Institution: University of Exeter		
Unit of Assessment: UoA 7 Earth Systems and Environmental Sciences		
Title of case study: Research on the Ecological Impacts of Plastics in the Marine Environment Influences National and International Policy		
Period when the underpinning research was undertaken: 2010-2019		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Prof Tamara Galloway	Chair in Ecotoxicology	2007-present
Dr Ceri Lewis	Associate Professor in Marine Biology	2007-present
Prof Brendan Godley	Chair in Conservation Science	
Dr Matt Cole	Research Fellow	2006-present 2013- 2018
Period when the claimed impact occurred: 2014 - 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Pioneering research by the University of Exeter showed, for the first time, the extent to which microscopic plastic waste (microplastic) is ingested by marine animals and its potential to cause harm. These findings were pivotal in supporting **policy change across the world**, including a UN Resolution; a legal ban on plastic microbeads in cosmetics in the UK in 2018, which removed 4,000 tonnes of microplastic per year from the supply chain; and a proposal by the EU to remove microplastics from all commercial products, which will prevent a further **500,000 tonnes** (or **9.76 trillion microplastic particles a year**) from entering the oceans. **Prolific media coverage has reached hundreds of millions of people and** supported voluntary and regulatory initiatives around the world to reduce microplastic waste, protecting the environment and human health.

2. Underpinning research

Microplastics are ubiquitous pollutants

Microplastics are fragments of plastic debris <1 mm in diameter that form from the breakdown of larger plastic pieces. They are also deliberately manufactured to be of a small size (e.g., when added as microbeads to face scrubs and toothpaste). Each time these products are used, hundreds of thousands of microplastics are released down the drain and into the marine environment where they remain for centuries. Before the research by the team at the University of Exeter, virtually nothing was known of the potential for microplastics to cause harm in the environment. Since 2007, Prof Galloway and her team have conducted pioneering research on the fate and toxicity of microplastics, producing the first, and now highly cited, publications to document the negative impacts of microplastics in the marine environment, which have generated positive impacts far beyond academia.

Initially, Prof Galloway (with Prof Richard Thompson, Uni of Plymouth) was funded by the **Leverhulme Trust** to study the fate and behaviour of microplastics in the oceans. After first developing methods to identify microplastics, they discovered that UK shorelines were widely contaminated. They then extended their studies to 18 sites across six continents, from the poles to the Equator, showing microplastics to be ubiquitous contaminants in the marine environment **[3.1].**

Contamination of marine animals

Building on the persuasive evidence of widespread contamination, and following Prof Galloway's move to Exeter in 2007, the team received funding from **Defra** to study what toxic effects, if any, microplastics have on marine animals. They used highly sensitive *fluorescence bio-imaging* to show that microplastics were taken up by filter-feeding shellfish (edible mussels and oysters). The particles were translocated across the gut into the animal's tissues, where they remained for several months **[3.2]**. Similar results were found for a wide range of marine species including

crabs, seals, dolphins, and whales (e.g. **[3.3]).** This raised concern that microplastics could transfer through the food chain to other animals and ultimately to humans.

Harmful effects to animals on the seafloor

Heavier plastics tend to settle out to the ocean floor and can be ingested by the animals that live there. In 2013, the team showed that marine worms lost up to 50% of their energy stores when inhabiting sediments contaminated by polyvinyl chloride (PVC), which is commonly found in marine litter. This was due to reduced feeding, inflammation of the gut and ingested material taking longer to pass through the gut **[3.4].** Since marine worms help to maintain the healthy function of marine sediments and are important food sources for fish and wading birds, these ground-breaking findings emphasized the need to reconsider the hazard classification of PVC and other plastics.

Implications for the marine ecosystem

Lighter plastics float in the water column, gathering in places where ocean currents meet. Plankton accumulate in these areas of confluence too. With a **NERC** grant, the Exeter team (with Dr Pennie Lindeque from Plymouth Marine Laboratory) examined the impact of microplastics on microscopic plankton through laboratory-based experiments and subsequent field sampling. They found that microplastics were ingested by more than a dozen zooplankton species common to the northeast Atlantic, and that the plastics impeded survival **[3.5].** *Hyperspectral Raman bio-imaging* was used for the first time to visualise microplastics accumulating between the copepod's limbs, affecting their ability to move and subsequently aggregating in the gut, obstructing their feeding **[3.6]**Error! Reference source not found.

