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Development of a 'Matrix Scoring Technique' to determine litter sources at a Bristol Channel beach

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Abstract. Litter at beaches can come from more than one source and determining the proportions to assign pollution to different sources is very complex. There is no widely accepted methodology at present that links litter items to their source. The aim of this study was to create a method of assigning a source to litter found on beaches of the Bristol Channel but which could equally be used on any beach. Various methods that attempt to establish the source of beach litter were evaluated; their strengths, weaknesses, applicability and reliability for use on Bristol Channel, UK beaches were considered. Elements of existing methods coupled with new ideas were utilized in the production of a 'refined' methodology; consequently a new method of assigning a source to beach litter was developed. The developed 'Matrix Scoring Technique' was applied to data collected at Minehead beach on the Bristol Channel, UK. Several numerical and nomenclature variations were used to produce a system that reflected the various sources and eliminated as much bias as possible. This cross-tabulated matrix scoring system can produce an insight into the contribution of different source groups to litter found on beaches. This novel approach requires further testing with emphasis on a control data set.

Keywords: Beach litter; Coastal Zone Management; Marine debris; Minehead beach; Pollution.

Abbreviation: SRD = Sewage related debris.

Introduction

Litter blights oceans, seas, coastlines and beaches across the globe. This has very serious effects on the amenity value of beaches, local economies, the well-being of beach and ocean users, the health of terrestrial and marine fauna and flora, and the public perception of the coastal environment (Velander & Mocogni 1998; Nelson et al. 2000; Derraik 2002; Cunningham & Wilson 2003; Tudor & Williams 2003). Marine debris has been defined as 'any manufactured or processed solid waste material (typically inert) that enters the marine environment from any source' (Coe & Rogers 1997, p. xxxi). Marine debris is also often termed marine or beach litter.

Bathing water and beach award schemes, beach clean efforts, beach adoption projects and other initiatives abound that attempt to tackle this problem. Most are noteworthy because of their continuous efforts to educate the public, raise awareness and ultimate aim of reducing litter on beaches; examples include projects run by the Marine Conservation Society in the UK, Ocean Conservancy in the US, and Clean Up Australia. However, partly because of the persistence of plastics in the environment, this does not appear to have led to any great reduction in the amounts of debris being found on beaches world-wide. To make any pragmatic attempt at reducing and preventing the marine litter problem it is essential to determine its source and to establish a useable and repeatable methodology to achieve this.

Beach litter can be classified in two source groups, which can further be divided to allow a more valuable attribution. Firstly, marine-based sources of litter include all types of sea-going vessel as well as offshore installations (Earll et al. 1999). Secondly, land-based sources incorporate litter left by beach users, litter entering the sea via rivers or municipal drainage systems, and litter directly deposited at or near the beach (Golik & Gertner 1992; Nash 1992). Many published studies have attempted to attribute beach litter to a

broad source, but this has often been based on local knowledge, assumptions and seemingly an absence of a rigorous methodology. For example, Willoughby (1986), found that rubbish slicks on islands surrounding the city of Jakarta, Indonesia, contained large quantities of freshwater hyacinth, a plant which does not grow on the islands, thus linking the source of the litter to rivers of the mainland. Such local knowledge and anecdotal evidence can be extremely useful. However, there are very few published studies that have set out to determine the precise source of beach litter using a specific methodology; a repeatable and transferable method is desirable to allow comparison and use as a management tool. At present there is no accepted methodology that enables researchers to link litter items to their source.

Identifying the origin of beach debris is a difficult task. On occasions the source of the pollution is clear and local (Johnson 1989; Walker et al. 1997). All too often sources are not obvious and can be international either in terms of shipping (Dixon 1995), or land based litter from other continents e.g. American litter on west coast European shores (Olin et al. 1995). The movement patterns, sinks, and degradation rates of marine debris are still not completely understood, although there is research in this area (Williams & Simmons 1996; Bowman et al. 1998). One cannot generalize or make assumptions about sources, and site specific measurements will almost always be required (Earll et al. 2000). There are numerous occasions when litter items can come from more than one source, and determining which source is the primary polluter is extremely difficult. For example, plastic pellets discovered on beaches have been found to have more than one potential source, i.e. plastic manufacturing companies, or ships bringing in this raw material from further afield (Gregory 1977; Shiber & Barrales-Rienda 1991).

