Fisheries as a source of marine debris on beaches in the United Kingdom

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Abstract

Marine debris from ships has persisted and remains a concern despite international agreements such as MARPOL. We report on an analysis of beach litter based on a data set established by the Marine Conservation Society (MSC) Beachwatch weekends. Debris collected around the UK was divided into three main types of debris: (1) plastic (2) fishing, (3) fishing related plastic and rubber. Correspondence analysis (CA) was used to examine patterns in the occurrence of debris types on a total of 1023 beaches and debris attributable to fishing was identified on clusters of beaches mainly located on the coasts of Scotland and along the English Channel. General Linear model (GLM) identified fishing as the highest explanatory factor when testing for relationships between litter and proximity to fishing ports and grounds. The results add to the growing body of evidence that the fishing industry is largely responsible for marine debris.

Keywords

marine litter, plastic debris, beach survey, MARPOL, fishing, U.K.

1. Introduction

Around 6.4 million tonnes of litter enter the sea each year (UNEP, 2009), most of which comprises extremely durable synthetic fishing gear, packaging materials, raw plastics and convenience items (Derraik, 2002; Pruter, 1987) which can persist in the environment for many years showing minimal biological or mechanical degradation (Alsopp *et al*., 2006). There are two principal types of marine debris: debris made from polymers denser than seawater which immediately sinks to the seafloor and debris that has high floating capacity, drifting on the ocean's surface over long distances, finally washing up on beaches driven by inshore currents and winds (Barnes and Millner, 2005; McIlgorm *et al*., 2011; Thiel *et al*., 2003). As the numbers of items of debris are increasing so does the magnitude of the resulting problems making it pro-

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gressively harder to address or manage. MARPOL is the main international convention responsible for the prevention of marine environmental pollution by ships both operational and accidental and was adopted by the International Maritime Organisation (IMO) in 1973 (IMO, 2011). The six MARPOL Annexes implement regulations aimed at preventing and minimizing pollution from ships by oil, noxious liquid substances, packaged harmful substances, sewage, garbage and air pollution; Annex V, prevention of pollution by garbage from ships specifies the distances from land and disposal method (IMO, 2011). It bans plastic disposal at sea and requires ports, marinas and terminals to provide waste disposal facilities for any garbage that is accumulated on ships at sea (IMO, 2011). Since January 2013 the discharge of all garbage into the sea is prohibited except under specific circumstances (IMO, 2011).

The aim of this study was to determine the origin of marine debris found on UK beaches including England, Wales, Scotland, Northern Ireland and the Channel Islands with particular emphasis on the relationship between debris and commercial fishing and shipping. The influence of tidal currents and winds is considered due to their impact on distribution and movements of marine debris (Slip and Burton, 1991) often leading to concentrations at oceanic convergence fronts in coastal waters around cities particularly industrialised harbours and ports (Ailliot *et al*., 2006; Carr, 1987; Derraik, 2002). We hypothesize that fishing is the major explanatory factor for marine debris pollution, including plastic, on UK beaches. Beach litter surveys provide valuable information on the amount and types of garbage that are currently disposed into the oceans (Benton, 1995). Because of the complexity of the data set with many items of debris of ambiguous origin, multivariate methods (correspondence analysis) is used to identify relationships between litter types and beach location. Multivariate analyses can be a suitable tool to determine the origin of marine debris particularly when looking at relations between distribution and environmental variables (Gauch, 1982; Randerson, 1993). However, because ordinations are only descriptive, general linear modelling (GLM) is used to test the subsequent predictions and to determine the biggest explanatory factor for pollution on British beaches.

2. Methods

The Marine Conservation Society (MCS) provided the raw data collected by volunteers for the MCS as part of the MCS Beachwatch Weekend on around 1000 UK beaches between 1999 and 2007 (MCS, 2014). MCS took environmental variables such as wind direction, tides and storm patterns into consideration restricting the survey to certain time frames. Beaches were classed as sand, shingle, rock or a combination of those and were either part of tourist resorts, rural coastal stretches or nature reserves. The 1-2 hour surveys were conducted along a stretch of coast a minimum of 100m in length. Litter was observed between the current high water mark and the upper limit of the beach and recorded onto a prepared data sheet, classifying the items into suitable categories according to material and type i.e. plastic, metal, sanitary etc. as well as exact identity i.e. bottle, cigarette stub, gloves etc.

