100% of the work for this paper was done at Plymouth University). Building on Thompson's earlier work, which had shown that a range of invertebrates could ingest microplastics (Thompson *et al.* 2004), Browne used laboratory experiments to show that, after ingestion by the commercially important mollusc (*Mytilus edulis),* microplastics translocated from the gut to the haemolymph where they could be retained for more than 40 days (Browne *et al.* 2008; 90% of the work for this paper was done at Plymouth University). The team established that microplastics originated from various sources; including the fragmentation of larger items together with waste water from domestic washing machines, and showed that these particles were now an important component of marine debris on shorelines worldwide (Browne *et al.* 2010, 2011; 100% and 90% respectively of the work for these papers was done at Plymouth University).

This body of research is important because it describes a previously neglected, but widespread, constituent of marine litter. This missing fraction helps to clarify why, despite exponential increases in the quantity of plastic waste generated; monitoring data from the environment showed no related increase in plastic debris. By contrast this work, and subsequent monitoring by others, shows a significant increase in the abundance of small fragments over time. The research also indicated that contamination of marine habitats by microplastics presented risks that differed from those

described for larger items of debris.

3. References to the research (indicative maximum of six references)

Staff based at Plymouth University at time of the research shown in bold. The following information is included: 1) ISI Impact Factor: an indication of the relative importance of each journal within its field, journals with higher impact factors are deemed to be more important; 2) The number of times a paper has been referred to as source of information / evidence in other peer reviewed scientific publications (citations); 3) the percentage of the work done at Plymouth University together with a brief description of any contributions from collaborators at other institutions.

Thompson, R. C., Olsen, Y., Mitchell, R. P., Davis, A., Rowland, S. J., John, A. W. G., McGonigle, D. & Russell, A. E. 2004. Lost at sea: Where is all the plastic? *Science* **304**, 838-838. ISI Impact Factor for this Journal is 31.20. 156 citations upto September 2013. 90% of the work for this paper was done at Plymouth University. The roles of the other authors were: John (Sir Alister Hardy Foundation for Ocean Science), to provide access to archived plankton samples; McGonigle, who as part of his undergraduate disseration extracted fragments from beaches (at Southampton University and co-supervised by Thompson) and Russell, an electrochemist (at Southampton), provided expertise on FT-IR spectroscopy to confirm the identity of the fragments. **DOI:** 10.1126/science.1094559.

Teuten, E. L., Rowland, S. J., Galloway, T. S. & Thompson, R. C. 2007. Potential for plastics to transport hydrophobic contaminants. *Environmental Science and Technology* **41**, 7759-7764. ISI Impact Factor for this Journal is 5.228. 67 citations to September 2013. 100% of the work for this paper was done at Plymouth University. DOI: **10.1021/es071737s**.

Browne, M. A., Dissanayake, A., Galloway, T. S., Lowe, D. M. & **Thompson, R. C.** 2008. Ingested microscopic plastic translocates to the circulatory system of the mussel, Mytilus edulis (L.) *Environmental Science and Technology* **42**, 5026-5031. ISI Impact Factor for this Journal is 5.228. 59 citations upto September 2013. 90% of the work for this paper was done at Plymouth University. All authors, except Lowe, were based at Plymouth Univesity (Lowe contributed technical expertise in hisology and was based at Plymouth Marine Laboratory). Between completion of the work and publication Galloway moved to Exeter University, this is reflected in her author affiliation on the paper. DOI: **10.1021/es800249a**

Browne, M. A., Galloway, T. S. & Thompson, R. C. 2010. Spatial Patterns of Plastic Debris along Estuarine Shorelines. *Environmental Science & Technology* **44**, 3404-3409. ISI Impact Factor for this Journal is 5.228. 22 citations upto September 2013. 100% of the work for this paper was done at Plymouth University. Between completion of the work and publication Galloway moved to Exeter University and Browne moved to University College Dublin, this is reflected in their author affiliations on the paper. DOI: **10.1021/es903784e**

Browne, M. A., Crump, P., Niven, S. J., Teuten, E., Tonkin, A., Galloway, T. & Thompson, R. 2011. Accumulation of Microplastic on Shorelines Worldwide: Sources and Sinks. *Environmental Science & Technology* **45**, 9175-9179. ISI Impact Factor for this Journal is 5.228, 19 citations upto September 2013. 90% of the work for this paper was done at Plymouth University. Between completion of the work and publication Galloway moved to Exeter University and Browne moved to University of Sydney, this is reflected in their author affiliations on the paper. DOI: **10.1021/es201811s**.

