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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.

Keywords: Macroplastic, Microplastic, Fish, Ingestion, Northeast Atlantic

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, 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 < 5mm (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 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 microplastic 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 (Figure 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 to 78 m while 9 species were collected offshore at depths between 290 to 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 – 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 (Table 2). Ingestion was significantly lower in megrim and greater argentine than in the plaice dab and flounder (Figure 2). The mean number of items found in all fish analysed was 0.6 ± 1.3, while the mean number of items in fish that contained plastic was 1.8 ± 1.7.

Coastal fish ingested significantly higher amounts of microplastic then the offshore species ($p < 0.000$). Demersal species also ingested significantly higher amounts of microplastic than the pelagic species ($p < 0.000$). Amongst the species that had ingested macroplastic and microplastic, there was no significant difference in the number of plastic items ingested between coastal species ($p > 0.05$) or between the two offshore species ($p = 0.813$). There was significantly fewer plastic items ingested by megrim and greater argentine compared to plaice, flounder and dab ($p < 0.05$). Site 366 had significantly lower number of plastic items ingested compared to all other sites where macroplastic and macroplastic ingestion occurred ($p < 0.05$) with the exception Hunterson ($p = 0.059$). No microplastic was found in fish below 350 metres, the majority of macroplastic and microplastic was found in coastal waters which were below 100 m. Only one of the offshore site, site 366 contained fish with ingested macroplastic and microplastic and contained two items identified as a clear polystyrene fibre measuring 5.3 mm and a black polyamide fibre measuring 4.5 mm. There was no correlation between the number of macroplastic and microplastic items present and the gastrointestinal weight ($p = 0.96$).

Plastics ranged in size between 0.1 mm – 15 mm (Figure 3), 88 of which were below 5 mm in size. Due to an error during analysis a number of larger items (> 10 mm) were not measured precisely and were only given rough measurements of greater than 10 mm. The largest item found was measured accurately hence why the largest size class ranges from 10 to 15 mm. Polyamide was the most common polymer found (Table 3) followed by polyethylene terephthalate (PET), acrylic, polypropylene (PP), and one item each of polystyrene (PS) and a mixture of PET and PP (Figure 4). Polyamide was found in all sites while acrylic was only found in plaice samples from Garroch Head, Holy Loch and Hunterson (Figure 5). Polystyrene was only recovered from the offshore site 366. Fibres were the most commonly found type of macroplastic and microplastic (82.1%) followed by beads (13.7%) and flakes (3.4%) while one tubular item was found (0.9%). Black (43.0%) was the colour most commonly found followed by clear (21.9%), blue (13.2%), red (11.4%), green (9.6%) and white (0.9%) (Figure 6). No atmospheric contamination was observed over the course of this study.

4. Discussion

This is the first study to show the uptake of microplastics by fish in Scottish waters, with four demersal and one pelagic species found to have ingested plastic of some size (Figure 3). The results show that a range of fish species located in several locations in Scottish waters are ingesting macroplastic & microplastic. The percentage of coastal species that contained macroplastic and microplastic ranged from 45.2% to 51.1%, while offshore species ranged from 0% to 10%. There was a clear difference in the uptake rate of plastics between the coastal and offshore areas. The coastal sampling was conducted in shallow waters (8 to 78 m depth) in areas with high anthropogenic activity. Sampling sites are located off the coast of what is known as the central belt of Scotland, an area of Scotland containing 3.5 million people (70% of the population) in an area of 10,000 m^2. The high level of urbanisation may result in high rates of plastic pollution due to debris being transported off shore or entering through wastewater effluent (Murphy et al., 2016). For example, Murphy et al., (2016) determined the amount of microplastic being released from a wastewater treatment works into the River Clyde finding that polyamide and acrylic combined made up 32% of the microplastic being released. Polyamide and acrylic were the two most commonly found microplastics in the west coast samples in the current study and is also the area where the River Clyde meets the sea. This area of the Scottish coast is relatively sheltered particularly the sites on the west coast compared to the offshore sampling locations. On the west coast of Scotland, there are high levels of marine recreational activity as well as a substantial aquaculture and marine fishing presence. However, although these are all potential sources of microplastic pollution it is difficult to determine the exact source of the polymers identified.