2.1 Data analysis

The full data set included 1023 beaches, most of which were very similar to one another in regards to number of debris items. Using ordination allowed us to differentiate the central block of the data from those with more debris. The analysis then focussed on those HOW MANY? beaches. For most of the identified items the province and therefore its specific source is unknown, however, where the source was fisheries this was specified in the data analysis. If at least some part of the debris was identifiable it was also included into the analysis in order to be able to explore the potential for, as yet, unattributed debris to be from fishing grounds. The data were then summarized into different categories according to their type and most probable source: plastic, fishing and fishing related plastic and rubber, before being statistically analysed via correspondence analysis (CA) within the multivariate statistical package (MVSP) (Kovach, 1999). Based on the outcome of the CA further analyses focused on beaches identified as atypical, with a large volume and/or large diversity of debris including 32 beaches related to fishing, 30 beaches for plastic and 25 beaches for plastic and rubber analyses.

General linear modelling via IBM SPSS Statistics 20 (IBM, 2011) was used in order to determine if fishing activity is the principal explanatory factor at 95% confidence interval, focusing on the relationship of individual debris items to the presence of fishing ports or fishing grounds. Proximity to port was defined based on fisheries statistics maps (Figure 1) (Radford, 2014) and information derived from relevant websites (MacIntosh, n.d.).