The team then showed that faecal pellets excreted by copepods that had ingested microplastics settled more slowly through the water column compared to those that fed normally. Not only does this increase the chance that the microplastics would be ingested by other animals that feed on the detritus, but it also has the potential to impede the **ocean's biological pump**, which removes organic carbon from the ocean surface and deposits it in the deep oceans. As copepod plankton are the most abundant multicellular lifeforms on the planet, and form a key trophic link between primary producers and animals further up the food web, these critically important discoveries raised global conservation concern.

3. References to the research (6 papers chosen from a core of 50+ related articles cited >25,000 times). Four of the team's papers are identified by bibliometric analysis to be in the top ten most influential in the field (Zhang et al 2020, *J. Haz. Mat.* 400: 123110), whilst the European Chemicals Agency identifies several of the team as the most influential authors in the field worldwide **[5.9]** (p 52-55). Exeter authors are shown in bold.

3.1 Browne MA, Crump P, Niven SJ, Teuten E, Tonkin A, **Galloway TS**, Thompson R (2011). Accumulation of microplastic on shorelines worldwide: Sources and sinks. *Environmental Science and Technology,* **45**(21): 9175-9179. doi: 10.1021/es201811s

3.2 Cole M, Galloway TS (2015). Ingestion of Nanoplastics and Microplastics by Pacific Oyster Larvae. *Environmental Science & Technology*, **49**(24): 14625-14632 http://pubs.acs.org/doi/10.1021/acs.est.5b04099

3.3 Watts, A, Urbina, M, Corr, S, Lewis, C, Galloway TS (2015) Ingestion of Plastic Microfibers by the Crab *Carcinus maenas* and Its Effect on Food Consumption and Energy Balance *Environmental Science and Technology*, 49 (24): 14597–14604 https://doi.org/10.1021/acs.est.5b04026

3.4 Wright SL, **Rowe D**, Thompson RC, **Galloway TS** (2013). Microplastic ingestion decreases energy reserves in marine worms. *Current Biology,* **23** (23): R1031-R1033. doi: 10.1016/j.cub.2013.10.068

3.5 Cole M, Lindeque P, Fileman E, Halsband C, **Goodhead R, Moger J, Galloway TS** (2013). Microplastic ingestion by zooplankton. *Environmental Science and Technology,* **47** (12): 6646-6655. doi:10.1021/es400663f

3.6 Cole, M, Lindeque, P, Fileman, E, Clark, J, Halsband, C, **Galloway, TS** (2016). Microplastics alter the properties and sinking rates of zooplankton faecal pellets, *Environmental Science and Technology*, **50** (2): 3239-3246 https://pubs.acs.org/doi/10.1021/acs.est.5b05905

4. Details of the impact

The impact of this research on policy and society has been widely recognised at an international level. It led Prof Galloway to be awarded the OBE in 2019 and to be listed by Web of Science (2017-2020) as one of the '*World's Most Highly Cited Scientists'*. The Exeter team has won numerous awards; *The Guardian*'s **University Award 2018** for Research with Outstanding Societal Impact; NERC's **Societal and Policy Impact Award** 2018 and **Overall Impact Winner** for the most outstanding piece of impactful research from all NERC's funded work in 2018. In 2019, the team received the **Queen's Anniversary Prize**, the highest national honour awarded in higher education, recognising work of exceptional societal benefit**.**

Why was policy change needed?
In addition to face scrubs and body washes, microbeads are added to diverse products – e.g., as anti-caking agents in detergents, as fibre reinforcements in building materials, in diagnostic and medical products, waxes, polishes and 3D printing inks. Around **51,500 tonnes** of microplastics end up in the environment each year after products containing them are used. Although this is a small proportion of the **18 million tonnes** of plastic waste released each year **[5.1]**, it still represents **9.76 trillion plastic particles** (or 5.64 times the amount of plastic in the Great Pacific Garbage Patch) and is **entirely preventable**. Exeter's work documenting the ubiquity and negative impacts of microplastics in marine environments provided **critical impetus for policy changes** to prohibit the use of microbeads both in the UK and abroad. In 2018 Energy & Clean Growth Minister Claire Perry stated that in *"revealing the harmful effects of microplastics … the UK research team has influence[d] policy and behavioural change across the globe"* **[5.2].**

