Marine Pollution Bulletin 137 (2018) 12–23

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Ingestion of plastic by fish: A comparison of Thames Estuary and Firth of Clyde populations

Alexandra R. McGoran[a,c,*], Phillip R. Cowie[b], Paul F. Clark[c], James P. McEvoy[a], David Morritt[a]

[a] School of Biological Sciences, Royal Holloway University of London, Egham, Surrey TW20 0EX, UK
[b] School of Health and Life Sciences, University of the West of Scotland, Paisley, PA1 2BE, UK
[c] Department of Life Sciences, The Natural History Museum, Cromwell Road, London SW7 5BD, UK

ARTICLE INFO

Keywords:
Microplastics
Microfibres
Thames Estuary
Firth of Clyde fish populations
FTIR spectroscopy

ABSTRACT

This study compared plastic ingestion between pelagic and benthic fish populations from two UK watersheds: the Thames Estuary and the Firth of Clyde. The alimentary canals of 876 individuals were examined. Of twenty-one estuarine species investigated, fourteen ingested plastics, including predator (fish) and prey (shrimp) species. Overall, 32% of organisms ingested plastic, mostly fibres (88% of total plastics). More flatfish (38%) ingested plastics than other benthic species (17%). In the Thames, more plastic was ingested by pelagic species (average number of plastic pieces ingested: 3.2) and flatfish (average number of plastic pieces ingested: 2.9) than by shrimp (average number of plastic pieces ingested: 1). More fish from the Clyde ingested plastic than similar Thames species (39% compared to 28% respectively); however, the average amount of plastic ingested did not differ between the sites.

1. Introduction

Plastic has been mass-produced since the 1940s and is now a huge source of marine pollution world-wide (Galgani et al., 2000; Moore, 2008; Barnes et al., 2009; Browne et al., 2011; Corcoran, 2015; Jambeck et al., 2015). In 2016, 335 million tonnes of plastic were produced globally and production increases yearly (PlasticsEurope, 2018), as does the amount entering the marine environment (Jambeck et al., 2015). In 2010 alone an estimated 12.7 million tons of plastic entered the ocean (Jambeck et al., 2015). Plastic debris has been reported to be ingested by ca. 220 species (Lusher et al., 2017), including marine and freshwater fish (Lusher et al., 2013; Phillips and Bonner, 2015), crustaceans (Murray and Cowie, 2011; Devriese et al., 2015), molluscs (Van Cauwenberghe and Janssen, 2014; Van Cauwenberghe et al., 2015), seabirds (Avery-Gomm et al., 2013) and mammals (Lusher et al., 2015).

It is estimated that, in the marine environment, plastics take hundreds to thousands of years to degrade (Barnes et al., 2009), with Corcoran et al. (2015) reporting the presence of microplastics in lake sediment that had been accumulating for 38 years. Despite this, tide action, photodegradation, biodegradation, thermo-oxidative degradation and hydrolysis can breakdown plastics in the marine environment into ever decreasing smaller fragments (Andrady, 2011). Pieces of plastic < 5 mm in size are referred to as microplastics (Wright et al., 2013) and these have now become an accumulative problem.

Estuaries are hotspots for microplastic accumulation (Browne et al., 2010; Wright et al., 2013). Galgani et al. (2000) noted that litter, largely plastic, on the seafloor around Europe was most concentrated near estuarine inputs. It is also the case in freshwater catchments that plastic concentrates around water inputs (Corcoran, 2015). Rivers and estuaries receive plastics from terrestrial sources and can transport these to marine systems (Cole et al., 2011; Lechner et al., 2014; Jambeck et al., 2015). For example, it is estimated that over 4 tonnes of plastic flows into the sea each day from the River Danube (Lechner et al., 2014). Despite this, research has focussed on marine species (Boerger et al., 2010; Foekema et al., 2013; Lusher et al., 2013). There are only a limited number of studies conducted in estuaries (McGoran et al., 2017; Murphy et al., 2017; Bessa et al., 2018).

