An Analysis of Beach Debris Accumulation in Table Bay, Cape Town, South Africa

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Two sites in Table Bay, South Africa, were examined for stranded debris between October and December 1994. One beach (Milnerton) is a popular recreation area in the metropolitan area whereas the other (Koeberg) is closed to public access. Daily and weekly accumulation rates were measured for both sites. A total of 40 041 items were collected, of which 81.7 % was plastic. Half of this was styrofoam. The majority of the debris was related to floating recreational litter, packaging material and polystyrene trays. Indications of increased inputs during the peak holiday season were recorded at the public beach (Milnerton). Locale was found to influence debris abundance and relative composition. Within-site variation was great, and longer sampling periods are necessary to overcome this variability. Daily and weekly sampling intervals were compared; weekly sampling yielded relatively lower totals and weights of articles than daily intervals. Total article weights were positively correlated to total article number. There were few foreign articles and articles supporting epiphytic marine organisms. Most persistent litter washed ashore, but appeared to derive from local, land-based sources. Daily accumulation rates were generally not correlated to weather conditions.

Introduction

Human-generated solid waste is a world wide problem of increasing proportions (Gilligan *et al.*, 1992; Lucas, 1992; Garrity & Levings, 1993). In the marine environment, plastic is one of the most abundant pollutants due to its persistence in the environment and the ability to float which allows long-distance dispersal and concentration into specific locations by ocean currents and wind (Corbin & Singh, 1993). Marine debris has several economic and ecological consequences (Ryan, 1990). Marine organisms may be killed or injured through ingestion or entanglement with debris (Furness, 1983; van Franeker, 1985; van Franeker &

Bell, 1988; Beck & Barros, 1991; Bjorndal *et al.*, 1994). Debris may provide substrata for invertebrate settlement and/or dispersal (Winston, 1982; Song & Andrady, 1991). Floating debris may interfere with fishing and shipping activities (Laws, 1993). Stranded debris is aesthetically displeasing as well as causing direct and indirect costs to shore-line communities (Garrity & Levings, 1993).

Long term debris surveys along the South African coast have shown that the densities of all types of plastic objects have increased significantly between 1984 and 1989, especially packaging and disposable items (Ryan & Moloney, 1990). However, little quantitative information is currently available on rates of input, and, short- and long-term accumulation patterns. The present study was designed to examine stranded debris along the Cape southwestern shoreline of South Africa.

This paper describes the distribution, abundance, composition, weights and rates of accumulation of beach debris at two sites in Table Bay, collected during three months of intensive sampling. The Milnerton site is a popular recreation area in the metropolitan area whereas Koeberg is closed to public access. The temporal and spatial patterns of debris accumulation are discussed, and daily and weekly sampling strategies are compared.

Materials and Methods

Study sites

Cape Town is a metropolitan area with a growing population of approximately 1.3 million people (Clayton, 1993). The city overlooks Table Bay and Robben Island. Two beaches in Table Bay were sampled (Fig. 1). The Milnerton site is used for recreational purposes (bathing, surfing, walking and angling), and is the beach nearest to Cape Town Harbour. The Koeberg site was located in the Koeberg Private Nature Reserve and is closed to the general public. Recreational use of this beach is restricted to hiking (approximately 170 persons during December). The sites were chosen to be as uniform as possible in terms of morphology, aspect, size and exposure. The Table Bay current deflects offshore near Duynefontein Bay (Cloete & Oliff, 1976). Hence the two sites chosen are at the extremes of the land bordering the Table Bay current.

Data collection and analysis

Two sampling strategies were tested; daily sampling during October and December and weekly sampling during November. The two daily sampling periods chosen represent a peak holiday season (December) and an out of season period (October). The two sampling strategies were also compared to once off sampling of 50 m stretches of beach at the two sites prior to this study commencing (Ryan, unpublished data).

The study period extended from October to December 1994. Collections were made daily for a two week period each in October and December, and on a weekly basis for the period inbetween. Both sites are cleaned by local authorities; Koeberg approximately four monthly and Milnerton weekly. At each site, a 500 m stretch of beach was marked out. Both beaches were cleaned prior to sampling commencing. All anthropogenic macro debris (artefacts $>$ 10 mm) occurring between the low water and vegetation lines were collected and recorded. The debris was removed from the sites after each observation so that debris found represented litter that had washed ashore recently, had been left by beach-users or was the reemergence of previously buried debris. Wood was counted if it was 'worked' rather than natural drift wood. Debris in the transects was categorised according to 1) type (e.g. plastic, styrofoam, wood, paper, etc.), and 2) probable function and source (e.g. household, recreational litter, commercial fisheries, etc., (Ryan, unpublished data)). In the type categorisation, polystyrene foamed plastic (styrofoam) was treated separately from other plastics due to its buoyancy and hence unique floating and stranding characteristics (Garrity & Levings, 1993). Thirteen broad functional types were recognised: bottles, bags (including shrink-wraps), recreational litter that floats (sweet and chip packets, cigarette wrappers, cooldrink lids, straws, lolly sticks, etc.), recreational litter that sinks (disposable glass drink bottles, cans and cartons, metal lids, cigarette packets, match boxes, etc.), styrofoam trays and cups, packing material (polystyrene packing chips and lumps, bubble pack sheets, etc.), one-use items (disposable pens, eating utensils, cigarette lighters, etc.), household goods (buckets, pipes, hair curlers, rawlplugs, toys, balloons, etc.), medical wastes and personal use items (sanitary towels, nappies, condoms, earbuds, syringes, etc.), commercial fishery wastes (floats, ropes, traps, trays, nets, etc.), recreational fishery wastes (monofilament line, line and bait reels, bait boxes, etc.), miscellaneous floating debris (unidentified plastic fragments, cork, wax, wood, sealed glass bottles, light bulbs, aerosols, etc.), and miscellaneous debris that sinks (paper, cardboard, cloth, cans, foil, etc.). Many of these categories overlap, and it is evident that these categories cannot reflect the origins of all debris. However, the intention is merely to look for patterns in occurrence that may be indicative of the major sources of different types of debris. Weights were obtained (to the nearest 25 g) for the daily and weekly debris accumulations. Articles were cleared of sand prior to weighing. Very large or heavy (> 1 kg) objects and wood were counted but not weighed. All articles were checked for manufacturers marks, and foreign articles, identified from markings indicating the country of origin, were recorded as were the number of articles supporting marine organisms. At Milnerton, the debris was divided into articles found above and below the high tide driftline. The articles occurring above the high tide driftline are assumed to either have been 1) dropped by visitors, 2) windblown material or 3) exposed after being buried. This stratification was not done at Koeberg since the high tide driftline coincides with the vegetation line.

Weather data, obtained from the Koeberg Weather Station (Mr Fick, pers. comm.), was used to test for correlations between daily debris accumulation and weather conditions. Linear correlations were estimated for log transformed data.

