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The use of multivariate statistical techniques to establish beach debris pollution sources

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ABSTRACT

Beach litter found along the Bristol Channel and the coastline of mid-Wales, UK, together with litter obtained from Turkey, Malta, Spain, Tunisia and U.S.A. tourist beaches, and litter gathered from rural roads in Gloucestershire, England, UK, was analyzed by principal component analysis (PCA). PCAdistinguished between riverine, sewage-related debris and shipping/fishing source items, but sourcing beach user litter was more problematic. This was attributed to a difference in litter transport mechanisms. PCA for the Bristol Channel distinguished between riverine and marine sources (inner vs. outer channel) and also a sewage sourced group. PCAindicated a land-based source for marine debris found on Mediterranean and USA beaches together with roadside litter from England. Three 'litter markers'introduced into the analyses, were comprised of different source groupings: 'vessels'(both fishing and other sea going vessels), 'beach users', and sewage-related debris (SRD). The former stood out from the latter two markers with beach user and SRD markers appearing to be indistinguishable. The item numbers in each group were six, five and three respectively and this could account for the findings.

ADDITIONALINDEXWORDS: *Litter, beach, marine debris, sourcing, Principal Component Analysis.*

INTRODUCTION

Litter is currently one of the premier problems facing world coastlines. Numerous researchers have tabulated litter items and the consensus is that the bulk of litter found on world beaches is plastic in origin (GOLDBERG, 1995, 1997). However, few research papers comment on its origin, which should be the fundamental goal of litter research. Currently, no explicit sourcing methodology exists, and this is badly needed in order to put an end to countless tabulations of litter categories based simply on material composition, e.g. percentage of plastics, paper, metal.

Beach litter can be divided into two main sources, sea based sources (EARLL *et al*., 1999) and land-based sources (GOLIK and GERTNER, 1992). The latter incorporates beach user litter (GOLIK and GERTNER, 1992), riverine litter (WILLIAMS and SIMMONS, 1997) and litter directly deposited at/near a beach - e.g. wind blown litter or deliberate dumping (NASH, 1992). In addition, there is a sub-group of truly pelagic litter comprising items which have been afloat for a long period that could be derived from either land or sea sources (GREGORY, 1998).

Several factors influence source identification. These are:

- Correct identification: this is absolutely essential as much evidence of misidentification is apparent in any literature trawl (WILLIAMS *et al*., 1999). The use of photographs can help enormously in correct identification (TUDOR and WILLIAMS, 2001).

- Function: this aspect reflects the litter item usage. Caution must be exercised when attributing a function to an item, as frequently some items have a secondary usage. For example, tyres with ropes still attached would have been used as boat fenders; containers cut in half would have been used as small boat bailer's etc (EARLL *et al*., 2000).
- Quantity: for example, one piece of fishing netting found on a beach is not conclusive evidence of the influence of fishing sources, but large quantities would indicate this origin.
- Associations: the association between items is key. For example, cotton bud sticks (Q tips) would indicate a sewage pathway, netting a sea source. Plastic drink bottles found in conjunction with lots of fishing netting would usually indicate a shipping source; if found with lots of sewage and domestic containers, potentially a land based source (TUDOR, 2001).

