Patterns of Debris Movement: From an Urban Estuary to a Coastal Embayment

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Introduction

Beach or shoreline surveys are the most common form of quantifying human generated debris. They reveal a lot about the amounts and types of persistent wastes that end up in these environments, however, the movement and specific source of these items have not commonly been categorically defined. Sourcing debris items has been difficult due to their mobile nature (Williams and Simmons 1999) and usually left to an individual's discretion. Some items can easily be identified and sourced (e.g. fishing nets), other items are reliant on weight of evidence to determine where they originated. Statistical techniques and modelling have shown some success in determining sources (Kubota 1994; Belas *et al*. 2001; Tudor *et al*. 2002) but are reliant on background studies or site specific testing to verify results.

Water–based surveys of floating debris provide valuable information on distribution patterns and extent of movement of these types of items (Moore *et al*. 2001) but the residence times and individual patterns of movement cannot be examined by this method alone. One approach that goes some way to answering these issues is through tagging studies. This has been applied to selected items on coastal beaches (Bowman *et al*. 1998; Johnson & Eiler 1999; Williams and Tudor 2001) but does not target the main source of coastal debris, particularly in urban areas, the rivers. Bulk movement patterns of selected riverine litter have been detailed by Williams and Simmons (1997), however there have been few studies looking at individual movement patterns of a range of debris types from river/estuary sources. To this end, tracking of debris from a potential source to an end destination was undertaken along the Cooks River and in Botany Bay, Sydney. The importance of tidal movement, riparian vegetation and rainfall is highlighted.

Methods

The study area was the Cooks River, a heavily urbanised river in Sydney, Australia (Fig. 1). The main river channel is approximately 15 kilometres long and tidal for approximately 11 kilometres. There are also a number of smaller creeks that feed into the Cooks River. The river has a history of high levels of pollution, draining residential, commercial and industrial areas. The river has been progressively channelised with concrete, iron or rock walls since the 1940s. Over this time sediment has built up and mangroves have colonised the upper and middle reaches of the brackish parts. The river flows out into Botany Bay, a major port facility for Sydney but also contains important wetlands and fisheries stocks.

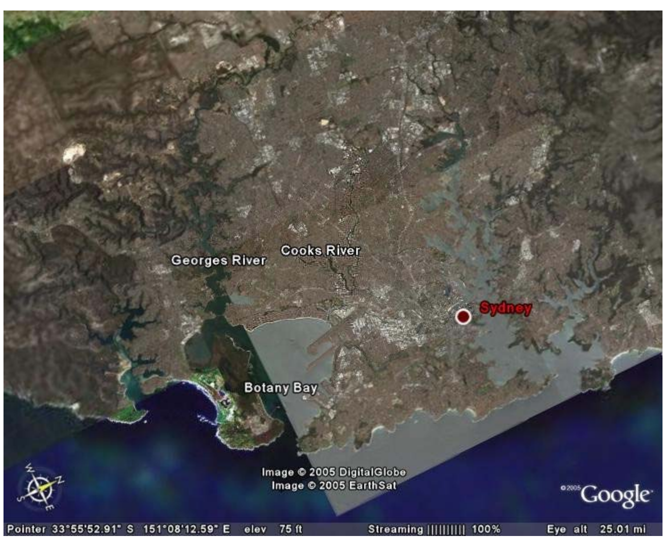

Figure 1: Cooks River and Botany Bay Location Map

The experimental design involved a repeated three-week tag/release study, whereby items were monitored during this period for recovery rates and patterns of movement. The two tests conducted were separated by a two week period. Selected items included: plastics (bottle - 600 ml; kitchen tidy bag - 50 x 75 cm; cigarette butt; ear bud piping; polystyrene block – 9 x 9 x 2.5 cm; confectionary wrapper – 18 x 12 cm), glass (bottle - 375 ml), metal (aluminium can – 375 ml), rubber (balloon – 8 cm long) and wood (ice cream stick – 10 cm long). Each experiment was colour coded with fluorescent paint and individually numbered 1 to 30 for each item type. Items were selected based on their common presence in the river system. All items were released approximately 10 km from the river mouth directly into the water column on an outgoing tide.