Other differences were tested using contingency tables and Student's *t* test (Zar, 1984).

Results

Debris composition

During the study period a total of 40 041 items and fragments were collected from the survey sites. The total weight of items removed was 158 kg.

The most common materials were plastic (81.7 %) of which 40.8 % was styrofoam. Wood and miscellaneous items comprised 2.1 % and 12.7 % respectively of the total number of items collected. Rubber and paper were relatively rare, each comprising < 1 % of the total. The plastic, styrofoam and miscellaneous categories were subdivided into further categories. Food packets, lids, straws and packaging material comprised the majority of the items in the plastic class (19.8 %, 16.9 %, 12.4 % and 15.9 % respectively). Polystyrene lumps (41.2 %) and trays (39.8 %) formed the major component of the styrofoam class, chips and cups making up the remainder. The miscellaneous class included items such as cigarette butts, glass and metal. Cigarette butts were the most abundant in this class (67.7 %). Overall, cigarette butts constituted 8.6 % of the total number of items collected.

The majority of the debris were related to recreational floating litter, packaging material and polystyrene trays (37.8 %, 22.1 % and 16.3 % of the total, respectively). Collectively, recreational litter and polystyrene trays contributed 54.4 % of all litter collected.

Spatial aspects

Locale influenced debris abundance and relative composition. The total number of articles collected at Koeberg during October and December was 4 771 whereas at Milnerton the total number of articles collected during this period was 21 739. Hence, the absolute number of articles was less at Koeberg. The relative proportions of plastic, styrofoam and wood were greater at Koeberg (Fig. 2), but Milnerton had relatively greater proportions of rubber, paper and miscellaneous items. Milnerton had relatively more bottles, miscellaneous sinking items, bags and floating recreational litter than Koeberg (Table 1). Koeberg however, had relatively more polystyrene trays, packaging material, household items, one-use items, commercial fishery items, medical and miscellaneous floating items.

The total number of foreign articles found was less than 1 % (n = 54) of the total number of articles collected. There was no significant difference between Koeberg and Milnerton of the relative number of foreign articles ($\chi^2 = 0.06$, df = 1). Most of the items for which the country of origin could be identified were from the Orient. It is unlikely that these items are available locally as imported goods, suggesting their likely inputs from ships.

The total number of articles supporting marine organisms was less than 1 % (n = 46) of the total number of articles collected during the daily sampling period, suggesting a short residence time in the water (Cundell, 1974; Stevens, 1992). Most obvious of the marine organisms were bryozoans and crustaceans. Koeberg had relatively more articles supporting marine life than did articles found at Milnerton ($\chi^2 = 3.84$, df = 1, $P < 0.08$), but absolutely less (n = 13).

Temporal aspects

No significant difference was found between the mean accumulation rate during October and December at Koeberg (Table 2). Milnerton, however, showed a significantly greater ($t = 5.406$, df = 26, $P < 0.001$) rate of accumulation in December than in October. Similarly, the average weight of articles at Koeberg between October and December showed no significant difference, whereas the mean weights of Milnerton showed significant differences (t = 2.056, df = 26, P < 0.05). At Milnerton, although the total mean was greater in December, not all categories showed a significant increase in average number. Wood, rubber, medical items, bags, household items and recreational fishing gear showed no significant difference in mean number, suggesting a constant input.

Only 18 % of the articles occurring on Milnerton beach were found above the high tide driftline during October. During December, 15.7 % of the articles were found above the high tide drift line. There was no correlation between tide height and the number of articles found above the high tide line. Floating day litter accounted for 48.3 % and 44.5 % of the total number of articles occurring above the high tide driftline in October and December, respectively.

Wind speeds and wind direction (onshore versus offshore) were correlated with daily sample totals in an attempt to explain within-site variation. Wind direction was not correlated with article numbers or weight. Wind speed (using a one day lag) was positively correlated with article numbers and weights during October only (r = 0.74 for article number and weight at Koeberg; r = 0.87 for article numbers and r = 0.67 for article weights at Milnerton, all for P < 0.05). Residuals from the wind speed correlation were plotted against wind direction but no variation was accounted for.

Total weight was positively correlated with total numbers at Koeberg during both October and December and at Milnerton during October (r = 0.76, r = 0.76 for df = 12, P < 0.005 and r = 0.79 for df = 12, P < 0.001, respectively). Overall, total weight was positively correlated with total numbers (r = 0.799, df = 54, P < 0.001).

Sampling strategies

Variation within sites was great (Table 2). If the population mean is to be estimated having a 90 % probability that the 95 % confidence limit will not be wider than 100 articles for Koeberg, a sampling period of 20 days is necessary to overcome this variability. Similarly for Milnerton, approximately 50 sampling days are necessary to ensure that the 95 % confidence limit is not wider than 200 articles.

Accumulation rates between daily and weekly sampling strategies were compared (Table 3). Daily observations were extrapolated to an expected weekly accumulation rate. The observed weekly accumulation rate (by weight and number) were less than the expected accumulation rates.

Once off sampling at the two sites yielded 2 936 articles.100 m^{-1} at Milnerton and 1 822 articles.100 m^{-1} at Koeberg (Ryan, unpublished data). Plastic items were proportionally greater for once off sampling than for daily or weekly sampling (Fig. 3). Floating recreational litter formed the largest percentage of the total at Milnerton (32.1 %). Miscellaneous floating articles comprised 12.5 % of the total. At Koeberg, packaging material constituted 26.3 % of the total number of articles collected. Miscellaneous floating items and floating day litter contributed 20.5 % and 11.4 % of the total. Both sites are cleaned on a regular basis, but it is assumed that only large artefacts are collected during local authority cleanups and consequently the figures presented here would contain a large percentage of small items and fragments accumulated over a longer period. The proportions of bottles, sinking recreational litter, household, medical, fishery and miscellaneous floating items increased with sampling interval at both sites, as did the number of bags at Milnerton (Table 4). There was a decrease in polystyrene trays, floating recreational litter and one-use items at both sites with an increase in sampling interval.

Discussion

Debris composition

Lucas (1992) reports accumulation rates of 21.9 $items.month^{-1}.100\ m^{-1}$, for Nova Scotia, Canada. Corbin & Singh report 450 - 1 120 $items.100\ m^{-1}$ in the Caribbean. Hence, the accumulation rates reported here would seem to be intermediate, although differences in sampling methodology makes direct comparisons impossible. Most of the items stranded on the coast were made from plastic and styrofoam. These results are consistent with reports from elsewhere in the world (Gilligan *et al.*, 1992; Lucas, 1992; Garrity & Levings, 1993), and serve to show the ubiquitous distribution and abundance of these products.

Functionally, most of the items had come from floating recreational litter, packaging material and polystyrene trays, indicating a large input of litter from local, land-based sources. More than half of all the articles were related to recreational litter and polystyrene trays. This demonstrates a consumer orientated society that emphasises packaged goods and inadequate disposal of solid wastes on land. However, similar litter could come from sources such as ships.

