Water Qual. Res. J. Canada, 2006 • Volume 41, No. 3, 256–262

Accumulation of Marine Debris on an Intertidal Beach in an Urban Park (Halifax Harbour, Nova Scotia)

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This study evaluated monthly accumulation rates and types of marine debris washed ashore at a recreational beach in Point Pleasant Park, Halifax Harbour, between April and September 2005. Black Rock Beach is 70 m long and a total of 2129 marine debris items were collected and sorted, representing a mean accumulation rate of 355 (±68 SE) items month^{-1}. The total weight of debris items was only 10.8 kg (mean 2 kg ±0.4 SE), however eighty-six percent of this debris was plastic material. The types of litter found included: tampon applicators, condoms (i.e., sewage-related debris [SRD]); plastic fast food packaging, confectionary wrappers, Styrofoam fragments, plastic bottles and caps, items of clothing, soft drink cans, cigarettes and cigarette holders (i.e., recreational or land-based debris); packing bands, nylon rope and nets (i.e., shipping- or fishing-related debris). These items were generated by recreational use of the park (52%), sewage disposal (14%) and from shipping and fishing activities (7%). It is suggested that a significant reduction in marine debris at recreational beaches may arise by improving public awareness of the environmental and aesthetic impacts of marine litter and future improvements to the municipal sewage disposal system.

Key words: **Nova Scotia, marine debris, plastic debris, sewage disposal, public beaches**

Introduction

Marine debris is defined as any item appearing on beaches or at sea, as a result of anthropogenic activities and may be categorized according to material type (e.g., plastics, sanitary, Styrofoam), derived from four main sources: recreational litter, fishing debris, sewage-related debris (SRD) and shipping waste (Marine Conservation Society 2002; Somerville et al. 2003). Marine debris is not only confined to densely populated coastlines, for example, remote islands in the Southern Ocean are also subject to similar levels of accumulation (Ryan and Watkins 1988; Walker et al. 1997; Convey et al. 2002; Otley and Ingham 2003). The impacts of marine litter on marine mammals and birds, caused by entanglements and ingestion, are well documented in the literature (Ryan et al. 1988; Ashford et al. 1995; Robards et al. 1995; Huin and Croxall 1996; Walker and Taylor 1996). Sea-borne plastic debris also poses threats to global biodiversity through transport and distribution of floating biota and the subsequent colonization of alien marine organisms (Barnes 2002). Derraik (2002) recently conducted an extensive literature review on pollution of the marine environment by plastic litter and concluded that marine debris is an increasing worldwide problem that causes impacts on coastal economic activity through aesthetic degradation. The aesthetic degradation (and potential health risks associated with SRD, medical, military and industrial wastes) of beaches by marine litter results in lost revenue from tourism, and local authorities are then faced with clean up costs in order to attract visitors (Roehl and Ditton 1993; Ballance et al. 2000; Silva-Iñiguez and Fischer 2003; Somerville et al. 2003).

Halifax Harbour has been the dumping site for sewage waste for over 250 years, with 220,000 people discharging 55 million m^3 of raw sewage into the harbour annually through 100 municipal and industrial outfalls, contributing significantly to organic and nutrient loading, anoxia and pollution of sediments (Petrie and Yeats 1990; Dalziel et al. 1991). Some surface sediments near sewage outfalls are entirely devoid of oxygen and laced with heavy metals such as mercury and organic contaminants such as petroleum hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) (Hellou et al. 2002, 2003). The harvesting of clams and mussels in the entire harbour area has been permanently closed since 1965 owing to bacteriological contamination (Wristen 1999). Beaches on the harbour and Northwest Arm are usually closed to swimming in the summer because of bacterial contamination, and in certain areas of the harbour, bacterial and viral concentrations are high enough to cause problems for swimmers and scuba divers. Odours and floating debris, such as condoms and tampon applicators, also cause aesthetic concerns for sailors, rowers and canoeists. With projected growth in sewage flows, the aesthetic problems of the harbour water and shoreline will most likely increase. As the present poor

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aesthetic quality of the water already interferes with tourists' enjoyment, additional sewage pollution may well have adverse repercussions for the future of this prosperous industry; tourism is one of the prime industries in Nova Scotia (Wilson 2000). While contamination of the harbour water and sediments by chemical pollutants is no longer disputed, much less is known about the adverse short- and long-term effects of marine debris (Ross et al. 1991). The Halifax Port Authority prohibits the disposal of plastic, glass and metal objects and Canada is a signatory to the 1978 Protocol to the International Convention for the Prevention of Pollution from Ships (MARPOL), although this legislation is largely ignored worldwide (Derraik 2002). Halifax Harbour is a thriving port with numerous cargo ships, an Atlantic Naval fleet, cruise ships and seasonal fishing activities (DFO 2005). In the Southern Ocean the fishing industry has been shown to be one of the primary sources of marine debris, particularly at sites with adjacent fishing grounds (Ryan and Watkins 1988; Walker et al. 1997; Otley and Ingham 2003).

Beach surveys are the most widely used method for monitoring the amount and type of debris accumulating in a specific area with time (Ribic 1998) and numerous methods are employed to survey beach litter, making the comparison of studies difficult (Velander and Mocogni 1999). Previous surveys around Nova Scotia found sources of marine debris to comprise mainly of plastic items in Halifax Harbour (Ross et al. 1991) and Sable Island (Lucas 1992). The objectives of this study were to classify and evaluate the different sorts of marine debris present on Black Rock Beach, Point Pleasant Park in Halifax Harbour, during the high season (April to September 2005) and to determine whether there have been any changes in waste disposal practices in the harbour since the survey by Ross et al. (1991). In addition, we looked at relative exposure of the beach with respect to accumulation under different wind conditions.

