BEACH LITTER SOURCING: A TRAWL ALONG THE NORTHERN IRELAND COASTLINE

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ABSTRACT

Fourteen non-recreational coastal locations in Northern Ireland were investigated as to whether beach litter deposition was related to seasonal or site specific factors. Litter items were counted in 100 m width transects and 1 km strand-line surveys over a five-season period (autumn to autumn). Survey sites comprised fishing ports; estuarine areas, north (high energy) and east coast (low energy) beaches. Fishing ports accumulated the most litter. In the 100 m beach surveys, plastics, string and cord, drink containers/drums, bottle caps, food items, rope, and drink containers dominated. In strand-line surveys, large plastic pieces were dominant, followed by rope, string and cord, strapping bands (absent on beach surveys), cloth, wood (mainly pallets, fish boxes) and metal items. Multivariate analyses revealed major litter category differences between the ports and all other sites, with a lesser distinction between exposed and estuarine sites. There was no simple coastline trend and no apparent effect of seasonality between samples.

KEY WORDS N Ireland, beach litter, beach/strand-line surveys, statistical analysis.

RUNNING HEAD Northern Ireland, Litter.

INTRODUCTION

Marine debris (litter) is a fundamental ubiquitous problem which arises from human activity, either intentional or unintentional (Slavin *et al*., 2012; Williams *et al*., 2016a) and includes any manufactured or processed solid waste material that enters the marine environment from any source (Coe and Rogers, 1997). It has become a serious problem of rising magnitude (Tudor and Williams, 2006; Barnes, 2009) and debris can originate from land or sea sources, but most researchers postulate that the dominant input comes from land (Coe and Rogers, 1997), although Sheavly and Register (2007) argued that some 50% is of marine origin. Global studies of marine litter over the past two decades have shown that plastic - synthetic organic polymers derived from polymerisation of monomers obtained from oil or gas - is the modal litter type, with more being found in the northern than southern hemisphere (Moore *et al*., 2001; Ivar do Sul and Costa, 2007; Thompson *et al.,* 2009; Corcoran *et al.*, 2009; Williams *et al.*, 2012; Eriksen *et al*., 2014; Poeta *et al*., 2014). Plastics appeared on the world scene in 1907 with 'Bakelite' and since the start of mass plastic production in the 1950s, they can be found globally on beaches (Thiel *et al*, 2013; Eriksson *et al*, 2013); not only on the surface but buried beneath sediments (Barnes *et al.*, 2009; Williams and Tudor, 2001). They are extremely versatile and can be tailored to meet very technical needs, *i.e.* they are light in weight, durable, inexpensive, resistant to chemicals, have good safety, hygiene, thermal and electrical insulation properties and Andrady (2011) showed that demand for plastics is increasing with an annual global production at 245 million tonnes. The packaging industry utilises some 40%, building and construction 20% and landfill takes 30-50% of all plastics produced (www.plastics). OSPAR (2007b), and Cheshire (UNEP/IOC, 2009) have been among the forerunners in assessing the marine debris problem on a global basis; whilst other workers e.g. Galgani, *et al.* (2103, 2015) studied large regional areas. Plastic marine debris is very mobile and can spread over vast areas, as it can float, as well as sink to the sea bed (Morrison, 1999, Carson *et al.*, 2013). Therefore, they dominate marine litter and represent a significant threat to the marine envirnment as a result of their longevity, abundance and ability to cross large distances (Thompson, *et al*., 2009) and constitute between 40-80% (Kusa and Noda, 2003); 50-80% of all marine litter (Barnes *et al*., 2009). Management of this litter is a massive issue (Earll *et al.*,2000) and McIlgorm *et al*. (2008) has given a sound review of the economic costs involved.

Plastic litter occurs as whole manufactured products (e.g. cartons, bottles), or as fragments/pellets, with high socio-economic costs and constitutes a huge threat to biota (Gregory, 2009; Mouat *et al.,* 2010; Potts and Hastings, 2012; Thompson *et al.,* 2009):

- *via* ingestion/entanglement for mammals, sea birds, fish, (Gregory 2009; Williams *et al.,* 2016a).
- by accumulating in plankton and subsequently passing up the food chain to a host of sea creatures (Setälä *et al*., 2014).
- by absorption of chemicals that can persist in organisms (Fossi *et al*., 2014) and cause later problems.

In many cases, beach debris originates from outside sources (Nixon and Barnea, 2010) and accumulates due to wave/current action, but is usually left to local authorities to remove it (Liu *et al*., 2013). An excellent resume of the issue is given by Potts and Hastings (2012), whilst Pilkey and Cooper (2014) offer a discussion on litter as a threat to beaches, writing about the plastisphere.

This study aims to determine whether the categories and abundance of litter items deposited on some Northern Ireland beaches varies with respect to site-specific factors (coastal morphology, exposure, adjacent land use, etc), and whether consistent differences occur between seasons.

PHYSICAL BACKGROUND

In terms of wave and wind conditions, the Northern Ireland coast can be divided at its most north-easterly point, near Ballycastle, into two dynamic zones: the north and east coasts (Figure 1a).

The North coast is primarily affected by refracted Atlantic swell waves, which approach the coast from the northwest and reduce in height toward the east, but seldom penetrate the Irish Sea beyond Ballycastle (Carter, 1990). Dominant waves (swell) refract from the west and so the dominant transport under waves is to the east as the winds are dominantly offshore here. Mean significant wave height exceeds 2 m between Magilligan and Ballycastle (Jackson and Cooper, 2010) and the 50-year maximum wave height reduces from 25 m at Magilligan to 15 m at Ballycastle (Carter, 1990). A much lower 50-year return wave (12-14 m) was estimated by Carter and Challenor (1989). Most waves are fully refracted at the shoreline and have created a series of headland-embayment cells (Jackson and Cooper, 2010). Winds on the north coast are predominantly from the SW and consequently are offshore-directed. Mean wind speed at Malin Head is 7 m/s, with gusts of 50 m/s likely to occur once every 50 years (Met Eireann, 2016). Tidal range reduces from Magilligan (2.5 m) to Ballycastle (1 m) in line with a degraded amphidromic point. Tidal flow into and out of the Irish Sea generates reversing tidal currents that have a slight easterly dominance at the surface and westerly dominance at depth (Knight and Howarth, 1999). Current speeds are maximized in the constrictions created by the narrowing of the North Channel and around Rathlin Island where whirlpools and tidal overflows are generated (Howarth, 2005). Currents in the region are difficult to assess, as reversing tidal currents that flow in both directions are common. The largest direct river discharge on the north coast derives from the Bann and Bush, while the rivers Roe, Foyle and Faughan, flow into Lough Foyle. In the Foyle estuary, along-shore transport is northwards under the dominant southerly winds.

The East coast gradually increases in tidal range from 1 m at Ballycastle to almost 5 m at Dundrum Bay. On this coast, sea waves dominate (Orford, 1989) and are relatively consistent from N to S (Hs = 1.2 m or less). Extreme wave heights reach 4.5 m (Cooper and Navas, 2004) and a 50-year return period wave was estimated at almost 8 m (Carter and Challenor, 1989). Waves are generated by dominant S-SE winds in the Irish Sea, producing the Irish Sea waves which are predominantly obliquely onshore and drive strong wave-driven longshore currents (Bowden and Orford, 1984). It is therefore safe to assume a net transport to the north at a macro scale. Wind speeds average 6 m/s and gusts of 45 m/s are expected once in 50 years (Met Eireann, 2016). Several small, steep rivers discharge directly to the coast between Glenarm and Ballycastle. South of Glenarm most rivers discharge into Larne, Belfast, Strangford and Carlingford Loughs.

In sheltered marine embayments (Sea Loughs), estuarine-type flow patterns (although not salinity patterns) are developed and the shoreline orientation strongly influences the degree to which wind-generated wave action affects the shoreline (Greenwood and Orford, 2007). Onshore winds are important in generating surges in these sheltered environments (Ryan and Cooper, 1994) whilst rivers of various sizes discharge into each of the sea loughs.