The importance of beach location where litter sources are concerned is shown in that, 'there are indications that most Mediterranean coastal litter is land-based, in contrast to the reported marine-based litter on the western European shores' (Gabrielides et al. 1991, p. 437). Whilst the evidence for the Mediterranean certainly points towards beach user sources (Golik & Gertner 1992; Williams & Markos 1995), there is contrasting evidence regarding western Europe, particularly the UK, with respect to marine origins of litter. Certainly in heavily utilized shipping lanes this is true (Gilbert 1996), but in the Bristol Channel region the impact of marine derived litter is known to be minor in eastern extremities (Williams & Simmons 1996). When attempting to assign sources to litter encountered on beaches it is important not to regard the item in isolation but to consider factors such as location, the presence of the other litter, any indicator items present (such as Q-tips/cotton bud sticks as an indicator of sewage pollution sources), the function of the litter and the quantity present. A detailed critique of the importance of such factors can be found in Earll et al. (1999) and Williams et al. (2003).

The aim of this study was to create a method of assigning a source to litter found on beaches of the Bristol Channel but which could equally be used on any beach. Some research has been conducted into providing a theoretical and knowledge based framework to determine litter sources and certain notable examples are assessed in this paper for their applicability to the Bristol Channel study area. A desk study was initiated to determine the suitability of the methods already in use, with the best elements of these and new ideas utilized in the production of a 'refined' methodology. Only those methods with an explicit and clear process to establish litter sources were reviewed, with the multitude of studies that rely heavily on assumptions excluded from consideration.

Methodology

Following the desk study, to enable a realistic assessment to be carried out, data collected from Minehead beach on the coast of the Bristol Channel, UK, was applied to the developed method; this trial was part of a larger litter study carried out on numerous Bristol Channel beaches (Tudor 2001). Litter items encountered on the beach were recorded in as much detail as possible, with a note made of all printed and additional information. The size of the survey site followed the EA/NALG (Anon. 2000b) methodology. The site was chosen as it was not based in an area recognized for suffering from specific types of pollution, e.g. open coasts or areas near shipping lanes, in order to give an unbiased view.

Physical background

The Bristol Channel is a large inlet of the Atlantic Ocean, on the southwestern coast of Britain situated between south Wales to the north and the English counties of Cornwall, Devon and Somerset to the south. Near the head (eastern end) of the Channel the tidal range is one of the largest in the world and at Avonmouth can reach 16.4 m (Huntley 1980). Many towns and cities are situated away from the coast on inner tidal stretches of river, for instance Bristol and Newport. Those that are on the coast are often large tourist

centres that receive visitors during the summer months, for example Minehead and Tenby; Minehead is on the southern shore of the Channel in the county of Somerset. This large sand beach runs parallel to a road with car parking spaces, shops, food outlets, toilet facilities and amusement arcades. There is a large holiday resort to the east of the town and situated close to the beach. The beach depth is circa 50 m and extends > 1 km.

Applicability of methods used to determine the source of beach litter

1. Attribution by litter type

This method assigns each litter item to one specific source (e.g. Marine Conservation Society Beachwatch Surveys - MCS (Anon. 2000a). The attribution process is carried out away from the beach and the items themselves, simply by attributing all records (from a form) of a particular item, as recorded by a volunteer, to the particular source (Earll et al. 1999). The use of volunteers has been shown to be a valid and reliable means of collecting large amounts of data (Williams et al. 1999), particularly if trained as is the case with *Beachwatch* surveys (Anon. 2000a). There is invariably a large category of non-sourced litter that consists of items which do not easily fall into specific source categories, e.g. plastic bags, caps/lids. These items have come from one source or another but there is no means of apportioning these to a specific source.

This method of attributing litter certainly has merits and the use of lists of items linked to sources serves as a useful database of information. The method was based solely on *all* litter items of a certain *type* being classified from a particular source. The appropriateness of this method for use in *Beachwatch* is not in doubt, but its lack of flexibility and prescribed nature meant that further implementation for detailed study was deemed inappropriate.

2. Use of container information

This method was used by Dixon (1995) and based on a national ocean focused vessel-source litter assessment study. The method seeks to identify any major differences in the composition and quantities of beach litter from paired observations, approximately 10 years apart, at 185 sampling units situated around the UK coastline (Dixon 1995; Earll et al. 1999). It was specifically designed to assess whether MARPOL Annex V (International convention for prevention of pollution of the sea from ships) was achieving its goals and the method does meet this criterion.

Sources were primarily established from 'the identified contents and geographical origins of the containers located on sampling units' (Dixon 1995, p. 61). This information was cross-referenced with products taken aboard ships following discussions with trade and fishing bodies and packaging manufacturers. The information regarding containers, together with the types of containers used on-board ships, gathered from this study is very useful and can be applied to other methodologies.

