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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, 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.

1. 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, 2004; Barnes et al., 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., 2014; Erikssen et al., 2014; Poeta et al., 2016). 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. (2013, 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 and 80% (Kuase 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 Mcllgorm 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;

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Potts and Hastings, 2012; Thompson et al., 2009):

- via ingestion/entanglement for mammals, sea birds, fish, (Gregory, 2009; Williams et al., 2013).
- 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.

2. 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 (Fig. 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, whilst 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 long-shore 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, 1998) whilst rivers of various sizes discharge into each of the sea loughs.

3. Investigated sites

a) Fishing ports (Fig. 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 (Fig. 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; Fig. 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; (Fig. 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, whilst 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.

4. 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.

4.1. Beach litter surveys

4.1.1. 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 (Fig. 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).

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

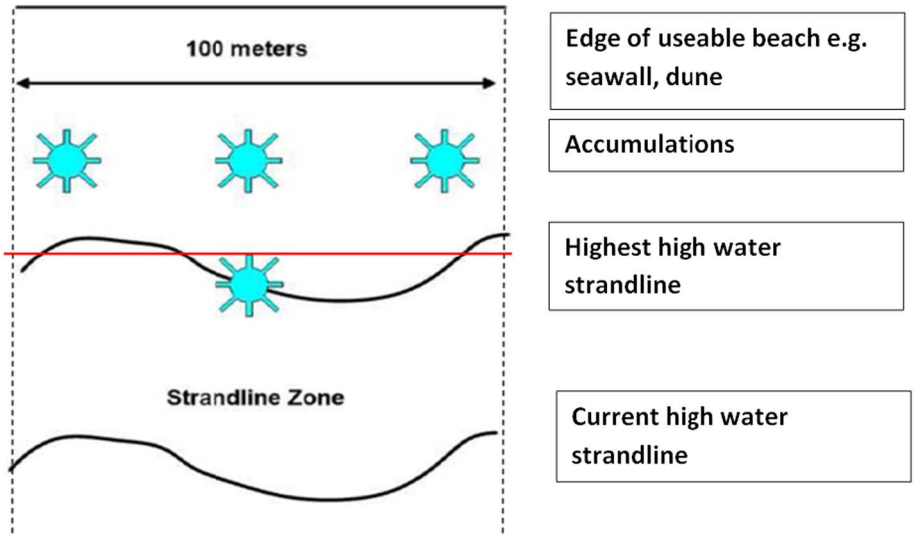

Fig. 2. Beach litter survey zones (adapted from EA/NALG, 2000).

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 < 2% of litter being found below the strand line.

4.1.2. 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.

4.2. 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 (Appendix 1) 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.

4.2.1. 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.

4.2.2. 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).

4.2.3. 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).

4.2.4. 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).

5. Results

5.1. 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; c) of various sizes were extremely dominant among

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).

Location, season & litter item	1 String/cord < 1 cm diam					2 Plastic/polystyrene pieces > 2.5 cm					3 Plastic/polystyrene pieces < 2.5 cm					4 Drinks containers/drums				
	Au	W	Sp	Su	Au	Au	W	Sp	Su	Au	Au	W	Sp	Su	Au	Au	W	Sp	Su	Au
Fishing ports																				
Ardglass	102	44	166	122	87	21	59	40	39	38	40	50	40	50	29	28	9	79	57	24
Kilkeel	25	13	40	72	93	335	108	117	45	110	70	75	83	29	0	109	179	226	272	97
Portavogie	20	14	85	45	54	91	104	78	45	40	109	31	124	87	28	31	75	130	4	3
High energy																				
Rathlin	94	157	214	115	108	80	35	22	10	63	55	31	54	4	0	5	5	2	0	2
Runkerry	9	13	1	20	8	98	33	45	32	39	231	51	86	37	34	3	7	10	0	1
White Park	105	65	0	6	22	17	24	47	13	33	83	36	148	23	33	8	2	1	5	9
Estuaries																				
Minearny	0	0	2	3	0	5	18	8	5	1	13	11	25	9	0	19	8	13	20	4
Hazelbank	5	0	1	0	0	7	8	6	3	2	0	4	3	0	1	7	6	3	3	4
Rostrevor	5	1	5	0	4	15	21	23	8	35	7	46	22	5	14	41	29	28	0	34
Low energy																				
Ballyhornan	70	47	132	130	191	110	54	43	61	97	38	65	52	70	87	14	32	15	35	56
Ballywalter	1	6	82	12	4	2	39	14	2	3	0	30	3	7	4	0	1	3	0	0
Cloughy	10	20	22	45	4	28	24	3	4	5	30	9	5	5	7	0	13	1	1	3
Drains	5	0	7	5	3	9	5	21	10	1	5	10	18	3	3	10	3	10	2	0
Tyrella	38	125	114	32	21	0	45	16	18	9	3	23	16	10	9	2	22	25	4	9