Selected tidal portions of the river shoreline and waterway were searched at low tide for tagged items every 72 - 96 hours for three weeks. Intermittent searching of bay beaches was also carried out. Items located during this time were logged with a GPS and left until the end of the experiment. All items relocated during the experiment were mapped revealing pathways of movement and residence times along the river.

A background survey of shoreline debris was also conducted during the study to aid in the understanding of accumulation rates. Three 10 m x 5 m strand line belt transects were taken at selected sites along the river every five weeks. All litter, excluding tagged items, was collected at each survey time and categorised. The initial collection time was discounted from any sample time comparisons because of residual debris loads.

Results

The overall recovery rates of tagged litter declined for the first half of both Tests 1 and 2, dropping below 40% after 4 days, below 30% after 7 days and below 15% after 11 days. The rates remained around this level for the rest of the experiment. The most recovered individual items were plastic bags, plastic bottles and polystyrene blocks (Fig. 2). Test 1 recovery rates for these items ranged between 17 - 30% by Day 21. Test 2 recoveries were generally higher with between 33 – 57% recovery of those aforementioned items. Other items with moderate recovery rates were glass bottles and aluminium cans.

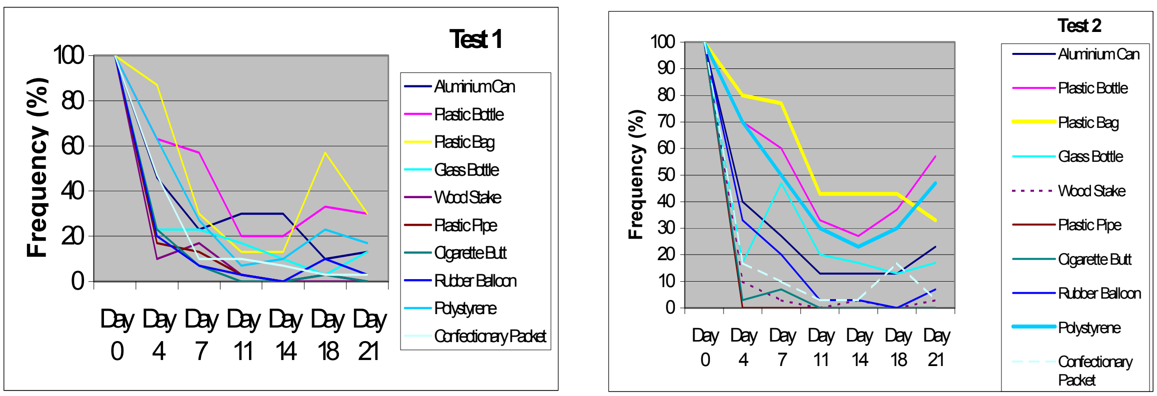

Figure 2: Recovery of tagged litter items from Tests 1 & 2 over 21days

Sites closer to the release point (up to 2.5 km downstream) had higher proportions of debris in the first 0 – 11 days for Test 1 (Fig. 3). This trend persisted for a longer period in Test 2. A higher proportion of debris was seen to shift to the mid river reaches in the latter stages of the tests. In particular the Beaman Park site (3.5 – 4.2 km downstream from release point) had accumulated close to 60% of all tagged items found on Days 18 and 21 in Test 1. There were few items found at the lower river sites during both tests.