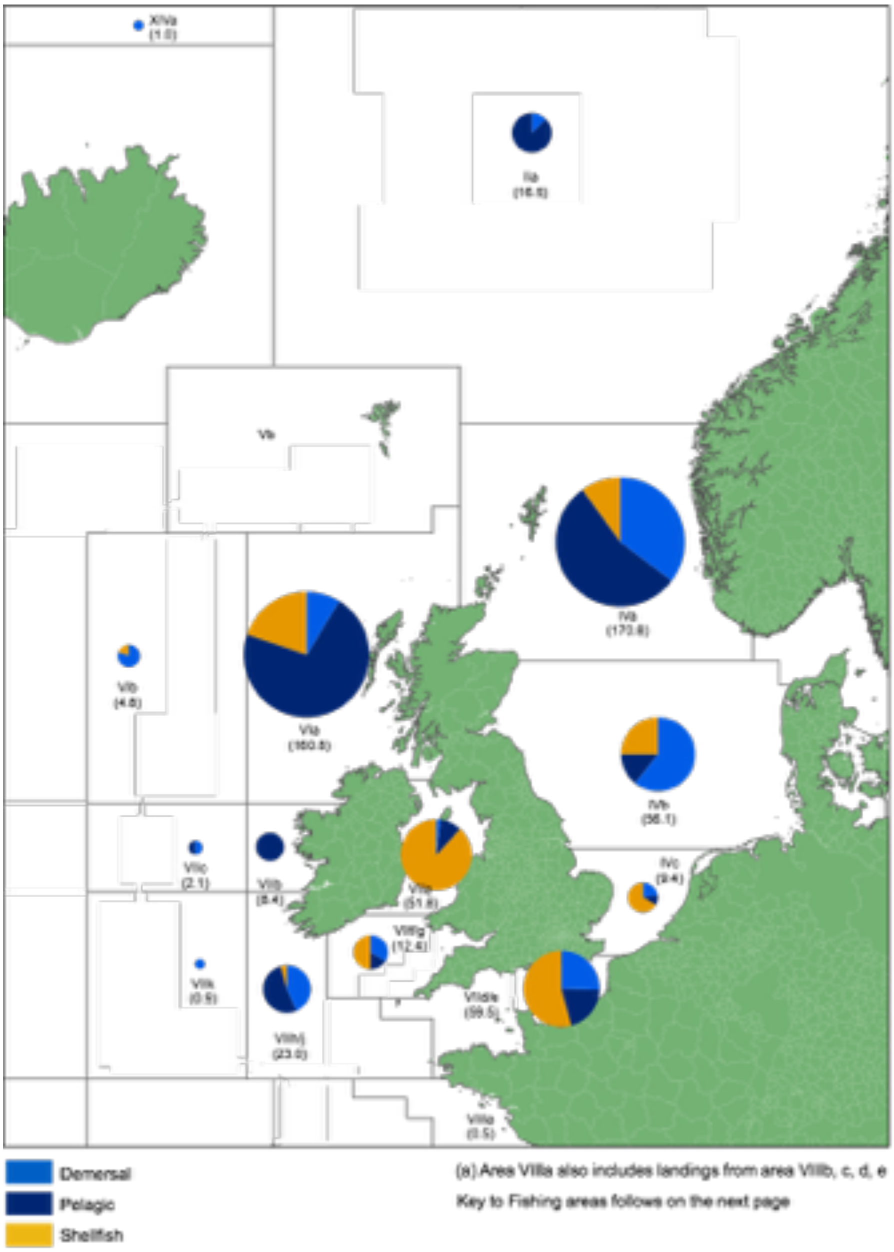

Figure 1: Map illustrating fishing grounds around the UK and quantity (t) of fish caught within (Radford, 2014). Fishing grounds IVa, Northern North Sea, IVb, Central North Sea, IVc, Southern North Sea, VIId/e, English Channel (East/West), VIIf/g, Bristol Channel (South-East of Ireland), VIIa, Irish Sea, and VIa, West of Scotland, were used in this study.

3. Results

3.1 Patterns of marine debris on beaches

Axis 1 of the CA explains 63.5% of variance apparently related primarily to fishing activity. Outlier beaches were identified and correlated to proximity to fishing ports and fishing grounds. Most of these beaches were found in area IVa, northern North Sea, VIId/e, English Channel (East/West) and VIa, West of Scotland, with a few on the Irish Sea, Wales, NE England (Lancashire) and within the Bristol Channel (Wales) coasts. Figure 2 shows distinct litter groupings of plastic net (size 1/2), polystyrene fish boxes and heavy-duty rubber gloves. Figure 3 shows groups of coherent clusters of plastic items including plastic fish boxes, plastic bottles (foreign) and plastic rope as well as plastic net (size1/2). The CA did not produce coherent grouping for plastic debris other than that related to fishing. Figure 4 shows several groups including plastic fish boxes, heavy-duty rubber gloves, plastic rope and plastic pieces (size 1/2).

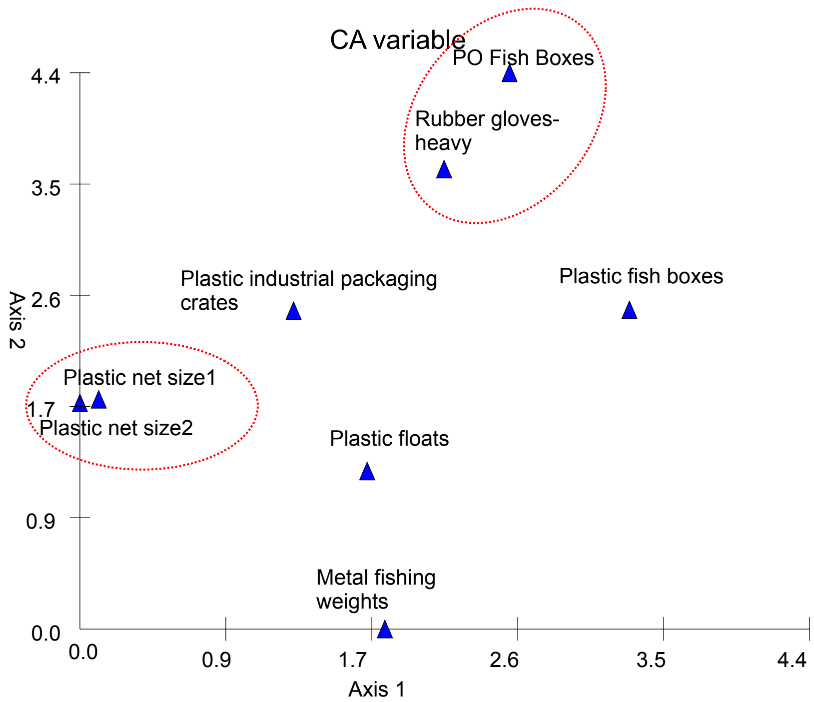

Figure 2: Variables, fishing debris, found on beaches around the UK verified by correspondence analysis. Plastic net (size 1 and 2), polystyrene fish boxes and heavy-duty rubber gloves formed distinct groupings.