Location, season & litter item	5 Bottle caps					6 Crisp/sweet/food wrappers					7 Rope > 1.5 cm					8 Drink cans				
	Au	W	Sp	Su	Au	Au	W	Sp	Su	Au	Au	W	Sp	Su	Au	Au	W	Sp	Su	Au
Fishing ports																				
Ardglass	7	0	19	23	2	31	22	48	27	27	43	15	55	17	22	37	17	36	43	33
Kilkeel	22	20	7	34	34	21	4	17	17	35	40	41	45	17	60	38	74	63	65	52
Portavogie	26	37	61	26	11	19	39	105	20	7	7	14	66	30	41	41	60	118	27	23
High energy																				
Rathlin	77	23	14	1	36	36	32	17	7	58	6	21	21	14	19	0	6	2	2	0
Runkerry	123	57	31	57	42	19	12	4	8	5	11	4	0	10	5	0	12	1	10	1
White Park	15	21	31	9	0	23	11	7	9	13	16	19	27	8	9	3	1	0	1	1
Estuaries																				
Minearny	0	7	1	2	1	6	3	10	16	3	0	1	0	1	0	4	2	2	8	4
Hazelbank	0	0	0	0	2	2	1	6	2	3	3	4	3	3	1	3	3	1	1	4
Rostrevor	2	14	10	4	39	13	14	14	5	19	*1*	0	0	0	0	17	5	17	10	14
Low energy																				
Ballyhornan	22	42	48	45	96	53	26	25	50	63	35	42	33	52	99	4	8	3	8	7
Ballywalter	0	2	21	5	1	0	1	33	5	0	1	3	17	2	0	0	6	1	2	0
Cloughy	5	7	10	9	0	21	17	6	6	7	0	5	7	9	1	0	6	1	2	0
Drains	8	3	21	9	1	2	2	24	6	3	1	2	4	0	0	3	2	2	1	0
Tyrella	8	27	25	14	0	77	74	17	16	8	2	34	42	23	7	2	14	1	2	9

(continued on next page)

Table 1a *(continued)*

Location, season & litter item	9 Cotton bud sticks					10 Other glass					11 Plastic carrier bags					12 Food containers				
	Au	W	Sp	Su	Au	Au	W	Sp	Su	Au	Au	W	Sp	Su	Au	Au	W	Sp	Su	Au
Fishing ports																				
Ardglass	0	0	14	1	1	5	170	112	17	1	12	5	12	16	10	0	0	26	14	3
Kilkeel	1	0	0	0	4	0	0	0	0	3	7	20	25	12	8	41	21	38	26	22
Portavogie	31	108	33	67	6	5	1	11	9	7	26	25	92	40	22	14	12	48	14	1
High Energy																				
Rathlin	3	30	9	0	59	0	0	0	0	0	23	10	19	0	12	1	5	1	0	1
Runkerry	92	35	21	41	21	0	1	0	0	0	2	2	0	0	0	20	21	3	2	10
White Park	23	1	58	22	8	0	0	0	0	0	0	2	0	6	4	9	2	0	0	0
Estuaries																				
Minearny	0	5	0	4	0	0	1	0	9	3	5	24	47	15	3	0	3	7	13	1
Hazelbank	0	0	0	0	0	300	0	2	40	0	8	4	22	3	6	0	0	4	0	3
Rostrevor	0	8	5	0	3	3	1	0	0	0	0	9	7	29	9	6	1	2	0	3
Low energy																				
Ballyhornan	3	22	12	8	30	1	0	0	0	0	7	8	13	5	3	19	6	16	9	15
Ballywalter	0	0	10	3	1	0	0	0	0	0	0	20	18	5	0	0	3	0	0	0
Cloughy	4	5	1	1	0	0	0	0	0	0	14	1	2	9	18	1	5	1	1	2
Drains	1	0	0	0	0	0	0	0	1	0	2	3	1	1	1	5	1	6	1	0
Tyrella	9	6	22	9	0	0	1	0	0	0	3	24	13	13	23	0	5	0	2	5

Location, season & litter item	13 Fishing line					14 Bottles					15 Tampons/sanitary towels					16 Heavy duty gloves				
	Au	W	Sp	Su	Au	Au	W	Sp	Su	Au	Au	W	Sp	Su	Au	Au	W	Sp	Su	Au
Fishing ports																				
Ardglass	18	3	7	169	20	127	90	80	46	80	0	1	4	3	1	7	4	26	15	11
Kilkeel	10	5	8	6	16	1	5	3	13	4	1	0	1	0	0	52	21	44	65	44
Portavogie	3	1	9	13	3	7	4	11	8	8	360	15	48	10	58	19	9	61	7	6
High energy																				
Rathlin	6	7	5	4	15	0	0	1	1	0	1	0	2	0	0	0	0	0	1	0
Runkerry	7	3	1	1	3	3	0	0	0	0	5	0	0	0	5	0	0	0	1	1
White Park	4	4	4	1	0	0	0	0	0	2	5	0	0	0	5	0	0	0	0	0
Estuaries																				
Minearny	0	1	0	0	1	4	0	8	15	8	0	1	0	0	0	0	1	0	0	0
Hazelbank	0	0	0	0	0	0	0	20	12	2	3	41	2	0	1	0	0	0	0	1
Rostrevor	1	0	4	1	3	7	1	5	6	3	1	0	3	1	1	0	0	0	0	0
Low energy																				
Ballyhornan	57	2	5	6	46	0	3	0	0	1	2	11	0	2	2	10	3	5	15	11
Ballywalter	0	0	6	3	2	0	0	0	0	1	0	2	0	0	0	1	8	1	0	0
Cloughy	2	0	1	2	2	0	1	0	0	0	3	1	0	0	0	0	2	0	0	1
Drains	1	0	2	0	0	0	2	2	0	0	3	0	7	1	0	0	2	0	0	0
Tyrella	1	10	15	6	2	0	0	0	1	0	0	4	1	0	0	0	7	4	1	6