INVESTIGATED SITES

a) Fishing ports (Figure 1a, b); Ardglass; Kilkeel; Portavogie. These beaches are all on the East coast. The 100 m survey extends north from the harbour wall in each case. Portavogie is an extensive flat sand beach; Ardglass a narrow sand and shingle beach in a bay; and Kilkeel had a steeply sloping pebble beach.

b) Estuarine (Figure 1a, b); Hazelbank; Minearny; Rostrevor. All three beaches are narrow (max width ~5 m) sand and shingle rising from extensive sand and mud flats. Hazelbank is the only beach surveyed close to a major population centre (Belfast metropolitan area).

c) East coast (low energy, rural beaches; Figure 1a, b); Ballywalter; Ballyhornan; Cloughey; Drains Bay; Tyrella. Drain's Bay (the most northerly of this group) is the only beach not composed of wide, flat sand. Ballyhornan is backed in part by a till escarpment up to 10 m high.

d) North Coast (higher energy, exposed rural beaches; (Figure 1a, b); Rathlin; Runkerry; White Park Bay. Runkerry and Rathlin are both exposed sand beaches where bathing is prohibited due to strong currents, with Runkerry also having some 2-4 m depth of cobbles over the 100 m stretch (at the eastern end). Rathlin was a split area, with the 100 m section on sand within the bay next to the marina, while the remainder of the 1 km was on the exposed pavement and pebble beach on the other side of the seawall. White Sand Bay is owned by National Trust, with no surrounding development. The survey area was the beach centre – flat, fine-grained sand, backed by dunes located at the base of a high limestone cliff.

INSERT Figures 1a, 1b

Figure 1a: Beach litter sampling site locations:
Figure 1b: Examples of four diverse area locations: a) Fishing Port; b) East Coast site; c) Estuarine site; d) North coast site.

METHODOLOGY

Litter items were categorised according to OSPAR (2007a, 2007b) at 14 Northern Ireland beach sites, carried out on five survey occasions: Autumn 2012, Winter 2012-13, Spring, Summer, and Autumn 2013 (total 70 samples). These data form part of a UK data set, which is being used to compile a response for Descriptor 10 of the EU Marine Strategy Framework Directive. Other than three harbour beaches (Ardglass, Kilkeel, Portavogie), the areas surveyed were located at least 500 m from any frequently visited beach section and no beach cleaning was carried out, apart from removal of 300 bottles at Hazelbank in 2012. Even at Tyrella, it was unusual to see anyone other than kite surfers or dog walkers within the area hence fewer people discarded fewer recreational litter items directly on site.

Beach litter surveys

a) 100 m beach transect.

At each location, a detailed count of litter items from the highest strand line to the back of the beach (seawall, dunes etc.) down to the sea, were undertaken if possible within a 100 m wide strip located either side of the access point (Figure 2; EA/NALG, 2000). A surveyor's wheel measured the distances and the points were marked with GPS. At some beaches, with a distant, or poorly-defined access point, the 100 m section was located arbitrarily. All litter items within the transect area were recorded (107 OSPAR categories). There was little variation in the extent of study areas between sites. This methodology ensures that virtually all litter types present on a beach are recorded (Tudor and Williams, 2001). .

At Rostrevor, Minearny and Ardglass, the area surveyed was confined to the strand line and back beach. Repeated surveys showed that about 1% of litter could be found on the intertidal flats, so it was most efficient to concentrate on areas above the strand line. Where litter items did occur further down shore, they were generally prominent items such as tyres or clothing. This confirmed the work of Tudor and Williams (2001) who showed that apart from purely recreational beaches, litter accumulates in the area between the strand line and back beach, with less than 2% of litter being found below the strand line.

INSERT Figure 2

Figure 2. Beach litter survey zones (adapted from EA/NALG 2000)

b) 1 km strand-line survey.

At each location, litter items were counted along 1 km of the lowest (most recent) continuous high water strand line (22 categories). In some areas e.g. Drains Bay, there was only a faint strand-line.

Multivariate statistical analysis

Counts of individual litter items at each site and sampling season for 100 m beach survey and 1 km strand-line survey, were analysed using several multivariate methods, with the aims of:

- Searching for pattern or structure in a set of data (Tudor *et al.*, 2002; Tudor and Williams, 2004).
- Describing or summarising the data efficiently to reduce the data matrix to a more manageable form (Randerson, 1993).
- Searching for possible causal relationships between litter distribution, site location and associated geophysical/human factors (Williams *et al.*, 2003).

Multivariate analysis methods follow strategies either of Ordination (arranging data items on geometric axes), or Clustering (assigning items to discrete groups), based on the numerical composition of litter categories in the beach samples. In this, and previous studies of beach litter distribution (Williams *et al.*, 2014; 2016a; 2016b), results from several methods were evaluated. The 100 m beach litter categories (total 107) were reduced to 61 prior to analysis by excluding those with low maximum occurrence across all samples (5 or less per sample). All categories (total 22) in the 1 km strandline data were used.

i) Principal components analysis (PCA)

PCA ordinates both the samples (for site and season) and the variables (litter categories) onto constructed axes based on a calculated matrix of similarity between variables. Typically, only the two principal axes (components) are displayed in the form of a 2-axis scatter plot or vector plot. The choice of similarity matrix (covariance or correlation coefficient), which determines whether data are implicitly standardized, may have a profound impact on the results, as discussed below. No rotation was applied to the axes, hence the % variance of each component is a direct measure of its relative importance.

ii) Principal Coordinates Analysis (PCO)

Similarly, PCO provides an ordination axis plot for samples (but not variables), based on a distance matrix, for which several options are available, e.g. Euclidean distance. The Bray-Curtis dissimilarity coefficient between samples i and j was used (Bray and Curtis. 1957), calculated as $C_{ij} = 1 - 2W/ (A + B)$; where W is the sum (for all litter categories) of the lesser score for each pair of samples i and j; A is the sum of all scores for sample i; B is the sum of all scores for sample j. For any pair of samples, the coefficient is scaled between 0 (numerically identical) to 1 (completely dissimilar).

iii) Correspondence Analysis (CA) and Detrended Correspondence Analysis (DCA)

These ordination methods follow an iterative procedure for axis construction (Hill and Gauch, 1980; Shaw. 2003) and are appropriate for categorical data where samples differ widely in their composition such as ecological data (species-in-sites), as discussed below. In such cases, axis 2 may be compromised by the "arch effect" (a quadratic distortion of axis 1), hence the process of de-trending is routinely applied (DCA).

iv) Cluster Analysis

Cluster-grouping (of either samples or variables) involves a family of methods, depending on the choice of distance measure (between pairs of entities), and clustering algorithm (to define inter-cluster distances). For both data sets the combination of Squared Euclidean Distance with Ward's linkage was selected (a hierarchical method which minimizes the within-cluster variability and typically produces even-sized, distinct groups, despite highly variable data).

Multivariate analyses were performed using Minitab 17 and MVSP (Multivariate Statistical Package).

RESULTS

a) 100 m beach transect

Total amounts of the main litter categories found at the sites are given in Table 1a, whilst litter type rankings are shown in Table 2. String and cord, plastics (which constituted the main body of litter (52%; Table 1b; 1c) of various sizes were extremely dominant among litter found throughout all investigated seasons (Table 2).

The three fishing ports stand out for most of the litter types shown in Table 1. For example, heavy duty gloves found throughout the year at Ardglass, Kilkeel and Portavogie. These items also occurred in similar numbers at Ballyhornan, an east coast low energy location adjacent to Ardglass, which invariably mirrored litter items found there (Tables 1a, 2). Cotton bud sticks were prevalent at Portavogie (31, 100, 33, 67 and 6; Table 1a). Tampon applicators and sanitary towels also were found in large numbers at Portavogie (Table 1a).

Ardglass was by far the main location for glass items, e.g. autumn 27 bottles and 7 other glass items; Winter 90/170; Spring 80/130 and Autumn 80/1 respectively.