There are 155 British estuaries, including 35 coastal-plain estuaries (e.g. Thames Estuary; Tinsley, 1998) and 6 fjords (e.g. Firth of Clyde; Jardine, 1986). Reports of plastic pollution in some of these estuaries are escalating. Gallagher et al. (2016) recovered plastics from estuaries in the Solent estuarine complex, Morritt et al. (2014) recorded 8490 pieces of litter, mainly plastic, during a three-month fyke net fishing programme in the Thames Estuary, and 65% of debris on the shoreline of the Tamar Estuary was found to be in the form of microplastics (Browne et al., 2010).

The Thames Estuary and the Firth of Clyde are comparable with

* Corresponding author at: School of Biological Sciences, Royal Holloway University of London, Egham, Surrey TW20 0EX, UK.
E-mail address: alexandra.mcgoran.2012@live.rhul.ac.uk (A.R. McGoran).

https://doi.org/10.1016/j.marpolbul.2018.09.054
Received 24 April 2018; Received in revised form 26 September 2018; Accepted 27 September 2018

respect to potential plastic pollution: both are in close proximity to several microplastic sources, including major cities and shipping traffic. The 16,000 km^2 catchment of the River Thames includes 15 million residents (Environment Agency, 2016) whilst the River Clyde has a catchment of over 3000 km^2 which encompasses 1.7 million people (SEPA, 2015).

The Clyde and Thames are ecologically diverse and are important habitats and nurseries for marine fish. The Thames Estuary supports over 950 species, including 112 fish species, and has been recognised as a key habitat for commercial flatfish (Thomas, 1998). The European flounder (*Platichthys flesus*) spends most of its lifecycle in the estuary, and juveniles are able to penetrate the entire tidal reach of the river. Consequently, flounder is a key species to measure the health of the Thames Estuary (Thomas, 1998). Recently McGoran et al. (2017) collected European flounder from two sites in the Thames Estuary to measure the extent of microplastic ingested. The results revealed that up to 75% of sampled *P. flesus* had plastic fibres in the gut. Scotland's coastline supports ca. 8000 species (WWF & Scottish Wildlife Trust Joint Marine Programme, 2004), including 59 demersal fish species (The Scottish Government, 2012). The Firth of Clyde is a fjordic system with deep valleys and steep sills (Edwards et al., 1986; Jardine, 1986) and a weak tidal current ($< 0.5\ ms^{-1}$; Wilding et al., 2005; The Scottish Government, 2012) which may aid the accumulation of plastics in the sediment which could be available to these demersal species (Haig, 1986). Prior work in the Firth of Clyde revealed that 83% of *Nephrops norvegicus* had ingested plastic (Murray and Cowie, 2011) whilst < 30% of fish had consumed plastic (Murphy et al., 2017). At present, Murphy et al. (2017) and McGoran et al. (2017) are the only studies to report plastic ingestion by fish in these two estuaries.

The present study extends a preliminary study in the Thames Estuary by McGoran et al. (2017). The aims were to compare (1) samples collected from Thames Estuary and Firth of Clyde fish populations (2) the samples collected in the Thames Estuary to the previous study by McGoran et al. (2017), in which it was found that 20–75% of fish examined had ingested plastic (3) feeding groups and assess if feeding mode affects plastic ingestion in fish and (4) a common prey species (brown shrimp; *Crangon crangon*) with predator fish species. The data collected in this study were also used to determine whether there were any relationships between gender and plastic ingestion.

2. Materials and methods

2.1. Sampling

Using beam trawls (mesh size: 80 mm), fyke, trammel and shrimp nets eight teleost fish species, two cartilaginous fish species, and one shrimp species were caught in the Thames Estuary. Three sampling sites, downstream of London were used: Thamesmead (51°30.637′N 000°06.591′E), Erith (ca. 51°28.005′N 000°12.122′E) and Isle of Sheppey (51°29.048′N 000°41.800′E; Fig. 1). Sampling was conducted on 17, 18 and 23 November 2015 at Erith, Thamesmead and Isle of Sheppey, respectively. *Crangon* were not caught from the Isle of Sheppey. Fish were identified, dissected, the gut contents searched and analysed, and blank controls (see Section 2.3) collected at Royal Holloway, University of London (RHUL) following the method of McGoran et al. (2017) based on that of Lusher et al. (2013). The resulting data sets are thus directly comparable with these studies.