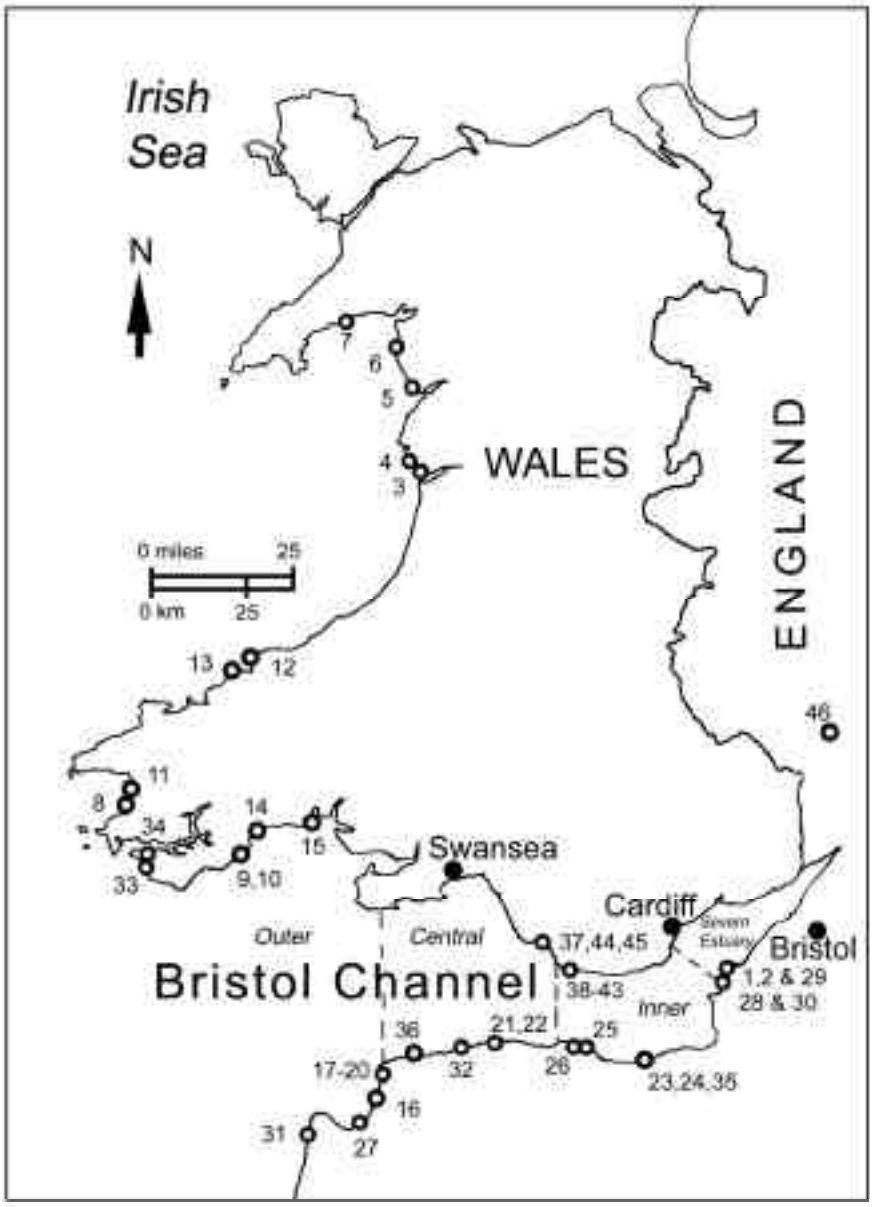


Figure 1. Location of UK beaches studied. (Numbers represent beach survey sites. Key: see Table 1).

THE STUDYAREAS

Some 33 beaches located around the Welsh coastline and southern shores of the Severn Estuary and Bristol Channel, UK, rural roads in Gloucestershire, UK (Figure 1), and beaches in the Mediterranean (four in Turkey, one in Spain, one in Malta and one in Tunisia) together with Miami beach, USA, were chosen for litter sourcing studies as described in this paper.

Bristol Channel beaches (inner, central and outer) are located in an area having the second highest tidal range in the world (16.4m) with the opposing sides of the estuary having a contrasting nature (Figure 1). The southern side is an agricultural/tourist region, the eastern portion having high, steep sided cliffs, with the western segment comprising wide golden sand beaches. At the eastern extremity is the county of Gloucestershire, which straddles both sides of the estuary into which the river Severn drains. The eastern and central segment of the northern shore is the heavily industrialized and populated South Wales area, which is drained by many rivers e.g. the Afan, Towy, unlike its southern counterpart, which has few rivers e.g. the Lyn. This differing land usage suggests a possible variation in litter types and sources that are ultimately found on beaches within the Bristol Channel.

The mid-Wales area grades into a rural/tourist dominated environment that is continued in the northern coastal sweep of the country where small towns provide focal points for tourism e.g. Harlech, Barmouth (Table 1, sites 3-7). Five beaches were investigated along the mid-Wales coast. Apart from Harlech, all beaches are located within the infrastructure of small coastal towns. All are wide sand beaches that are regularly cleaned during the bathing season.