Estuarine locations rarely had large amounts of litter. However, at Hazelbank, in autumn 2012, 300 glass items (and 1 glass bottle) were found. This anomaly was due to its being an informal dumping place for bottles and the beach had not been cleaned until winter 2012, when zero items were found.

East coast low energy locations, e.g. Drains Bay, Cloughy, Ballywalter and Tyrella, had the lowest relative litter amounts, apart from string and cord, sweet wrappers and crisp packets at Tyrella (Table 1a).

North coast (high energy) locations produced high numbers of litter items in several categories, especially plastics, string and cord, caps and sweet wrappers (Table 1), mirroring the fishing ports in this respect. Cotton bud sticks were commonly found at Runkerry where their numbers stood out from all other sites (Table 1a).

With respect to Table 1a, of other litter items found, plastic cutlery items were sparse (Autumn 2012: Ardglass 8, Ballyhornan 10; Winter: Portavogie 11; Summer 2012: Kilkeel and Portavogie 9 each)**.** Numbers of angler fishing line items varied widely (Autumn 2012: Ardglass 18, Ballyhornan 57, Kilkeel 10; Winter: virtually none; Spring 2013: Ardglass 7, Ballyhornan 5, Tyrella 15; Summer: Ardglass 168; Autumn: Ardglass 20, Ballyhornan 46). Infrequent categories included: oyster/lobster pots trays, buoys, shoes, as well as pallets, crates, engine equipment, etc. Fast food items occurred predominately at the fishing ports (e.g. Autumn 2012: Kilkeel 41, Portavogie 14; Winter: Kilkeel 21, Portavogie 12; Spring 2013: Ardglass 26, Ballyhornan 16, Kilkeel 21, Portavogie 48; Summer 2013: Ardglass 14, Kilkeel 26, Portavogie 14; Autumn 2013: Kilkeel 22, Portavogie 38). Varying amounts were found at Runkerry (20) in Autumn, 2012 and 2013 (10) and at Ballyhornan (10) in Autumn, 2012 (Table 1a). Few cigarette packets/cigarette stubs were seen at any site. Anglers' fishing lines appeared spasmodically mainly in the fishing port areas, e.g. at Ardglass and Ballyhornan in the Summer of 2012, 169 and 6 items respectively and in the Autumn of 2013, 20 and 46 respectively (Table 1a), whilst Kilkeel and Portavogie had 8 and 9 items respectively for the Spring period (Table 1a). Rubber items consisting usually of belts and tyres were found in very small numbers (2 or 3 per survey).

INSERT Tables 1a, 1b

Table 1a. Numbers of items for 16 most abundant litter categories recorded at the 14 sites, ranked by abundance (100 m transect). (text key: Au. Autumn; W. Winter; Sp. Spring; Su Summer).

Table 1b. Total litter amounts found and percentage of plastics.

INSERT Table 2

Table 2. Seasonal variation in litter item total numbers (n over 14 sites) in rank order for 16 most abundant litter categories (100 m transect survey). *Italic* figures indicate rank order.

Multivariate analysis (PCA) of beach litter item abundances (61 categories), at all sites and seasons (70 samples) (Figure 3a), showed a marked distinction (on Axis 1), between fishing port sites (Kilkeel, Ardglass, Portavogie), and all other samples which appear as a tight cluster. Kilkeel samples in Winter '12 and Summer '13 were the most extreme, and Portavogie in Spring '13 differed from other fishing port samples (Axis 2), while Ballyhornan was close to its neighbouring site, Ardglass, as noted above.

The orientation of litter categories (PCA variables, displayed as a vector plot) (Figure 3b) provided some explanation as to sample location in component space. Categories associated with the fishing industry related strongly to PC1, e.g. variables 113 (heavy duty gloves), 52 (tyres, belts), 31 (rope diameter >1cm). Those oriented positively to PC1 and negatively to PC2 included food-related items, e.g. variables 19 (crisp packets, sweet and sandwich wrappers, lolly sticks), 54 (clothing), 22 (plastic cutlery, trays), whereas a group of sanitary products, e.g. variables 98 (cotton bud sticks), 99 (sanitary towel plastic backing strips), 102 (tampon applicators and tampons) lay negatively on PC2. Positive on both PC1 and 2 were a variety of plastic items. In opposition to all the above was variable 205 (dog faeces), originating from direct deposition on the beach, unrelated to sea-borne transport.

INSERT Figure 3a, 3b

Figure 3a. Scatter plot: 70 sites/seasons; components 1 vs 2 (PCA; correlation coefficient; 61 litter categories; 100 m transects). Fishing port sites separate from others, indicating distinct composition of their litter items, regardless of season. Sample labels denote Site, Season, Year (e.g. Kil-Su13: Kilkeel Summer 2013; Por-Sp13: Portavogie Spring 2013; Ard-A12: Ardglass Autumn 2012).

Figure 3b. Vector plot: 61 litter categories (variables) (Appendix 1); components 1 vs 2 (PCA; correlation coefficient; 100 m transects). Orientation of the numbered vectors relates to the relative composition of litter items in samples.

An alternative method, Principal Coordinates analysis (PCO), displayed a fuller separation of the seasonal site samples, such that four groups were seen, occupying the four sectors of the axis 1 vs 2 space (Figure 4). These groups corresponded to the character and/or location of the beach sites, namely:- the three fishing ports, Kilkeel, Ardglass Portavogie (+/+ sector; positive scores on both axes 1 and 2); north coast high energy sites, Runkerry, White Park Bay, Rathlin (+/- sector; positive on axis 1, negative on axis 2); east coast low energy sites, Ballywalter, Cloughy Drains Bay, Tyrella (-/- sector); estuarine sites, Hazelbank, Minearny Rostrevor (-/+ sector). Separation by season was not apparent, whereas litter abundance clearly differentiated sites according to local human activity and/or geophysical factors.

INSERT Figure 4

Figure 4. Scatter plot: 70 sites/seasons; axes 1 vs 2 (PCO; Bray-Curtis coefficient). Sites are distributed by human activity and/or geophysical factors, due to litter abundance. Sample labels denote Site, Season, Year (e.g. Haz-Su13: Hazelbank Summer 2013; Clo-Sp13: Cloughy Spring 2013; Kil-W12: Kilkeel Winter 2012; Bal-A13: Ballyhornan Autumn 2013; Wal-A12: Ballywalter Autumn 2012).

Cluster analysis produced two major groups (Figure 5), one comprising all samples from the three fishing ports, Kilkeel, Ardglass, Portavogie, together with one sample each from Ballyhornan and Runkerry, the second group containing all other samples. Within the first group, two Kilkeel samples were the most distinct, as in PCA.

INSERT Figure 5

Figure 5. Cluster dendrogram: 70 sites/seasons; (Ward linkage; 61 standardized litter categories; 100 m transects). Fishing port sites (Kilkeel, Ardglass, Portavogie) separate from others, indicating distinct composition of their litter items, regardless of season. Sample numbers (listed on x-axis) show no clear separation between clusters, apart from the above.

b) 1 km strand line survey (Table 3).

Most of the strand line litter accumulated near to the fishing ports, the least at the estuarine areas. Large items also followed this trend apart from the island of Rathlin and the estuarine site of Minearny (Figure 1; Tables 3, 4). Litter items could be grouped into five general categories (plastic, rubber, wood, cloth and metal). Apart from heavy duty gloves (found in exceptionally high numbers at Kilkeel in 2013), the most numerous items were large plastic pieces, followed by rope (>1cm in diameter), string/cord (<1cm diameter) and strapping bands. Cloth items were mainly duvets, carpets, mattresses, shirts; wood included machined pieces, fence posts, decking, stakes, toilet seats; metal consisted mainly of wire, pieces of unknown origin, frames, pipes, bikes, shovels, barbed wire, lorry axels, corrugated sheets; plastics were mainly shopping bags, pipes, toys, tape, fertiliser bags, linoleum or pieces of these. Plastic buoys, gloves, jerry cans etc. were all found in extremely small quantities. Drink cans, sanitary items, rubber (mainly at Kilkeel), fishing lines, glass and food items, were remarkable for their very small numbers or absence on the strand line. Similarly, lobster pots, pallets, fish boxes, fishing crates, and 15 rubber items (belts etc), were found at Minearny but virtually nowhere else. The greatest numbers of all litter items again occurred at the fishing ports, with Ballyhornan closely mirroring Ardglass once again. Plastics were found at all sites and seasons, with Minearny and Rathlin amongst the sites with greatest abundances. Wooden items accumulated in large numbers at Rostrevor and at the fishing ports; Tyrella was one of the main sites for clothing items. Medical items (variable 103) and faeces were again found only as traces; rubber items, were mainly tyres and belts and numbers were small, e.g. 2 or 3 per survey, with the occasional balloon.