The technique used by Dixon (1995), was not felt to be transparent enough, the attribution process could not easily be followed, and a large data bank of historical information that was required was unavailable. There is an enormous amount of knowledge regarding products and packaging used in these studies and is its major strength. Assumptions about the proportion of *non-container* garbage originating from sea-going vessels were based on information found *on containers* at the survey sites. This is an inherent weakness of the method as containers with no markings and all other 'non-containers' are not included in any attempt to source litter. Containers do carry a wealth of information but excluding non-containers from the analysis risks missing vital signs to the source of beach litter. The great diversity of items found on Bristol Channel beaches meant that a more holistic method was necessary, with *all* litter items included in the analysis.

3. Use of indicator items

This method is similar to that employed by *Beachwatch* (Anon. 2000a) in that lists of items are considered for each source, the difference being that only specific indicators are considered and only these are recorded at each beach survey. This scheme was developed to give an indication of changing litter amounts over time, rather than establishing sources (Ribic 1998). However, the lists of litter items arranged into source groups could be utilized to establish a source. The inclusion of all litter encountered on beaches, rather than selecting indicator items, was deemed to be more appropriate for this Bristol Channel study. The exclusion of certain litter items at this pilot stage would increase the potential for 'lost information'; this method was therefore not investigated further.

Silva-Iniguez & Fischer (2003) also utilized indicator litter items. Items found on a beach were classified as either 'terrestrial key objects' or 'marine key objects' depending whether an item could *only* come from a 'land or marine activity'. If the item encountered could originate from *either* land or marine activities then its float ability and distribution along the beach were considered to establish if the origin could

be defined. If the litter could not be placed in these two groups then it was considered to be of mixed origin, that is a 'mixed key object'.

Silva-Iniguez & Fischer (2003) found that over 68% of litter encountered in their study was classified as mixed or of unclear origin with approximately 31% deemed to have arisen from a marine or land source. The use of indicator items or 'markers' appears to be a useful method of determining a beach litter source and has been touched upon in other research (e.g. Tudor et al. 2002 and Williams et al. 2003); further research is needed to test the potential of this technique. The large number of litter items with an unclear origin illustrates the complexity of determining beach litter sources and consequently the method was not utilized for this study.

4. Multivariate analysis

Some of the aims of multivariate analysis are pertinent for use in beach litter source studies, particularly when searching for possible causal relationships between distribution and environmental factors (Gauch 1982; Randerson 1993). Multivariate analysis uses an inductive, non-experimental approach to generate rather than test hypotheses. Two methods of multivariate analysis have been utilized by Tudor et al. (2002) and Williams et al. (2003) in an effort to ascertain patterns amongst beach litter items and survey sites – namely principal component analysis and cluster analysis. This technique is an innovative and novel method of assigning a source to beach litter. It is beyond the scope of this paper to attempt its use but information regarding its application can be found in Tudor et al. (2002) and Williams et al. (2003).

5. Percentage allocation

This method utilizes percentage allocation, where several input sources make a possible contribution to litter on a beach and are apportioned an appropriate allocation (e.g. Earll et al. 1999). In these cases a percentage allocation would be split between potential sources.

The source categories considered by Earll et al. (1999), were as follows:

- Tourism (beach users)
- Sewage related debris
- Fly tipping (which is waste disposed of illegally, often at the roadside or in rivers)
- Land (urban/rural) run off
- Shipping
- Offshore installations (e.g. oil rigs)
- Fishing related debris

Distinctions made between potential sea-borne sources in the above scheme (i.e. shipping, offshore installations and fishing) are perhaps too intricate – for example, there are certain items, such as lobster pots, that clearly originate from fishing sources; however, there are a number of items that alight on beaches that are in common usage on all shipping vessels and are used on offshore installations. Attempting to distinguish between vessel types when attributing a source to litter should only be attempted once a general sea-based source is established.

One potential drawback with this method is that it is difficult to allocate a certain percentage to a particular source due to numerous potential sources. This is where the percentage allocation process can become arbitrary and subjective.There is a level of transparency that made this method repeatable and allowed for application by those other than the authors. However, the focus being on shipping vessels means it is not a comprehensive methodology for all beach litter. The elimination process – which is discussed later – used to exclude certain items of arising from a particular source is a useful procedure and one that could be partially used for litter attribution on beaches within this study of the Bristol Channel.