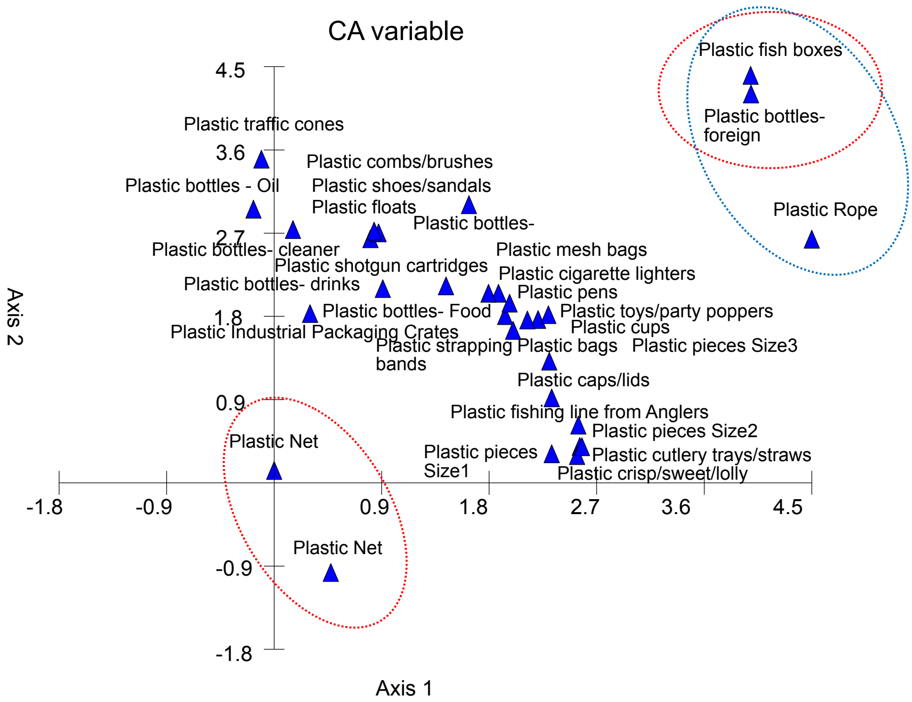

Figure 3: Variables, plastic debris, found on beaches around the UK verified by correspondence analysis. Foreign plastic bottles, plastic rope as well as plastic net (size 1 and 2) form distinct groupings.

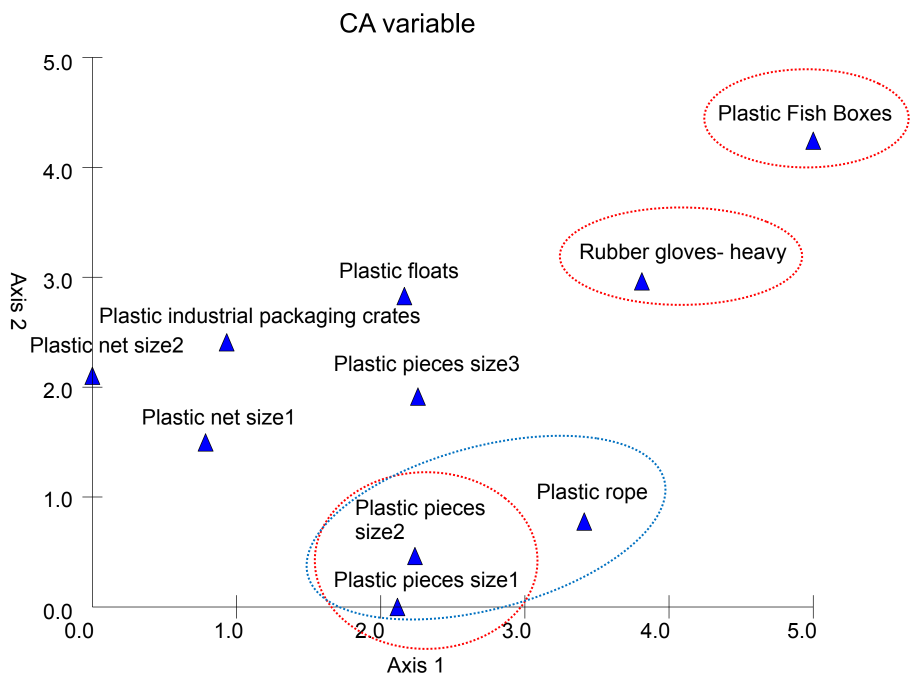

Figure 4: Variables, fishing related plastic and rubber debris, found on beaches around the UK verified by correspondence analysis (CA). Plastic pieces (size 1 and 2), plastic rope, heavy-duty rubber gloves and plastic fish boxes form distinct groupings.

