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The uptake of macroplastic & microplastic by demersal & pelagic fish in the Northeast Atlantic around Scotland

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ABSTRACT

This study reports plastic ingestion in various fish found from coastal and offshore sites in Scottish marine waters. Coastal samples consisted of three demersal flatfish species (n = 128) collected from the East and West coasts of Scotland. Offshore samples consisted of 5 pelagic species and 4 demersal species (n = 84) collected from the Northeast Atlantic. From the coastal fish sampled, 47.7% of the gastrointestinal tracts contained macroplastic and microplastic. Of the 84 pelagic and demersal offshore fish, only 2 (2.4%) individuals from different species had ingested plastic identified as a clear polystyrene fibre and a black polyamide fibre. The average number of plastic items found per fish from all locations that had ingested plastic was 1.8 (± 1.7) with polyamide (65.3%), polyethylene terephthalate (14.4%) and acrylic (14.4%) being the three most commonly found plastics. This study adds to the existing data on macroplastic and microplastic ingestion in fish species.

1. Introduction

Plastic has become a vital part of modern life and has grown in production from 1.7 million tonnes in 1950 to an estimated 322 million tonnes worldwide annually in 2015 (PlasticsEurope, 2016). Plastics represent a wide range of synthetic material that is cheap, persistent and lightweight (Derraik, 2002). It is for these reasons, amongst others that plastic pollution has become a major threat to the marine environment (Wilber, 1987; Derraik, 2002). Due to its light weight nature it can travel far from its original source covering vast distances being carried by wind and ocean currents and its durability means it can take many years to fully breakdown (Singh and Sharma, 2008). The impact of plastic on marine mammals (Stelfox et al., 2016), turtles (Ryan et al., 2016) and seabirds (Tanaka et al., 2015) has been widely documented for a number of years.

Attention has turned to the threat of much smaller pieces of plastic known as microplastics (Thompson et al., 2004). Microplastics are any piece of plastic < 5 mm in size (Arthur et al., 2009) and can be separated into two different types, primary microplastics and secondary microplastics. Primary microplastics are plastics that are designed to be of a microscopic size. Primary microplastics include pre-production pellets or nurdles used in the plastic manufacturing industry as well as microbeads used in personal care products as an abrasive material (Costa et al., 2010; Napper et al., 2015). Secondary microplastics are formed through the degradation of larger plastic material by environmental stressors such as sunlight, wind, rain and wave action (Singh and Sharma, 2008). Most microplastics in the marine environment originate from land based sources that are transported off shore (Jambeck et al., 2015). Waste water treatment works have also been shown to release microplastics into the environment in treated effluent (Browne et al., 2011; Murphy et al., 2016). Discarded fishing nets and line made of plastic are also a source of microplastics in the environment (Andrady, 2011) due to accidental loss or careless handling by the commercial fishing industry (Gilman, 2015). Overtime this material will fragment into smaller pieces due to weathering and biodegradation (Sivan, 2011).

Many marine organisms with differing feeding behaviours are known to ingest microplastics (GESAMP, 2016). There has been a number of studies looking at the uptake in fish (Lusher et al., 2013; Neves et al., 2015; Romeo et al., 2015; Bellas et al., 2016; Lusher et al., 2016; Nadal et al., 2016) showing that a wide range of species from various geographical locations and depths are interacting with microplastic in the environment. The rate of uptake differs with species and location for example 17.5% of demersal fish (n = 212) consisting of 3 different species sampled from the Spanish Atlantic and Mediterranean coasts had ingested microplastic (Bellas et al., 2016). While 35% of demersal fish (n = 279) sampled from the English Channel consisting of 5 species had ingested plastic over 90% of which was < 5 mm (Lusher et al., 2013), with ingestion rates ranging from 23.5 to 51.5%. There is also the issue of differing techniques used to extract and

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identify microplastic from fish tissue, for example relying solely on visual identification has the potential to overestimate the amount of microplastic present (Hidalgo-Ruz et al., 2012; Rocha-Santos and Duarte, 2015) while digestion methods have the potential to destroy microplastics that are present.

The impact of microplastics on fish is not fully understood but has a number of potential impacts as reviewed by (GESAMP, 2016), these impacts include ingestion, exposure to the gills, uptake into tissues and cells, excretion and trophic level transfer. The transfer of microplastic through the food change could result in these microplastics accumulating in predatory fish from consuming contaminated prey species or the transfer of microplastic from exposed to unexposed species (Lusher et al., 2016). Due to their size, microplastics may be more bio available to lower trophic organisms, which tend to display limited food selectivity and will ingest any item of appropriate size (Cole et al., 2013; Moore, 2008). Fur seals (*Arctocephalus spp.*) were thought to accumulate microplastic through the ingestion of a pelagic fish that had fed on floating microplastic debris (Eriksson and Burton, 2003).