Table 1. Key to litter survey sites in all Figures

PCA code	Location	PCA code	Location
1	Sand Bay 20/7/00	32	Combe Martin 22/3/00
2	Sand Bay 22/3/00	33	Freshwater West 12/9/99
3	Aberdyfi 23/8/00	34	Angle 12/9/99
4	Towyn 23/8/00	35	Blue Anchor 6/8/00
5	Barmouth 23/8/00	36	Ilfracombe 8/8/00
6	Harlech 24/8/00	37	Merthyr Mawr 26/1/98
7	Pwllheli 24/8/00	38	Tresilian 20/12/98
8	Broadhaven 6/11/00	39	Tresilian 21/2/99
9	Tenby North 6/11/00	40	Tresilian 8/3/99
10	Tenby South 6/11/00	41	Tresilian 4/1/99
11	Nolton 6/11/00	42	Tresilian 17/1/99
12	Mwnt 6/11/00	43	Tresilian 3/2/99
13	Poppit Sands 6/11/00	44	Merthyr Mawr 1/4/98
14	Wisemans Bridge 6/11/00	45	River Ogmore 1/4/98
15	Pendine Sands 6/11/00	46	Gloucestershire roadside
16	Croyde 10/9/00	47	Kemer survey site 1
17	Putsborough 10/9/00	48	Kemer survey site 2
18	Putsborough 22/3/00	49	Kemer survey site 3
19	Woolocombe 10/9/00	50	Çirali survey site 1
20	Woolocombe 22/3/00	51	Çirali survey site 2
21	Lynmouth 20/9/00	52	Çirali survey site 3
22	Lynmouth 21/3/00	53	Side survey site 1
23	Blue Anchor 20/9/00	54	Side survey site 2
24	Blue Anchor 21/3/00	55	Konyaalti survey site 1
25	Dunster Beach 21/3/00	56	Konyaalti survey site 2
26	Minehead 21/3/00	57	Konyaalti survey site 3
27	Westward Ho! 21/3/00	58	Konyaalti survey site 4
28	Brean 21/3/00	59	Mellieha, Malta
29	Weston 21/3/00	60	Sitges, Spain
30	Berrow 21/3/00	61	Miami, USA
31	Hartland Quay 22/3/00	62	Hammamet, Tunisia

Twelve litter surveys were conducted at four popular tourist beaches in Turkey (Konyaalti, Side, Kemer and Çirali; Table 1, sites 47-58), an area with no riverine inputs and located in a virtually tideless sea (the maximum tidal range is 60cm). They were all situated near to the large city of Antalya (36º N Latitude, 31º E Longitude) in Mediterranean Turkey, one of the largest tourist resort cities in Turkey. Further surveys were carried out at Mellieha beach, Malta (36º N 14º E), this is the largest and most popular tourist beach (circa 300m in length) in the Maltese archipelago. Sitges beach (41º N 2º E), Spain, is part of a much larger continuum of beaches extending on both sides of the city of Barcelona, in which extensive beach nourishment practices have been carried out. Hammamet beach (36º N 11º E), Tunisia, is located downdrift of a new marina and is a very wide (100m) natural beach. Miami beach (26º N 80º W), USA, is world famous, and has undergone large-scale beach nourishment. It is a long extensive beach with a width >100m that brings in more tourist visits annually (21 million) than any National Park Service property in continental USA. This is twice the combined number of tourist visits to Yellowstone, Yosemite and Grand Canyon National Parks (HOUSTON, 1996). Federal tax revenues from foreign tourists visiting this beach are >$130 million per year, which equates to some 65 times the Federal share of the capitalized annual cost of the beach nourishment. Beach survey locations are listed in Table 1, with UK sites being displayed in Figure 1.

METHODOLOGY

All litter was counted according to the EA/NALG (2000) protocol, i.e. 100 m of beach was selected at the most convenient access point and all litter within this transect recorded. This was coded (Table 2) and subjected to principal component analyses (PCA). As far as possible, litter was coded as an individual item rather than grouping similar types together. The grouping together of litter items would have added a further layer of assumption, i.e. that similar items (e.g. beverage containers) alighted from the same source. This was deemed undesirable and would not

Table 2. Key to litter items in all Figures

PCA code	Litter items	PCA code	Litter items
1	Soft drink bottle container	24	Cloth, shoe
2	Aluminum can - beer or soft drink	25	Party popper
3	Milk container	26	Pen
4	Toiletry container. e.g. toothpaste, toothbrush, shampoo, deodorant	27	Syringe
5	Food containers- e.g. margarine, mayonnaise	28	Balloon
6	Take away food container/plastic cups/ wooden forks-plastic spoon	29	Children's toys
7	Detergent container	30	Tangles of netting
8	Cotton Bud Stick	31	4 pack holder
9	Sewage Related Debris	32	Polyurethane
10	Netting/line	33	DIY/Maintenance containers (e.g. diesel injector cleaner, bucket)
11	Other fishing items(e.g. lobster pot, fish box, etc)	34	Toilet freshener
12	Shipping general (e.g. tire with rope, fender, buoy)	35	Flower pot
13	Unidentifiable fragments	36	Wood
14	Sweet wrappers, drinking straw, lollipop sticks, soft drink cartons	37	Balloon
15	Packing strap	38	Piping/ducting
16	Polystyrene	39	25l oil drum
17	Cigarette lighter	40	5/10 l oil containers
18	Cigarette stubs	41	Bait bag
19	Beverage bottle top, tamper proof ring	42	Plastic sheet
20	Plastic bag	43	Glass bottle
21	Secondary use container	44	Paper
22	Land based items: e.g. Hub cap, traffic cone, car products, shopping trolley, road works	45	Light bulb
23	Shotgun cartridge		

aid accurate sourcing; only where items were almost 100% certain to come from a source (e.g. buoys, fenders) were they grouped in a small assemblage (e.g. code 12, Table 2).