Spatial aspects

Locale influenced debris abundance and relative composition. There was a decrease in article density with distance from Cape Town. There was a four fold increase in the amount of litter from Koeberg to Milnerton during the daily sampling period. Absolute values were greater for all litter types at Milnerton. Similar gradients have been discussed by Colton *et al.* (1974) and Willoughby (1986). Debris composition at the two locales was related to the probable sources of litter. Milnerton supported relatively more paper, styrofoam and day litter whereas Koeberg debris had greater proportions of more persistent articles and fishing items.

Temporal aspects

Seasonal differences in the amount of litter exist at Milnerton, with December having approximately double the amount of litter than October. This can be ascribed to the greater number of tourists during the December holiday period. A seasonal trend would be expected between summer and winter. Ryan (1988) found seasonal trends in the amount of meso-debris at sea.

Total weights for the various sampling periods were well correlated with total numbers of articles. Weights can be used as an index of the abundance of litter provided the weights of large objects and wood are excluded.

There was little evidence of debris from foreign sources (< 1 %) and ships at sea. However, it was difficult to distinguish materials that came from ships as many of the items used on ships could have had a land-based origin as well. The absolute numbers of epiphytic marine organisms and foreign articles was greater at Milnerton than at Koeberg. However, only the relative proportions of epiphytes increased at Koeberg, suggesting a relatively greater marine input at Koeberg. A relatively constant input from ships is suggested by the results.

Only 15 % - 18 % of the items collected at Milnerton occured above the high tide driftline. Not all the articles found here can be ascribed to litter left by beach-users. Litter found in this region could be wind blown material from elsewhere or it represents buried material that has resurfaced. Milnerton is not a very high utility beach relative to other beaches in the region. Hence, beach-users could contribute more significantly to the amounts of litter found on high utility beaches elsewhere.

Corbin and Singh (1993) report that the direction of the prevailing winds and ocean currents are important factors influencing the distribution of marine debris on a monthly basis. Ryan and Moloney (1990) suggest that local sources play a larger role in the distribution of macro-plastics than do inshore currents. Ryan (1988) has also shown that a seasonal trend exists in the distribution of meso-marine debris on the Cape west coast, with more debris present in winter than in summer. This is probably due to the winter rainfall which the region receives, resulting in pulsed inputs from rivers and storm water drains. Also, in winter, northwesterly winds oppose the northward advection of plastic by the Benguela Current (drift card returns in Shannon *et al.*, 1983), while in summer, the prevailing southerly winds move plastics offshore in a northerly direction. However, in this study, variation in daily accumulation rates could not be accounted for by weather conditions. Debris abundance was weakly linked to wind speed in October only.

Daily variation in abundance was great; the distribution of items on the beach showed no clear pattern on a daily basis. Currents in Table Bay are wind driven and generally weak and flushing of the Bay is therefore poor (Quick & Roberts, 1993). Ryan (1988) described the dispersion of plastic particles at sea as clustered, presumably at convergence zones. It is likely that the same clustering effect is present in Table Bay and that this will account for the variation found in daily abundances. In addition, light-weight articles may be moved by the wind or other articles such as wood and fishing floats may be removed by local inhabitants for further use.

Sampling strategies

Variability within sites was great and longer sampling periods are necessary to overcome this variability. Daily sampling at Milnerton requires approximately 50 days to have a 90 % probability that the 95 % confidence interval is not wider than 200 articles.

Daily and weekly sampling intervals yielded different results both in terms of absolute number of articles collected and the relative proportions of various categories. Weekly sampling intervals gave consistently lower totals and weights of articles than daily intervals summed over a week. Observed weekly accumulations were half of the expected accumulations at Koeberg, and were seven fold less at Milnerton. This could be because Milnerton beach is partially cleared by the public. Accumulation weights did not display as great a difference between observed and expected values, suggesting that small items are lost between samples. Using a weekly sampling interval there appeared to be a reversal in the relative proportions of the different categories with Koeberg supporting relatively more styrofoam and Milnerton supporting more persistent articles. It is not entirely clear why there would be this apparent reversal.

Generally, the longer the sampling interval the smaller the proportion of polystyrene trays, floating recreational litter and one-use items at Koeberg and Milnerton, and the greater the proportion of bottles, sinking recreational litter, household, medical, fishery and miscellaneous floating items. Therefore, more persistent items tend to accumulate whereas lighter items such as styrofoam decrease in relative abundance over time as they get exported by wind.

Hence, the best sampling interval to use depends on the objectives of the study. Long term sampling intervals can be used to show trends in litter abundance bearing in mind that certain categories will be under-represented. Daily sampling intervals are best for estimating litter that washes ashore but does not necessarily accumulate, since articles are removed by wind, waves, people or become buried.

Conclusions

This study suggests that most litter stranded in Table Bay enters the sea from land-based sources. Offshore and longshore currents may move litter out of the Bay. However, due to the poor flushing of the Bay, it is possible that litter reaching the Bay becomes 'trapped' with limited dispersal occurring from the Bay. The degree of benthic littering is unknown. The sources of litter, especially land-based inputs should be investigated so that they can be targeted for control and mitigation.