3.2.Fisheries as a source of marine debris on beaches

GLM analysis was conducted but indicated no significant relationship between plastic marine debris and proximity to fishing ports. However, within the analyses fishing related materials, several plastic items, including fish boxes (GLM: $F_{5,24} = 3.763$, $P = 0.012$), floats (GLM: $F_{5,24} = 3.840$, $P = 0.011$), net (size 2) (GLM: $F_{5,19} = 2.833$, $P = 0.045$), rope (GLM: $F_{5,19} = 2.904$, $P = 0.041$) and plastic pieces (size 3) (GLM: $F_{5,19} = 2.753$, $P = 0.049$), indicate a strong relationship between fishing grounds and beached marine debris (Table 1-2). Plastic industrial packaging crates were the only items significant in both analyses (GLM: $F_{5,24} = 4.713$, $P = 0.004$; GLM: $F_{5,19} = 4.192$, $P = 0.01$). Furthermore, fishing weights (GLM: $F_{1,30} = 3.822$, $P = 0.06$; GLM: $F_{4,27} = 2.469$, $P = 0.069$), plastic cleaning product bottles (GLM: $F_{5,24} = 2.152$, $P = 0.058$), plastic pieces (size 3) (GLM: $F_{5,24} = 2.608$, $P = 0.051$) and plastic floats (GLM: $F_{5,19} = 2.516$, $P = 0.066$) show a near significant trend within the different analyses.

Table 1: GLM model for plastic debris in relation to fishing areas around the UK.

Debris item (Parameter)		Intercept	Statistics	Significance (P)
PLBags	Fishing area	0.016	GLM: $F_{5,24} = 1.641$, ns	0.187
PLBottlesDrinks	Fishing area	0.114	GLM: $F_{5,24} = 0.670$, ns	0.65
PLBottlesCleaner	Fishing area	0.03	GLM: $F_{5,24} = 2.152$, ns	0.058
PLBottlesFood	Fishing area	0.018	GLM: $F_{5,24} = 2.266$, ns	0.08
PLBottlesOil	Fishing area	0.298	GLM: $F_{5,24} = 1.796$, ns	0.152
PLBottlesToiletries	Fishing area	0.555	GLM: $F_{5,24} = 0.730$, ns	0.608
PLCapsLids	Fishing area	0.083	GLM: $F_{5,24} = 0.393$, ns	0.848
PLCigLighters	Fishing area	0.096	GLM: $F_{5,24} = 0.929$, ns	0.48
PLCombsBrushes	Fishing area	0.283	GLM: $F_{5,24} = 1.906$, ns	0.131
PLCrispSweetLollyPackets	Fishing area	0.107	GLM: $F_{5,24} = 0.909$, ns	0.492
PLCups	Fishing area	0.52	GLM: $F_{5,24} = 0.734$, ns	0.605
PLCutleryTraysStraws	Fishing area	0.166	GLM: $F_{5,24} = 0.598$, ns	0.702
PLFishBoxes	Fishing area	0.022	GLM: $F_{5,24} = 3.763$, sig	0.012
PLFishingLineFromAnglers	Fishing area	0.21	GLM: $F_{5,24} = 1.720$, ns	0.168
PLNetSize1	Fishing area	0.052	GLM: $F_{5,24} = 0.877$, ns	0.511
PLNetSize2	Fishing area	0.011	GLM: $F_{5,24} = 0.386$, ns	0.854
PLFloats	Fishing area	0.049	GLM: $F_{5,24} = 3.840$, sig	0.011
PLIndPackagingCrates	Fishing area	0	GLM: $F_{5,24} = 4.713$, sig	0.004
PLMeshBags	Fishing area	0.543	GLM: $F_{5,24} = 0.768$, ns	0.582
PLPens	Fishing area	0.262	GLM: $F_{5,24} = 1.182$, ns	0.347
PLRope	Fishing area	0.409	GLM: $F_{5,24} = 0.449$, ns	0.81
PLShoesSandals	Fishing area	0.083	GLM: $F_{5,24} = 0.867$, ns	0.517
PLShotgunCartridges	Fishing area	0.213	GLM: $F_{5,24} = 1.817$, ns	0.148
PLStrappingBands	Fishing area	0.213	GLM: $F_{5,24} = 0.511$, ns	0.765
PLToysPartyPoppers	Fishing area	0.514	GLM: $F_{5,24} = 0.739$, ns	0.602
PLTrafficCones	Fishing area	0.311	GLM: $F_{5,24} = 1.904$, ns	0.131
PLPlasticPiecesSize1	Fishing area	0.197	GLM: $F_{5,24} = 1.529$, ns	0.218
PLPlasticPiecesSize2	Fishing area	0.013	GLM: $F_{5,24} = 0.507$, ns	0.768
PLPlasticPiecesSize3	Fishing area	0.021	GLM: $F_{5,24} = 2.608$, ns	0.051