Policy change in the UK
In February 2013, the team's findings were cited in two position papers submitted to the UK House of Commons Science and Technology Committee **[5.3]** underpinning a successful effort to include microplastics in the Committee's inquiry into water quality. The Government's response to the inquiry in 2014 noted Exeter's work on the potential harm of microplastics and its advice that Government engage with industry to ensure momentum towards the phasing out of microplastics from consumer products **[5.4].** In 2015 and 2016 Exeter's research, cited in Parliamentary Office of Science and Technology notes **[5.5]**, further alerted UK policy-makers to the risks of microplastics. In June 2016, the team submitted written evidence and Prof Galloway submitted oral evidence to an **Environmental Audit Committee** hearing on 'Microbeads in the Marine Environment' **[5.6];** the submissions directly led to a ban on the addition of microplastics to rinse-off consumer products, announced in August 2016 and which came into full force in January 2018. Galloway's success in influencing policy was highlighted in a 2016 *Nature* article on advocacy, noting that '*presenting science to politicians in a way they can understand can have good outcomes'* **[5.7].**

The new law banning microbeads from rinse-off consumer products, informed by the Exeter research, has directly led to the removal of an estimated **4,000 tonnes of microbeads** from the UK supply chain alone each year **[5.6],** preventing an estimated **76 billion microplastic particles** from entering the oceans.

Policy change around the globe
Exeter's research has influenced policy change far beyond the UK's borders, building on the impetus of the ground-breaking UK policy change to restrict microbeads:

Canada and USA: A 2015 **Canadian** Environment Agency report references 16 papers by the Exeter team and recommends that "microbeads be considered toxic under subsection 64(a) of the Environmental Protection Act 1999"**.** In the **US**, the Microbead-Free Waters Act (2015) was informed by National Oceanic and Atmospheric Administration sources produced as part of its Marine Debris Program, including a 2011 workshop referencing Prof Galloway's research **[5.8].**

United Nations: Oral evidence provided in June 2016 by Prof Galloway to a UN session on marine plastic debris was cited four times in a presentation to the UN General Assembly on 13th September 2016, leading to a December 2017 resolution by more than 200 nations at the UN Environment Assembly to eliminate marine plastic pollution. The resolution referenced a 2016 UN Environment Programme report, citing 24 publications including Prof Galloway as author. In addition, 34 papers co-authored by Exeter team members are cited in a 2015 report from the UN on how to measure microplastics **[5.9].**

Europe: In 2018, the European Chemicals Agency (ECHA) reviewed the scientific basis for taking regulatory action at an EU level. Citing all of the papers listed in section 3 and many others from the team, the report notes Galloway and Cole to be the 2 most influential authors in the world regarding the ecotoxicology of microplastics (p52). It identifies 5 of the Exeter team's papers to be in the top 10 most influential (p55). The report recommends restriction of intentionally added microbeads **from all consumer products by 2022**, a proposal which is expected to be approved and come into force in 2021. This groundbreaking legislation is considered the most comprehensive in the world **[5.1**]. The EU legislation alone will prevent around **500,000 tonnes** of microplastics waste reaching the environment, generating funding of **€91 billion** for reformulations and new materials innovations**.**

Improving public understanding

The research has stimulated public interest and debate, and supported the campaigns of numerous non-profit organisations to reduce the release of microplastics into the environment.

Two examples of **evidence-based science reporting** are: '*Mounting microplastic pollution harms "earthworms of the sea" –Guardian report'*, [**37 million unique visitors**]; and an interview by Galloway based on the NERC funded science with *BBC News at Ten* and the *BBC World News.* This interview was given on September 28th, 2015 to coincide with the introduction of a charge on plastic bag use in the UK and reached an estimated international **audience of 500 million**. Profs Galloway and Lewis were appointed as scientific advisers to the BBC Natural History Unit's highly influential ***Blue Planet II*** series, bringing the issue of plastics in the ocean to unprecedented international attention. An estimated **80 million viewers** worldwide watched the first episode in 2017 **[5.10].**

In the UK, Exeter's research has featured on *Inside Out Southwest*, *The One Show*, *Food Unwrapped*, *Springwatch,* Sky News, BBC Radio 4's *Today*, while overseas, the findings have been covered by Fox News, the Canadian Broadcasting Company, Russian State television and multiple media outlets in China and Japan, among numerous others worldwide. The research has also supported a myriad of NGO initiatives. For instance, a 2016 Greenpeace report on the dangers of plastics in seafood references multiple papers by the Exeter team, and the research is also cited in position papers released in 2019 by the 'Beat the Microbead' (BTMB) campaign calling for companies to remove microbeads from products **[5.11].**