4. Details of the impact Superscript numbering refers to corroborative sources in Section 5

The most significant impacts, with consistent and broad reach are in terms of policy[1-3]. The first parliamentary discussions were within days of Thompson's 2004 publication and policy interest has been sustained resulting in the regulation of microplastics being incorporated into European Union Policy during 2010.

The first two microplastics papers from the team prompted the United States Department of Commerce, National Oceanic and Atmospheric Administration (NOAA) to organise the first international meeting on microplastics at the University of Washington (2008), Thompson gave the opening presentation outlining his research. The meeting resulted in a White Paper summarising current understanding on microplastics as an emerging contaminant and associated environmental

concerns, Immediate beneficiaries were NOAA and Defra ([4]Arthur *et al.* 2009, published by NOAA). In 2009 the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (an advisory body of the United Nations) organised an international meeting dedicated to microplastics. This resulted in a position statement for policy makers worldwide outlining the potential concerns arising from microplastic contamination ([5]GESAMP 2010).

Within the EU, policy to reduce microplastic contamination was implemented via the Marine Strategy Framework Directive (MSFD) in April 2010. To achieve good environmental status in the EU waters member states would need to achieve a '*measurable and significant decrease'* in the abundance of microplastics by 2020 ([7]Galgani 2010). To inform implementation Thompson presented on his research at the European Parliament (Brussels, June 2010) and EU Committee of the Regions (Brussels, November, 2010). These meetings were widely attended by MEPs and the European Commission and Prof. Thompson was subsequently asked by the EU to be a scientific expert in a Technical Subgroup to define methodological standards for member states to implement MSFD policy with respect to microplastic ([8]policy document, EC, 2011).

The importance of research by Thompson's Group, in influencing EU MSFD Policy, is summarised in a testimonial from a [1]DG Environment Policy Officer ''*Research at Plymouth directly led to the inclusion of microplastics as part of the assessment of good environmental status. In 2010, microplastics were identified in the Commission Decision on criteria and methodological standards for determining GES (2010/477/EU) as one of the key-indicators of the characteristics of litter in the marine environment."*. The research continues to be a key source of information to EU policymakers, for example: [9]Science for Environment Policy DG Environment, February 2012 is entirely based on a microplastics paper from Thompson's group (Browne *et al*. 2011) which is also cited in the 2013 Green Paper '*European Strategy on Plastic Waste in the Environment*.

As part of the UK contribution to achieving good environmental status within MSFD the Department for Environment, Food and Rural Affairs (Defra) awarded a competitively won tender (ME 5416, 2010 – 2014) to Thompson together with colleagues Rowland at Plymouth University and Galloway (now at University of Exeter), to establish the extent to which microplastics might cause harm in the marine environment. The importance of research by Thompson's group in influencing policy is outlined in a testimonial from a [2]Defra Policy Officer (2012) '*'The inclusion of a requirement to understand trends in the amount, distribution and composition of microplastics in a legally binding European Directive was only made possible by the compelling evidence put forward by the group"* Similarly, the importance in the US is outlined by a [3]Programme Director within Ocean Conservancy (2013).). ''His work has helped re-shape how scientists and policymakers view the persistent problem of marine debris and influenced a number of processes here in the United States. This includes the strategies employed by Ocean Conservancy and other non-profit organizations to confront the threat of plastic pollution in the ocean. Thompson's insights have also influenced how the U.S. Environmental Protection Agency approaches the issue of marine debris''. In 2013 Thompson was invited to present evidence on microplastics to the [6]House of Commons Science and Technology Select Committee as part of their consideration of water quality in the UK. An outcome being a discussion on banning microplastics in cosmetics. Several global companies including Unilever, Colgate Palmolive and L'Oreal have voluntarily withdrawn microplastics (described by manufacturers as '*microbeads'*) from their products in 2013.