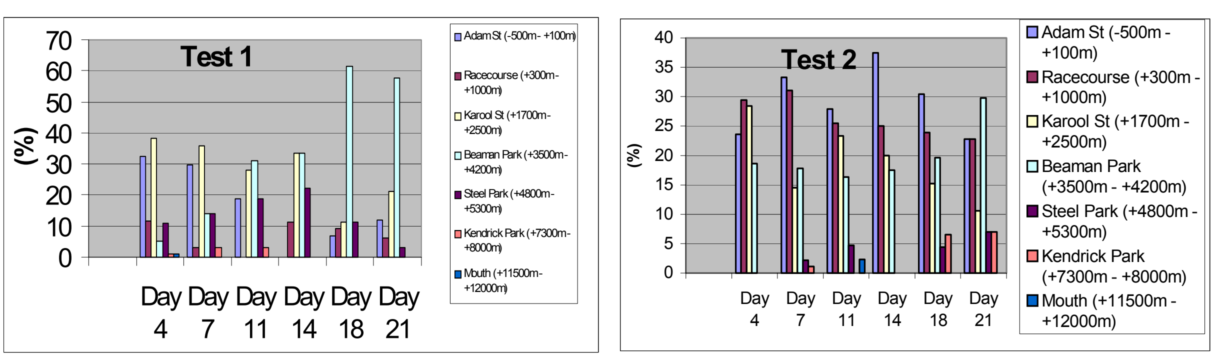

Figure 3: Frequency of tagged litter items per site over 21 days for Test 1 & 2

The trends in the mean distance moved for litter items revealed that the large solid floatable items (plastic bottles, polystyrene, aluminium cans) moved consistently down river to between 3 – 3.5 km after 21 days (Fig. 4). Plastic bags appeared to move downstream in Test 1 but were relatively static for Test 2. Confectionery wrappers were very mobile over the sample period. Glass and rubber varied in their patterns of movement between tests. Other items were not sufficiently recovered to accurately determine movement patterns. Individual items were tracked during the course of the tests. Examples of the variable patterns in movement are illustrated in Figures 5-8.

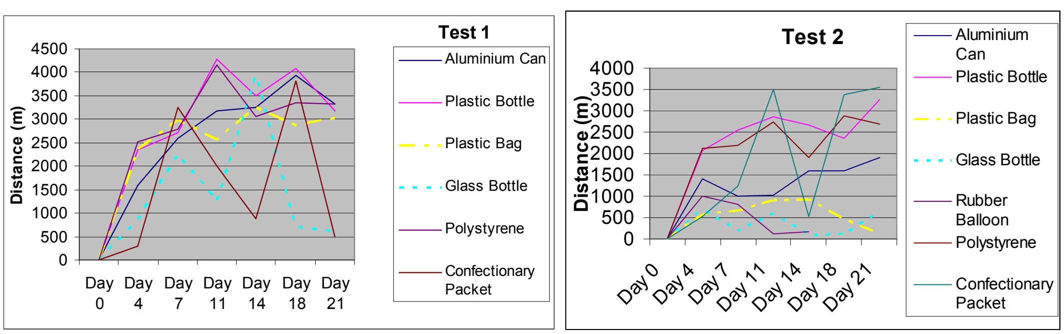

Figure 4: Mean distance moved for tagged litter items from two tests over 21 days

Figure 5: Tracking of Plastic Bag 27 (Test 2)

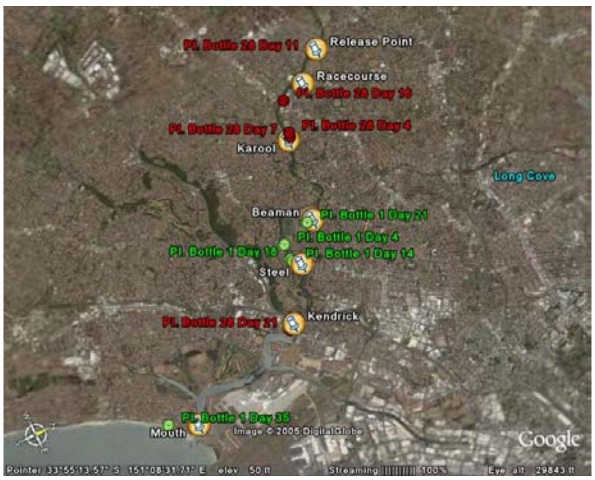

Figure 6: Tracking of Plastic Bottle 1 (Test 1) and Plastic Bottle 28 (Test 2)