INSERT Table 3

Table 3. Seasonal variation in litter item total numbers (totals over 14 sites) in rank order, for 9 of the *most abundant* litter categories (1 km strandline survey). *Bold, italic* figures indicate rank order.

INSERT Table 4

Table 4. Seasonal variation in litter item total numbers (totals over 14 sites) in rank order, for 9 of the *most abundant* litter categories (1 km strand-line survey), at locations. Site key: *BH Ballyhornan*; BW Ballywalter; PV Portavogie: Fishing ports, normal font; *low energy sites, italic*; **NE high energy sites, bold**; estuarine sites, underlined.

Multivariate analysis (PCO) of strand-line litter item abundances (22 litter categories), at all sites and seasons (70 samples) (Figure 6), showed a tendency for separation into four groups, as in the 100 m transect survey, but less clearly so. The three fishing ports (Kilkeel, Ardglass, Potavogie) clustered in the lower right (+/-) sector. In contrast the upper left (-/+) sector contained mostly estuarine and low-energy sites (Hazelbank, Minearny, Ballywalter). High energy sites (Runkerry, White Park Bay) occupied mostly the lower left (-/-) sector, whilst estuarine sites (Rostrevor, Minearny) were in the upper right (+/+) sector. Although less precise than for the 100 m transect data, indicating greater variability between samples, these results showed somewhat distinct patterns of strand-line litter deposition in relation to location and human activity. As before, there was no clear separation according to season.

INSERT Figure 6

Figure 6. Scatter plot: 70 sites/seasons; axes 1 vs 2 (PCO; Bray-Curtis coefficient; 22 categories; 1 km strand-line). Sites are distributed by human activity and/or geophysical factors, due to litter abundance. Sample labels denote site, season, year (e.g. Haz-Su13: Hazelbank Summer 2013; Clo-Sp13: Cloughy Spring 2013; Kil-W12: Kilkeel Winter 2012; Bal-A13: Ballyhornan Autumn 2013; Wal-A12: Ballywalter Autumn 2012).

Cluster analysis again produced two major groups (Figure 7), one comprising the three fishing ports, but including also one sample each from Rathlin and Tyrella and two from Ballyhornan, whereas the other group of the remaining samples included one sample from Kilkeel. This result, although dominated by the expected dichotomy between fishing port and other sites, reflects the greater variability in strand-line litter composition as noted in PCO.

INSERT Figure 7

Figure 7. Cluster dendrogram: 70 sites/seasons; (Ward linkage; 22 standardized litter categories; 1 km strand-line). Fishing port sites separate from others, indicating distinct composition of their litter items, regardless of season. Sample numbers (listed on x-axis) show no clear separation between clusters, apart from the above.

DISCUSSION

a) 100 m beach transect survey.

Marine plastic sources are extremely variable and a function of human behaviours and/or weather conditions. Similarly, it is difficult to compare beach litter surveys between different methodologies, e.g. varying width transects, number of bin bags filled. Even well-known litter checklists, e.g. OSPAR, GBCC, frequently show generic similarity but specific differences. As shown in Table 5, cigarette stubs were remarkably absent from Northern Ireland, an indication that the beaches were non-recreational. Cigarette stubs, plastic bottles and food wrappers appear to dominate beach surveys globally (OC, 2016; Table 5). Most abundant in the Great British Beach Clean (GBBC, 2016) surveys were large and small plastic/polystyrene pieces (comparable with Table 2), where they were ranked second for Northern Ireland, string and cord being the top litter item. The OC (2016) survey collected

1,332,788 pieces of these globally ubiquitous items, but did not rank them in their top ten litter items (Table 5). Plastic fragments, which are subjected to physical/chemical breakdown, are ingested by fauna and accumulate in higher organisms e.g. sea birds, predatory fish – now an active area of research and of global concern (Falconer, 2017). Cotton bud sticks and wet wipes (ranked 6th and 8th respectively in the GBBC (2016) survey were again remarkably absent from the global survey top 10 (OC, 2016), although these items were ranked 9th at Runkerry and Portavogie (Table 1a). Fishing lines ranked 8th and 13th respectively for the GBBC (2016) survey and this paper were not mentioned in the OC (2016) study and in Northern Ireland these litter items occurred in proximity to fishing ports, as did rope ranked 7th (Table 2). Food wrappers were more common in the OC (2016) and GBBC (2016) surveys, again confirming the difference between recreational and non-recreational beaches.

Insert Table 5

Table 5. Top 10 litter items found in recent surveys: Ocean Conservancy, 2016 (97 countries); Great British Beach Clean, 2016 (364 beaches); This paper.

Jambeck *et al*., (2015) estimated that 275 million metric tons of plastics are produced from 192 countries, with 4.8 - 12.7 million metric tons entering the oceans each year, but it is unknown how much of this plastic waste entering the marine environment lies on beaches as whole items, or broken-down into micro-plastics. In this survey plastic/polystyrene items, were combined into one category. In the UK, the Marine Conservation Society is one of the premier organisations involved in litter research and a comment on British beaches by Eyles (2014) is pertinent here: '*Plastic is a real issue for our oceans and beaches*. *This year we also picked up lots of lids and caps. However, despite it being a really warm summer, we saw less crisp, sweets and lolly wrappers and fewer plastic bottles*.' In contrast, on the Northern Ireland beaches investigated, caps and crisps, sweet and lolly wrappers, as well as bottles were found in abundance.

String, rope, cotton bud sticks, fishing line, heavy duty gloves and sanitary items (tampons etc.) were the main litter components found on investigated beaches, in direct contrast to Ocean Conservancy (2016) findings. Although cotton bud sticks occurred in profusion at Runkerry and Portavogie, this was nowhere near the 30% of all items found along the Tyrrhenian coast of Italy (Poeta *et al*, 2016). As they are indicative of sewage sources, local management should investigate. Of the other items reported above, all relate to fishing sources; small pieces of fishing nets/tangled nets with cord/string are found at the fishing ports (Ardglass, Kilkeel and Portavogie), probably washed ashore by currents (Chiappone *et al*., 2002). As mentioned previously, Ballyhornan located to the north of Ardglass, mirrors the litter items found at that site; probably the litter load is strongly influenced by the presence of Guns Island and Killard Point and their effect on local currents. Cloughy is located close to Portavogie, but litter deposition differs markedly between them, as the site lacks similar topographical features and is therefore much more exposed.

Longshore drift controls sediment flow and budget (Komar, 1976) and some of the first researchers to comment on litter movement aligned with longshore drift were Hayward (1984) and Barnes (2002). Taffs and Cullen (2005), working in Australia, showed that beach litter accumulated to a greater density at the northern ends of their beaches, as it was transported by longshore drift. Fernandino, *et al*. (2016) also confirmed that analogous to sediment transportation by longshore currents, these currents can also transport litter. Local conditions play a large part in the hydrodynamics of any area and floating litter especially follow longshore drift pathways (Lebreton *et al*., 2012). Tudor and Williams (2001) and Williams *et al*. (2014) showed that litter items were consistently found down-drift of major urban and manufacturing regions (Leite *et al*., 2014). Edyvane *et al.* 2014 postulated the connection between litter movement and longshore drift but failed to find evidence of such transport in their Australian field work. Rosevelt *et al*. (2012) found that season (contrary to the findings of this paper) and location (in agreement with this paper) had the greatest effect on litter abundance. Nelms *et al.* (2107, 1403) from analysis of results from a 10-year study of British beaches found that, '*the overall abundance of litter was not significantly affected by season,*' a finding corroborated in this paper.