With the respect to Figures 2-7, for clarity sites/items grouped around the zero position have not been labeled. PCA involves eigen analysis of a symmetric matrix of similarities which produce a series of eigen values and corresponding eigen vectors (MARSHALL and ELLIOTT, 1998), considered to measure the strength of an axis. Each eigen value has an associated eigen vector which determines its orientation in space. Correlation coefficients (standardized variables) were used for all analyses, as beaches with large litter amounts can unduly influence results. Cluster analysis was also conducted on this same data in order to identify groups of similarity; details of this procedure are described fully in TUDOR (2001). Initial assessment was made with data obtained from Bristol Channel beaches. To these PCA analyses were added data from the various other beaches mentioned above, in order to determine if differences existed with respect to litter sourcing.

RESULTS AND DISCUSSION

Inspection of Table 1 shows that several beaches were visited on a number of occasions, and all beaches that were visited were included in the analyses. Initial analyses showed three clear outliers – namely, Berrow (30), Hartland Quay (31) and Merthyr Mawr (37), positioned because of the inordinate amount of litter items found on the beach. Therefore, these beaches were excluded from subsequent analyses in order to tease out further relationships. Further details may be found in TUDOR and WILLIAMS (2001) and WILLIAMS *et al*., (in press).

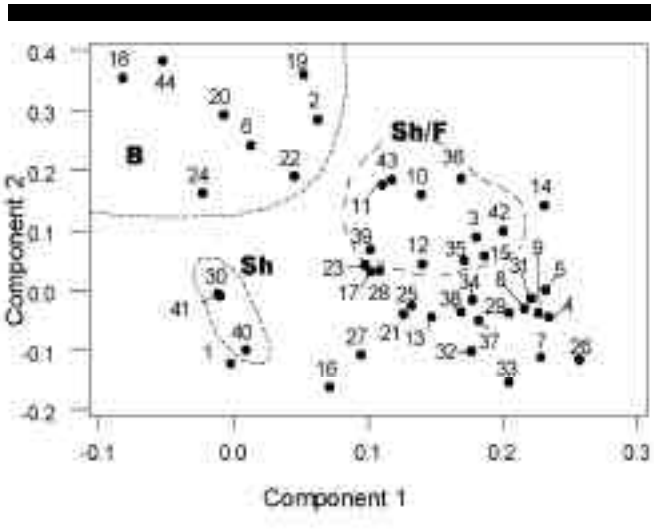


Figure 2. Principal Component Analysis of UK Litter Items (excluding three UK outliers) using Specific Litter Item Classification. Principal Components 1 and 2. Key: Sh= Shipping source; F= Fishing source; B= Beach user source. See Table 2 for key.

Bristol Channel

PCA assists in illustrating relationships (patterns) in the variables, shown by the clear divisions between fishing debris, shipping debris, and river debris sources (Figures 2 and 3a) in the 28 beaches investigated along the Bristol Channel coast (sites 1 and 8-45). The identification of sourcing patterns/groupings, e.g. Sh and B in Figure 2, were determined by the factors influencing litter sources illustrated by the "bullet points" in the Introduction section of this paper. Beach user sources (i.e. land/'dry waste') were separated from other litter categories, but were not grouped closely together and many potential beach user sources were not clearly represented. This illustrates the problem of assigning these items (e.g. soft drink cans) to a potential source. The transport mechanism of the litter types may be a factor here as most litter behaves as sediment (WILLIAMS and TUDOR, 2001). With respect to Figure 2, where an item such as no. 43 (glass bottle; Table 2) is found in conjunction with obvious shipping/fishing material, e.g. netting/line (no. 10; Table 2), there is obviously a high possibility that these items have a shipping source at locations surveyed.

Figure 3a illustrates the riverine nature of the litter found at sites 44 and 45. The riverine litter group is difficult to describe, as particular items (e.g. shopping trolleys) can almost certainly come from a land/river source, but other items, such as DIY/maintenance containers, are less certain to emanate from this source. Site 45 is situated on the river Ogmore, and 44 is Merthyr Mawr beach, situated at the mouth of the Ogmore, an area heavily affected by riverine debris (SIMMONS and WILLIAMS, 1997). These two sites are separated from other beaches; indicating a different litter profile and differing litter sources.