More generally, three of the publications in Section 4 were independently acknowledged in the journal Environmental Science and Technology**'**: in 2008, Teuten *et al.* (2007) and Browne et al. (2008) were highlighted as **'***two of the most influential papers in the field'*, and in 2012 Browne *et al.* (2011) was awarded *'best paper of the year'.* Following the discovery of microplastics, there have been themed sessions at international conferences in Europe and the USA. In addition, there have been over 100 media articles and programmes on the topic (including New York Times, Washington Post, Das Spiegel, El Pais, Guardian, BBC). The research has inspired artistic representations, educational projects (e.g., El Viaje de Jurella y los Microplásticos, a national educational programme throughout Chile) and been incorporated into popular science books (*The World Without US*, A. Weisman and *Reporting Live form the End of the World, D.* Shukman). In 2010 Thompson was invited to participate in a public debate as part of the Plastics Europe Annual Meeting (a trade organisation representing European plastics industry). Facilitated by a BBC journalist this took the form a discussion between representatives from the plastics industry and

international marine pollution experts (Thompson, Galgani, van Franeker). It was held in front of an audience of 200 who indicated their opinions on marine litter in real time using hand-held electronic voting tools and was broadcast live as a pod-cast.

In terms of global solutions to the growing problem of marine debris, of which microplastics are a part, Thompson was asked by the United Nations Environment Programme to identify '*Global and Regional Solutions to the Marine Debris Problem* ([10]STAP 2011).

5. Sources to corroborate the impact

Statements from policy beneficiaries

1. DG Environment Policy Officer, EU (2012), DG Env Unit Marine Environment and Industrial Water. D" B-1049 Brussels, Belgium. Statement indicating importance of work by Thompson's Group at Plymouth in providing evidence leading to inclusion of microplastics in policy relating to Good Environmental status in EU waters.
2. Marine Policy Advisor, Defra (2012). Marine Division, DEFRA, 8B Millbank, Nobel House, 17 Smith Square, London SW1P 3JR. Statement indicating importance of Thompson's research in providing evidence to UK Government in relation to Marine Strategy Framework Directive and informing UK Government position paper on marine litter.
3. Director of Trash Free Seas, 2013, US Ocean Conservancy, 725 Front Street, Suite 201, Santa Cruz, CA 95060. Statement indicating that Thompson's research reshaped how scientists and policymakers in the US view the problem of marine debris.

Documented evidence of policy debate/relevance of the work on microplastics

4. Arthur, C., Baker, J. & Bamford, H., 2009 Proceedings of the international research workshop on the occurrence, effects and fate of microplastic marine debris: NOAA Technical Memorandum NOS-OR&R30. The first White Paper on microplastics
5. Proceedings of the GESAMP International Workshop on plastic particles as a vector in transporting persistent, bio-accumulating and toxic substances in the oceans, 2010 in*: GESAMP Reports and Studies* (eds. T. Bowmer & P. J. Kershaw) MO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP. Position statement for policy makers worldwide outlining the concerns arising from microplastic contamination.
6. House of Commons Science and Technology Committee, Water Quality: Priority Substances. First Report of Session 2013-14, Volume II, Oral and Written Evidence. HC 272-11, 17th June, 2013. HMSO. ISBN 978 0215 05906 2.

Documents evidencing policy implementation of Thompson's work on microplastics

7. Galgani, F., et al., Task Group 10: Marine Litter. In *JRC Scientific and Technical Reports*. Ispra: European Commission Joint Research Centre. This document incorporates Thompson's work on microplastics into EU policy requiring Member States to achieve a 'measurable and significant decrease' in the abundance of microplastics by 2020.
8. EC, 2011 European Commission, Joint Research Centre, MSFD GES Technical Subgroup on Marine Litter Marine Litter, Technical Recommendations for the Implementation of MSFD Requirements. Ispra: European Commission Joint Research Centre. EUR 25009 EN – 2011.

Documents evidencing international policy guidance stemming from Thompson's work

9. Science for Environment Policy, DG Environment: Microplastics from washing machine wastewater are polluting beaches, 2012. Policy brief based entirely on Browne *et al.* 2011.
10. STAP, 2011 Marine Debris as a Global Environmental Problem: Introducing a solutions based framework focused on plastic. United Nations Environment Programme, Global Environment Facility Washington, DC, pp. 40.