OSPAR (2007a, 2007b) found an average of 542 litter items per 100 m survey on recreational beaches. This compares with the Autumn to Autumn slightly lower findings in this paper of respectively: 421, 355, 433, 315 and 301 per 100m survey, indicative of the summer impact of recreational activites. Total litter item amounts found for this paper were respectively for Autumn to Autumn: 7,407, 6,685, 7,189, 3,602 and 5,132 (Table 1b), much lower than those found by the NIEA (2011), which were taken over the summer season only, inferring recreational litter is an extremely large problem in Northern Ireland. A point to note is that the NIEA (2011) survey was done predominantly for testing water quality, litter being a secondary consideration.

Of an average of 8,198 items collected from 13 bathing beaches in Northern Ireland (total length 6.7km) studied annually since 1999 to the present during the bathing season (June 1-Sept 15), the NIEA (2011) found that 39% were plastic items. These would equate to OSPAR IDs 117 and 46, and possibly 32, which made up 32% of all litter *i.e.* less than found in the NIEA (2011) survey, confirming the role of plastics in recreational litter. In the NIEA (2011) survey, plastic wrapping and food wrappers were recorded separately from plastic with no mention of string/cord pieces. Metal drinks cans would be expected to be more common on recreational beaches: metal cans comprised 3.5% on the beaches investigated, compared to 7% on recreational beaches.

Direct comparions with the NIEA (2011) data set and the 14 beaches selected for this paper are difficult, as the latter beaches were deliberately chosen to be non-recreational beaches, but percentages of *total* plastic litter for Autumn to Autumn were respectively: 74, 79, 79, 65 and 75 (Table 1b). Percentages of plastic litter can vary greatly with site location and beach usage; for example in Colombia, Botero and Garcia (2011) found 21% at El Rodadero beach, Marquez (2016) found 36%, at Riohacha beach. whilst Blanco and Blanco (2011) found 69% at Playa Blanco beach. Nelms *et al*. (2017) found that 42% of the litter from British beaches came from land based sources mainly public littering and 18% from marine sources, mainly fishing. This paper found that public littering accounted for 31%, whilst fishing litter constituted 21% and sewage items formed 6%. Overall comparison (Table 6) with Nelms *et al.* (2017) indicated a very close correlation of litter percentages., but the total amount of litter was very much less than that found on beach surfaces at Henderson Island in the Pitcairn Group, South Pacific Ocean, a UNESCO World Heritage site, by Lavers and Bond (2017) which was 671.6 items/m^2 (www.pnas.org).

INSERT Table 6

Table 6. Overall percentage of litter items found: this paper and Nelms *et al.* (2017).

Indicative of fishing and its ancillary industries were: light sticks (tubes with fluid), floats (fishing buoys), buckets, hard hats, lobster/crab pots/tops, fish tags, shoes/sandals, octopus pots, oyster nets or mussel bags including plastic stoppers, oyster trays (from oyster cultures), pallets, crates, fish boxes, fishing weights/hooks/lures, electronic appliances, oil drums, industrial scrap, paint tins, engine oil containers and drums. A recreational source would include items, such as, pens, combs, hair brushes, sunglasses, shoes, sandals. Litter from dogs and medical items were found as traces only.

b) 1 km strand-line survey.

This survey method indicated five main litter groups (plastic, metal, wood, cloth, rubber; Table 4), and the fishing ports again appear to be the predominant source. As plastics tend not to decompose (Galgani *et al.,* 1996) these together with discarded/derelict fishing items are common litter items found on strandlines (Keller *et al*., 2010). A total of 4,921 litter items occurred, the top three being heavy duty gloves, large plastic pieces and rope (Table 3). Heavy duty gloves, comprising almost a quarter of litter items were found almost entirely at fishing ports – numbers being skewed by exceptionally high numbers found in the Spring, Summer and Autumn surveys on the Kilkeel strand line (Table 3; Figure 8), which contrasted with only 431 at all sites in the 100 m transect survey (Table 2). Located south of Ardglass, Tyrella also had a surprising number of gloves on the strand line in Autumn 2013 (Table 4). These were possibly thrown overboard from a fishing vessel along with other litter. The main *Nephrops* fishing grounds are directly offshore (O'Sullivan *et al*., 2014) and an anti-clockwise circular gyre develops during July and August. This, coupled with its location on the northern (downwind) margin of Dundrum Bay, makes it a likely repository for floating debris derived from fishing activities. The next largest categories were large plastic pieces, rope and string. Plastic sheeting/pieces were not quite as abundant as in the 100 m surveys (Tables 2, 3), but more than 1,000 were found on non-harbour sites and numbers of smaller pieces of plastic/polystyrene were very few. In contrast to the 100 m surveys, wooden pallets, clothing, net pieces were found in high numbers, and floating items (oil drums and particularly strapping bands), made up the remainder of litter items found (Duhec *et al*., 2015). Macfadyen *et al.* (2009) estimated that 10% of all marine litter, *i.e*. 640,000 tonnes per year was from lost or discarded fishing gear and Sheavly (2005) stated that the most problematic of all marine debris were fishing nets and ropes, monofilament lines, six-pack rings and packing strapping bands: the latter was ranked 4/5th in these surveys. An interesting new development regarding old fishing lines/nets has been that of the Fishy Filaments project under the first new business model of Creative Metallurgy (www.fishyfilaments.com), whereby end of life used nets/plastics found on Cornish, UK shorelines are sorted to remove non-recyclable parts. These are washed, dried and reformatted into larger diameter filaments that can be used in high value 3D printers, a local upcycling of currently a waste product. No chemicals are involved and the economics of the recycling operation look very promising.

INSERT Figure 8

Figure 8. Heavy duty gloves at the Ardglass beach strandline.

At estuarine locations, various litter items seem to be far more abundant on the main strand line than within the 100 m surveys (14 *vs* 4 occurrences respectively, Tables 1 and 4). Numerous large plastic pieces were found at these sites (as well as Rathlin and the ports; Table 4). Drains Bay was not prominent in any of the analyses, but Tyrella, Cloughy and Rathlin, had large amounts of net pieces/broken fishing lines, cloth and strapping bands at all seasons on the strand-line. Apart from the ports, the high-energy site Rathlin (heavy duty gloves being the only item absent at this site), is the only site that scores highly on litter items in both surveys (Tables 1 and 4), probably because of the strong currents and whirlpool activity occurring at this location. Drink cans, sanitary items, rubber (mainly at Kilkeel), fishing lines, glass and food items, all found in abundance in the 100 m surveys were notable for the very small numbers, sometimes zero, found on the strand line.

The Autumn 2012 to Autumn 2013 average number of litter items per km of strandline (Table 3), were respectively: 105, 54, 75, 89, 98 from a total of 4,921 litter items counted. These are much fewer than were found by Slater (1991) for 88 remote Tasmanian beaches (300-350/km), or Taffs and Cullen (2005) in Australia (138-197/km), but higher than Frost and Cullen (1997) at Heard Island and Macquarie island (13 and 9.1 respectively). On 1 km surveys, OSPAR (2007a, 2007b) found 67 marine items per km, similar to the findings of this paper.

c) Multivariate analysis methods employed: a critical appraisal

A variety of analyses were performed on both 100 m transect and 1 km strand-line survey data sets to evaluate different multivariate methods in revealing patterns or trends of variation in the beach litter data which do not readily emerge by interrogating tabulated raw results. PCA is routinely used to analyse matrices of cases-by-variables data in a diversity of applications and subject areas. In surveys of beach litter distribution in Wales and Spain (Williams *et al.*, 2014, 2016a, 2016b), PCA provided a robust approach to search for underlying patterns and trends among large numbers of samples and variables. Results differed greatly, depending whether data were standardized (using correlation coefficient) or not (covariance). With the present data sets, both methods were used but only PCA/correlation results are presented here (Figures 3a, 3b). Using covariance, results were largely similar, except that only those variables with the highest abundance values were effective in the analysis: in the 100 m beach transect survey, plastic pieces (small and large), drink bottles and string/cord dominated the analysis.