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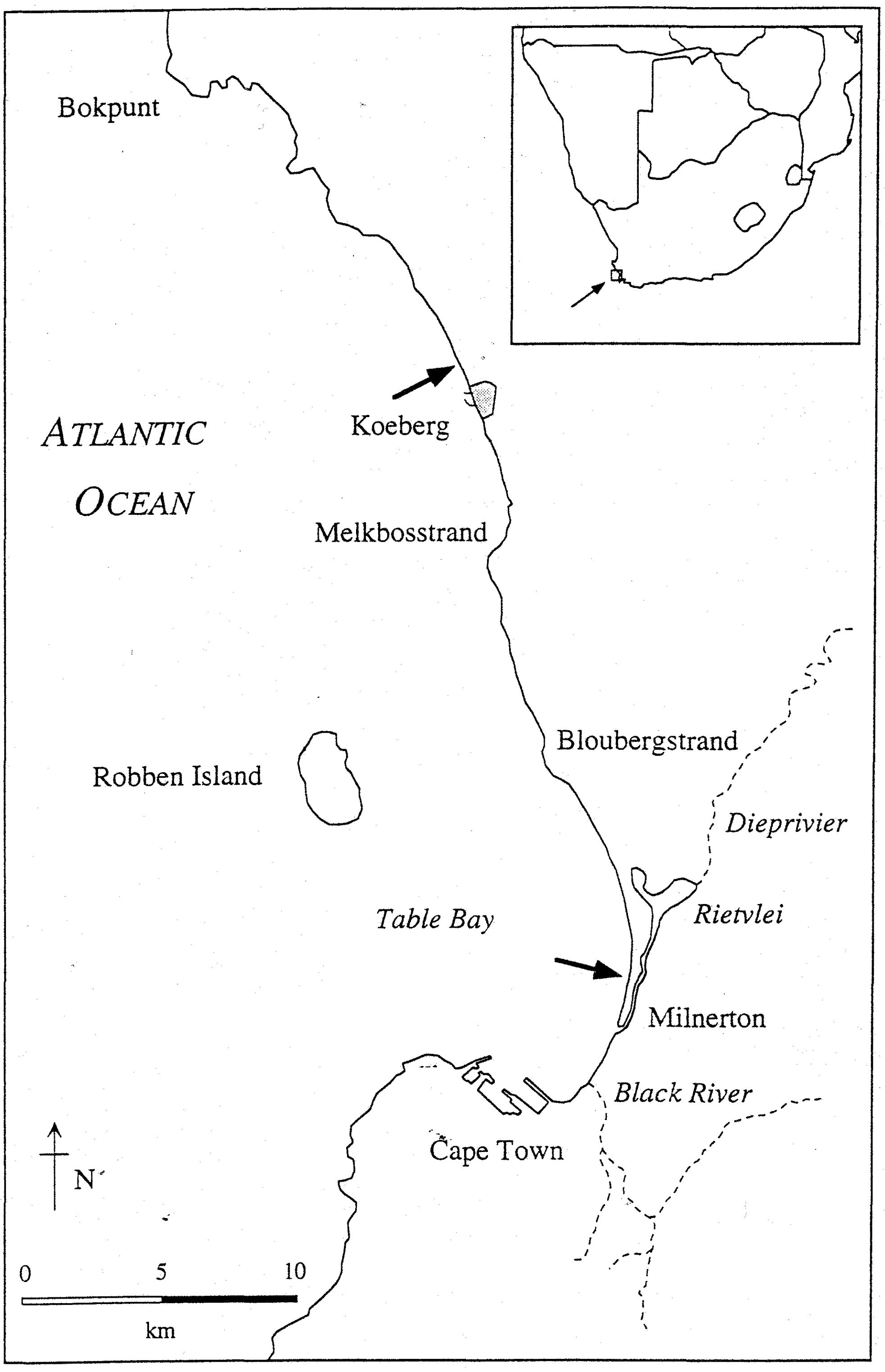

Fig. 1 Map showing Table Bay and study area.

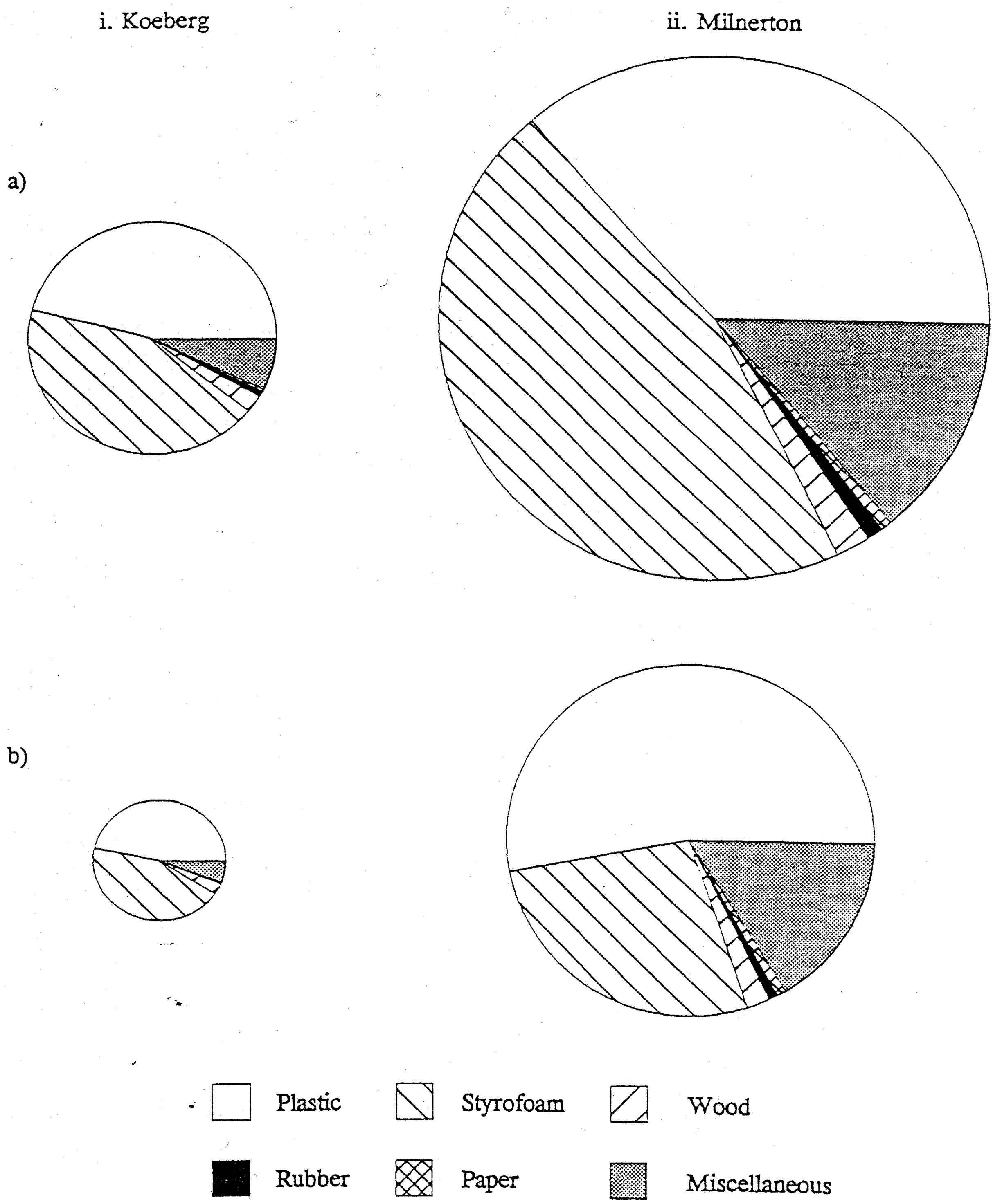

Fig. 2 The proportions (number.day^{-1}.100 m^{-1}) of litter types found stranded at i. Koeberg, and ii. Milnerton, from October to December 1994. The size of the circle indicates the relative amount of litter collected.

a) daily sampling interval (i. n = 4 771, ii. n = 21 739),

b) weekly sampling interval (i. n = 3 644, ii. n = 9 887).