Shipping waste is clearly separated from other litter items (Figures 2 and 4). This litter group consists of items (Table 2) such as rope, fenders, buoys, milk containers, food containers (margarine tubs etc.), and secondary use containers (e.g. bailers). Fishing debris was also broadly grouped together (Figure 2), with netting/line found in conjunction with lobster pots, fish boxes, packing straps, etc. Many items from source groupings cluster together (Figure 3a), with particular beaches indicating that they either have large numbers of items from one source, e.g. SRD -items 8 and 9 at Sand Bay, - site 1 (Table 2), or have large amounts of litter from one category and modest amounts from any other (e.g. Shipping/Fishing debris at Freshwater West, site 33). A more detailed account of the use of PCA for litter sourcing within the Bristol Channel can be found in TUDOR and WILLIAMS (2001).

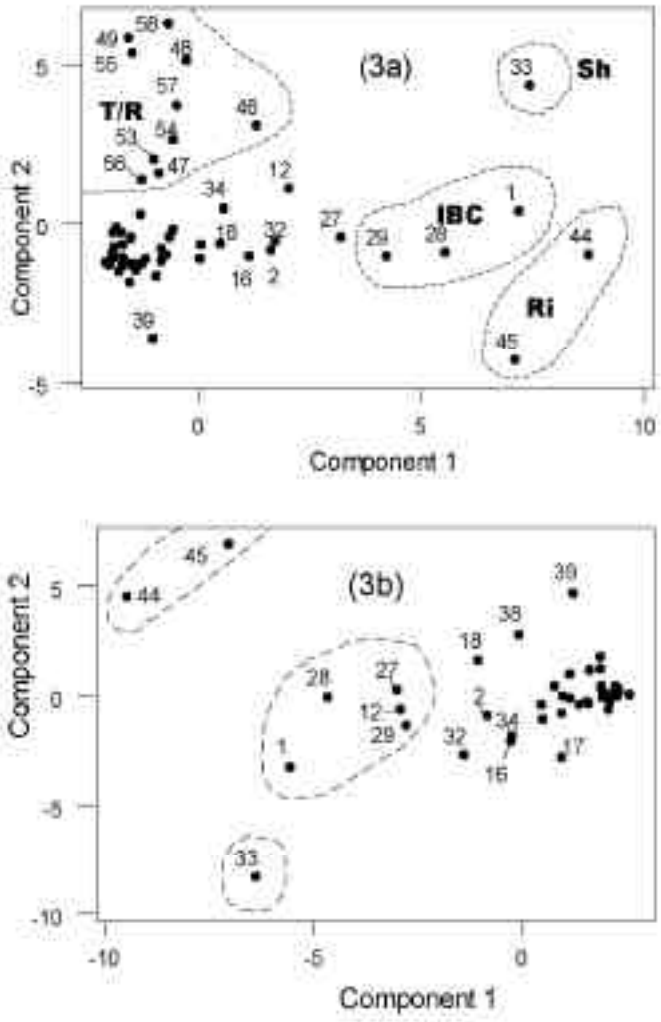


Figure 3a. Principal Component Analysis of UK and Turkish Beach Survey Sites (excluding three UK outliers) using Specific Litter Item Classification. Principal Components 1 and 2 Key: T/R= Turkish/Roadside survey sites; IBC= Inner Bristol Channel survey sites; Ri= River source litter; Sh= Shipping source. See Table 1 for key.

Figure 3b. Principal Component Analysis of UK Beach Survey Sites (excluding three UK outliers and Turkish/Roadside litter) using Specific Litter Item Classification - Principal Components 1 and 2. See Table 1 for key.

Mid-Wales Beaches

The amounts of litter found at these sites were very small, with all these beaches clustering together in the centroid position of the PCA. The low amounts of litter found meant that no patterns or source groups could be easily identified.

Turkey beaches/Gloucester roadside surveys

Turkish beach litter comprised large amounts of what can be considered 'beach user' items, namely: cigarette ends; 'take-away'/convenience food wrappers and containers; confectionery wrappers, etc. In total, only 10 sewage derived items were recorded on these four beaches out of a litter total of 2,601 items. Figures 2 and 3a indicate that certain litter items (labeled 'B' in Figure 2; e.g. cigarette ends, take away containers; 18 and 6 respectively Table 2) have a similar orientation to the Turkish beaches investigated (sites 47-58, Figure 3a) as well as the roadside litter survey (site 46, Figure 3a). Similar groupings occurred when PCA plots involving the introduction of component 3 were produced (Figures 4 and 5a).