PCA may perform poorly with data which include a high proportion of zero values (absence of a variable in many samples), or where the variables are far from normally distributed, as in the data sets presented here. PCA typically relies on a measure of "similarity" between all variables (e.g. matrix of correlation coefficient or covariance values), the validity of which may be compromised numerically where cases share few, if any, variables in common. Despite this limitation, PCA is effective with many datasets when used as a hypothesis generating tool, as here. A related method, PCO, employs a calculated measure of "distance", and is typically less sensitive to zero occurrences. PCO with Euclidean Distance gave results comparable to PCA, indicating the robustness of both methods. It was found that PCO, together with the Bray-Curtis coefficient (see Methods), gave more useful results for the beach litter data (Figures 4, 6), which aided interpretation of the pattern of litter deposition on Northern Ireland beaches, leading to better insight into factors affecting the measured abundances of items.

An alternative method, Correspondence Analysis (Figure 9), which similarly calculates geometric axis positions for samples and variables is appropriate for categorical data, and is a favoured method for ecological (species-in-samples) data which routinely contain zero values and non-normality. Applied to the 1 km strand-line data, this method separated 3 distinct Kilkeel samples and other fishing-related sites on Axis 1, whereas the remaining samples formed a diagonal trend on Axis 2, between high-energy (Runkerry) and estuarine (Hazelbank, Minearny, Rostrevor) plus low-energy sites (Ballywalter). Although showing the 2-axis "Arch" effect typical of Correspondence Analysis, within the main group of samples there appears to be a meaningful sheltered-to-exposed coastal trend. Using Detrended Correspondence Analysis on the same data, in contrast only the familiar pattern separating Kilkeel samples from others was visible.

INSERT Figure 9

Figure 9. Scatter plot: 70 sites/seasons; axes 1 vs 2 (Correspondence Analysis; scores scaled by variables; 1 km strand-line). Axis 2 trend of low-to-high energy sites, contrasting with fishing-related sites, with 3 Kilkeel samples extreme on Axis 1. Sample labels denote site, season, year (e.g. Haz-Su13: Hazelbank Summer 2013; Clo-Sp13: Cloughy Spring 2013; Kil-W12: Kilkeel Winter 2012; Bal-A13: Ballyhornan Autumn 2013; Wal-A12: Ballywalter Autumn 2012).

With the 100 m transect survey data, this method again contrasted all five seasonal samples from a north coast exposed site (Runkerry) with sheltered Estuarine sites (Hazelbank, Minearny), but other relationships between samples, and the role of particular variables remained unclear.

A different approach to multivariate analysis is to determine relationships in the form of discrete groups (clusters), for both samples and variables using Cluster Analysis, of which there are many related methods. Minimum variance clustering (Ward's linkage) was performed using squared Euclidean distance coefficient on the 100 m beach transect and 1 km strand-line data (Figures 5, 7). Results mirrored those obtained by PCA and PCO, placing Kilkeel and Ardglass samples in a group distinct from other samples, whereas there was no apparent association due to season. Clusters obtained using standardized variables were preferred, because this confers equal relative weighting for all litter categories and hence avoids dominance in the untransformed analyses by those items occurring in large abundance, such as small plastic pieces.

The relative merits of different modes of analysis depend specifically on the form of variability of the data (normality, range, absences, etc). Whereas different methods often provide a robust repetition of results, as here, alternative patterns may appear unexpectedly, offering a valuable aid to interpretation.

d) Survey methods

Comparing results of analysis of the two survey methods (100 m transect; 1 km strand-line), fewer categories of litter items occurred on the strand line compared to the whole beach profile, despite the origins of such marine-sourced litter being the same for any given location. This probably, relates to the mode of transport and deposition of items onto the site (e.g. the ability of items to float for a period; the response of items to high energy waves, etc). Galgani *et al*. (2013) pointed out that, '*floating debris constitutes but a fraction of the marine environment debris, transported by wind and currents at the sea surface and is therefore directly related to sea litter pathways.'*

These characteristics vary greatly between sites where different types of human activity or natural geophysical forces apply (e.g. fishing industry, recreational activity, long-shore currents, wave energy, etc).

Of the two survey methods employed, the time spent on surveys is a function of beach width. On narrow beaches a 100 m transect survey can be carried out faster than a 1 km strandline survey, but on wide beaches (many beaches have an intertidal extent of over 300 m), it is very time-demanding. However, most litter in 100 m surveys actually occurs at the top edge of the beach and on any strand lines present (Figure 2). At some sites, defining the "best" strand-line level to survey may not be an obvious choice, a potential source of sampling bias. Similarly, categorizing and enumerating the multitude of litter items found in both survey methods can lead to bias in subsequent analysis due to fragmentation. For some types, e.g. plastic pieces, a weight may be a more relevant measure of abundance than a count (Cheshire *et al.,* 2009).

CONCLUSIONS

Beach litter types most commonly found in the transect surveys were plastic pieces of all sizes, followed by string and cord, although these became the dominant items if plastic pieces were segregated by size (above/below 2.5 cm in length). Other frequent items included plastic drinks bottles, bottle tops and sweet wrappers, metal cans and fast food containers. Northern beaches were less affected by litter than the easterly low energy ones. The bordering site of Ballyhornan (low energy, east coast site) invariably followed litter amounts found at Ardglass due to the influence of longshore currents. Seasonal change in litter abundance was relatively small, the smallest number of litter items being found in summer. It is possible that calmer seas during these months meant that litter is not transported as strongly, dropping out of the water column before it reaches the beaches. Winter storms churn the water suspending it for longer, plus larger waves throw litter further up the beach. Location is supremely important with respect to litter findings.

Heavy duty gloves were scarce in beach surveys but occurred in large numbers at Kilkeel in the strand-line surveys of Spring, Summer and Autumn 2013. Plastics, string/cord, and rope were common to both methods. Strapping bands were not found in beach transects but 392 accumulated along the strand lines. Cotton bud sticks were a large component of the litter found at both Runkerry and Portavogie, indicating a sewage disposal problem for management. Typical recreational litter was found, e.g. crisp packages, wrappers, food/drink containers etc. Strand line litter also included wood pallets, clothing items - all floatable objects, probably transported in by currents and wave action.

Multivariate analyses showed major differences in litter categories between fishing ports and the other three locations, with a minor distinction between exposed (open coast) and sheltered (estuarine) locations. No seasonality effect was found. Similar patterns and trends in the data were found using a variety of analyses, but some methods provided greater sample discrimination with respect to coastal morphology and local anthropogenic activity. In common with the findings of similar studies around the coast of UK and Europe, a clear need for improved management practices for beach litter was identified.

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REFERENCES

www.fishyfilaments.com (accessed 15.5.17)

www.Plastics20151216062602-plastics_the_facts_2015_final_30pages_14122015 (accessed 20.05.2017).

www.pnas.org/cgi/doi/10.1073/pnas.1619818114 (accessed 15.05 2017).

Andrady, A.A., 2011. Microplastics in the marine environment. Mar. Pollut. Bull. 62, 1596–1605.

Barnes D.K.A., 2002 Invasion by marine life on plastic debris, *Nature,* 416, 808-809.

Barnes D.K.A., Galgani F., Thompson R.C., Barlaz M. 2009. Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transactions of the Royal Society B Biological Sciences,* 364 (1526): 1985-1998.

Blanco L.R., Blanco L.C. 2011. Formulacion y diseño de un Sistema de gestion comunitaria de residuos solidos en playas turisticas estudio de casa playa Blanca (Santa Marta). B. Env. Eng. thesis, Univ. del Magdalena, 106pp.

Botero, C.M., Garcia L.C. 2011. Cuantificacion y clasificacion de residuous solidos en playas turisticas. Evaluacion en tres playas de Santa Marta, Colombia. *XIV Congresso Latino-Americano do Mar - XIV COLACMAR. Balneáno Cambonú (SC/Brasil*), Oct. 30 - Nov. 4.