6. Cross tabulation probability scoring method

This method, developed by Whiting (1998), attempts to assign a percentage proportion probability figure for each debris category to each source. First, all debris on a beach was regrouped into similar categories of use (e.g. fishing gear, common domestic items, etc.) to help identify potential sources. Major groups of debris items were then cross-tabulated with seven potential sources and given a score based on the likelihood that they originated from each source. These scores were based on several factors, namely: markings and labelling of items, type of debris, distance to each source, amount of activity of each source within the region, seasonal wind and current patterns. The percentage that each potential source contributed to the total debris was then estimated. This method uses the following likelihood scoring system for source attribution: 3 = Highly probable; 2 = Probable; 1 = Possible; 0 = Unlikely.

Although background knowledge and an understanding of the vagaries of marine debris is needed before utilizing this system, some subjectivity is used in apportioning a likelihood score to each item of litter. Whiting (1998) applied the method to one area in Northern Australia, and the sources chosen for attribution were:

- Recreational boaters
- Domestic merchant vessels
- Commercial fishing vessels
- Urban / land based
- Camping
- Foreign vessels

Table 1. Elimination list – Linkage of litter items to various sources.

Indications of source	Sea source	River source	Beach user source	Is quantity found applicable?
Litter item				
Tyre	Yes if rope is attached for use as fender	Yes if no rope is attached	Not applicable	Not generally - other information is more useful.
Oil drum	Yes if marked for ship use or signs of ship specific grade of oil.	Yes if marked for domestic use in cars etc.	Not applicable	Large amount would indicate dumping or ship wreck.
Cigarette lighter	Yes – thrown overboard	Yes – tossed in river or even flushed down toilet	Yes	Very large amounts could mean wreck or spill
Milk container	Yes – especially UHT / long life	Only if wind blown into river – fly tipping is unlikely	Not likely- especially not large containers (> 2 pints)	Large amounts would point to systematic input from ships
Light bulb	Yes – possibly if still intact	Possibly – but unlikely	No	Large amount could mean wreck or spill
Wooden pallet	Yes	Some possibly	Not applicable	Large amount could mean wreck or spill

- Foreign shores

The sources chosen for use highlight the influence of site / regional specificity where litter is concerned. As with the Percentage Allocation method (Method 5), whether the attribution to specific sea going vessels is robust enough is open to question. The method allows for the possibility of specific item types originating from more than one source; this flexibility and transparency of the technique means that it is less prescriptive than some other methods. Several sources were examined for each item, not simply shipping sources as some other procedures. Although 'this method is an estimate only, it does examine in detail all debris items and major litter categories' (Whiting 1998, p. 905). For these reasons, this method can be adapted for use in this Bristol Channel pilot study.

Results and Discussion – Application and development of a 'Matrix Scoring Technique'

Elements from the Percentage Allocation (Method 5 - Earll et al. 1999) and Cross Tabulation Probability Scoring (Method 6 – Whiting 1998) methods were adapted to produce a methodology that could be used to determine the source of beach litter. The attribution process was based on the Earll et al. (1999) method of elimination of potential sources and then an attempt to allocate scores and subsequent proportional percentage figures to each source was made using the Whiting (1998) method as a basis. Adaptations and different scoring schemes were tried to produce a refined 'Matrix Scoring Technique'.

Before any allocation to source is attempted a rationale and step by step process must be initiated. Once a list

Table 2. Litter items and the likelihood of source. Key to probability phraseology: Very unlikely (UU); Unlikely (U); Possible (P); Likely (L); Very likely (LL).

	Tourism (Beach users)	SRD	Fly tipping – land	Land (run off)	Shipping	Offshore installations	Commercial fishing
Sweet wrapper	LL	UU	UU	U	UU	UU	UU
Food container	L	UU	UU	U	U	UU	UU
Plastic drinks bottle < 500 ml	LL	UU	UU	U	U	UU	UU
Take away food container	LL	UU	UU	U	UU	UU	UU
Lollipop stick	LL	UU	UU	U	UU	UU	UU
Straw	LL	UU	UU	U	UU	UU	UU
Fishing line	UU	UU	UU	UU	UU	UU	LL
Unidentifiable plastic fragment	P	UU	UU	U	P	UU	P
Polystyrene piece	P	UU	UU	U	P	UU	P
Cigarette stubs	LL	UU	UU	U	UU	UU	UU
Cigarette box	LL	UU	UU	UU	UU	UU	UU
Childrens toy	LL	UU	UU	UU	UU	UU	UU

Table 3. Scheme of probability and percentage allocation of an item originating from a source (Earll et al. 1999).