The addition of Turkish beach litter and UK roadside survey litter, did not change the orientation of outlying sites such as 33, 44, and 45; for example, compare Figure 3a with 3b and Figure 5a with 5b. What has changed is the distancing of site 44 from 45. Site 44 has been 'pulled' toward the Turkish beaches and roadside sites (compare Figure 3a with 3b and Figure 5a with 5b). This indicates that whilst site 44 (beach situated near the mouth of the River Ogmore) still has major similarities with site 45, it contains elements that are akin with Turkish/roadside sites, i.e. land based sources of litter. Therefore, similarities occur in the litter source at these sites. None of the U.K. beaches were

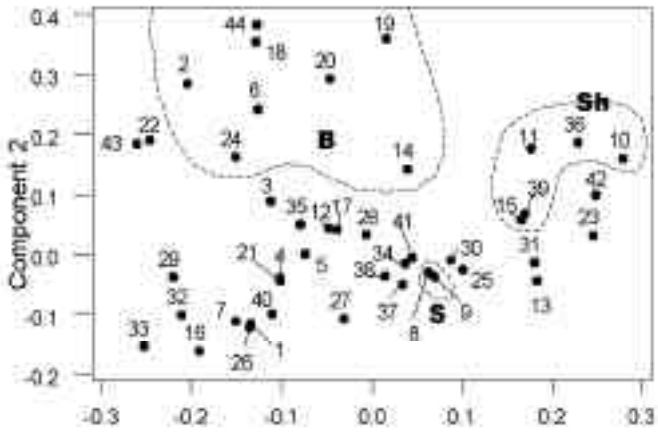
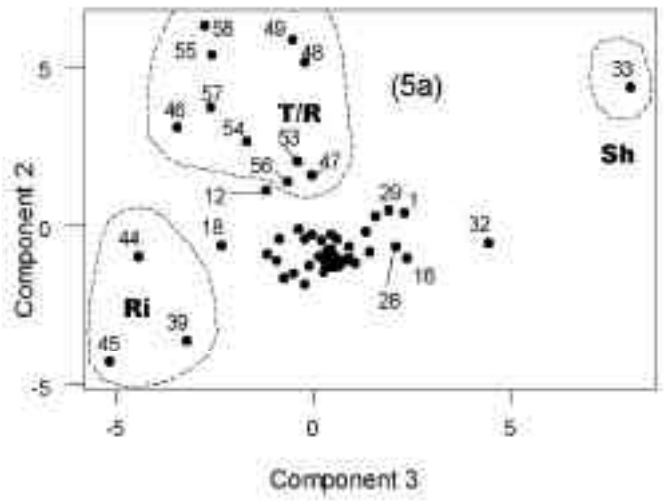


Figure 4. Principal Component Analysis of UK and Turkish Litter Items (excluding three UK outliers) using Specific Litter Item Classification. Principal Components 2 and 3 Key: Sh= Shipping source; B= Beach user source; S= Sewage related debris source. See Table 2 for key.



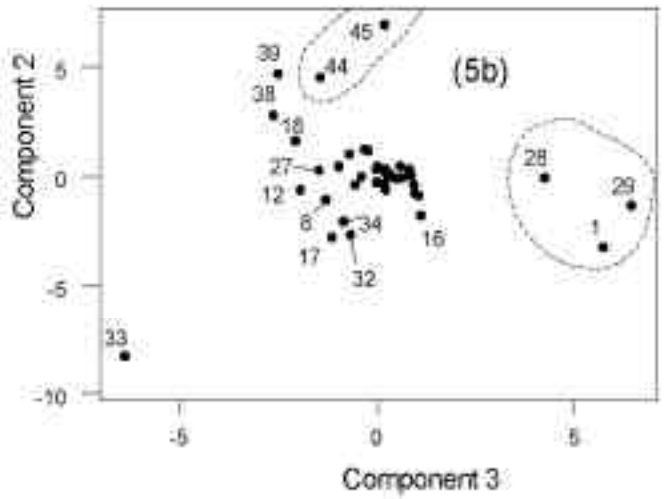
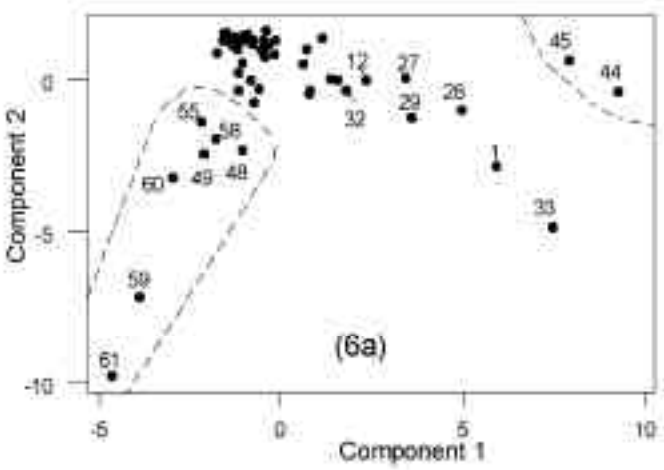


Figure 5a. Principal Component Analysis of UK and Turkish Beach Survey Sites (excluding three UK outliers) using Specific Litter Item Classification. Principal Components 2 and 3 Key: T/R= Turkish/Roadside survey; Ri= River source litter; Sh= Shipping source. See Table 1 for key.