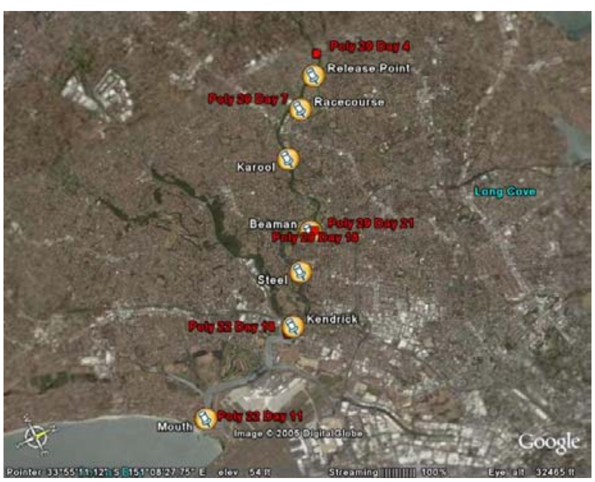

Figure 7: Tracking of Polystyrene 22 & 29 (Test 2)

Figure 8: Tracking of Glass Bottle 18 (Test 1) and Glass Bottle 15 (Test 2)

The background shoreline survey revealed that plastics were the most common item, making up over 80% of all items found at each site. The greatest contributors were hard plastics, polystyrene or sheet plastic which varied with site (Figure 9). The litter items found at the Mouth had the greatest difference to the other sites with a higher proportion of cigarette butts (sheet plastic) and fishing line or rope. Glass, metal and paper/wood was also present in considerable amounts. At all sites except Adam St., there was proportionally less debris over the subsequent samples. The Adam St. site remained relatively stable in debris amounts during the time of study and still had less litter overall than the other sites.

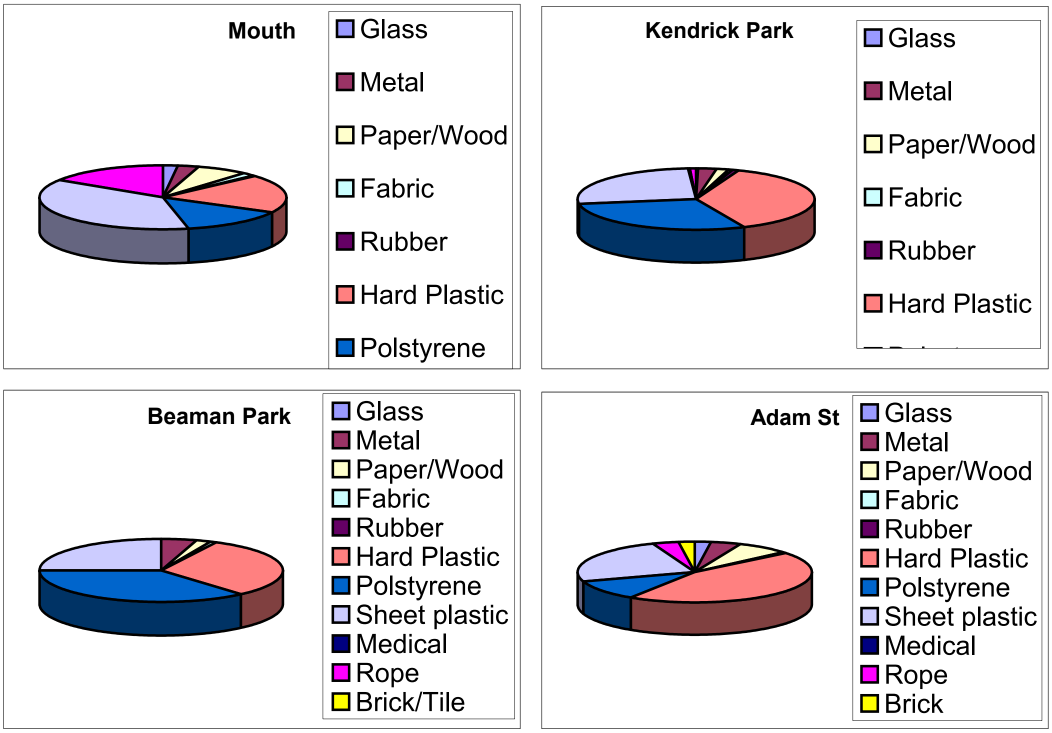

Figure 9: Proportional shoreline litter data per Cooks River sites

Discussion

The tagging experiment revealed that the larger, more visible items (bottle, cans, bags) were recovered more often than the smaller items (butts, piping, stakes). This trend is more than likely due to the burial of these smaller items in the other refuse and leaf matter that accumulated along with the tagged items. Williams and Tudor (2001) found similar trends on a cobble beach, where smaller fragments were lost from the surface between the spaces in the cobbles.