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

Location	Autumn		Winter		Spring		Summer		Autumn	
	Total	%	Total	%	Total	%	Total	%	Total	%
Fishing ports										
Ardglass	918	53	741	51	1074	60	690	61	372	63
Kilkeel	1417	88	1974	83	983	82	701	68	1037	80
Portavogie	1145	53	807	71	1661	73	543	63	584	55
High energy										
Rathlin	496	96	473	92	494	94	184	93	492	85
Runkerry	1108	89	372	87	245	90	244	75	933	96
White Park	469	91	305	92	627	87	81	93	100	81
Estuaries										
Minearny	218	66	152	78	200	79	189	59	28	0
Hazelbank	380	12	97	48	97	63	72	13	51	70
Rostrevor	169	78	174	85	245	74	65	64	189	83
Low energy										
Ballyhornen	677	94	568	84	577	90	466	93	1050	94
Ballywalter	11	72	225	90	273	91	49	79	31	90
Cloughy	199	90	161	90	102	80	80	91	83	95
Drains	95	77	75	77	236	72	72	68	22	72
Tyrella	105	83	561	90	375	80	80	73	160	83
TOTAL/Av %	7407	74	6685	79	7189	79	3602	65	5132	75

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,

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.

Category: total/rank order		Autumn 2012		Winter '12/13		Spring 2103		Summer 2013		Autumn 2013	
String/cord < 1 cm diam. n = 2735	*1*	89	*3*	507	*2*	945	*1*	607	*1*	587	*1*
Plastic/polystyrene pieces > 2.5 cm n = 2514	*2*	881	*1*	577	*1*	491	*4*	295	*4*	270	*3*
Plastic/polystyrene pieces < 2.5 cm n = 2397	*3*	691	*2*	472	*3*	679	*2*	339	*3*	216	*6*
Drink containers/drums n = 1919	*4*	277	*6*	391	*4*	546	*3*	424	*2*	281	*2*
Bottle caps n = 1287	*5*	245	*8*	270	*5*	299	*7*	238	*5*	235	*4*
Crisp/lolly/sweet/food wrappers n = 1210	*6*	252	*7*	213	*7*	333	*5*	194	*7*	218	*5*
Rope > 1 cm diam. n = 1083	*7*	166	*9*	205	*9*	320	*6*	187	*8*	205	*7*
Drink cans n = 932	*8*	152	*11*	213	*7*	250	*8*	170	*9*	147	*8*
Cotton buds n = 861	*9*	157	*10*	220	*6*	203	*9*	156	*10*	125	*9*
Other glass n = 704	*10*	314	*5*	175	*10*	125	*13*	76	15	14	*15*
Plastic carrier bags n = 542	*11*	84	*15*	101	*12*	191	*10*	93	*14*	73	*13*
Food containers (pots, sachets, etc.) n = 538	*12*	146	*12*	87	*13*	152	*11*	82	*13*	71	*14*
Fishing line n = 538	*12*	110	*13*	36	*15*	67	*16*	212	*6*	113	*10*
Bottles n = 496	*14*	50	*16*	107	*11*	130	*12*	102	*12*	107	*11*
Tampons/applicators/ Sanitary towels n = 479	*15*	362	*4*	21	*16*	70	*15*	18	*16*	8	16
Heavy duty gloves n = 431	*16*	89	*14*	54	*14*	96	*14*	105	*11*	87	12