Table 2: GLM model for plastic and rubber debris in relation to fishing areas around the UK.

Debris item (Parameter)		Intercept	Statistics	Significance (P)
PLFishBoxes	Fishing area	0.469	GLM: $F_{5,19}$= 0.745, ns	0.6
PLNetSize1	Fishing area	0.054	GLM: $F_{5,19}$= 1.353, ns	0.285
PLNetSize2	Fishing area	0.005	GLM: $F_{5,19}$ = 2.833, sig	0.045
PLFloats	Fishing area	0.004	GLM: $F_{5,19}$= 2.516, ns	0.066
PLIndPackagingCrates	Fishing area	0.016	GLM: $F_{5,19}$= 4.192, sig	0.01
PLRope	Fishing area	0.023	GLM: $F_{5,19}$= 2.904, sig	0.041
PLPlasticPiecesSize1	Fishing area	0.157	GLM: $F_{5,19}$= 0.931, ns	0.483
PLPlasticPiecesSize2	Fishing area	0.384	GLM: $F_{5,19}$= 0.932, ns	0.482
PLPlasticPiecesSize3	Fishing area	0.015	GLM: $F_{5,19}$= 2.753, sig	0.049
RGlovesHeavy	Fishing area	0.006	GLM: $F_{5,19}$= 1.319, ns	0.298

4. Discussion

4.1 The fishing industry as a source of marine debris on beaches in the UK

These results suggest that fishing industry is responsible for a large proportion of the marine debris on UK beaches, particularly in areas with adjacent fishing grounds (Gregory, 1999; Jones, 1995; Slip and Burton, 1991). Few studies have focused on the composition and distribution of marine debris on UK beaches, mainly on areas along the coast of Wales and the Bristol Channel (Balas *et. al*., 2006; Tudor and Williams, 2003; 2004; 2006; Williams and Simmons, 1997; Williams and Tudor, 2001; Williams *et al*., 2003). Debris collected from other North Sea coastlines such as Germany, the Netherlands, Belgium, France, Norway and Denmark, has been largely attributed to shipping and fishing activity (Galgani *et al*., 2000; van Franecker *et al*., 2005; Vauck and Schrey, 1987). Furthermore, fishing gear, operational as well as floating fragments, has been shown to cause entangling and mortality of marine animals (Derraik, 2002) including seabirds (Bugoni *et al*., 2008; Simeone *et al*., 1999; Stempniewicz, 1994; Votier *et al*., 2011; Zador *et al*., 2008), cetaceans (Johnson *et al*., 2005; Neilson *et al*., 2009; Ramos *et al*., 2011; Robbins and Matilla, 2004), turtles (Carr, 1987), sharks (Sazima *et al*., 2002) and seals (Hanni and Pyle, 2000; Hofmeyr *et al*., 2006; Page *et al*., 2004).