A study conducted in the English Channel also looked at microplastics in demersal and pelagic fish finding that 35% of demersal samples had ingested plastic from fish sampled at an average depth of 55 m (Lusher et al., 2013). This is 12.7% lower than in the coastal samples in this study which had an average sampling depth of 40.4 m, however of the five demersal species sampled in the English Channel one species (*A. cuculus)* was found to have an ingestion rate as high as 51.5%. Lusher et al. (2013) which is similar to this to the highest ingestion rate observed in this study. Fibres were also found to be the most common type of plastic found (68.3%) which was lower than the current study (82.1%) (Lusher et al. 2013). The offshore samples were located in the Northeast Atlantic Ocean in much deeper water (209 to 1010 m) (Figure 1), only one offshore site (366) was found to have fish with ingested macroplastic and microplastic with no ingested polymers found below 350 m. Pelagic fish were also sampled from the English Channel with 38% were found to contain plastic (Lusher et al. 2013). This is much higher in the present study, where only a single pelagic fish was found to have ingested plastic. This is likely due to the much greater depths that the offshore pelagic species were found, the average depth of these offshore sites was 502 m ranging from 290 to 1010 m. The offshore sampling sites are located far from high levels of urbanisation, which may result in significant dispersal of the macroplastic and microplastics originating from on shore activities and help to explain the relatively low concentrations found at these sites. The areas near the Shetland Islands and North of Scotland are much less populated and rural then the areas of central western and eastern Scotland.

The average number of plastic pieces found in fish that had ingested plastic (1.9±0.10) (Lusher et al. 2013) was similar to what was found in this study (1.8±1.7). Foekema et al., (2012) examined 1203 individual fish from seven North Sea species for microplastics, with 2.6% of individuals containing plastic although the depth samples were taken was not specified. The coastal samples consisted entirely of bottom feeders inhabiting areas with considerable anthropogenic inputs. Microplastic originating from anthropogenic activity may settle and accumulate in the sediment where these species reside resulting in the higher amounts of ingestion.

Lusher et al., (2016) investigated microplastic ingestion in mesopelagic fish from the Northeast Atlantic with 11% of the 761 fish sampled observed to contain microplastic with sampling depth ranging from 0 to 4000 m. The average number of particles per fish with microplastic was on average 1.2 (±0.54), while amongst all fish sampled this was lower than 0.13 particles per fish. With microplastics primarily consisting of black and blue fibres and ranged in size from 0.5 mm to 11.7 mm (Lusher et al., 2016). The lower amounts observed in the offshore samples may also be due to the much smaller number of individuals collected from each trawl in the offshore samples where for most species only 10 individuals were collected. Low microplastic uptake rates have previously been observed in demersal and pelagic fish sampled from the North Sea and the Baltic Sea with just 16 (5.5%) of the 290 fish sampled having ingested macroplastic or microplastic (Rummel et al., 2015). This is quite similar to the results found in the current study where just 2.4% of fish sampled in the offshore sites contained macroplastic or microplastic.

The ingestion rate in the present study was also higher than that found in mesopelagic and epipelagic fish sampled from the North Pacific Central Gyre (35%) (Boerger et al., 2010), however the mean number of plastic items per fish was similar (2.1±5.78). Microplastic sub-surface water concentrations have been observed to be higher in coastal areas of the Northeast Pacific, with concentrations decreasing further offshore (Desforges et al., 2014). However, Lusher et al., (2014) recorded significantly higher sub-surface concentrations of microplastic in off shore Northeast Atlantic locations compared to coastal locations. Although sub-surface waters off the coast of Scotland were sampled by Lusher et. al., (2014), they were mainly confined to the Northwest of Scotland with no sampling near the Firth of Clyde undertaken. Difference in the uptake of plastic in fish found in urban rivers compared to rivers in areas with low anthropogenic activity has been observed previously in gudgeons (Sanchez et al., 2014).