Probability phraseology	Probability score	Percentage allocation
Very unlikely (UU)	0.001%	0%
Unlikely (U)	0.001-10%	0 to 10%
Possible (P)	50 – 50%	between 10 - 90%
Likely (L)	> 90%	over 90%
Very likely (LL)	100%	100%

Table 4. Scoring systems (A-E) – Likelihood of litter item originating from a particular source.

Probability phraseology	A	B	C	D	E
Very likely	4	9	16	16	16
Likely	3	7	8	4	4
Possible	2	5	4	2	2
Unlikely	1	3	2	1	1
Very unlikely	0	1	1	0.25	0.25
Not considered					0

of litter items from a beach is established, the next step is to place them in an 'elimination list'. An example of part of an elimination list is detailed in Table 1. Each item of litter is considered individually and assessment is made of the likelihood of it originating from each of the broad source categories. This is done by considering its identity, function, beach location, the 'mix' of litter, any indicator items present (such as sewage related items) and the quantity (Earll et al. 1999). This elimination process helps to set out the reasoning behind the subsequent allocation to a specific source.

An illustrative example of the usefulness of the elimination list is demonstrated by considering the source of a rubber tyre on a beach. The elimination list (Table 1) shows that the possible source of a tyre will be indicated by the presence of any attachments. If the tyre is found with a rope attached then it is likely to have been used as a fender on a ship and therefore a 'sea source', whereas if there are no attachments then a land-based or 'river source' is more likely. Clearly the 'beach user' source is eliminated from consideration for this object.

Following on from the 'elimination list' items are given an allocation using probability phraseology (Table 2). The Whiting (1998) probability expressions were not followed; Earll et al (1999) suggested five possible likelihood phrases and these have been used for this study (Table 2). Assigning each litter item a probability phrase such as this may seem trivial but it is all important in clearly displaying the rationale behind attempting to produce a methodology to ascertain litter sources. This rationale is absent from most statements of litter pollution source found in the literature. The litter items listed in Table 2 were found on Minehead beach and the probability assigned to the item is based on the physical location of this beach. A different beach location (such as a remote beach situated at a river mouth) would produce a different set of probabilities for these same items.

Following this stage Earll et al (1999) proposed a percentage allocation using the scheme outlined in Table 3. However, at this point a scoring system similar to that used by Whiting (1998) was introduced to

Table 5. Application of Scoring System 'A'.

Litter item	**Possible litter sources**								
	% Contribution to total amount of litter on beach	Tourism (beach users)	SRD	Fly tipping - land	Land (run off)	Shipping	Offshore installation	Related debris	Fishing total scores
Sweet wrapper	14.3	4 (11.4)	0	0	1 (2.9)	0	0	0	5
Food container	2.4	3 (1.4)	0	0	1 (0.5)	1 (0.5)	0	0	5
Plastic drinks bottle < 500 ml	2.4	4 (1.6)	0	0	1 (0.4)	1 (0.4)	0	0	6
Take away food container	7.1	4 (5.7)	0	0	1 (1.4)	0	0	0	5
Lollipop stick	7.1	4 (5.7)	0	0	1 (1.4)	0	0	0	5
Straw	4.8	4 (3.8)	0	0	1 (1.0)	0	0	0	5
Fishing line	7.1	0	0	0	0	0	0	4 (7.1)	4
Unidentifiable plastic fragment	9.6	2 (2.7)	0	0	1 (1.4)	2 (2.7)	0	2 (2.7)	7
Polystyrene piece	2.4	2 (0.7)	0	0	1 (0.3)	2 (0.7)	0	2 (0.7)	7
Cigarette stubs	38.0	4 (30.5)	0	0	1 (7.6)	0	0	0	5
Cigarette box	2.4	4 (2.4)	0	0	0	0	0	0	4
Children's toy	2.4	4 (2.4)	0	0	0	0	0	0	4
Percentage Totals	TOTAL (100%)	(68.30)	0	0	(16.9)	(4.3)	0	(10.5)	

Values in parentheses represent the possible percentage allocation of each source to each debris category. Data collected from Minehead beach, Bristol Channel, UK.

Table 6. Summary of results using different scoring systems.

