Institution: Queen Mary University of London		
Unit of Assessment: 8		
Title of case study: Informing the Public Debate on the Environmental Impact of Plastic-based Pollutants		
Period when the underpinning research was undertaken: 2012 - present		
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:**
1) Marina Resmini	1) Professor of Materials Chemistry, School of Biological and Chemical Sciences	1) 1999 - present
2) Ruth Rose	2) Protein Facility Manager, School of Biological and Chemical Sciences	2) 2009 – present
Period when the claimed impact occurred: 2016 – present		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

When plastics degrade, they release toxic pollutants into soil and water, causing long-lasting damage to the environment. To address this issue, it is vital that international policymakers have accurate data on how both traditional and new plastics degrade. A team of scientists at Queen Mary has developed new, accurate methods for determining rates of biodegradation of different plastics. They have also generated new evidence on how some plastics are naturally broken down by bacteria. This research has i) informed public policy debate on the biodegradation of plastics in the UK and Europe and ii) underpinned the development of new UK guidelines on the analysis of plastics in the environment. The research has informed European Commission debate on the introduction of new regulations governing new biodegradable plastics, and has been used by not-for-profit and governmental organisations, including the Oxo-biodegradable Plastic Association (OPA) and the Department for Environment, Food & Rural Affairs (Defra) to develop policy.

2. Underpinning research

There is overwhelming evidence that plastic materials are accumulating in large quantities on land, and in oceans, seas, rivers and lakes across the world, damaging some of our most important natural environments. Traditional plastics, such as low-density polyethylene, commonly used in plastic bags, are non-degradable. This has led to a rapid search for viable alternatives. Biodegradable polymers, such as plant-based hydrodegradable, compostable plastics and oxo-biodegradable plastic, which contains a catalyst to aid degradation when exposed to oxygen, are among the new materials developed. Industries are being urged by governments, regulators and consumers to adopt these new materials and their use is increasing exponentially, with 2,110,000 tonnes manufactured in 2018 alone.

When developing legislation and guidelines on the use of these new plastics, regulators need to weigh the advantages and disadvantages of different materials and evaluate their biodegradability and the environmental impact of any derived micro-sized particles. By 2050, it is estimated that 12,000,000,000 tonnes of microplastic from the degradation of waste plastic will have entered the environment. Until recently, this evaluation has been challenging due to a lack of high-quality analytical methods and poorly reproducible measurements of biodegradability. A multidisciplinary team of polymer chemists, biochemists, microbiologists and environmental biologists at Queen Mary has worked to address this problem, developing reproducible measurements of biodegradability of different plastics and a standardised approach to analysing their impact on the environment.

The team's research started in 2011 in the Department of Chemistry, when Prof. Resmini developed an interest in degradable plastic, which resulted in an EPSRC grant [EQR.1] to explore the concept of 'self-immolative' polymers, where the main backbone chain of the plastic was expected to breakdown, following the activation by an enzymatic trigger. This led to an interest in studying micro- and nano-particles and their behaviour at the air-water interface [3.1], which in turn led to a new collaboration with Dr. Rose, a biochemist based in

the School of Biological and Chemical Sciences. The team initiated a programme of research that focused on biodegradable plastics and environmental pollution.

In a significant innovation, the researchers developed a new, accurate and highly reproducible method for evaluating the biodegradability of different plastics in water [3.2], which was achieved by monitoring bacterial respiration in an aqueous media supplemented with plastic samples. The scientists use gas-chromatography to measure levels of CO_2 evolved from a fully defined liquid media containing a single microbial culture and a single carbon source, the plastic polymer. The assay is reliable, is not dependent on the source of the micro-organisms, and does not require the use of soil samples. Most importantly, it enables precise and reproducible comparison of the biodegradability of different types of plastic.

Building on this advance, Resmini developed a new collaborative project with Dr. Jones, an environmental scientist in the School of Biological and Chemical Sciences with significant experience in pollution pressures in aquatic systems. Jones is an expert in the analysis of long-term, large-scale data to determine trends in the environmental impacts of stressors from agriculture, industry and invasive species [3.3]. The aim of their collaboration was to generate new and improved understanding of the impact degraded microplastics have on the environment.