The occurrence of macroplastic & microplastic has been observed to be widespread in the sub-surface waters of the Northeast Atlantic (Lusher et al., 2014), with microplastic concentrations of 2.46 ± 2.43 per m^3 calculated. Within the Scottish marine environment there are few published studies on microplastic ingestion in marine organisms, the existing studies have looked at *Nephrops norvegicus* (Nephrops) (Murray and Cowie, 2011; Welden and Cowie, 2016a) and marine mussels (Courtene-Jones et al., 2017). Nephrops a coastal demersal species were observed to have high rates of plastic ingestion (83%) (Murray and Cowie, 2011). High concentration of microplastic were observed in the Clyde but areas outside of the Clyde had much lower concentrations (Welden and Cowie, 2016a) suggesting that proximity to coastal areas may result in higher ingestion rates than in offshore areas. The collection of environmentally relevant data is important as this will help guide toxicology testing in determining the actual effects of microplastics in a way that reflects what is happening in the environment (Rochman, 2016). It is therefore vital to determine the extent that marine organisms are ingesting microplastics. To our knowledge there are no known published peer reviewed studies that have been carried out on fish species in the Northeast Atlantic around Scotland despite these high rates of microplastic uptake in *Nephrops norvegicus* and this being an important fishing ground.

In this study, we investigate the presence of microplastics in demersal and pelagic fish taken from around shallow coastal and deep offshore areas of the Scottish waters of the Northeast Atlantic. The aims of this study were: (i) to determine if fish present in Scottish waters are ingesting macroplastic and microplastics, (ii) to identify the types of polymers that are found, (iii) to determine differences in macroplastic and microplastic uptake in different species, location (coastal and offshore) and habitat (demersal and pelagic) (iv) to attempt to identify the potential sources of these macroplastic and microplastics.

2. Materials & methods

2.1. Site location and sample collection

Fish were collected using a bottom trawl (polyethylene net) from the coastal waters near the east (Firth of Forth) and west (Clyde Estuary and Firth of Clyde) of Scotland (Fig. 1) by Marine Scotland Science (MSS) between November and December 2013 & 2014, see Table 1 for exact locations. Three species of fish were sampled in coastal waters at depths between 8 and 78 m while 9 species were collected offshore at depths between 290 and 1010 m (Table 2). Fish sampled in 2013 in Scottish coastal waters consisted entirely of demersal species while the 2014 samples collected further offshore were a mixture of pelagic and demersal species (Table 2). Fish had their entire gastrointestinal tracts dissected on the vessel, individually placed in plastic bags and immediately frozen at − 20 °C until analysis. The fish sampling was opportunistic and was dependent on storage space onboard the vessel therefore there was no selectivity when it came to what fish and the numbers that were received for this study.

2.2. Sample processing and identification

In the laboratory, samples were defrosted over ice and using clean scissors and forceps the gastrointestinal tracts were dissected and examined under a dissection microscope (Lusher et al., 2013). There was no specific time that the gastrointestinal tracts were examine as they could vary in size considerably. The contents were examined thoroughly by systematically examining the tissue from one end to the other three times. Any ingested material was removed and placed on a petri dish and analysed separately. After examining the tissue, the contents were washed with doubly distilled H_2O and re-examined to dislodge and clean any potential macroplastic or microplastic that had been obscured by the gastrointestinal tissue or contents. Any non-prey item, which is any item that did not appear to be part of the natural diet of the sample or appeared to be synthetic in nature, was removed and placed on a clean filter paper and sealed in plastic petri dish for further examination by micro Fourier Transform Infrared (FTIR) spectrometry. This was undertaken in a clean laboratory following a strict contamination protocol (Murphy et al., 2016). Briefly, all equipment used was cleaned and examined under a dissection microscope, clean cotton lab coats were worn at all times and all work surfaces were cleaned thoroughly before use, clean filters were also left out when analysing samples to collect any atmospheric microplastics.

2.3. Identification: Fourier Transform Infrared (FTIR) spectrometry

All potential macroplastic and microplastics found were examined under a dissection microscope, described by their morphology (fibre, bead, flake, etc) and colour and then positively identified using micro FTIR. A Perkin Elmer Spectrum One FTIR Microscope (manufactured in Llantrisant, United Kingdom) was used in the reflection mode using gold-coated glass microscope slides. Infrared radiation from 400 to 4000 cm^{-1} was used allowing for the identification of chemical bonds present in the samples and also giving a characteristic signal in the "fingerprint" region. Using this technique and with the aid of a library of reference spectra polymers could be identified (Murphy et al., 2016). Samples of the plastic bags used to store the gastrointestinal tracts were analysed in order to exclude them as a potential source of contamination.

2.4. Statistical analysis

Statistical analysis was conducted using R Studio version 3.2.2 statistical computing software. Mann-Whitney *U* tests were used to determine differences in the amount plastic items in the fish that had ingested macroplastic and microplastic based upon species, location (coastal and offshore) and type (demersal and pelagic). A Pearson moment correlation was conducted on the gastrointestinal weight and the number of plastic items found in the fish containing macroplastic and microplastic.

3. Results

From the 212 fish analysed, 63 (29.7%) were found to contain macroplastic and microplastic. In total 118 macroplastic and microplastic items were identified from the fish samples and were present in 5 of the 12 species investigated (Table 2). Of the 63 fish to have macroplastic and microplastic present in the gastrointestinal tissue, 61 were sampled from coastal waters or 47.7% of coastal samples. From the 84 offshore fish gastrointestinal tracts sampled only 2 (2.4%) individuals contained either macroplastic or microplastic or 0.94% of all fish sampled, a greater argentine and a megrim had ingested plastic