	Percentage contribution of possible litter sources						
	Tourism (beach users)	SRD	Fly tipping - land	Land (run off)	Shipping	Offshore installations	Fishing related debris
Scoring system A	68	0	0	16	4	0	10
Scoring system B	46	5	5	16	8	5	11
Scoring system C	59	4	4	8	7	4	10
Scoring system D	73	1	1	6	5	1	9
Scoring system E	73	1	1	6	5	1	10

provide a more precise allocation than the broad range proposed by Earll et al (1999). The proportion figure (i.e. scores) are arrived at by considering the identification, function, and quantity of each litter item as previously mentioned. The items were not considered independently of other litter found in conjunction, therefore a rigid litter item 'type' or 'grouping' was not the defining characteristic of source. It is irrelevant to discuss whether an individual item or item type, taken in isolation comes from one defined source. It 'is the association of items types that is the key to making the link to an input source from shipping.' (Earll et al. 2000, p. 21). This statement can apply to all litter and all sources, not just to shipping. Most litter items are not in themselves linked to a source but if the litter they are found with point to one source then the likelihood of the whole litter mix arising from that source is increased. However, it may still be difficult to accurately attribute an item a probability of arising from a source. This problem of what probability phraseology to use for an item is a clear limitation of this method and open to question. Several attempts at refinement of the methodology were made, with various sources and scoring systems employed; the different scoring systems devised by the authors are shown in Table 4.

Table 5 shows a matrix of scores that are used to estimate the percentage of debris items that may be attributed to possible sources, scores are based on the probability of each source contributing to each category of debris. Scoring System 'A' is shown as an illustrative example of the process (Table 5). The large numbers of unidentifiable plastic fragments cannot reliably be included in any litter source attribution (Table 5). Fragmentation of plastic items occurs due to the processes of sunlight and seawater, as well as abrasion with beach substrates. Williams & Simmons (1996) showed that after 9 months in the beach environment plastics lose only some 20% of their intact strengths. Many of these fragments are unidentifiable because of lost markings or their small size.

Results shown in Table 5 indicate that approximately 68% of litter found were from a 'beach user' source, with other smaller contributions made from shipping, fishing and run off (i.e. rivers) sources. There were no signs of sewage related debris (SRD) or waste that had been dumped illegally, therefore the SRD and fly-tipping categories made no contribution to the litter found on the beach. There are no offshore installations in the vicinity and so this category was also excluded from making a contribution to the beach litter encountered.

Due to the difficulty in assigning a source, a case can be made for each source making at least a very small contribution to beach litter. Therefore, it was decided to apply a new scoring scheme, System 'B', without a zero value (Table 4). As a result, every source would make some kind of contribution to the litter found on the beach. The results for this scoring system show that the beach user source now makes up a smaller proportion (46%) of the overall contribution, with SRD, Land (run off) and offshore installations now contributing 5% of the litter total (Table 6).

Another scoring system was applied, System 'C', in this instance via a geometric progression scale (Table 4). This scheme enabled those items that were considered to be very likely to come from a specific source to make a larger contribution to the overall picture of the litter sources (Table 6). Therefore, items that were considered as being very unlikely to come from a certain source would not constitute a larger weighting than was appropriate. The outcome of this scoring system was to slightly reduce the contribution of SRD, Fly-tipping and offshore installations sources whilst halving the Land (run off) input (Table 6). Scoring System 'D' gave even less weighting to those items considered as 'very unlikely' to originate from a named source (Table 4). This returned the beach user source to a 73% proportion and further reduced the contribution of those sources deemed to be providing small litter inputs (Table 6).

Finally, there are some items that were so unlikely, or impossible, to originate from a particular source that the zero value was re-introduced in Scoring System 'E' (Table 4). As a result, for example, in areas where there were no rivers, this source could be completely ruled out and would not make any contribution to the

profile of sources. This made little difference to the percentage contribution of each source at this beach (Table 6) but it would be important on certain beaches. Scoring System 'E' would allow for subtleties in the sources of beach litter to emerge with sources that are irrelevant to a location unable to unduly influence the picture.

In summary, Scoring System 'A' was over simplistic and did not allow subtleties in the data to emerge, System 'B' over-emphasized minor source categories and Systems 'C', 'D' and 'E' gave greater weighting to the most likely source categories (Table 6). Systems 'D' and 'E' are very similar; the only difference between them is the addition of a 'not considered' parameter. Scoring system 'E' attempts to eliminate over and under estimates of the contribution by each source and produce a realistic picture. Examination of the results in Table 6 shows that whilst System 'E' is not vastly different to 'A' at this beach, the differences would be more apparent at other locations where a single source does not dominate.