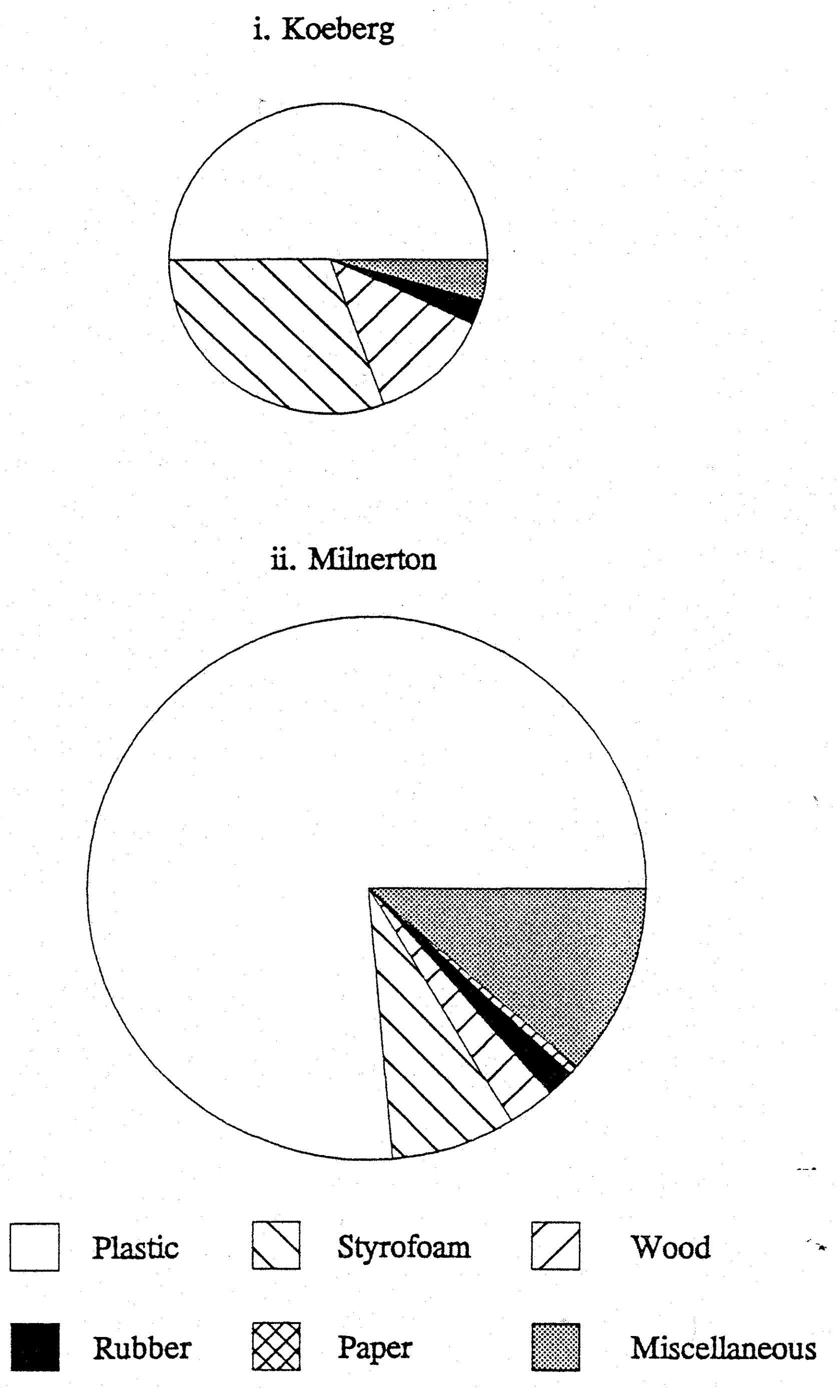

Fig. 3 The proportions (number.100 m^{-1}) of standing stock litter types collected at Koeberg (n = 1 824) and Milnerton (n = 3 236) beaches during 1994. The size of the circle indicates the relative amount of litter collected.

TABLE 1

Percentage composition by function and probable source. October and December totals represent daily sampling (n=14) and November totals represent weekly sampling (n=6).

Category	Site							
	Milnerton				Koeberg			
	October	November	December	Total	October	November	December	Total
Bottles	1.9	4.5	2.0	2.8	1.3	4.3	1.2	2.6
Polystyrene trays	16.6	11.4	19.4	16.2	16.1	16.6	16.5	16.4
Packaging materials	22.1	15.5	24.5	21.1	19.3	24.8	33.7	25.7
Floating recreational litter	37.3	46.6	35.4	39.4	34.9	31.2	29.5	31.8
Sinking recreational litter	0.4	0.5	0.4	0.4	0.0	0.1	0.0	0.0
Bags	2.7	3.8	1.6	2.5	5.3	0.1	2.2	2.2
Household items	3.2	3.2	2.5	2.9	3.4	3.2	2.4	3.0
One-use items	5.5	5.8	5.4	5.5	9.6	10.2	5.6	8.7
Medical items	0.0	0.0	0.0	0	0.2	0.1	0.1	0.1
Commercial fishery	1.6	3.0	1.8	2.1	2.9	2.4	2.7	2.6
Recreational fishery	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1
Miscellaneous floating	7.1	4.0	5.4	5.4	6.2	5.5	5.7	5.8
Miscellaneous sinking	1.5	1.6	1.6	1.6	0.8	1.5	0.5	1.0
Total number	7321	9887	14418	31626	2435	3644	2336	8415

TABLE 2

The total number, mean, standard deviation, range and total weight of articles during October, November and December for Milnerton and Koeberg

	Site					
	Milnerton			Koeberg		
	October	November	December	October	November	December
Total number	7321	9887	14418	2435	3644	2336
Mean	522.9	1647.8	1029.9	173.9	607.3	166.9
Standard deviation	256.6	421.9	239.2	76	333.2	68.8
Range	744	1007	883	243	824	226
Total weight (g)	25850	60590	38825	9290	16265	7170

TABLE 3

Average actual and expected accumulation rates and weights for daily and weekly sampling periods per 100 m

	Accumulation rate			Accumulation weight		
	Daily Observed	Weekly Expected	Weekly Observed	Daily Observed	Weekly Expected	Weekly Observed
Koeberg	34.04	238.25	121.46	117.57	822.95	542.16
Milnerton	155.3	1086.99	141.2	461.94	323.58	2019.66

TABLE 4

Totals and percentages of the numbers of articles occurring in functional categories for daily (n=28), weekly (n=6) and long term (n=1) sampling intervals for Koeberg and Milnerton