Bowden R., Orford J.D. 1984. Residual Sediment Cells on the Morphologically Irregular Coastline of the Ards Peninsula, Northern Ireland. *Proceedings of the Royal Irish Academy.* Section B: Biological, Geological, and Chemical Science, Vol. 84B, 13-27.

Bray J.R., Curtis J.T. 1957. An ordination of upland forest communities of southern Wisconsin. *Ecological Monographs* 27:325-349.

Carson H.S., Lamson M.R., Nakashima D., Toloumu D., Hafner J., Maximenko N., McDermid K.J., 2013. Tracking the sources and sinks of local marine debris in Hawaii, *Mar. Environ. Res*. 84, 76–83. doi:10.1016/j.marenvres.2012.12.002.

Carter R.W.G. 1990. *The Impact on Ireland of Changes in Mean Sea Level.* Programme of Expert Studies, Number 2. Department of the Environment, Dublin. 128pp.

Carter D.J.T., Challenor P.G. 1989. *Estimation of extreme waves. Metocean Parameters – wave parameters*, Dept. of Energy report OTH 89 300, 7-66.

Cheshire A.C., Adler E., Barbière J., Cohen Y., Evans S., Jarayabhand S., Jeftic L., Jung R.T., Kinsey S., Kusui E.T., Lavine I., Manyara P., Oosterbaan L., Pereira M.A., Sheavly S., Tkalin A., Varadarajan S., Wenneker B., Westphalen G., 2009. *UNEP/IOC Guidelines on Survey and Monitoring of Marine Litter.* UNEP Regional Seas Reports and Studies, No. 186; IOC Technical Series No. 83: xii + 120 pp.

Chiappone M., White A., Swanson D.W., Miler, S. 2002. Occurrence and biological impacts of fishing gear and other marine debris in the Florida Keys, *Marine Pollution Bulletin*, 44, 597-604.

Coe J.M., Rogers D.B. 1997. *Marine Debris: sources, impacts and solutions*, 1st ed. Springer. 432 pp

Cooper, J.A.G., Navas, F., 2004. Natural bathymetry change as a control on century-scale shoreline behavior. Geology 32, 513–516.

Corcoran P.L., Biesinger M.C., Grifi M. 2009. Plastics and beaches: A degrading relationship. *Marine Pollution Bulletin*, 58, 80–84.

Duhec A. V., Jeanne R.F., Maximenko N., Hafner J. 2015. Composition and potential origin of marine debris stranded in the Western Indian Ocean on remote Alphonse Island, Seychelles. *Marine Pollution Bulletin*. 96, 76–86. doi:10.1016/j.marpolbul.2015.05.042

EA/NALG. 2000. Environment Agency and the National Aquatic Litter Group. *Assessment of aesthetic quality of coastal and bathing beaches. Monitoring protocol and classification scheme*, 15 pp

Earll R. C., Williams A.T., Simmons S. L., Tudor D. T. 2000. Aquatic litter, management and prevention — the role of measurement. *J. Coast. Conserv*. 6, 67–78.

Edyvane S., Dalgetty A., Hone P.W., Higham J.S., Mace N.M. 2014. Long-term litter marine monitoring in the remote Great Australian Bight, South Australia, *Marine Pollution Bulletin,* 48, 1060-1075.

Erikssen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, J.C., Galgani, F., Ryan, P.G., Reisser, J., 2014. Plastic pollution in the world's oceans: More than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. PLoS ONE 9, e111913.

Eriksson C., Burton H., Fitch S., Schulz M., van den Hoff J. 2013. Daily accumulation rates of marine debris on sub-Antarctic island beaches. *Marine Pollution Bulletin*, 66 (1), 199-208.

Eyles L. 2014. www.mcsuk.org/what_we_do/Clean+seas+and+beaches/Pollution+and+litter+problems/British+beaches+are+dumping+ground+for+litter

Falconer I. 2017. Washed up but not wasted, *Materials World,* 25,40-41.

Fernandino G., Elliff C.I., Silva I.R., Brito T. de S., Bittencourt, A.C. da S.P. 2016. Plastic fragments as a major component of marine litter, *Int. Jn. Coastal Management,* 16. 3, 281-287.

Fossi M. C., Coppola D., Baini M., Giannetti M., Guerranti C., Marsili L., Clò S. 2014. Large filter feeding marine organisms as indicators of microplastic in the pelagic environment: The case studies of the Mediterranean basking shark (Cetorhinus maximus) and fin whale (Balaenoptera physalus). *Marine Environmental Research*, 100, 17-24.

Frost A., Cullen M. 1997. Marine debris on northern New South Wales beaches(Australia). Sources and the role of beach usage. *Marine Pollution Bulletin*, 34, 348-352.

Galgani F., Souplet A., Cadieu Y. 1996 Accumulation of debris on the deep sea floor off the French Mediterranean coast, *Marine Ecology Progress Series,* 142, 225-234.

Galgani F., Hanke G., Werner S., Oosterbaan L., Nilsson P., Fleet D., McKinsey S., Thompson R., van Franeker J., Vlachogianni T., Scoullos M., Mira Veiga J., Palatinus A., Matiddi M., Maes T., Korpinen S., Budziak A., Leslie H., Gago J., Liebezeit G. 2013. MSFD technical group on Marine Litter, Guidance on Monitoring of Marine Litter in European Seas. *JRC Scientific and Policy rep*. 483-490, SJRC83985, EUR 26113 ENI, SBN 978-92-79-32709-4. ISSN: 1831-9424. http://dx.doi.org/10.2788/99475, 128.

Galgani F., Hanke H., Maes T. 2015. Global distribution, compositiion and abundance of marine litter. In: Bergmann M., Gutow L. Klages M. (Eds.) *Marine Anthropgenic litter*. 22-57.

Great British Beach Clean, 2016. Marine Conservation Society report. (Ross on Wye, UK, 5pp).

Greenwood R.O., Orford, J.D. 2007. Factors Controlling the Retreat of Drumlin Coastal Cliffs in a Low Energy Marine Environment—Strangford Lough, Northern Ireland, *Journal of Coastal Research*, 23, 285 – 297.

Gregory M.R. 2009. Environmental implications of plastic debris in marine settings--entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. *Philos. Trans. R. Soc. Lond. B. Biol. Sci*. 364, 2013–2025. doi:10.1098/rstb.2008.0265

Hayward, B.W., 1984. Rubbish Trends: beach litter surveys at Kawerua, 1974-82. In: Tane. 30. pp. 209–217.

Hill M.O., Gauch H.G. 1980. Detrended Correspondence Analysis: An Improved Ordination Technique. *Vegetatio,* 42, 47–58.

Howarth M.J. 2005. *Hydrography of the Irish Sea SEA6 Technical Report, POL internal Document,* No 174, Proudman Oceanographic Laboratory, Liverpool.

IEA. 2011. *States of Seas report, Ch 11 Litter*. Northern Ireland Environment Agency and Agri-Food Biosciences Institute.

Jackson D.W.T., Cooper J.A.G. 2010. Application of the equilibrium planform concept to natural beaches in Northern Ireland. *Coastal Engineering*, 57, 112-123.

Jambeck J.R., Geyer R., Wilcox C., Siegler T.R., Perryman M., Andrady A., Narayan R., Law K.L. 2015. Plastic waste inputs from land into the ocean. *Marine Pollution Bulletin*, 347, 768–771.

Keller A.A., Fruh E.L., Johnson M.M., Simon V., McGourty C. 2010. Distribution and abundance of anthropogenic marine debris along the shelf and slope of the US West coast. *Marine Pollution Bulletin*, 47, 1, 175-179.

Knight P.J., Howarth M.J. 1999. The flow through the north channel of the Irish Sea *Continental Shelf Research,* 19, 693-716.

Komar P.D. 1976. Beach Processes and Sedimentation, Englewood Cliffs, NJ, Prentice-Hall, 429pp.

Kuase T., Noda M. 2003. International survey of the distribution of stranded ad buried litter on beaches along the Sea of Japan. *Marine Pollution Bulletin,* 47, 175-179.