The developed method needs further trials on a wide variety of beaches and locations to assess its use outside the Bristol Channel area, this would also allow for further refinement of the methodology. The 'Matrix Scoring Technique' would benefit from a control data set of litter from known sources input to the system and the procedure carried out once litter arrives at a beach. It is notoriously difficult to track and trace litter items in the natural environment, but a successful attempt would be invaluable in developing the methodology further.

Conclusions

There are many unknown factors and natural vagaries that make accurate beach litter source attribution difficult but this method allows for a more systematic approach than currently exists. Various methods that attempt to establish the source of beach litter were evaluated for use on Bristol Channel beaches with elements of Percentage Allocation and Cross Tabulation Probability Scoring methods being utilized to produce a new method of assigning a source to beach litter. The developed 'Matrix Scoring Technique' is not prescriptive with stages 1 and 2 (elimination list and probability phraseology) allowing those carrying out the study to include local knowledge, the physical factors and the entire mix of litter to influence decisions of where the litter has originated. It does not dictate that all items of a certain type arise from one specific source as is the case with certain other methods. It also is transparent and allows others to apply the method and refine it to the location being surveyed. However, this relies somewhat on the knowledge of the surveyor, inexperienced surveyors may misinterpret some findings or place undue emphasis on certain physical factors or beach location. There is some level of subjectivity when apportioning scores to each item, but knowledge of beach litter characteristics will aid reliable attribution.

This Matrix scoring system gives a new alternative and offers a transparent and usable method of establishing beach litter sources. It is a detailed process which could give far more accuracy than is currently possible – it is potentially more valuable than simple estimation based on a loose rationale. The amalgamation of different methods makes this a novel approach, although trials would be required to determine its applicability and usefulness outside the study area. This cross-tabulated matrix system can produce a useful insight into the contribution of different source groups to litter on a beach.

References

Anon. 2000a. *Beachwatch '99 – Nationwide Beach Clean and Survey Report*. Marine Conservation Society (MCS).

Anon. 2000b. *Assessment of Aesthetic Quality of Coastal and Bathing Beaches*. Monitoring Protocol and Classification Scheme. May, 2000. Environment Agency and The National Aquatic Litter Group. London, UK.

Bowman, D., Manor-Samsonov, N. & Golik, A. 1998. Dynamics of litter pollution on Israeli Mediterranean beaches: a budgetary, litter flux approach. *J. Coastal Res*. 14: 418-432.

Coe, J.M. & Rogers, D.B. (eds.) 1997. *Marine debris: Sources, impacts and solutions*. Springer-Verlag, New York, NY, US.

Cunningham, D.J. & Wilson, S.P. 2003. Marine debris on beaches of the Greater Sydney Region. *J. Coastal Res*. 19: 421-430.

Derraik, J.G.B. 2002. The pollution of the marine environment by plastic debris: a review. *Mar. Pollut. Bull*. 44: 842-852.

Dixon, T.R. 1995. *Temporal trend assessments of the sources, quantities and types of litter occurring on the shores of the United Kingdom: Introduction and methods with results from paired observations 8 and 11 years apart on 63 sampling units in mainland Scotland and the Western isles*. Marine Litter Research Programme, Stage 7, The Tidy Britain Group, Wigan, UK.

Earll, R.C., Moore, J., Williams, A.T. & Tudor, D.T. 1999. *The measurement of oily waste and garbage disposed of into the marine environment by shipping*. A report to the Maritime and Coastguard Agency. Prepared by Coastal Management for Sustainability, Candle Cottage, Kempley, UK.

Earll, R.C., Williams, A.T. & Tudor, D.T. 2000. *Pilot project to establish methodologies and guidelines to identify marine litter from shipping*. Maritime and Coastguard Agency Research Project No 470. 137 pp. Prepared by Coastal

Management for Sustainability, Candle Cottage, Kempley, Glos. UK.

Gabrielides, G.P., Golik, A., Loizides, L., Marino, M.G., Bingel, F. & Torregrossa, M.V. 1991. Man-made garbage pollution on the Mediterranean coastline. *Mar. Pollut. Bull*. 23: 437-441.

Gauch, H.G. 1982. *Multivariate analysis in community ecology*. Cambridge University Press, Cambridge, UK.

Gilbert, C. 1996. The cost to local authorities of coastal and marine pollution – a preliminary appraisal. In: Earll, R.C. (ed.) *Recent policy developments and the management of coastal pollution*. Marine Environmental Management and Training, Candle Cottage, Kempley, UK.

Golik, A. & Gertner, Y. 1992. Litter on the Israeli coastline. *Mar. Environ. Res*. 33: 1-15.