Items identified as significant by GLM analyses can be related to fishing activity. Plastic fish boxes as well as industrial packaging crates are most likely being used for packaging purposes on fishing vessels for transportation and distribution of fish and other seafood. Plastic net and plastic ropes are part of fishing gear and items frequently used on fishing vessels (Henderson, 2001). As for plastic floats and plastic pieces the identification of their source is somewhat more difficult. However, plastic floats are often used in pelagic longline fishing gear to support the gear (Watson and Kerstetter, 2006). Metal represents a threat to marine organisms due to risk of poisoning when ingested (Borowski, 1997; Zabka *et a*l., 2006). It is often found on windward beaches (Debrot *et al*., 1999) since it does not float or can get blown away by wind. Items such as metal fishing weights that have low or no buoyancy cannot have been adrift for a very long time and must have been deposited in local coastal areas. This might explain why metal fishing weights showed a near significant trend. They most likely stem from local sources within close proximity to the coasts of the UK.. Plastic bottles (cleaner) and plastic pieces (size 3) also showed a near significant trend. Plastic bottles in particular contribute most to marine debris and are often the most dominant item of debris found on beaches (Dixon and Dixon, 1983). However, due to the lightweight and high bouyancy these bottles might not only be of local source but from sources further away either being carried by currents or blown around by winds (Astudillo *et al*., 2009; Garrity and Levings, 1993). Characteristics of plastic pieces are not further described making it hard to identify their origin. This illustrates the difficulty in determining the true trends of ocean sourced debris since often they are obscured by unknown sources because debris material is often found in small fragments due to degradation and weathering (Andrady, 2011). When plastics are exposed to UVB radiation by sunlight and hydrolytic properties of seawater they become brittle and break into smaller and smaller pieces, eventually becoming small molecules, a process taking considerable amount of time currently unknown (Andrady, 2005; Moore, 2008). However, the analyses in this study suggest that these might ultimately also be attributable to fishing. Most beaches identified by the ordination are in fishing grounds IVa, Northern North Sea, VIa, West of Scotland, and VIId/e, English Channel (East/West), all of which are highly productive areas making them commercially valuable for the fishing industry (Radford, 2014). Furthermore they also host some of the most important and busiest fishing ports in the UK (Jennings *et al*., 1999; Radford, 2014; Thurstan *et al*., 2010).

The world's oceans face such a high degree of litter pollution that it is difficult to identify particular sources (Jones, 1995). Moreover, it is often the association of debris to other items, which is an important indicator of its source (Williams *et al*., 2003). Therefore it is important not to isolate items but to consider their location and presence in relation to others (Tudor and Williams, 2004). The example of plastic cleaner bottles illustrates this. They were found with a number of items that could be related to fishing and showed to be almost significant. Therefore it can be assumed that these bottles could be fishing sourced and may not be of domestic or land- based origin as often assumed. In this study the enormous diversity of litter made it difficult to attribute a specific source but it illustrates the importance of association and correlations between debris found on beaches. However, the fact that most of the debris items shown to be significant within GLM analyses were found in the same areas identified by the ordination confirms that the fishing industry is indeed largely responsible for marine pollution by debris. By going through the multi-layered statistics we have been able to establish the extent to which the bulk of plastics that cannot be readily attributed, might be from the same source as the debris which with a high degree of certainty can be attributed to fishing vessels.

4.2 Currents explain observed patterns of marine debris on beaches in the UK

The accumulation of marine debris is influenced by ocean currents, which often create convergence zones forcing debris into central areas where it can remain for considerable time (Henderson, 2011; Howell *et al*., 2012), making it difficult to identify debris pathways and origins (Ryan *et al*., 2009) as even shores distant from major sources of litter can accumulate large amounts of debris (Torres *et al*., 1997). Furthermore, debris that is cast ashore often only represents a fraction of the litter that is floating out at sea (Thiel *et al*., 2003). Debris found on more remote beaches are a better indication of the quantity and source of garbage in the oceans than beaches on urban coasts (Barnes and Millner, 2005; Benton, 1995). Ordination identified two beaches on the Channel Islands of Guernsey, where the North Atlantic Drift divides into two main streams, one moving along the south coast of Cornwall and the other east towards Normandy and the Channel Islands where at the periphery of the North Sea large gyres form around Guernsey forcing the debris onto the island's beaches (Salomon and Breton, 1993). Another example illustrating the influence of currents is shown by the Firth of Forth, a tidal estuary, heavily influenced by wind- generated currents (Dyke, 1987). Slow- moving circulation is variable, causing litter to remain within the Firth of Forth for considerable time (Dyke, 1987). Storrier *et al*. (2007) reported that proximity to ports does not have a significant effect on the amount of litter found on these beaches, and suggest that climatic and tidal patterns exert the greatest influence on presence of debris. Overall, beaches identified that were not in proximity to major fishing ports generally were not located in areas of major fishing activity either.