The only other studies examining plastic uptake in Scottish waters found that 83% *Nephrops norvegicus* (*Nephrops*) sampled in the Firth of Clyde had ingested plastic (Murray and Cowie, 2011) and that there were differences in the microplastic uptake in *Nephrops* based on location (Welden and Cowie, 2016a), with uptake rates ranging from 29% to 84%. The higher rates of microplastic uptake were observed in the Clyde, an area in close proximity to microplastic sources and human activity (Welden and Cowie, 2016a). While Nephrops sampled from outside the Clyde had considerably lower amounts of microplastic present (Welden and Cowie, 2016a). These uptake rates are considerably higher than those found in the species examined in the current study. This may be due to differences in feeding behaviour, which may make *Nephrops* much more prone to the uptake of microplastics or differences in retention time. High uptake rates of microplastic were also observed in another crustacean species, brown shrimp (*Crangon crangon*) sampled from coastal waters of the Southern North Sea and the English Channel (Devriese et al., 2015) where 63% of individuals sampled contained microplastic, consisting almost entirely of fibres (96.5%).

The effects of the ingestion of microplastic on marine biota is not well understood. A study looking at the effects of microplastics on the health and mortality of *Nephrops* (Welden and Cowie, 2016b), showed mortality increased in *Nephrops* fed 1.5 g of squid mantle spiked with 5 polypropylene fibres (41.6%) compared to the control fed 1.5 g squid mantle only (33.2%). Plastic exposed groups also exhibited reduced growth compared to the control, as well as lower feeding rates and reduced nutrient uptake.

A study conducted on polychaete worms (*Arenicola marina)* chronically exposed to 5% unplasticised polyvinylchloride (UPVC) by weight significantly reduced feeding compared to the control and worms exposed to only 1% UPVC (Wright et al., 2013b). Available energy reserves were reduced in worms exposed to 1% and 5% UPVC, by up to 50%. Exposures to microplastic also led to an increase in the inflammatory response in the worms exposed to 5% UPVC, a metabolically demanding process. The time between ingestion and egestion events took 1.5 times longer in worms exposed to microplastic. A pelagic copepod (*Calanus helgolandicus*) exposed to 20 µm polystyrene beads for 24 hrs was found to ingest 11% fewer algae cells and sustained exposure resulted in significant reduction in reproductive output (Cole et al., 2015). This indicates that ingested microplastic has the potential to affect the health of organisms through reducing feeding or increasing metabolic demand. However, it is not fully understood whether this is applicable to fish that have ingested microplastic or if the concentrations present in the environment are capable of causing these negative effects. The potential impact of microplastic ingestion on commercial fisheries in Scotland is not well studied but may affect fitness which could have resultant effects on fecundity and the sustainability of populations particularly in Scottish coastal waters (Welden and Cowie, 2016a).

The physical blockage of macroplastic and microplastic is also a concern, ingested plastic may become lodged in the digestive tract preventing subsequent ingestion and egestion (GESAMP, 2016). Figure 4 shows a tangled ball of fibres which was isolated in a single fish from the 2013 samples, completely blocking the gastrointestinal tract. There is also the potential for ingested microplastic to give a false sense of satiation and cause a reduction in feeding. The uptake of microplastic may also increase metabolic demand due to the need to ingest/egest the microplastic or the time to process the microplastic as it travels through the digestive system and is eventually excreted.

The effect of the physical uptake of microplastic by fish is not the only concern, the uptake of harmful contaminants potentially absorbed on to the surface of the microplastics is a major issue (Velzeboer et al., 2014). Polyethylene beads were allowed to absorb environmental pollutants, these beads were then used in exposures on fish (*Oryzias latipes*) (Rochman et al., 2013). Exposed fish, were found to be able to bio-accumulate these chemicals and this caused liver toxicity and pathology. Microplastic co-contaminants have the potential to affect exposed fisheries health and sustainability representing another pressure to already threatened fish stocks (Hutchings and Reynolds, 2004). The uptake of microplastics and sorbed co-contaminants by commercially caught fish represents a risk to human health as these contaminants may transfer to fish tissue and eventually humans through consumption (Galloway, 2015). In future studies, it may be important to not only identify the type of macroplastic and microplastic ingested but to attempt to measure chemicals that may have sorbed on to the surface of the macroplastic and microplastic to fully understand the potential risk facing marine biota.