The trend over time saw a considerable drop in numbers of tagged items and for Test 2 a slight increase in recovered items over the last two sample periods. The trend for Test 2 was highly correlated (Pearson's Correlation 0.95, $P < 0.05$) with rainfall figures for the region. High rainfall (67-98 mm) between Days 11 and 14 was seen to be related to depressed recovery rates during this time. The higher water level makes spotting of debris more difficult. Flood events are also responsible for increases in litter accumulation in the days following such events (Williams and Simmons 1997). Test 1 was conducted during a period of low rainfall and no trends were apparent. Further testing of this model is required.

There was an obvious trend in Test 1 of net movement over time of items downstream from the release point. The majority of items stayed within the first 2.5 kms up to at least Day 11 and then moved to the middle reaches. Tides may play a part in the general patterns of debris movement and may help to explain the slow movement downstream. At high tide most items were re-suspended but because of the small tidal ranges evident in this region (0.7 -1.8 m) their movement was minimal. Tracking of individual items revealed an upstream/downstream movement of some items before being flushed down stream further (see Fig. 6). The importance of the mangrove vegetation in holding these items in place should also be highlighted. In Test 2 there was still over 50% residence of items in the upper reaches until Day 18. The mangrove systems with numerous pneumatophores along these shores played a role in halting downstream movement. A similar trend was found by Williams and Simmons (1997) with riparian vegetation along riverine watercourses. The eventual shift in Test 2 items could be related to the rainfall pattern described in the previous paragraph. These factors may all play a role in the movement patterns found and along with the relative short time of the tests might be a reason why few items reached the lower reaches. As there were fewer vegetated areas in the lower parts of the Cooks River what items that did make it to these parts would be quickly flushed into Botany Bay. The bay beaches recording a 10% recovery of plastic bottles were evidence for this.

An analysis of movement patterns of individual items revealed that the more buoyant objects (plastic bottles, polystyrene, aluminium cans) moved on average greater distances downstream than the other items over both test periods. Variable patterns of movement within a test were found for some items. These can be attributed to dispersion characteristics of an item, the physical nature of the site (eg. depositional zones, vertical walls), losses from the system or erratic recovery rates. To highlight the last point the mean distance that balloons had moved by Day 11 in Test 1 was approximately 5 kms, (this however was based upon one recovered item) but by Day 18 the mean distance was less than 1.5 kms (based on three items). Plastic bags followed the trend of the larger floatables in Test 1 but were found to reside in the upper reaches more so in Test 2, when items became stranded in the mangroves. There was however a significant correlation (Pearson's Correlation 0.82, $P < 0.05$) with bag movement and rainfall. Other items such as glass bottles and balloons also followed this Test 2 trend but there were however no other correlations.

The background shoreline survey revealed plastics to be the most prevalent type of debris. These levels corresponded to proportions of debris found in surveys undertaken on coastal beaches of the Sydney region (Cunningham and Wilson 2003) and highlight the importance of rivers as sources of debris to the nearshore coastal environment. Variations between sites in types of debris related to the site characteristics or activities carried out there. For example fishing activities were relatively high at the Mouth and so there was an increased abundance of line and rope as well as cigarette butts. The sampling and clearance of litter over time revealed a decrease in accumulated debris at three sites. The regular cleaning of these middle and lower reach sites may go some way in improving the aesthetics of the area. Adam St. in the upper reaches was the exception. The description of the patterns of movement from the tagging experiment may help in understanding the accumulation of debris at all these sites.

Conclusions

The tracking of individual items over the short term has revealed the varied nature in debris movement. A generalisation of patterns of movement based on few samples or indicator items can be misleading. Testing using large sample sizes and a suite of items will provide a more indicative account of litter residence times and therefore allow more accurate management decisions. The influence of site characteristics such as vegetation, tidal ranges and rainfall events have been highlighted in this study. A prolonged tagging study using radio transmitters may aid in further understanding the processes involved in litter movement.

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