Gregory, M.R. 1977. Plastic pellets on New Zealand beaches. *Mar. Pollut. Bull*. 8: 82-84.

Huntley, D.A. 1980. Tides on the Northwest European continental shelf. In: Banner, F.T., Collins, M.B. & Massie, K.S. (eds.) *The Northwest European shelf seas: The sea bed and the sea in motion. Physical and chemical oceanography and physical resources,* pp. 301-351. Elsevier Oceanography Series, Amsterdam, NL.

Johnson, S.W. 1989. Deposition, fate, and characteristics of derelict trawl web on an Alaskan beach. *Mar. Pollut. Bull*. 20: 164-168.

Nash, A. 1992. Impacts of marine debris on subsistence fishermen – An exploratory study. *Mar. Pollut. Bull*. 24:150-156.

Nelson, C., Morgan, R., Williams, A.T. & Wood, J. 2000. Beach awards and management. *Ocean Coastal Manage*. 43: 87-98.

Olin, R., Carlsson, B. & Stahre, B. 1995. The west coast of Sweden – The rubbish tip of the North Sea. In: Earll, R.C. (ed.) *Coastal and riverine litter: Problems and effective Solutions,* pp. 12-18. Coastal Management for Sustainability, Candle Cottage, Kempley, Glos. UK.

Randerson, P.F. 1993. Ordination. In: Fry, J.C. (ed.) *Biological data analysis*, pp. 173-217. IRL Press, Oxford University Press, Oxford, UK.

Ribic, C.A. 1998. Use of indicator items to monitor marine debris on a New Jersey beach from 1991-1996. *Mar. Pollut. Bull*. 36, 11, 887-891.

Shiber, J.G. & Barrales-Rienda, J.M. 1991. Plastic pellets, tar, and megalitter on Beirut beaches, 1977-1988. *Environ. Pollut*. 71: 17-30.

Silva-Iniguez, L. & Fischer, D.W. 2003. Quantification and classification of marine litter on the municipal beach of Ensenada, Baja California, Mexico. *Mar. Pollut. Bull*. 46: 132-138.

Tudor, D.T. 2001. *Aspects of debris pollution at selected Bristol Channel beaches*. Ph.D. Thesis, Bath Spa University, Bath, UK.

Tudor, D.T. & Williams, A.T. 2003. Public perception and opinion of visible beach aesthetic pollution: the utilisation of photography. *J. Coastal Res*. 19: 1104-1115.

Tudor, D.T., Williams, A.T., Randerson, P., Ergin, A. & Earll, R.E. 2002. The use of multivariate statistical techniques to establish beach debris pollution sources. *J. Coastal Res*. 36: 716-725.

Velander, K.A. & Mocogni, M. 1998. Maritime litter and sewage contamination at Cramond Beach, Edinburgh: a comparative study. *Mar. Pollut. Bull*. 36: 385-389.

Walker, T.R., Reid, K., Arnould, J.P.Y. & Croxall, J.P. 1997. Marine debris surveys at Bird Island, South Georgia 1990-1995. *Marine Pollut. Bull*. 34: 61-65.

Whiting, S.D. 1998. Types and sources of marine debris in Fog Bay, Northern Australia. *Mar. Pollut. Bull*. 36: 904-910.

Williams, A.T. & Markos, D. 1995. Persistent marine debris in the summer tourist season along the west coast of Evia, Greece. In: Özhan, E. (ed.) *Proceedings of the Second International Conference on the Mediterranean Coastal Environment, MEDCOAST 95,* pp. 1425-1440. Middle East Technical University, Ankara, TR.

Williams, A.T. & Simmons, S.L. 1996. The degradation of plastic litter in rivers: implications for beaches. *J. Coastal Conserv*. 2: 63-72.

Williams, A.T., Pond, K., Tudor, D.T., Jansen, H. & Liu, H.B. 1999. The robustness of litter transect data collection by different survey groups. In: Özhan, E. (ed.) *Proceedings of the MEDCOAST 99 - EMECS 99 Joint Conference: Land Ocean Interactions – Managing Coastal Ecosystems, 9-13 November 1999, Antalya, Turkey,* pp. 715-725. Middle East Technical University, Ankara, TR.

Williams, A.T., Tudor D.T. & Randerson, P. 2003. Beach litter sourcing in the Bristol Channel and Wales, U.K. *Water Air Soil Pollut*. 143: 387-408.

Willoughby, N.G. 1986. Man - made litter on the shores of the Thousand Island Archipelago, Java. *Mar. Pollut. Bull*. 17: 224-228.

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