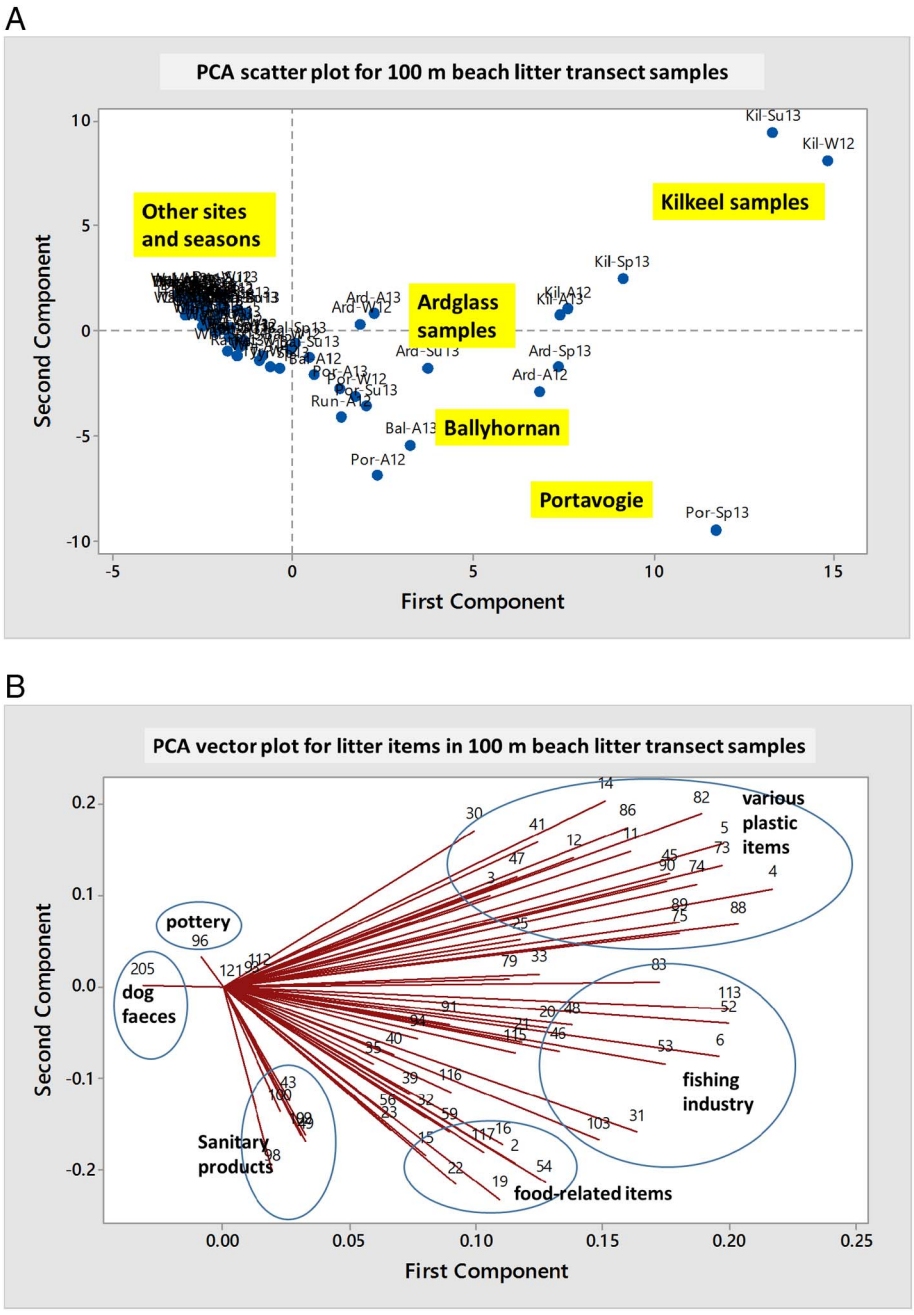

Fig. 3. A Scatter plot: 70 sites/seasons; components 1 vs 2 (PCA; correlation coefficient; 107 litter categories; 100 m transects). Fishing port sites separate from others indicating distinct composition of their litter items, regardless of season. Sample labels denote site, season, year (e.g. Kil-Su13: Kilkeel Summer 2013; Por-Sp13: Portavogie Spring 2013; Ard-A12: Ardglass Autumn 2012).
B 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.

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).

Multivariate analysis (PCA) of beach litter item abundances (61 categories), at all sites and seasons (70 samples) (Fig. 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 2012 and Summer 2013 were the most extreme, and Portavogie in Spring 2013 differed from other fishing port samples (Axis 2), whilst Ballyhornan was close to its neighbouring site, Ardglass, as noted above.

The orientation of litter categories (PCA variables, displayed as a vector plot) (Fig. 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 > 1 cm). 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.

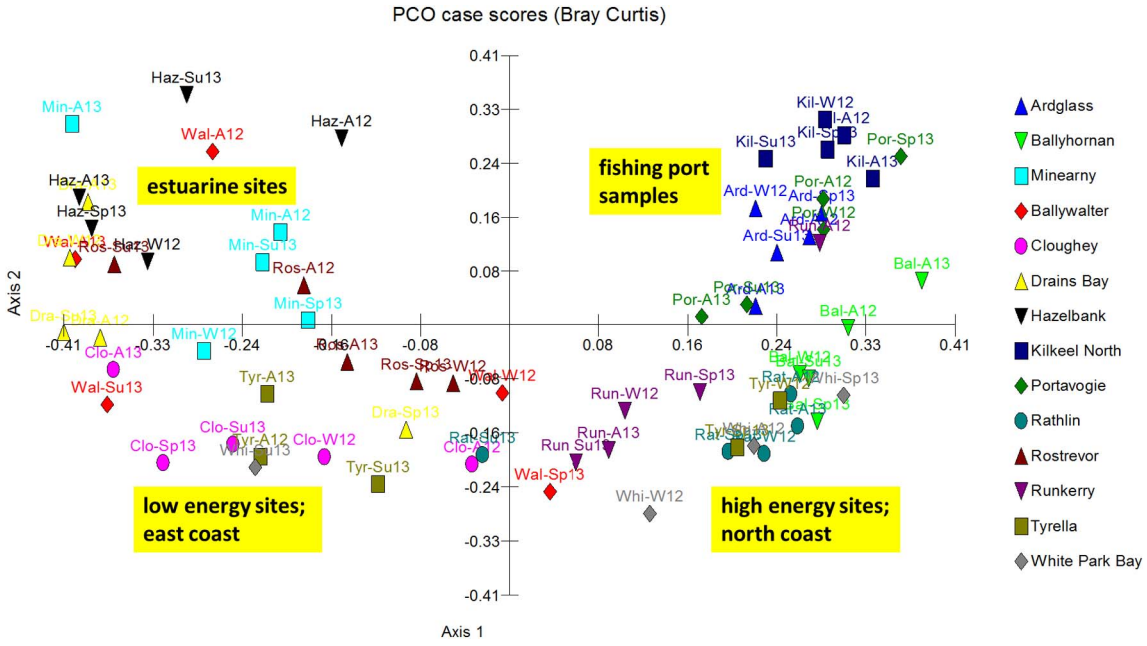

Fig. 4. Scatter plot: 70 sites/seasons; axes 1 vs 2 (PCO; Bray-Curtis coefficient). Sites are distributed by human activity and/or geophysical factors, due to litter abundance. Sample labels denote site, season, year (e.g. Haz-Su13: Hazelbank Summer 2013; Clo-Sp13: Cloughy Spring 2013; Kil-W12: Kilkeel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

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 (Fig. 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.