Lebreton L.C.M., Greer S.D., Borrero J.C. 2012. Numerical modelling of floating debris in the world's oceans. *Marine Pollution Bulletin*, 64, 653–661. doi:10.1016/j.marpolbul.2011.10.027

Leite A. S., Santos L.L., Costa Y., Hatje V. 2014. Influence of proximity to an urban center in the pattern of contamination by marine debris. *Marine Pollution Bulletin*, 81, 242–247. doi:10.1016/j.marpolbul.2014.01.032

Liu T.K., Wang M.-W., Chen P. 2013. Influence of waste management policy on the characteristics of beach litter in Kaohsiung, Taiwan. *Marine Pollution Bulletin*, 72, 99–106. doi:10.1016/j.marpolbul.2013.04.015.

Macfadyen G., Huntingdon T., Cappelli R. 2009. *Abandoned lost or discarded fishing gear*, UNEP 2009. www.fao.org/docrep/011/i0620e/i0620e00.htm

Marquez E. 2016. Calidad ambiental de las playas urbanas del Distrito Turistico y Cultural de Riohacha, La Guajira. M. Eng. Thesis, Univ. de La Guajira, Colombia, 172pp.

McIlgorm A., Campbell F.H., Rule M.J. 2008. *Understanding the Economic Benefits and Costs of Controlling Marine Debris in the APEC Region, Coffs Harbour, NSW, Australia.*

Met Eireann. 2016. *Climate of Ireland*. http://www.met.ie/climate-ireland/wind.asp

Morrison R. J. 1999. The regional approach to management of marine pollution in the south pacific. *Ocean and Coastal Management*, 42, (6–7), 503–521.

Mouat J., Lozano R.L., Bateson H. 2010. Economic Impacts of Marine Litter. KIMO, 117pp.

Nelms S.E., Coombes C., Foster L.C., Galloway T.S., Godley B.J., Lindeque P.L, Witt M.J. 2017. Marine anthropogenic litter on British beaches: A 10-year nationwide assessment using citizen science data, *Science of the Total Environment* 579, 1399–1409.

Nixon Z., Barnea N. 2010. Gulf of Mexico Marine Debris Model. *National Oceanic and Atmospheric Administration Technical Memorandum* NOS-OR&R-35, 20pp.

Ocean Conservancy. 2016. *Marine Litter*. www. ocean conservancy.com

Orford J.D. 1989. A review of tides, currents and waves in the Irish Sea. In: Sweeney, J. (Ed.), The Irish Sea: A Resource at Risk. Dublin, Ireland: *Geographical Society of Ireland,* Special Publication 3, 18–46.

OSPAR. 2007a. OSPAR *Pilot Project on Monitoring Marine Beach Litter*. Monitoring of Marine Litter in the OSPAR Region Publication No 306/2007. ISBN 978-1-905859-45-0.

OSPAR. 2007b. *Convention for the protection of the marine environment of the north-east Atlantic.*, 33pp

O'Sullivan D., Lordan C. Doyle J. Berry A., Lyons, K. 2014. Sediment characteristics and local hydrodynamics and their influence on the population of Nephrops around Ireland. *Irish Fisheries Investigations*, 26, Marine institute, Galway.

Pilkey O.H., Cooper J.A.G. 2014. *The Last Beach*. Duke University Press, Durham & London

Poeta G., Battisti C., Bazzichetto M., Acosta A.T.R. 2016. The cotton buds beach: Marine litter assessment along the Tyrrhenian coast of central Italy following the marine strategy framework directive criteria, *Marine Pollution Bulletin*, 113, 1-2, 266-270. http://dx.doi.org/10.1016/j.marpolbul.2016.09.035

Potts T., Hastings E. 2012. Marine Litter Issues, Impacts and Actions, *Marine Scotland,* Scottish Government, 131pp. **ISBN:** 9781782560821

Randerson P.F. 1993. Ordination, Chapter 5. In: *Biological Data Analysis*, (ed.) Fry J. C. IRL Press. 173-217.

Rosevelt C., Los Huertos, M., Graza C., Nevins H.M. 2012, Marine debris in central California: Quantifying and abundance of beach litter in Monterey Bay, CA. *Marine Pollution Bulletin*, 71, 299-306.

Ryan N.M., Cooper J.A.G. 1998. Spatial variability of tidal flats in response to wave exposure: examples from Strangford Lough, Co. Down, Northern Ireland. *Geological Society, London,* Special Publications, Volume 139, 221-230

Setälä O., Fleming-Lehtinen V., Lehtiniemi M. 2014. Ingestion and transfer of microplastics in the planktonic food web, *Environmental Pollution*, Volume 185, 77–83.

Shaw P.J.A. 2003. *Multivariate Statistics for the Environmental Sciences*. London: Hodder Arnold

Sheavly S.B. 2005. *Sixth meeting of the UN open ended forum and consultative process on Oceans and the Law of the Sea* www.UN.org/Depts/los/consultative_process/consultative_process.htm

Sheavly S.B., Register K.M. 2007. Marine debris and plastics: environmental concerns, sources, impacts and solutions. *Journal of Polymers and the Environment,* 15, (4): 301-305.

Slater J. 1991. The incidence of marine debris in the south west of the World Heritage area, *Tasmanian Naturalist*, 25 32-35.

Slavin C., Grage A., Campbell M.L. 2012. Linking social drivers of marine debris with actual marine debris on beaches. *Marine Pollution Bulletin*, 64, 1580–1588.

Taffs K.H., Cullen M.C. 2005. The distribution and abundance of marine litter debris on isolated beaches of northern New South Wales, Australia, *Australasian Journal of Environmental Management*, 12, 4, 244-250.

Thiel M., Hinojosa I.A., Miranda L., Pantoja J.F., Rivadeneira M.M., Vásquez N. 2013. Anthropogenic marine debris in the coastal environment: A multi-year comparison between coastal waters and local shores. *Marine Pollution Bulletin*, 71(1): 307-316.

Thompson R.C., Moore C.J., von Saal F.S., Swan S.H. 2009. Plastics, the environment and human health: current consensus and future trends. *Philos. Trans. R. Soc. Lond. B. Biol. Sci*. 364, 2153–2166. doi:10.1098/rstb.2009.0053

Tudor D.T., Williams A.T. 2001. *Investigation of litter problems in the Severn estuary /Bristol area.* Environment Agency, R and D, Tech Report E1-082/T.R, 301pp.

Tudor D.T., Williams A.T. 2004. Development of a "Matrix Scoring Technique" to determine litter sources at a Bristol Channel beach. J*. Coast. Conservation*. 10(1/2), 119-127.

Tudor D.T., Williams A.T., Phillips M.R., Thomas M.C. 2002. Qualitative and quantitative comparisons of some indices suitable for litter analysis. (In), *Littoral 2002. The Changing Coast,* Vol. 1, (eds.), Veloso-Gomes, F., Taveira-Pinto, F. and L das Neves, Eurocoast, Portugal, 367-374.

Williams A.T., Tudor D.T. 2001. Litter burial and exhumation: spatial and temporal distribution on a pocket pebble beach. *Marine Pollution Bulletin*, 42(11), 1031-1039.

Williams A.T., Tudor D.T., Randerson P.F. 2003. Beach litter sourcing in the Bristol channel and Wales, U.K. *Water Air Soil Pollution*, 143, 387–408.

Williams A.T., Randerson P.F., Alharbi O. 2014. From a Millennium base line to 2012: Beach litter changes in Wales. *Marine Pollution Bulletin,* 84, 17-26.

Williams A.T., Randerson P.F., Giacomo C.D., Anfuso G., Perales J.A., Macias A. 2016a. Distribution of beach litter along the coastline of Cádiz, Spain, *Marine Pollution Bulletin,* 107, 77-87.

Williams A.T., Rangel-Buitrago N.G., Anfuso G., Cervantes O., Botero C.M. 2016b. Litter impacts on scenery and tourism on the Colombian north Caribbean coast, *Journal of Tourism Management,* 53, 209-234.