	Koeberg			Milnerton		
Category	Daily	Weekly	Long term	Daily	Weekly	Long term
Bottles	1.2	4.3	6.5	2.0	4.5	6.9
Polystyrene trays	16.3	16.6	10.0	18.4	11.4	4.6
Packaging material	26.3	24.8	26.3	23.7	15.5	5.5
Floating recreational litter	32.2	31.2	11.4	36.1	46.6	32.1
Sinking recreational litter	0.0	0.1	0.8	0.4	0.5	1.1
Bags	3.8	0.1	3.7	2.0	3.8	8.1
Household	2.9	3.2	13.5	2.6	3.2	17.0
One-use	7.6	10.2	0.9	5.4	5.8	1.1
Medical	0.1	0.1	2.1	0.0	0.0	2.5
Commercial fishery	2.8	2.4	3.6	1.7	3.0	8.2
Recreational fishery	0.1	0.0	0.4	0.0	0.1	0.3
Miscellaneous floating	6.0	5.5	20.5	6.0	4.0	12.5
Miscellaneous sinking	0.7	1.5	0.2	1.6	1.6	0.1
Total	4771	3644	911	21739	9887	1468

A preliminary litter budget for Table Bay, Cape Town

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Abstract

There is considerable debate regarding the relative importance of land- and sea-based sources of marine debris. To address this question, a litter budget for Table Bay was constructed considering a variety of sources and sinks. Beaches (sinks), rivers and fencelines (sources) were sampled, and estimates based on weight, made of stormwater drain inputs. Processes such as inputs from ships, advection, sinking and degradation were not measured, and thus the budget cannot be balanced. However, land-based sources probably account for at least half the debris stranded on beaches of which rivers and stormwater drains contribute the greatest proportions of litter and should thus be targeted for control.

Introduction

Plastic litter is ubiquitous in the marine environment.[1,2,3] In addition to ecological impacts[4], stranded marine debris impairs the use of beaches for leisure and recreational purposes. This necessitates expensive cleaning of beaches.[5] In addition, the removal of litter may not be possible at more inaccessible places, where litter still accumulates on the beaches. The Cape Town City Council spent R2 658 050 during their 1992 / 1993 financial year on beach cleaning activities.[6] Domestic refuse removal costs approximately R 75 $tonne^{-1}$, whereas beach litter removal can cost up to R 3 000 $tonne^{-1}$ (Mr B. Black, Cape Town City Council, pers. comm.).

There is considerable debate regarding the relative importance of land- and sea-based sources of marine debris. The question of sources of marine debris was the primary focus of the recent Third International Conference on Marine Debris (Miami, May 1994). The importance of various sources needs to be identified so that they can be targeted for mitigation / control activities. Man-made articles enter the ocean from ships and from a diffuse array of land-based sources such as rivers, stormwater drains and wind blown material (Fig. 1).[7,8,9] The aim of this paper is to construct a litter budget for Table Bay, Cape Town, in the context of litter sources and sinks.

Methods

Study sites

The Black River, two beaches and two fencelines along the coast of Table Bay (Fig. 2) were sampled to estimate litter outputs and inputs.

Beach sites

The Milnerton beach site was located next to the Milnerton Golf Course whereas the Koeberg beach site was located north of the nuclear power station in the Koeberg Private Nature Reserve. The beach sites were chosen to be as uniform as possible in terms of profile, aspect, size and exposure. The study period extended from October to December 1994. Collections were made daily for a two week period each in October and December.

Both beaches were cleaned prior to sampling commencing. At each site a 500 m stretch of beach was marked out. All anthropogenic macro debris (artefacts > 10 mm) occurring between the low water and high tide drift lines was collected and recorded. The debris was removed from the sites after each observation so that debris found represented litter that had washed ashore recently, the reemergence of previously buried debris or debris that had been left by beach-users. Wood was counted if it was 'worked' rather than natural drift wood. The articles were categorised according to their probable function and source e.g. household, recreational litter, commercial fisheries, etc. Weights were obtained (to the nearest 25 g) for the daily debris accumulations. Very large or heavy (> 1 kg) objects and wood were counted but not weighed.

Fencelines

Two fencelines 300 m long, running parallel to the beach were sampled to estimate wind borne litter, which is trapped against the fences. All articles caught in the fence or within 1 m either side of it, were collected and recorded. Daily accumulations were weighed to the nearest 25 g. Sites were cleaned prior to sampling commencing. Sampling ran in sequence with beach sampling during December for a two week period. The Milnerton fenceline was situated south of the Diep River, and the Koeberg fenceline was situated north of the Koeberg Power Station entrance.

Black River site

The Black River forms the major drainage for much of the Cape Flats (184 km^2). It passes through industrial, middle- and low- income residential areas. The river was sampled in sequence with the beach and fence sampling during a two week period in December. Visual sampling was done by recording all anthropogenic macro debris passing a fixed point, using two observers each covering half of the river. The river is canalised (45 m wide) at this point with a flat cement bed, facilitating visual observations. Sampling was conducted on the outgoing high tide for an hour daily. Observations were made 200 m from the mouth of the river to reduce the influence of waves. The Black river is screened for debris along its course.

Stormwater drains and outfalls

No direct measurements were made of stormwater drain inputs. However, several drains entering the Cape Town Harbour (Duncan Dock) have litter nets and estimates were based on these. Four stormwater outlets draining part of the city centre have litter nets that can accumulate 1.5 tonnes of debris each. These are cleaned on average every three months (Mr F. Coetzee, Portnet, pers. comm.).

Other sources

The potential inputs of litter from the Waterfront and Harbour are great. However, both the Waterfront (Mr Fourie, Waterfront, pers. comm.) and the Harbour (Mr F. Coetzee, Portnet, pers. comm.) have intensive pollution control programmes. Clean up initiatives involve daily collection on the quays, harbour area and stormwater drains, and continuous collection from boats on the water. Considering the enclosed nature of these water bodies, the clean-up programmes involved and the lack of actual data, it has been assumed for this budget that little debris will enter Table Bay from these sources.

Results and discussion

This is a preliminary study and the results are indicative rather than quantitative. Seasonal trends should be accounted for. However, this is the first attempt at constructing a litter budget for the area and the data could show important contributors to marine pollution and its associated impacts. Litter weights and numbers are used to construct the litter budget. Beach data correlations between weight and article number were used to extrapolate the number of river articles to a weight figure, and the weight of stormwater drain inputs to numbers of articles.

Steady state conditions (i.e. inputs and outputs balance) are assumed in the calculations. In reality, pulsed inputs are expected that are correlated to weather and rainfall events. For example, rivers and stormwater drains would have greater inputs after the first winter rainfalls. Beach debris accumulation rates show seasonal trends and are linked to oceanic currents and wind conditions.[9,10]

Sources

Rivers

The Black River was sampled yielding on average 2 888 articles per day ($\bar{X} = 98.1 \pm 82.1$). A significant positive correlation was found between the total number of articles collected on a beach and their weight ($r = 0.799$, $P < 0.01$). An average of 3.06 $g.article^{-1}$ was used to calculate the weight of articles discharged by the river. Hence, an average of 8.8 kg was discharged per day.