Cluster analysis produced two major groups (Fig. 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.

5.2. 1 km Strand line survey

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 (Fig. 1, Table 3, Table 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 (> 1 cm in diameter), string/cord (< 1 cm diameter) and strapping bands. Cloth items were mainly duvets, carpets, mattresses shirts; wood included machined pieces, fence posts, decking, stakes, toilet seats;

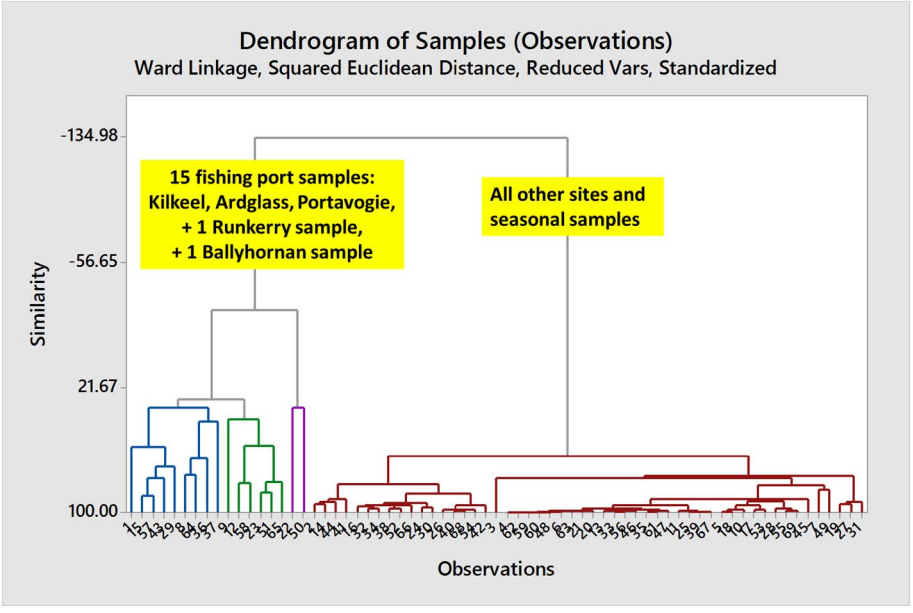

Fig. 5. Cluster dendrogram: 70 sites/seasons; (Ward linkage; 61 standardized litter categories; 100 m transects). Fishing port sites (Kilkeel, Ardglass, Portavogie) separate from others, indicating distinct composition of their litter items, regardless of season. Sample numbers (listed on x-axis) show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

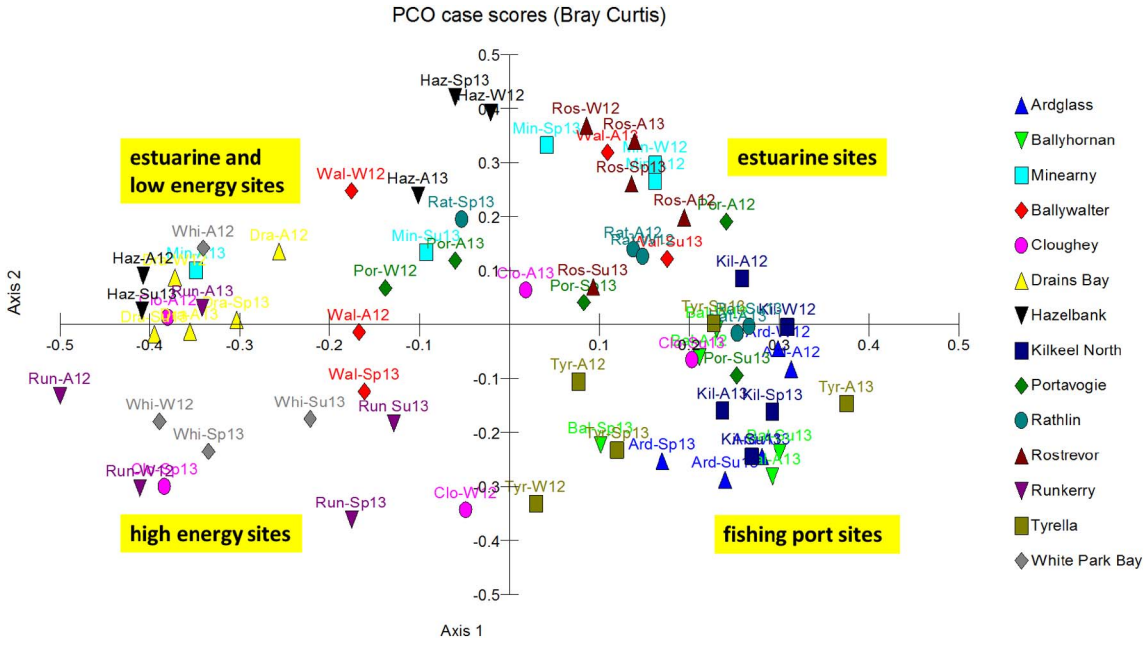

Fig. 6. Scatter plot: 70 sites/seasons; axes 1 vs 2 (PCO; Bray-Curtis coefficient; 22 categories; 1 km strand-line). Sites are distributed by human activity and/or geophysical factors, due to litter abundance. Sample labels denote site, season, year (e.g. Haz-Su13: Hazelbank Summer 2013; Clo-Sp13: Cloughy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

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 among 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.