Figure 5b. Principal Component Analysis of UK Beach Survey Sites (excluding three UK outliers and Turkish/Roadside litter) using Specific Litter Item Classification - Principal Components 1 and 2. See Table 1 for key.



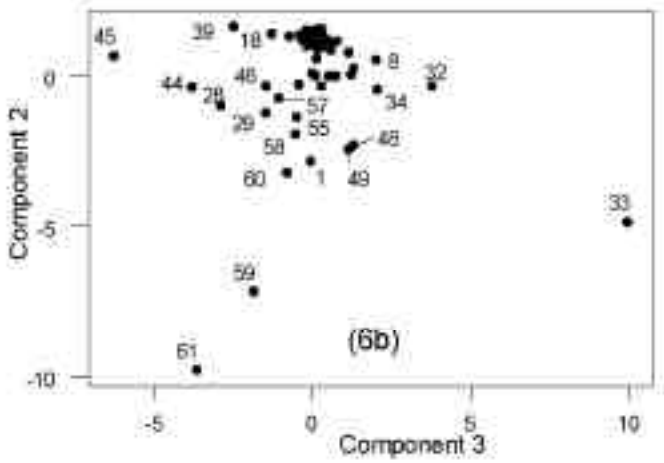


Figure 6a. Principal Component Analysis of UK and Turkish Beach Survey Sites (excluding three UK outliers) using Specific Litter Item Classification. Principal Components 1 and 2 Malta, Spain, Tunisia and USA beaches added. See Table 1 for key.

Figure 6b. Principal Component Analysis of UK and Turkish Beach Survey Sites (excluding three UK outliers) using Specific Litter Item Classification. Principal Components 2 and 3. Malta, Spain, Tunisia and USA beaches added. See Table 1 for key.

grouped with the Turkish beaches/roadside surveys (Figures 3a and 5a), suggesting that the latter differ significantly in composition and abundance of certain items (e.g. cigarette ends) to the other beaches studied, particularly the Bristol Channel, UK.

Principal component analyses showed that Turkish beach and rural England roadside litter surveys cluster together on component 2 (Figures 3a and 5a). It is interesting to note the proximity of results from litter roadside survey to Turkish beach litter, reinforcing the land based nature/source of litter on Turkish beaches.

What was unexpected was the distinction between the river Ogmore site (45), the Merthyr Mawr beach site (44), and the Turkish/roadside surveys (sites 46-58; Figures 3a

and 5a). It could be conjectured that Turkish/roadside litter surveys should cluster with the river Ogmore/ Merthyr Mawr sites - they did not. This difference could possibly result because roadside survey/Turkish beaches were not subject to any SRD inputs. The influence of large amounts of SRD at Merthyr Mawr has seemingly made this site distinctive from other litter land based surveys (i.e. roadside/Turkey surveys), and also dissimilar to sites subject to large amounts of shipping/fishing litter (e.g. Freshwater West, site 33; Figures 3a and 5a). The enormous accumulations and diverse nature of litter (and consequently inputs) at Merthyr Mawr (44) beach also make it distinctive from other sites which contain large amounts of SRD but little else, for example, Berrow, Sand Bay (sites 1 and 30).

Mediterranean and the USA

Extra scope was given to the research with the introduction of data from four further locations, namely: Mellieha, Malta (59); Sitges in Spain (60); Hammamet in Tunisia (62); and North Miami beach in the USA (61). Figures 6a and b illustrate the effect that beaches with enormous amounts of litter can have on subsequent analysis. Both Miami and Malta beaches consisted of very significant amounts of 'beach user' debris, e.g. >430 plastic bottles on Miami Beach and >250 'fast-food' items in Malta. These two sites are distanced from the main group of beaches, illustrating their extreme nature. The beach surveyed in Tunisia does not appear as a separate entity within the chart – it is located in the morass of sites centered around the zero co-ordinates, probably because of lower amounts of litter items compared to some other beaches. Malta, Sitges and Miami beaches all cluster near the Turkish beaches, or at least are in a similar orientation from the zero point - therefore strengthening the link between these beaches as sites of significant 'beach user' litter pollution.

Source group 'Markers'

Additional analysis was undertaken that involved the use of a series of 'markers'. Three 'markers' were introduced which comprised source groupings: 'beach users'; 'vessels' (both fishing and other sea going vessels); and 'sewage debris'. Three groups of litter items were chosen which were thought to accurately reflect these sources (Table 3). Abundance figures used in these 'marker' groups were extrapolated from data obtained at real survey sites. It was hypothesized that beach sites comprising significant numbers of litter items from each of these source 'marker' groups would cluster together and help illustrate the major litter sources.