The Diep River flows into Table Bay. Although this river flows through less urban impacted areas than the Black River does, its catchment is larger (1260 km^2) and outfalls from Milnerton are discharged into the river (Mr Abrahams, Milnerton Municipality, pers. comm.). Hence it is assumed that the debris output of the Diep River will be similar to that of the Black River. Therefore, the total input from rivers is approximately 17.6 $kg.day^{-1}$. Using the same assumptions made for article weight, the total number of articles discharged by the two rivers is 5 776 $articles.day^{-1}$.

Windblown

Fencelines were used to indicate the probable amount of wind blown material. The fenceline data showed a decrease in density of articles away from Cape Town. At Milnerton, 20.7 $g.day^{-1}.100\ m^{-1}$ was collected while at Koeberg the weight was 1.1 $g.day^{-1}.100\ m^{-1}$. The average was 10.9 $g.day^{-1}.100\ m^{-1}$. Using this average extrapolated over 28.8 km (the distance from the Black River to Koeberg), approximately 3.1 $kg.day^{-1}$ is contributed by wind blown material. It is interesting to note that the weight per article for wind blown material is 6.75 g as opposed to the 3.06 g per article used in the river data extrapolation. This is probably due to the articles on the beaches being broken up into smaller fragments (e.g. polystyrene trays). This means that the river mass may have been underestimated.

Based on article number, an average of 3.2 $articles.day^{-1}.100\ m^{-1}$ is blown into Table Bay. This is equivalent to 921.6 $articles.day^{-1}$ for a 28.8 km stretch of coast.

Stormwater drains and outfalls

It is assumed that the area of the outfall pipes is proportional to their flow and area drained, and hence to the amount of litter they carry. The total of the netted outfall area in the Harbour is 32.3 m^2. This yields an average of 2.1 $kg.m^{-2}.day^{-1}$ entering the nets.

Summing main outfalls (> 300 mm diameter) from Milnerton to Bloubergstrand, the total surface area of stormwater drains is 8.4 m^2. Hence, 17.6 $kg.day^{-1}$ enters Table Bay via stormwater drains.

Using an average of 3.06 g per article, the netted stormwater drain outfalls in the Harbour yielded an average of 679.7 $articles.m^{-2}.day^{-1}$. Extrapolating for the remaining stormwater drains, an average of 5 695.9 $articles.day^{-1}$ are discharged.

Other sources

Other inputs may come from vessels at sea and beach-users. Inputs from recreational use of the beach are unknown. The amounts contributed will depend on the degree and nature of beach utilisation.

Dumping of plastics at sea and other dumping is illegal in terms of Annex V of MARPOL. However, during the beach surveys, foreign articles, most probably discarded from ships at sea, were found, as were commercial fishery discards (nets, ropes, etc.). Some may have been lost during fishing operations, but others doubtless were discarded at sea. Although these articles accounted for approximately two percent of the total number of articles collected, it was almost impossible to establish the amount of litter discarded by local ships and recreational vessels.

Sinks

Beach accumulation rates

The total weights and number of litter article accumulation at Koeberg and Milnerton for the two sampling periods are shown in Table 1.

Table 1: Mass (g) and article accumulation rates expressed on a daily basis per 100m for Koeberg and Milnerton during October and December.

	Koeberg		Milnerton	
	October	December	October	December
Mass ($g.day^{-1}.100\ m^{-1}$)	132.7	102.4	262.5	535.8
Average	117.6		399.2	
Number ($day^{-1}.100\ m^{-1}$)	34.8	33.4	85.8	175.1
Average	34.1		130.5	

The increase in weight and article number at Milnerton during December is probably due to an increase in the number of people in the area during the Christmas holiday season. The results suggest a decrease in density in the amounts and overall weights of beach debris with distance from Cape Town. Similar gradients have been reported by Colton *et al.*[11] and Willoughby.[12]

A linear gradient is assumed between the Koeberg and Milnerton sites and the average of this gradient was calculated (258.4 $g.day^{-1}.100\ m^{-1}$). A 28.8 km stretch of coastline from the Black River to the Koeberg site was used to calculate the total weight of articles found along the coastline per day. Approximately 74.4 $kg.day^{-1}$ could be expected to wash up on the coast.

The average number of articles occurring between Koeberg and Milnerton is 82.3 articles.day^{-1}.100 m^{-1}. Extrapolated along the coast, approximately 23 702.4 articles.day^{-1} can be expected to be stranded.

Beaches act as sinks for litter in the ocean.[10] However, beach survey results of total numbers and weights are only indicative of the amount and weight of debris in the water. The Third International Conference on Marine Debris (Miami, May, 1994) suggested that the amount and weight of debris is influenced by beach dynamics, oceanic circulation patterns, weather, debris characteristics and recreational activities.

Other sinks

The influences of other outputs from Table Bay, such as litter that sinks and litter moved out of Table Bay by ocean currents, are undetermined. However, flushing of the Bay is poor due to weak currents and poor circulation.[13]

Conceptual model

A summary of the results are shown in the form of a conceptual model (Fig. 1). Approximately 48.5 % of the debris collected (by weight) on the beaches are unaccounted for, whereas 51.5 % of the debris articles collected (by number) are unaccounted for. The inputs from recreational beach use, Robben Island, the Harbour, the Waterfront, ships and other sources are unknown. Similarly, outputs such as sunk debris, degradation and currents that move the debris out of Table Bay are unaccounted for. These aspects will need to be considered in the future.

Conclusions

Marine debris can be considered in a systems perspective. Sources, sinks and the processes determining the transport of debris need to be identified in order that the fate of marine debris can be known. This knowledge facilitates management actions and may help to locate potential problems e.g. benthic debris.

The speculative findings of this report suggest that approximately half of the litter found in Table Bay has a shore-based origin of which rivers and stormwater drains contribute the greatest proportions of litter and should thus be targeted for control. However, nearly half of the beach debris is unaccounted for, suggesting large inputs from other sources. Other inputs and outputs of litter to Table Bay should be researched and refinements made to the existing variables so that a clearer picture is obtained.