5. Conclusions

This study adds to the existing evidence that macroplastic and microplastic is taken up by a range of fish species from various locations. Fish in Scottish marine waters are ingesting macroplastic and microplastic with a variety of polymers identified. Ingestion was much higher in species found in shallower coastal waters than species in deeper further offshore waters. The variability in ingestion rates across geographical regions and species presents difficulties in determining the risk that marine biota face from macroplastic and microplastic pollution. This variability could be due to differences in feeding behaviour, preferred habitat and the effects of wind and ocean currents transporting plastic debris. All these factors may contribute to the uptake of macroplastic and microplastics by marine biota, it is therefore important that as wide a range of species and habitats are investigated for the uptake and presence of macroplastic and microplastics.

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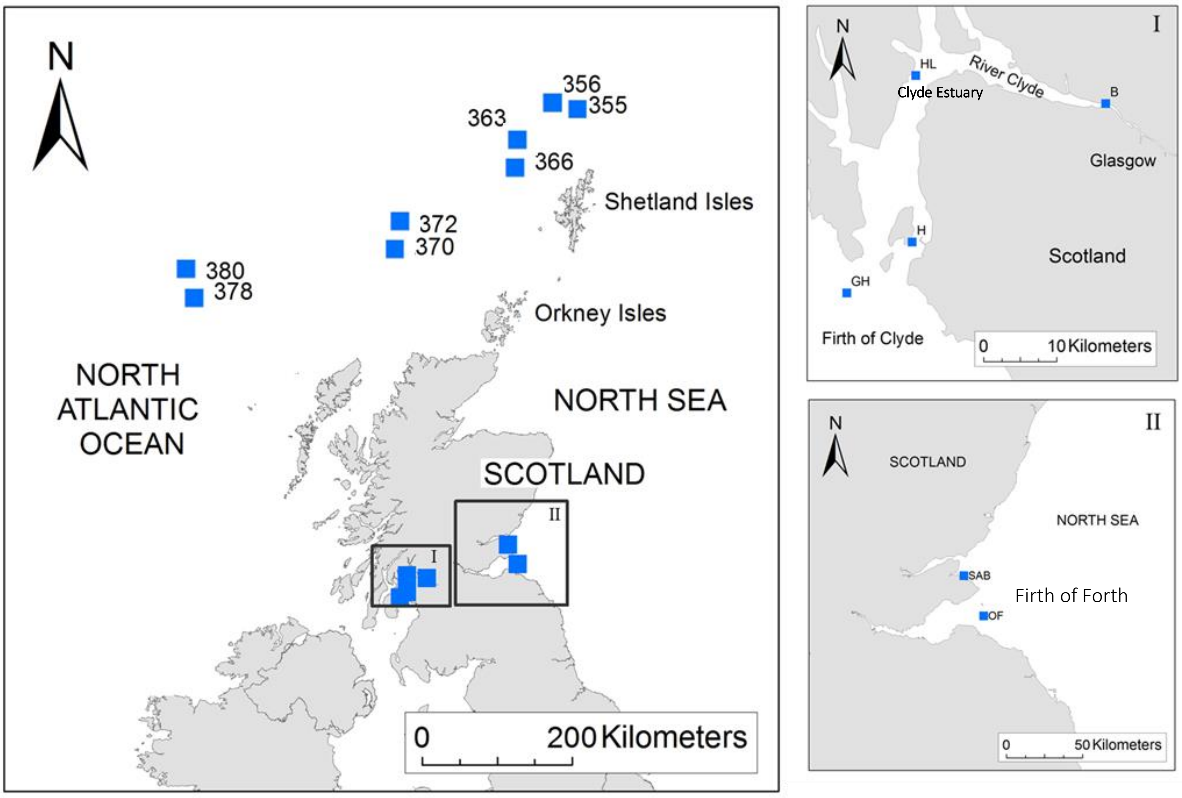

Figure 1. Map of sampling sites based on GPS data taken during the 2013 & 2014 Marine Scotland Science sampling (B = Bowling; HL = Holy Loch; GH = Garroch Head; H = Hunterson; SAB = St. Andrews Bay; OF = Outer Forth).