Multivariate analysis (PCO) of strand-line litter item abundances (22 litter categories), at all sites and seasons (70 samples) (Fig. 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

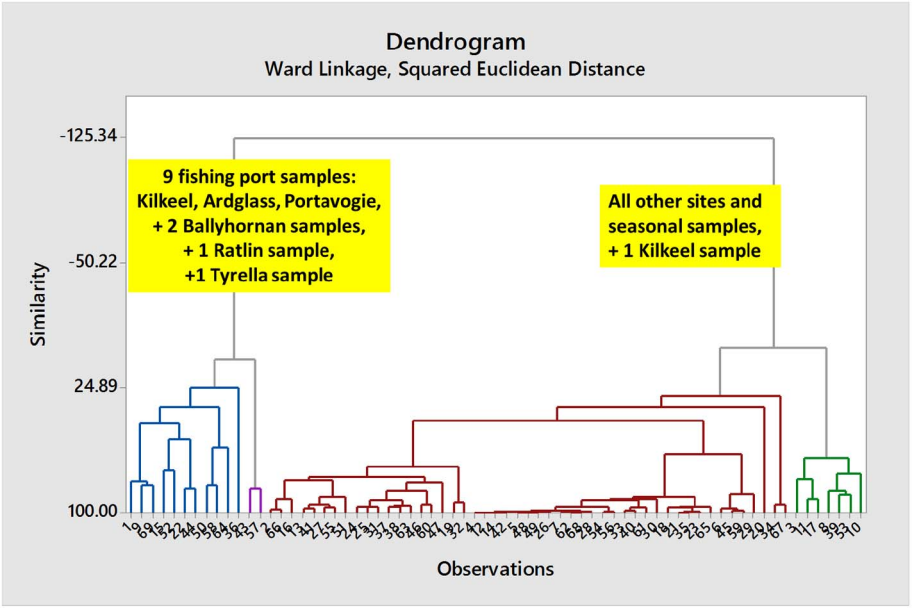

Fig. 7. Cluster dendrogram: 70 sites/seasons; (Ward linkage; 22 standardized litter categories; 1 km strand-line). Fishing port sites separate from others, indicating distinct composition of their litter items, regardless of season. Sample numbers (listed on x-axis) show no clear separation between clusters,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

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.

Category: total/rank order	Autumn 2012	Winter '12/13	Spring 2013	Summer 2013	Autumn 2013
Heavy duty gloves (752) ***1***	5 ***9***	0 ***9***	250 (215@Kilkeel) ***1***	277 (165@Kilkeel) ***1***	220 (85@Kilkeel) ***1***
Large plastic pieces (707) ***2***	289 ***1***	68 ***3***	101 ***2***	161 ***3***	179 ***2***
Rope (592) ***3***	83 ***3***	119 ***1***	75 ***4***	188 ***2***	127 ***3***
String/cord (392) ***4***	46 ***8***	37 ***7***	36 ***9***	154 ***4***	119 ***4***
Strapping bands (363) ***5***	74 ***5***	72 ***2***	59 ***5***	90 ***5***	68 ***6***
Cloth (323) ***6***	96 ***2***	60 ***5***	29 ***8***	88 ***6***	50 ***8***
Wood (322) ***7***	49 ***7***	60 ***5***	82 ***3***	74 ***7***	57 ***7***
Net pieces etc. (292) ***8***	81 ***4***	32 ***8***	48 ***6***	50 ***9***	81 ***5***
Metal (277) ***9***	63 ***6***	68 ***3***	43 ***7***	73 ***8***	30 ***9***

relation to location and human activity. As before, there was no clear separation according to season.

Cluster analysis again produced two major groups (Fig. 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.

6. Discussion

6.1. 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 (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 Great British Beach Clean, 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 Great British Beach Clean (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 Great British Beach Clean (2016) surveys, again confirming the difference between recreational and non-recreational beaches.

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

Fig. 8. Heavy duty gloves at the beach strandline.

(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. (2017), 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 100 m survey, indicative of the summer impact of recreational activites. Total litter item amounts found for this paper were respectively for Autumn to Autumn: 7407, 6685, 7189, 3602 and 5132 (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 8198 items collected from 13 bathing beaches in Northern Ireland (total length 6.7 km) 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).

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.

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 strandline 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.

