Towards a greater understanding of the presence, fate and ecological effects of microplastics in the freshwater environment

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SUMMARY

Plastics within the environment are becoming increasingly recognised as one of today's major environmental issues. Production and disposal of plastics continues to increase every year, with much of this being single-use items. Due to mismanagement of plastic waste globally, millions of tonnes of plastic ends up within the environment every year. Images of organisms entangled in plastic litter and discarded fishing gear are commonplace across the global media, often utilising images of charismatic marine megafauna such as whales and turtles, and as such, public awareness is now at an all-time high. This has translated to significant efforts to address this problem, primarily in the marine and coastal environment. This includes large-scale industry action including The Ocean Cleanup and Sky Ocean Rescue, alongside community-led action such as local litter clean-ups led by charities, and initiatives such as 'Plastic Free Communities' (linked to UK charity Surfers Against Sewage).

Despite efforts by many to reduce plastic waste entering the environment, it is not feasible to remove the majority of plastic that already resides within the environment and much of this will remain for tens, if not hundreds, of years. This is in part due to the fact that plastics will degrade over time, fragmenting and abrading into numerous small particles known as microplastics. As a result of this widespread plastic presence and subsequent degradation of large items, microplastics are now understood to be a pervasive environmental pollutant, ubiquitous across the globe. They have been found in every location that has been studied for this purpose, from remote mountain tops to the deep oceans. While it is understood that the majority of microplastics will derive from items produced and used on land, little attention has been paid to freshwaters as a receiving environment for microplastics, and the environmental and ecological implications of this. The key knowledge gaps in this area were explored in **Chapter 2**.

The sources, presence and abundance of microplastics within freshwater sediments in the River Thames Basin (UK) were investigated within **Chapter 3**. Four sites were selected to represent a range of influences, including those heavily influenced by sewage effluent, and those with little sewage input. Microplastic particles (1 mm–4 mm) were extracted from sediments using an optimised stepwise approach based on the most current literature recommendations, to include flotation, visual extraction and identification using Raman spectroscopy. Microplastics were found at all four sites. One site had significantly higher numbers of microplastics than

other sites, average 66 particles 100 g^{-1}, 91% of which were fragments. Many of the fragments at this site were determined to be derived of thermoplastic road-surface marking paints. This site was not the site most highly influenced by sewage effluent inputs, however it was directly downstream from a storm drain and therefore received urban runoff directly to the watercourse. This study therefore highlighted that the factors influencing microplastic concentration can be highly location-dependent, and that there may be a number of different routes of input for microplastics.

Due to the widespread presence of microplastics in habitats worldwide, it is recognised that microplastics are widely ingested by organisms spanning a range of trophic guilds. Despite this, prior to the research presented in this thesis, there was no evidence for ingestion of microplastics by any freshwater organisms within the UK. Following the identification of high concentrations of microplastics within sediments of the River Thames Basin (**Chapter 3**), **Chapter 4** aimed to investigate the ingestion of microplastics by a freshwater fish species within this river system, the common roach (*Rutilus rutilus*). This research also aimed to understand the factors affecting ingestion, including characteristics of the fish (size, gender) and location-specific factors based on the distance of the sampling site from the source of the river. The distance that the sampled fish could travel within the river was determined by the location of locks which would impede fish passage, and therefore each represented a known stretch of river. Microplastics were found within the gut contents of roach from six out of seven sampling sites. Of sampled fish, 33% contained at least one microplastic particle, with a maximum of six particles in one fish. Both fish size, gender and distance from the source of the river influenced the maximum number of particles a fish was likely to ingest. This study therefore provided valuable new insights into the factors influencing ingestion within riverine environments.

It is understood that plastics within the environment will associate with hydrophobic organic chemicals (HOCs), with the potential to transport these and influence their availability to organisms. These interactions were explored firstly within two separate studies. In the study presented in **Chapter 5**, polystyrene microplastics were used in combination with two different pesticides, deltamethrin and dimethoate, to investigate how microplastics may alter the toxicity of these pesticides to the model organism *Daphnia magna*. While these pesticides led to expected reductions in survival and mobility, these responses were not influenced by the presence of microplastics. Microplastics alone led to no observable responses. The research presented in **Chapter 6** further examined microplastic-HOC interactions, exposing the pond snail *Lymnaea stagnalis* to flame-retardant chemicals polybrominated diphenyl ethers (PBDEs), in the presence and absence of nylon microplastics, to determine whether the presence of microplastics would influence PBDE accumulation and the microbiome of the snail. Only subtle effects were seen: BDE 47 accumulation was reduced while the uptake of all other congeners was not significantly affected. No effect of microplastics, PBDEs or co-exposure was observed on the microbiome diversity or community composition. Only a few operational taxonomic units were affected by PBDEs, in the absence of microplastics only.

Based on these results it was therefore concluded that microplastics were a negligible factor in influencing bioavailability, bioaccumulation and toxicity of hydrophobic organic chemicals (HOCs) under the conditions tested. This is an important observation as many studies have previously stated that microplastics will enhance the bioavailability and bioaccumulation of HOCs. These results therefore show that this is highly variable between studies and likely extremely dependent on experimental conditions and the organisms studied. It would have been expected that effects would have been seen under the highly controlled conditions used here. Given the complexity and range of possible interactions between microplastics, chemicals, organic particles and inorganic matter within the environment, it can therefore be inferred that that microplastics are not likely to significantly influence HOC bioavailability or toxicity to organisms under natural environmental conditions.

Until recently, our knowledge of microplastic in freshwater systems has been limited. This PhD research therefore aimed to take a rounded approach to the issue and as such, a range of field and laboratory studies were conducted to develop a greater understanding of the sources, environmental concentrations and ecological effects of microplastics in freshwaters. The research presented here enhances our knowledge of microplastics in freshwater systems, and explores the challenges for further microplastic research.