Fifteen teleost and one cartilaginous fish species were caught in beam trawls (mesh size: 50 mm) in the Firth of Clyde (55°46.240′N 4°52.936′W; Fig. 1) on 3 November 2015 and 18 May 2016. Fish were identified, dissected, the gut contents searched, and blanks collected, as described above, at Field Studies Council Millport, Isle of Cumbrae and analysed at RHUL. Appendix A details the sampling sites and equipment used at both sites.

In total, 876 individuals were examined and 21 species identified (Table B.1; Appendix B). Fish were divided into three functional feeding groups for analysis: flatfish, other benthic fish (excluding flatfish) and pelagic fish. Shrimp were included as a fourth group.

2.2. Quantifying plastic ingestion

Samples were transported to the laboratory, stored in a freezer and identified with reference to Wheeler (1978). Prior to dissection, fish were measured (standard length and height), weighed (using a Sartorius 1413 MP8-1 balance accurate to one decimal place or Tesco Go Cook scales accurate to the nearest gram) and any signs of ill-health (i.e. ulcers; Wright et al., 2013) noted. *Crangon* were also measured (length, tip of rostrum to end of telson, and depth of the carapace) and weighed (using Sartorius 1413 MP8-1 balance). No digestion protocols were implemented to reduce the processing time, with some digestions requiring days or weeks (Foekema et al., 2013; Karami et al., 2017; Kühn et al., 2017; Lusher et al., 2017), and to prevent the degradation of polymers that can be caused by many digestive agents (Lusher et al., 2017). The digestive tract from all species was removed and inspected under a dissection microscope using mounted pins. For shrimp, only the foregut was examined for microplastics. The search time was not standardised for this study because of the variability of the size and volume of the digestive tracts from different fish. Searching was conducted in 1 cm sections of the gut thereby reducing its exposure to potential sources of airborne contamination. Any fibres considered to have originated from airborne sources were removed and not included in the examination. Additional controls against contamination are described in Section 2.3. Plastic items were removed from specimens and stored on filter paper in a Petri dish sealed with Parafilm®. Over 3000 particles were recovered from the gut contents of fish and *Crangon*.

Gut plastic was initially described by colour and shape. Pale colours, which were difficult to distinguish from one another and fibres without evident pigmentation were grouped together as “clear fibres”. Several of the potential plastics recovered did not fit into a defined colour category. Plastics with more than one colour were grouped as multi-coloured. Shape was determined as a film, synthetic fibre, sphere or an irregularly shaped fragment.

2.3. Controls against contamination

A clean, white laboratory coat and non-sterile, single-use gloves were worn during dissection procedures and during Fourier Transform Infrared Spectroscopy analyses (see Section 2.4). Samples were covered as much as possible to reduce exposure to airborne contamination. Equipment and laboratory space were cleaned with 70% ethanol and white lab roll prior to dissection and searching, as well as between specimens. In addition, empty Petri dishes were placed in each laboratory to monitor environmental contamination. Three replicates were taken, each lasting 30 min. Plastics recovered in the Petri dishes were analysed using the methods described for plastics recovered from samples. After FTIR, the limit of detection for each shape and colour plastic was calculated (see below). Plastics were removed from analysis if they did not exceed the limit of detection (LOD). Where the volume of plastic matching the description of a contaminant plastic exceeded that of the LOD, the count was reduced to compensate for contamination (i.e. if the LOD for black fibres was one and a fish ingested three black fibres, only two were reported).

$$LOD = A + SD$$

LOD = limit of detection, A = average number of plastics of a particular shape and colour (i.e. clear fibres, black films), SD = standard deviation.

2.4. FTIR spectroscopy

FTIR spectroscopy is well documented for microplastic analysis (Lusher et al., 2017). Gallagher et al. (2016), however, reported that