4.3 Need for enforcement of MARPOL

The results of this study suggest that new approaches for enforcement are needed to implement MARPOL within the fishing industry. MARPOL sets stern restrictions on the disposal of all plastics and the discharge of many other waste types from ships which carry 400t (IMO, 2011). However, many of the vessels on our oceans are well below 400t (Chen and Liu, 2013). Jones (1995) observed that at least one third of vessels did not abide with MARPOL regulations. However, the evaluation of its impacts is difficult since the numbers of sites surveyed are small and restricted to their geographical range (Barnes and Millner 2005). Shipping debris was expected to decline following the enactment of Annex V. However, there have been controversial reports of its effectiveness mainly due to difficulties in enforcement (Edyvane *et al*. 2004; Henderson, 2001; Iljstra, 1989; Johnson, 1994; Vlietstra and Parga, 2002) and there has been no significant decrease in debris pollution in the North Sea after the implementation of MARPOL overall (van Franecker *et al*., 2011) although coherent increases in shipping traffic and in the proportion of plastics need to be taken into account.

Enforcement regimes of MARPOL lie within the responsibility of the ships flagstates, responsible to inspect, monitor and enforce vessel compliance (Griffin, 1994). Coastal states and ports therefore have limited jurisdiction (Griffin, 1994). Often violators are not caught mainly because states do not have the resources to patrol the oceans thoroughly and once waste is detected it is very difficult to trace it back to a specific ship (Griffin, 1994). In many cases vessel will fly flags of convenience (FOC), which are flags of certain countries, whose laws make it particularly attractive to be owned by foreign countries undermining MARPOL efforts (Griffin, 1994). Commonly they do not have the facilities, interest or resources to comply with MARPOL regulations (Griffin, 1994). These countries should be encouraged to enforce regulations. Stricter controls are necessary and more power should be given to coastal states and ports so that they can inspect and penalise violations on site. The EU Commission (2000) requires ports to provide wastage reception facilities for all vessels that are using the port. An analysis of level uptake for 26 ports that completed the survey showed an uptake rate of 32.31% in 2001 with a slight increase to 33.29% in 2003 (Carpenter and MacGill, 2001; 2003). The general uptake was low although Annex V facilities were used most frequently possibly because it is mandatory (Carpenter and MacGill, 2005). However, the use and provision of disposal facilities can be very costly for both parties, which in response encourages illegal disposal of litter into the sea by fishing vessels and in turn might pose uneconomical for ports to provide facilities if few vessels use them (Carpenter and MacGill, 2001; 2005). As long as the correct disposal of garbage remains economically costly, most fishing companies will be unlikely to comply with MARPOL and EU commission laws and legislations.

Chen and Liu (2013) looked at different management implications and investigated the association between different factors and fishers intention of bringing the rubbish back to shore. A high motivational factor were incentives for bringing back garbage and deposing them in adequate reception facilities and that it could be sold for recycling purposes. They conclude that if those measures should be implemented, fishers will hopefully make it an everyday habit of seafaring to gather garbage on board and bringing it back to port rather than disposing it off into the sea (Chen and Liu, 2013). They further encourage the education of fishery employees about the environmental effects of arbitrary garbage disposal into the sea (Chen and Liu, 2013). Gold *et al.* 2013 suggest the enforcement of biodegradable nets and traps replacing plastic and synthetic gear along with an incentive program to encourage their use. A certification program requiring the tracking of fishing gear in vessel logs to determine how much gear is lost should be implemented and monitored by third parties and enforced by penalties (Gold *et al.* 2013). Nets should be tagged in order to ensure their easy tracking and consequential removal from the oceans (Gold et al. 2013). Litter clean up programs, such as the MCS Beach Watch Weekend, should also be expanded (Gold *et al.* 2013).

Conclusion

Given the vast quantity of marine debris in the world's oceans today and its dramatic effects on marine wildlife and ecosystems there is a compelling need for understanding it sources in order to limit its effects. This study suggests that fisheries are responsible for large amounts of marine debris floating around UK coasts, which is then washed up on beaches. It also shows that proximity to fishing grounds has an influence on debris deposited on beaches indicating that MARPOL is being ignored. Furthermore, it is reasonable to assume that there are a large number of unreported cases of marine debris being released into the world's oceans. Overall, more work is needed in determining the sources of marine debris on UK's beaches to secure consistent management and stricter actions against illegal disposal of debris at sea.

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