In 2018 Dr Phil Heads, NERC's Director of Research & Innovation, confirmed that Exeter's work on microplastics *"has captured phenomenal public interest and led to action all over the world from governments, businesses and citizens … It is in no small part thanks to these scientists … that our perceptions about the use of disposable plastics in our everyday lives have undergone a seismic shift."* **[5.2].**

5. Sources to corroborate the impact

5.1 European Chemicals Agency 2018 Annex XV Restriction Report: Proposal for a restriction. Intentionally added microplastics. https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18244cd73

5.2 NERC Impact Awards 2018. *Winners make an impact on our world. 4 Dec 2018.* https://webarchive.nationalarchives.gov.uk/20200930164851/https://nerc.ukri.org/press/releases/2018/57-impact-winners/.

UK policy debate and change

5.3 Position papers: North Sea Foundation, Marine Conservation Society, Seas at Risk and Plastic Soup Foundation. 2012. *Micro plastics in personal care products.* Position Paper. http://www.mcsuk.org/downloads/pollution/positionpaper-microplastics-august2012.pdf; 5 Gyres Institute, Plastic Soup Foundation, Surfrider Foundation, Plastic Free Seas and Clean Seas Coalition. 2013. *Microplastics in consumer products and in the marine environment.* Position Paper. http://5gyres.org/media/5_Gyres_Position_Paper_on_Microplastics.pdf

5.4 House of Commons Science and Technology Committee. 2014. *Water quality: priority substances: Government Response to the Committee's First Report of Session 2013–14 Fourth Special Report of Session 2013–14 (HC 648)* https://publications.parliament.uk/pa/cm201314/cmselect/cmsctech/648/648.pdf

5.5 Parliamentary Office of Science and Technology (POST) 2016. *Trends in the Environment. Research Briefing.* http://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-0516 and POST 2016. *Marine Microplastic Pollution. Research Briefing.* http://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-0528

5.6 Environmental Audit Committee (UK Parliament). 2016. *Fourth Report of Session 2016–17, Environmental impact of microplastics (HC 179). 24 August 2016.* https://publications.parliament.uk/pa/cm201617/cmselect/cmenvaud/179/17905.htm

5.7 Woolston, C. 2016. 'Science advocacy: Get involved'. *Nature,* 540 (7634): 611-612.

International policy debate and change

5.8 Department of Environment and Climate Change, Government of Canada. 2015. *Microbeads – A science summary. July 2015;* Arthur, C. and J. Baker (eds.). 2011. *Proceedings of the Second Research Workshop on Microplastic Debris. November 5-6, 2010. NOAA Technical Memorandum NOS-OR&R-39.* https://marinedebris.noaa.gov/proceedings-second-research-workshop-microplastic-marine-debris

5.9 IISD Reporting Services. 2016. Summary of the 17th Meeting of the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea 13-17 June 2016. *Earth Negotiations Bulletin.* 25 (107) 20 June 2016.https://enb.iisd.org/vol25/enb25107e.html ; UN Environment Programme. 2016. *Marine plastic debris and microplastics - Global lessons and research to inspire action and guide policy change.* https://wedocs.unep.org/handle/20.500.11822/7720; UN Joint Group of Experts on Scientific Aspects of Marine Protection (GESAMP). 2015. *Sources, fate and effects of Microplastics in the Marine environment: Part 2 of a global assessment*. http://ec.europa.eu/environment/marine/good-environmental-status/descriptor-10/pdf/GESAMP_microplastics full study.pdf
Also see **5.1** above for European Chemicals Agency details

Publicity and media interest

5.10 Aldred, J. 2013. Mounting microplastic pollution harms 'earthworms of the sea' – report. *The Guardian.* 2nd Dec 2013. https://www.theguardian.com/environment/2013/dec/02/microplastic-pollution-harms-lugworms-sea-oceans; Cumberbatch, A.G. 2017. Blue Planet II is so popular in China that it 'caused the internet to temporarily slow down'. *Evening Standard.* 13 November 2017. https://www.standard.co.uk/stayingin/tvfilm/blue-planet-ii-is-so-popular-in-china-it-caused-the-internet-to-temporarily-slow-down-a3689806.html

NGO campaigns

5.11 Greenpeace Research Laboratories. 2016. *Plastics in Seafood*. https://storage.googleapis.com/gpuk-static/legacy/PlasticsInSeafood-Final.pdf ; Beat the Microbead. 2019. *The BTMB campaign demands restriction of all intentionally added microplastics under REACH* [Position Paper]. https://www.beatthemicrobead.org/