In 2018, Defra commissioned Jones [EQR.2] to carry out an analysis of existing research evidence on the sampling and measurement of microplastic pollution in water. Simultaneous to this Defra commission, Resmini and Jones carried out a systematic analysis of reliable global data detailing the relative abundance of polymers in freshwaters and estuaries. The results [3.4] show that microplastics comprised of polyvinyl chloride and polyurethane are significantly less abundant than might be expected, given their levels of global production. This has implications for models of microplastic environmental pollution that are based on production levels and on the environmental fate of chemicals. When analysed by matrix (water, sediment or biota) distinct profiles were obtained for each category. The data suggest that the environmental distribution of microplastic particles, influenced by physical, chemical and biological processes, plays an important role in their environmental impact. However, attempts to explain the concentrations of different plastics found in matrices on the basis of their densities have not been successful, suggesting that the problem is far more complex. For example, the research team found that certain types of microplastics are found in much higher quantities in plant or animal life (biota) compared to water or sediment. This raises an important question about why biota absorb some microplastics but not others, highlighting the need for more and better-informed laboratory exposure studies.

The study of microplastics is relatively new, and the team at Queen Mary is leading the way in developing a standardised approach to analysing its environmental impact. This, combined with the new ability to compare a wide variety of plastic samples, including standard low-density polyethylene, oxo-plastic and bioplastic under identical experimental conditions has enabled the direct comparison of the relative biodegradability of various polymers. As such, the team has provided reliable and reproducible data that have been used by regulators, policymakers and industry groups to formulate positions on the use of plastics and policies on plastic degradation.

3. References to the research

[3.1] Zielinska, K., Campbell, R. A., Zarbakhsh, A. & Resmini, M. (2017). Adsorption versus aggregation of NIPAM nanogels: new insight into their behaviour at the air/water interface as a function of concentration. *Physical Chemistry Chemical Physics*, *19* (26), 17173-17179. https://doi.org/10.1039/C7CP02979A

[3.2] Rose, R. S., Richardson, K. H., Latvanen, E. J., Hanson, C. A., Resmini, M. & Sanders, I. A. (2020). Microbial degradation of plastic in aqueous solutions demonstrated by CO_2 evolution and quantification. *International Journal of Molecular Sciences*, *21* (4), 1176. https://doi.org/10.3390/ijms21041176

[3.3] Duerdoth, C. P., Arnold, A., Murphy, J. F., Naden, P. S., Scarlett, P., Collins, A. L., Sear, D. A. & Jones, J. I. (2015). Assessment of a rapid method for quantitative reach-scale estimates of deposited fine sediment in rivers. *Geomorphology*, *230*, 37-50. https://doi.org/10.1016/j.geomorph.2014.11.003

[3.4] Jones, J. I., Vdovchenko, A., Cooling, D., Murphy, J. F., Arnold, A., Pretty, J. L., Spencer, K. L., Markus, A. A., Vethaak, A. D., & Resmini, M. (2020). Systematic Analysis of the Relative Abundance of Polymers Occurring as Microplastics in Freshwaters and Estuaries. *International Journal of Environmental Research and Public Health*, *17* (24), 9304. https://doi.org/10.3390/ijerph17249304

Evidence of the quality of the research

[EQR.1] Resmini, M. [PI]. (01/02/2011). Grant focused on self-immolative polymers [IO14578/1]. *EPSRC*. Bright Ideas Awards. GBP212,000 (supported the recruitment of a postdoctoral researcher).

[EQR.2] Jones, J. I. [PI]. (2018). Evidence Reviews on Analysis, Prevalence and Impact of Microplastics in Freshwater Environments (WT15112). *Defra*. GBP56,943.

[EQR.3] Jones, J. I. [PI/Coordinator of international consortium] (2019-2022). Preventing Plastic Pollution: A Catchment Based Approach To Plastic Pollution (984616). *Interreg*. GBP12,044,442.

[EQR.4] Resmini, M, (2020-2024). A Queen Mary-funded CDT that supports 4 PhD students researching the environmental impact of biodegradable plastic, in collaboration with industrial partners Symphony Environmental (oxo-biodegradable polymers), Parkside Flex (biopolymers for foods), Jacobs Douwe Egberts UK (coffee production company) as well as the Food Standards Agency, Thames 21 and the Lloyds Register Foundation.