Table 1. Latitude & longitude data for 2013 & 2014 sampling sites (B = Bowling; HL = Holy Loch; GH = Garroch Head; H = Hunterson; SAB = St. Andrews Bay; OF = Outer Forth).

Year	Latitude	Longitude	ID
2013	55.9285	-4.4845	B
2013	55.9539	-4.9036	HL
2013	55.6828	-5.0342	GH
2013	55.7488	-4.8962	H
2013	56.3536	-2.7493	SAB
2013	56.1180	-2.5349	OF
2014	61.6073	-1.0568	355
2014	61.6462	-1.7127	356
2014	61.1980	-2.7010	363
2014	60.9328	-2.3938	366
2014	59.8767	-5.2342	370
2014	60.1465	-5.1818	372
2014	59.1405	-9.8707	378
2014	59.3735	-10.1197	380

Table 2. List of species sampled with habitat, the number (n) of each species sampled, number of fish containing plastic, number of plastics and the mean number of plastic found ± standard deviation for each species.

Location	Species	Common name	Habitat	n	No. of Fish with plastic	No. of Plastics	Mean No. of Plastic ± SD
Coastal	*Pleuronectes platessa*	Plaice	Demersal	62	28	55	0.9 ± 1.79
	Platichthys flesus	Flounder	Demersal	47	24	48	0.8 ± 0.94
	Limanda limanda	Common Dab	Demersal	19	9	13	1.3 ± 1.67
Offshore	*Pollachius pollachius*	Pollock	Demersal	5	0	0	0.0 ± 0.00
	Molva molva	Ling	Demersal	5	0	0	0.0 ± 0.00
	Hippoglossus hippoglossus	Halibut	Demersal	14	0	0	0.0 ± 0.00
	Lepidorhombus whiffiagonis	Megrim	Demersal	10	1	1	0.1 ± 0.32
	Micromesistius poutassou	Blue Whiting	Pelagic	20	0	0	0.0 ± 0.00
	Argentina silus	Greater Argentine	Pelagic	15	1	1	0.1 ± 0.26
	Trachurus trachurus	Horse Mackeral	Pelagic	5	0	0	0.0 ± 0.00
	Aphanopus carbo	Black Scabbard	Pelagic	5	0	0	0.0 ± 0.00
	Coryphaenoides rupestris	Round Nose Grenadier	Pelagic	5	0	0	0.0 ± 0.00