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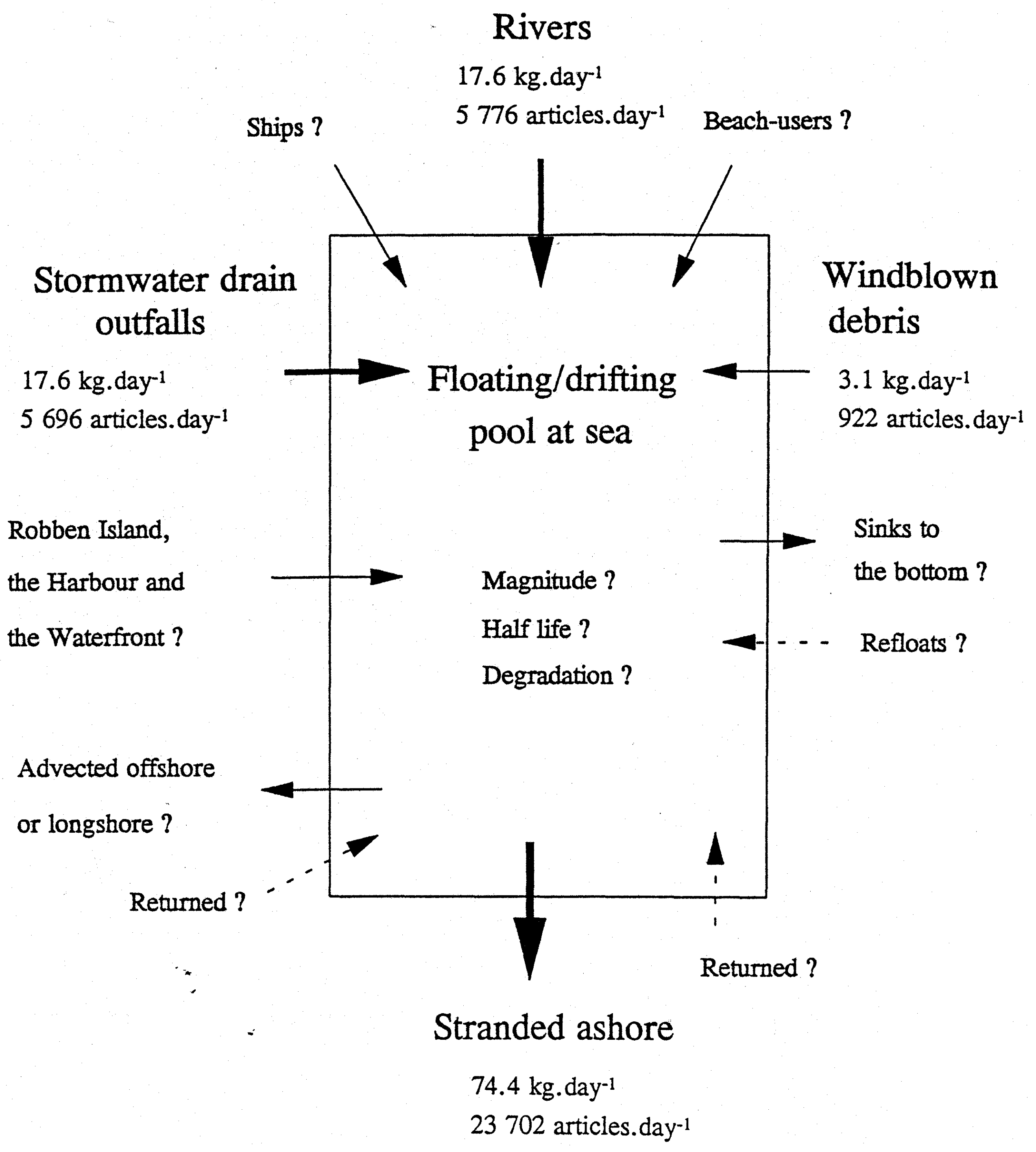

Fig. 1 Conceptual model of litter sources and sinks in Table Bay.

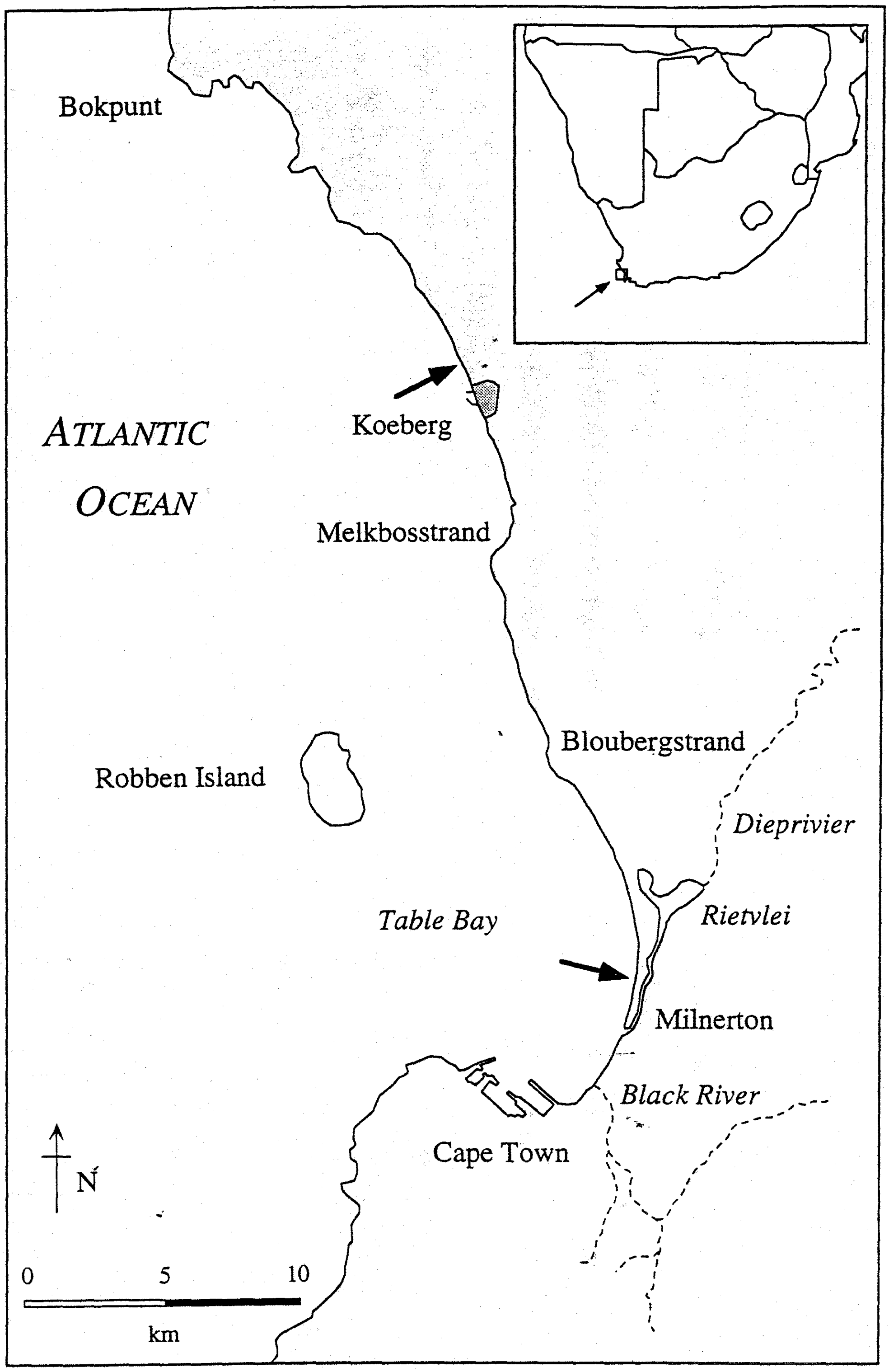

Fig. 2 Map showing Table Bay and study area.