4. Details of the impact

Opinion is greatly divided over the environmental impact and the biodegradability of traditional plastics versus new biodegradable plastics, in particular oxo-biodegradable plastics. This is due to inconsistency in methods used to sample, measure and analyse biodegradation. Both Defra, in the UK, and the European Commission, have driven the public debate on this topic, with the aim to establish clear policies and guidelines, benefitting both producers of the materials and the wider public. These regulators require reliable and consistent scientific data. The team at Queen Mary has informed and advanced the debate by: i) developing a new, reproducible method for evaluating the biodegradability of different plastics under identical conditions, and providing new data on the fate of oxo-biodegradable plastic in the environment; ii) demonstrating the urgent need for standardising approaches in monitoring microplastics and their environmental impact.

Informing regulators on the fate of oxo-biodegradable plastic in the environment

In 2016 the European Commission (EC) commissioned the environmental consultancy Eunomia Research & Consulting to carry out a project to evaluate the impact of the use of oxo-degradable plastic on the environment. A number of scientists were invited to present their work, including the Queen Mary team. Rose presented the team's key results, which had yet to be published. The final report presented to the EC by Eunomia [5.1] was designed to inform the European policy on oxo-biodegradable plastic. The report described the strength of Queen Mary's evidence, stating: "The findings are significant and the test method unique" (p. 45) [5.1]. As a result the EC in 2017 delayed a decision to ban oxo-degradable plastics.

The public debate on the impact of oxo-degradable plastic in the environment continued, led by the EC's Directorate-General for Environment, responsible for the EU's environmental policy, and the Oxo-biodegradable Plastic Association (OPA), a not-for profit organisation that represents over 1,600 companies worldwide involved in the use of oxo-biodegradable plastic.

The main issue was the concern that biodegradation technology could lead to the formation of large quantities of microplastic in the environment. This was raised as a query by the EC to the European Chemicals Agency (ECHA) in December 2017. The EC stated: "The United Nations Environment Programme estimates that damage to marine environments is at least USD 8 billion per year globally." In their response, the OPA published a report *Rethinking the Future of Plastics* [5.2], which addressed the issues raised by the ECHA (January 2018). Citing Queen Mary's research evidence extensively, the OPA argued that the degradation process is not a fragmentation of the polymer, but instead an entire change of the material into molecules that can be bio-assimilated. "This point is absolutely crucial to an understanding

of oxo-biodegradable plastic technology," they said in a supporting report to *Future of Plastics* [5.3]. The OPA described the Queen Mary team's observational studies in seawater in France: "Oxo-bioplastic has been degraded in real time in seawater [in] Bandol in France, and the scientists at Queen Mary observed the resulting material being used as a food-source by bacteria commonly found on land and in the oceans…in their view there is no reason why this process should stop in the natural environment until all the material has been consumed" [5.3].

The research evidence produced by Queen Mary has been used to address the debate on the key difference between oxo-degradable and oxo-biodegradable plastics, the latter designed to convert at the end of their useful life into biodegradable materials and to biodegrade under any conditions in the open environment within a much shorter timescale. In December 2020, Symphony Environmental Plc – a company that develops additives to make ordinary plastic biodegradable, which operates in more than 90 countries – presented a legal challenge to the EU on the basis that it is failing to differentiate between oxo-degradable and oxo-biodegradable plastic [5.4], citing Queen Mary's research.

The policy discussions around the biodegradability of novel types of plastics continues, as more scientific evidence is gathered to support new policy and guidelines. Mr. Michal Laurier, Chief Executive Officer of Symphony Environmental, has testified to the contribution the Queen Mary team has made to the policy debate on oxo-biodegradable plastic, stating: "Experiments conducted by Dr Rose and her colleagues…have shown that oxo-biodegradable plastics do indeed become biodegradable if discarded in the open environment, and are consumed by bacteria commonly found on land and by bacteria commonly found in the oceans…The University has therefore made an important contribution to the advancement of science in this area, and to the protection of the environment worldwide" [5.5]. In 2018, an independent review of the evidence on oxo-biodegradable technology by Peter Susman QC, cited Queen Mary's research [5.6] (p. 9). The contribution of Queen Mary to the public debate has been further recognised by the Chairman of the OPA in 2020 [5.7].