Category/*Rank*	Autumn 2012	Winter '12/13	Spring 2013	Summer 2013	Autumn 2013
Gloves			Ardglass 22	Ardglass 23	Ardglass 26
			BH 12	*BH 41*	*BH 42*
			Kilkeel 215	Kilkeel 165	Kilkeel 85
1.				PV 25	PV 6
				BW. 13	
	Tyrella 5				*Tyrella 50*
Large plastic pieces	Ardglass 23	Ardglass 18		Ardglass 4	
	BH. 28	*BH. 20*		*BH. 10*	
	Kilkeel 25	Kilkeel 29	Kilkeel 21	Kilkeel 10	Kilkeel 11
	PV 28	PV 6	PV 9	PV 3	PV 11
	Rathlin 11		**Rathlin 10**	**Rathlin 27**	**Rathlin 30**
	Rostrevor 38	Rostrevor 26	Rostrevor 20		Rostrevor 20
	Minearny 8	Minearny 37	Minearny 19	Minearny 1	Minearny 19
			Hazelbank 12	*Cloughy 14*	*Cloughy 13*
				BW. 22	*BW. 30*
2.				*Tyrella 24*	*Tyrella 43*
Rope	Ardglass 23	Ardglass 16	Ardglass 13	Ardglass 60	Ardglass 49
	BH. 18	*BH. 20*	*BH. 8*	*BH. 20*	*BH. 31*
	Kilkeel 18	Kilkeel 29	Kilkeel 14	Kilkeel 20	Kilkeel 8
				PV 8	
	Cloughy 11			*Cloughy 9*	
3.	**Rathlin 9**	**Rathlin 9**		**Rathlin 28**	**Rathlin 12**
	Tyrella 7	*Tyrella 9*			*Tyrella 16*
String/cord	Ardglass 23	Ardglass 6	Ardglass 6	Ardglass 81	Ardglass 82
	BH. 9	*BH. 10*	*BH. 6*	*BH. 18*	*BH. 6*
	Kilkeel 18		Kilkeel 10	Kilkeel 4	Kilkeel 6
				PV 7	
				Cloughy 16	
4.	**Rathlin 10**			**Rathlin 6**	**Rathlin 13**
			Tyrella 10		*Tyrella 8*
Strapping bands	Ardglass 28	Ardglass 13	Ardglass 4	Ardglass 22	Ardglass 11
	BH. 13	*BH. 17*	*BH. 5*		*BH. 11*
	Kilkeel 9	Kilkeel 14	Kilkeel 9	Kilkeel 19	Kilkeel 6
			PV 5		
		Rathlin 7		**Rathlin 10**	**Rathlin 16**
5.		*Tyrella 7*	*Tyrella 11*		*Tyrella 16*
Cloth, e.g.	Ardglass 21	Ardglass 17			Ardglass 12
Clothing,	Kilkeel 11	Kilkeel 21	Kilkeel 9		*BH. 9*
	PV 30		PV 11	PV 22	
shoes	**Rathlin 15**				
				Rostrevor 17	
				Cloughy 11	
6.		*Tyrella 9*	*Tyrella 9*	*Tyrella 12*	
					Tyrella 30
Wood, e.g.	Ardglass 9	Ardglass 21	Ardglass 13	Ardglass 6	Ardglass 8
pallets,			*BH. 13*	*BH. 15*	*BH. 7*
	Kilkeel 7	Kilkeel 8	Kilkeel 17	Kilkeel 7	Kilkeel 14
fish boxes	**Rathlin 10**				
			Rostrevor 24	Rostrevor 9	Rostrevor 10
7.	*Tyrella 7*				
Net pieces,	Ardglass 5	Ardglass 9	Ardglass 6	Ardglass 9	Ardglass 21
broken	*BH. 6*	*BH. 5*	*BH. 9*	*BH 14*	*BH 21*
	Kilkeel 5	Kilkeel 7	Kilkeel 15	Kilkeel 11	Kilkeel 2
fishing lines	PV 6	PV 3	PV 4	PV 8	PV 5
	Rathlin 4	**Rathlin 2**	**Rathlin 1**	**Rathlin 1**	**Rathlin 7**
Etc.	*Cloughy 1*	*Cloughy 1*	*Cloughy 2*	*Cloughy 16*	*Cloughy 4*
8.	*Tyrella 3*	*Tyrella 2*	*Tyrella 5*	*Tyrella 8*	*Tyrella 13*
Metal items	Ardglass 18				Ardglass 4
		Kilkeel 5	Kilkeel 11		Kilkeel 8
e.g. oil drums	PV 8	PV 6	PV 5		PV 5
	Minearny 10	Minearny 14			
	Rostrevor 16	Rostrevor 6			
9.	**Rathlin 12**	**Rathlin 4**		**Rathlin 10**	