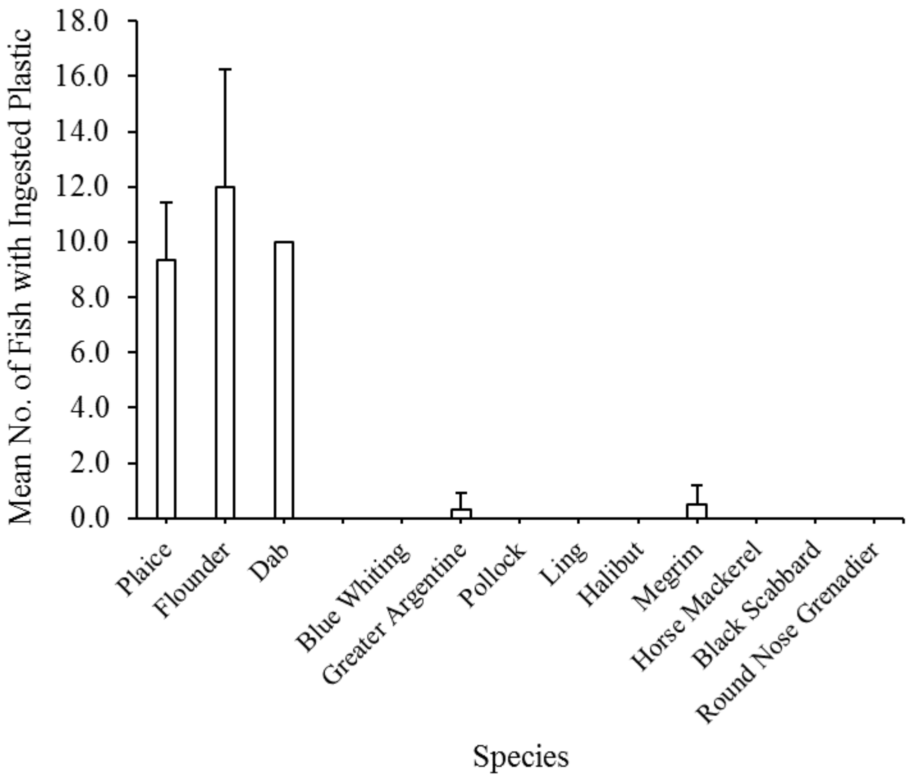

Figure 2. Barchart of mean number of fish with ingested plastic (macroplastic & microplastic) per species. Error bars = standard deviation (Note Dab (*L. limanda*) has no error bars as only one site contained this species).

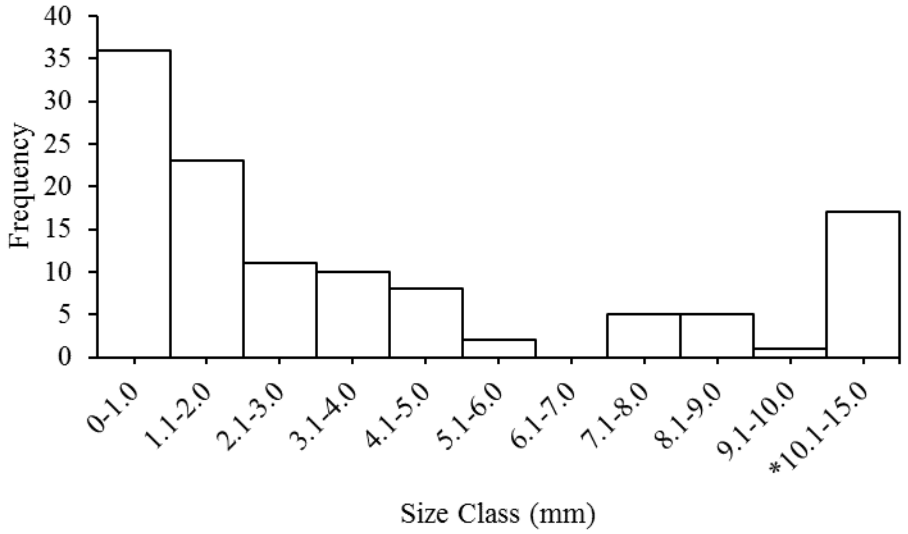

Figure 3. Frequency of microplastic by size classes (*Exact measurements were not taken of items >10 prior to identification, these items were between 10 to 15 mm).

Table 3. Polymers found in all fish with all plastics (macroplastic & microplastic combined) and microplastics only shown (PET = polyethylene terephthalate, PP = polypropylene, Mix = Mixture of PET & PP, PS = Polystyrene).

Polymer	All Plastics		Microplastics	
	No.	%	No.	%
Polyamide	77	65.3	60	68.2
PET	17	14.4	16	18.2
Acrylic	17	14.4	10	11.4
PP	5	4.2	1	1.1
Mix	1	0.8	1	1.1
PS	1	0.8	0	0.0
Total	118	100	88	100

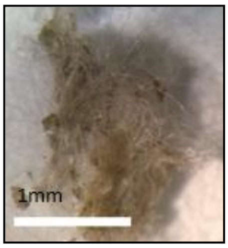

Figure 4. Photo of a ball of polyethylene terephthalate and polypropylene fibres from the gastrointestinal tract of a flounder taken during the 2013 sampling at the Outer Forth (OF).