Figure 7 illustrates the data set with 'markers' added for principal components 1 and 2. Clearly, the 'vessels'marker is far removed from any beach survey sites, with 'beach users' and 'sewage debris' nestling in an amorphous conglomeration of indistinguishable sites. Information garnered from Figure 7, shows the clear difference between the 'beach user' marker and sites 44, 45 and 33, indicating that the litter profile at these beaches contains very little 'beach user' debris. The 'Sewage debris' marker is less informative. Reasons for this are unclear, but it is perhaps due to the small number of items (3) making up this group compared to the 'beach users' source group, comprising 5 items, and 6 items for the 'vessels'group (Table 3).

Markers are subjective in that items included tend to be determined by the analyst. However, as long as this form of

Table 3. Composition of beach litter source 'markers'

'Vessel'source group	'Beach user' source group	'Sewage related debris' source group
Milk container	'Take-away'food container	Cotton bud sticks
Netting / line	Sweet wrappers	General sewage related debris
Other fishing components (e.g. lobster pot, fish box etc.)	Cigarette ends	Toilet cleanser
Shipping items (e.g. buoys, fenders etc.)	Plastic bags with specific markings	
Secondary use container	Children's toys	
25 liter ship grade oil drum		

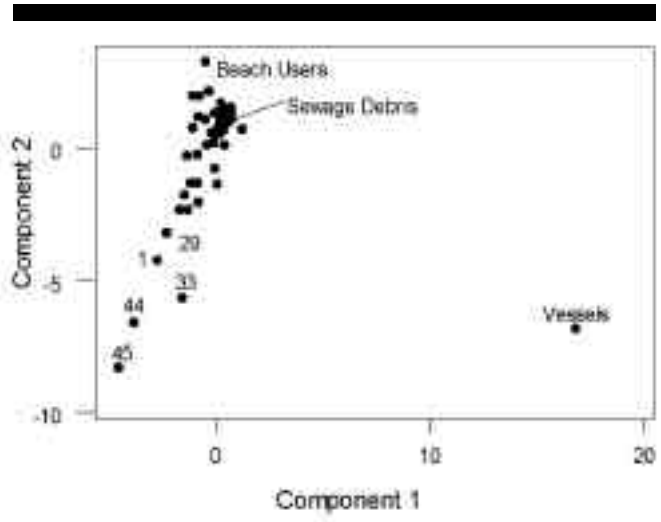


Figure 7. Principal Components 1 and 2. Analysis of Beach Survey Sites (excluding three UK outliers) using Specific Litter Item Classification. Turkish beaches and rural England roadside survey added with Source group 'markers' – Vessels, Beach users, Sewage related debris. See Table 1 for key.

attribution is robust and based on knowledge and only those items which are highly probable of coming from a pre determined source are used, then their use can be defended. For example, there is no possibility that a wooden pallet can be sourced to a sewage system; they invariably can be attributed to a shipping source. In addition, abundance figures placed into each marker group are arbitrary. Further work is needed in this area to establish the merits of using litter source group 'markers'.

CONCLUSIONS

Apart from beach user items, PCA analysis within the Bristol Channel distinguished between riverine, SRD, fishing and shipping litter items. Taking all three analysis components, the beaches of mid Wales could not be differentiated as they grouped around the PCA zero axis. Only small litter amounts were found at these beaches and this could have resulted in the findings given in this paper. Extremely different litter profiles were obtained for Freshwater West to other Bristol Channel beaches, the reason being that the western end of the Bristol Channel is influenced more by shipping/fishing inputs than the eastern.

Introduction of four Turkish beaches to the PCA illustrated the difference in litter profiles between these and Bristol Channel beaches. Litter at the Turkish beaches surveyed was considered to be from a 'beach user' source, e.g. cigarette ends, 'take-away'/ convenience food wrappers and containers. The land-based nature of litter found was confirmed by PCA; the UK roadside litter survey forming a close cluster with the Turkish beaches. Beaches of the Bristol Channel and Wales coast did not cluster with Turkish beaches or the roadside survey, therefore illustrating a more diverse litter input. Other beaches studied in various parts of the world (Malta, Spain, USA) helped to reinforce the 'beach user' category and illustrated that PCA can reliably highlight sites of similar litter pollution characteristics wherever they are on the planet.

Litter source 'markers'in PCAproved to be an interesting addition to the study, but the arbitrary nature of parameters chosen for each 'marker' meant that their use requires further testing in future research.

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