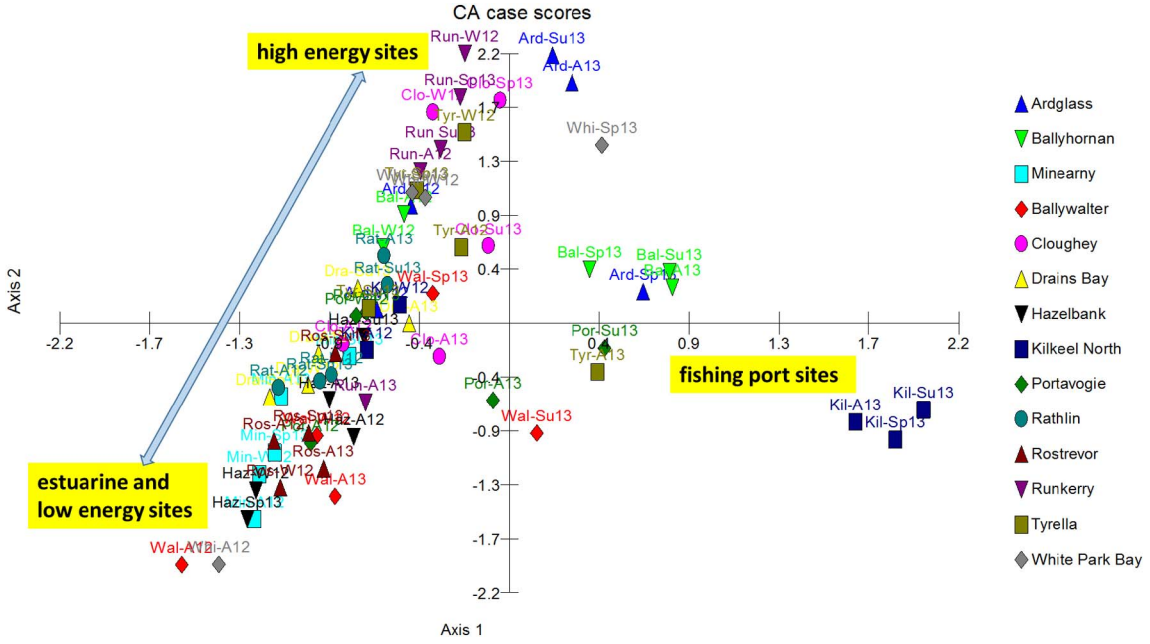

Fig. 9. Scatter plot: 70 sites/seasons; axes 1 vs 2 (correspondence analysis; scores scaled by variables; 1 km strand-line). Axis 2 trend of low-to-high energy sites, contrasting with fishing-related sites, with 3 Kilkeel samples extreme on Axis 1. Sample labels denote site, season, year (e.g. Haz-Su13: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

6.2. 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 4921 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, Fig. 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 > 1000 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 t 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.

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

Item	OC (2016) Rank	GBBC, 2016 Rank	This paper Rank
Cigarette stubs	1	2	–
Plastic drink bottles	2	10	8
Food wrappers	3	3	6
Plastic caps/lids…	4	4	5
Straws	5	–	–
Plastic bags	6	–	–
Glass	7	7	10
Metal cans	–	–	5
Plastic/polystyrene pieces	–	1	2 and 3
Plastic grocery bags	8	–	–
String and cord	–	5	1
Cotton bud sticks	–	6	9
Rope	–	–	7
Drinks	–	–	4
Wet wipes	–	8	–
Fishing lines	–	9	–
Metal bottle caps	9	–	–
Plastic lids	10	–	–

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

Table 6
Overall percentage of litter items.

Item	%	% Nelms et al. (2017)	Item	%	% Nelms et al. (2017)
Plastic	74	76	Metal	8	4
Rubber	1	2	Glass	3	3
Cloth	3	3	Pottery	1	neg
Wood	2	2	Sanitary ware	6	5
Paper	1	4	Medical & faeces	1	1

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 (Fig. 3), were respectively: 105, 54, 75, 89 and 98 from a total amount of 4921 litter items counted. These are much fewer numbers 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.

6.3. 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 (Fig. 3a, b). 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 (Figs. 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 (Fig. 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.

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 (Figs. 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.

6.4. 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 transport 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 (Fig. 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).

7. 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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Appendix A. OSPAR LITTER ID table (reduced 61 categories for analysis).

	OSPAR ID	
Plastic	2	Bags (including supermarket)
Plastic	3	Small plastic bags, e.g. freezer bags
Plastic	112	Plastic bag ends
Plastic	4	Drinks (bottles/containers/drums)
Plastic	5	Cleaner (bottles/containers/drums)
Plastic	6	Food (e.g. fast food, pots, tubs, sachets)
Plastic	11	injection gun container
Plastic	12	Other bottles, containers and drums
Plastic	14	Car parts
Plastic	15	Caps/lids
Plastic	16	Cigarette lighters
Plastic	19	Crisp/sweet/lolly/sandwich wrappers
Plastic	20	Toys/party poppers/fireworks/dummies
Plastic	21	Cups
Plastic	22	Cutlery/trays/straws
Plastic	23	Fertiliser/animal feed bags
Plastic	25	Gloves (light weight)
Plastic	113	Gloves (heavy duty)
Plastic	30	Plastic sheeting from Mussel Culture (Tahitians)
Plastic	31	Rope diameter > 1 cm
Plastic	32	String & cord diameter < 1 cm
Plastic	115	Fishing net & net pieces < 50 cm
Plastic	116	Fishing net & net pieces > 50 cm
Plastic	33	Tangled fishing nets/rope/cord/string
Plastic	35	Fishing line (anglers)
Plastic	39	Strapping bands
Plastic	40	Industrial packaging/sheeting
Plastic	41	Fibre glass
Plastic	43	Shotgun cartridges
Plastic	45	Foam sponge
Plastic	117	Plastic/polystyrene pieces < 2.5 cm
Plastic	46	Plastic/polystyrene pieces > 2.5 cm
Plastic	47	Plastic/polystyrene pieces > 2.5 cm < 50 cm
Plastic	48	Other (specify)
Rubber	49	Balloons/balloon string
Rubber	52	Tyres and belts
Rubber	53	Other rubber pieces (specify)
Cloth	54	Clothing
Cloth	56	Sacking

Cloth	59	Other (specify)
Wood	73	Paint brushes
Wood	74	Other wood pieces < 50 cm
Wood	75	Other wood pieces > 50 cm
Metal	79	Electric appliances
Metal	82	Food cans
Metal	83	Industrial scrap
Metal	86	Paint tins
Metal	88	Wire/wire mesh/barbed wire
Metal	89	Other metal pieces < 50 cm
Metal	90	Other metal pieces > 50 cm
Glass	91	Bottles
Glass	93	Other glass items
Pottery	94	Construction material e.g. tiles
Pottery	96	other ceramic/pottery items
Sanitary	98	Cotton bud sticks
Sanitary	99	Towels/panty liners/backing strips
Sanitary	100	Tampon applicators/tampons
Sanitary	102	Other (specify)
Medical	103	Containers/tubes/pill packet
Faeces	121	Bagged dog faeces
Faeces	205	Non Bagged dog faeces

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