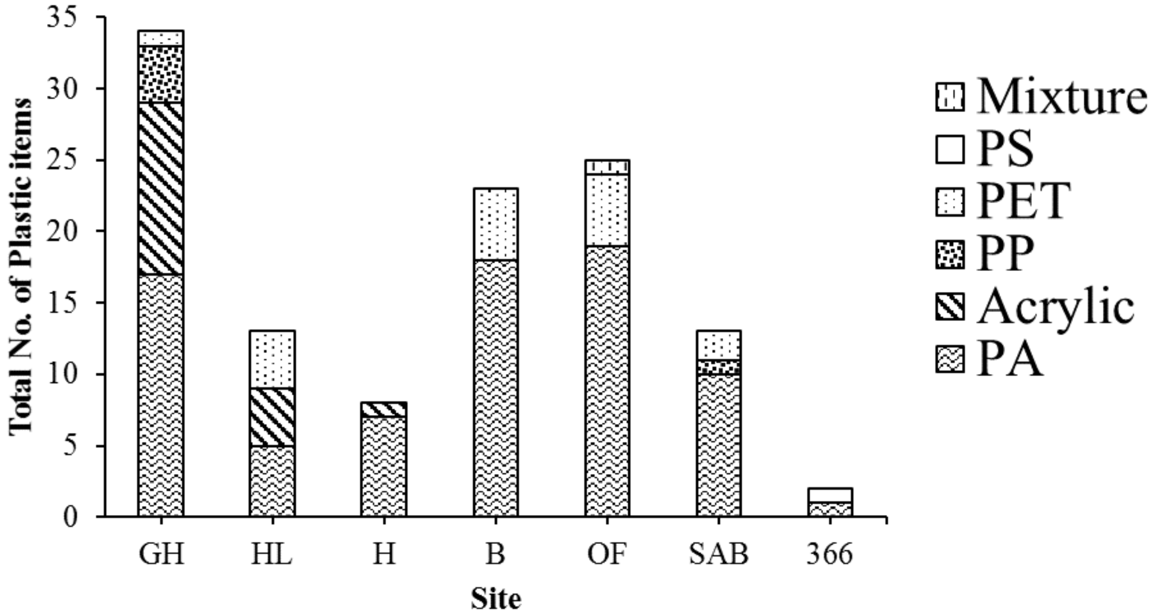

Figure 5. Number of macroplastic & microplastic items and their polymer type found at each site where ingestion was found. GH = Garroch Head; HL = Holy Loch; H = Hunterson; B = Bowling; OF = Outer Forth; SAB = St Andrews Bay. The polymer types are: PS = Polystyrene, PET = polyethylene terephthalate, PP = polypropylene and PA = polyamide.

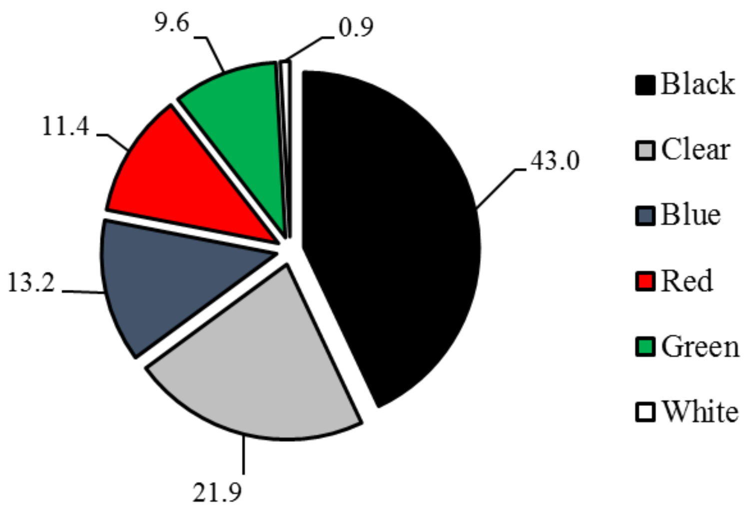

Figure 6. Pie chart showing the abundance of each colour of plastic (macroplastic & microplastic) found as a percentage.