Informing new policy on the sampling and analysis of plastics in the environment

In 2018, Jones was commissioned by Defra to provide evidence to inform new guidelines and standards on the sampling and analysis of microplastics in fresh water. In the spring of 2020 the research evidence was published and presented by Defra (view the report). A Scientific and Policy Advisor at Defra commented on the report [5.8], saying: "it will prove to be a valuable reference document when reviewing and evaluating new and reported 'microplastic' studies/research irrespective of whether they have been performed in fresh, estuarine or offshore waters." In relation to how Defra will use the research evidence contained in the report, the Scientific and Policy Advisor said: "We see this review being a key document and playing an important part in the early development of standardising methodologies from sampling, sample preparation, analysis, characterisation, to reporting" [5.8].

Developing this work, Resmini and Jones undertook more analysis on the environmental impact of microplastics, which resulted in new evidence of the lack of standardisation in sampling and measurements. The researchers also identified important gaps in the understanding of the sources and fate of microplastics in the environment. The findings were shared with Defra, who then invited the Queen Mary team to present them in a meeting of the UK Academics-Regulators Nanomaterial Risk Assessment Group (11/11/2020) [5.9] to ensure wider dissemination of the data to important stakeholders. This Group is a European Commission consortium bringing together 25 influential partners across Europe to discuss the latest research and regulatory priorities in this policy field. Members include large multinationals, such as Unilever, BASF and AkzoNobel and national regulatory agencies, such as the National Institute for Public Health and the Environment in The Netherlands, and the Istituto Italiano di Tecnologia in Italy.

When describing the impact of Queen Mary's research on policy development at Defra [5.10], Dr. Steve Morris, Senior Scientific Advisor at Defra, says that it has had a "distinct and material contribution" to Defra's position on "future policy on the environmental impact of microplastics" in freshwater and estuarine environments. Dr. Morris states that the researchers have identified "gaps in our current understanding of the sources and fate of microplastics…[and] new and key factors influencing the environmental effects of microplastics and the

interpretation of data from real-world monitoring and experimental studies." Dr. Morris concludes: "The environmental impact of microplastics is an important priority for Defra and the findings by Jones and Resmini have highlighted key issues that are being considered as we develop policy" [5.10].

5. Sources to corroborate the impact (indicative maximum of 10 references)

[5.1] Eunomia. (2016). *The Impact of the Use of "Oxo-degradable" Plastic on the Environment*. For the European Commission DG, Environment. Project conducted, under Framework Contract No, ENV.A.2/FRA/2015/0008. Report for DG Environment of the European Commission. http://publications.europa.eu/resource/cellar/ab9d2024-2fca-11e7-9412-01aa75ed71a1.0001.01/DOC_1 – https://doi.org/10.2779/081633

[5.2] Oxo-Biodegradable Plastics Association. (2018). *Rethinking the Future of Plastics* (pp. 24-25). https://www.biodeg.org/wp-content/uploads/2020/05/re-thinking-the-future-of-plastics-report-3-10-17.pdf

[5.3] Oxo-Biodegradable Plastics Association. (2018). *OPA responds to European Commission*.

[5.4] *Symphony Environmental Technologies*. Document presenting the legal challenge to EU on plastics (21 December, 2020).

[5.5] M. Laurier. Chief Executive Officer. *Symphony Environmental* (testimonial letter, 18 January, 2018). [Corroborator 1]

[5.6] Susman, P. (QC). (5 November, 2018). *Oxo-biodegradable Plastic Technology*. An independent review. https://www.biodeg.org/wp-content/uploads/2020/05/qc-opinion.pdf

[5.7] M. Stephen. Chairman. *Oxo-biodegradable Plastic Association* (testimonial letter, 20 January, 2020). [Corroborator 2]

[5.8] Scientific and Policy Advisor. *Defra* (testimonial letter, 9 March, 2021). [Corroborator 3]

[5.9] *UK Academics-Regulators Nanomaterial Risk Assessment Group*. (11 November, 2020). Agenda for the UK Academic and Regulators Nanomaterial Risk Assessment Workshop.

[5.10] S. Morris. Senior Scientific Advisor. *Defra* (testimonial letter, 12 December, 2020). [Corroborator 4]