Materials and Methods

Study Area

Black Rock Beach (44°37'455N, 63°33'864W) is one of the only beaches suitable for monitoring debris in Point Pleasant Park, Halifax, Nova Scotia (Fig. 1). The beach is 70 m long, composed mainly of a mixture of sand with some boulders and shingle on a 10 to 20 degree slope facing northeast at the eastern side of the park, with prevailing winds from the south or southwest in summer with an average speed of 10 to 15 km h^{-1}. Wind data for 2005 was gathered by Environment Canada (2005). The park lies on a rocky, 75-hectare peninsula jutting into the Atlantic Ocean at the eastern end of Halifax Harbour, and has been a place of recreation since the founding of the city. It continues to attract locals and tourists, especially during the summer months. There is no motorized traffic other than maintenance vehicles, but the park is heavily used by pedestrians and cyclists since it is the only significant parkland on the Halifax peninsula.

Survey Methods

The study began in March 2005, when all debris accumulated since the previous summer was collected and removed, then continued monthly from April until September. The beach was surveyed three times on each occasion during low tide, taking care to cover from just above the high water mark to the low water mark. All debris, excluding driftwood and timber products, was weighed, classified and sorted into seven main categories: plastics, paper/cardboard, rubber, cloth, Styrofoam, metal and glass. The main sources of marine debris were also determined according to Ross et al. (1991) and were categorized as: recreational/land-based, shipping/fishing, sewage-related debris (SRD) and other miscellaneous items, which could not be classified. No surveys were undertaken during winter months due to difficulties in accessing the beach.

Beach Exposure

The appearance of material on a beach is a function of both availability of debris and the likelihood of accumulation due to wind and wave conditions. We used a relative exposure index (REI) as an indicator of possible forcing of debris accumulation, and it provides a useful summary of the wind (Rodil and Lastra 2004). Only four wind directions between north to east (0–90°) were analyzed, based on the orientation of the beach. Using a method modified from Shafer and Streever (2000), an REI was calculated for Black Rock Beach (equation 1):

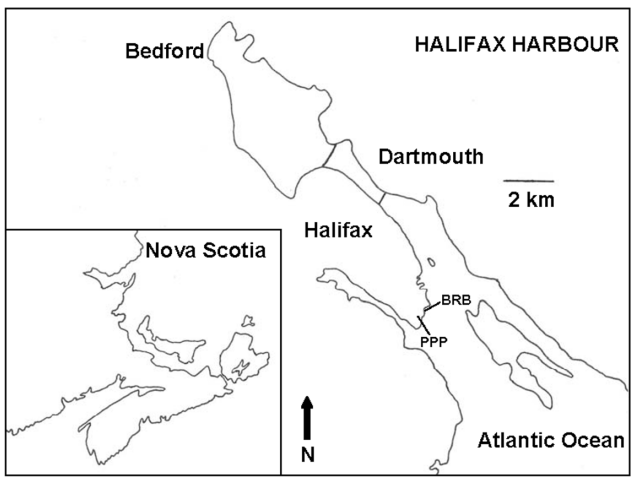

Fig. 1. Map showing location of the study site at Black Rock Beach (BRB) in Point Pleasant Park (PPP), Halifax Harbour.

$$REI = \sum_{i=1}^{4} \frac{\left(V_i P_i F_i\right)}{100} \quad (1)$$

where V_i is the mean monthly wind speed (km h^{-1}) for wind directions 0 to 90° categorized as N (0–20°), NNE (20–50°), ENE (50–80°) and E (80–90°); F_i is the fetch distance (km) and P_i is the percent frequency from which the wind blew within each category.

Mean monthly wind speed and directional frequency was calculated using 2005 data collected by Environment Canada (2005) at a weather station on McNabs Island (2 km away).

Results

Debris Accumulation

A total of 2129 persistent marine debris items were collected and sorted over a six-month period from April to September 2005. This represents a mean accumulation rate of 355 (±68 SE) items $month^{-1}$. The total weight of debris items was 10.8 kg, with a mean weight of 2 kg (±0.4 SE). Eighty-six percent of this total debris was low-density plastic material, which accounts for the low total weight. The types of litter found included: tampon applicators, contraceptive pill containers, condoms (i.e., sewage-related debris [SRD]); paper coffee mugs, drinking straws, plastic Styrofoam fragments, plastic spoons, plastic bottles and bottle caps, items of clothing, plastic nets, soft drink cans, confectionary wrappers, items of clothing, cigarettes and cigarette holders (i.e., recreational or land-based debris); packing bands, nylon rope and nets (i.e., shipping- or fishing-related debris).

Sources of debris are shown in Fig. 2A. Recreational or land-based debris represented the majority of items (52%), followed by other unclassified debris at 28%, and sewage-related debris (14%). The proportion and types of items collected are shown in Fig. 2B, with plastic items (86%) dominating. Other types of litter contributed very little to the overall composition. A single glass bottle, representing <0.1% of the total debris collected was not illustrated in Fig. 2B. These items were generated by various activities, which were dominated particularly by the recreational use of Point Pleasant Park and from municipal sewage disposal. Marine litter from shipping and fishing activities were also present, although were less abundant than items from terrestrial sources (7%).

The proportion (%) of litter by origin each month at Black Rock Beach is highly seasonal (Fig. 3), with the exception of SRD, which varies only between 8 to 22%. Visitors to the park increase throughout the summer months and this is reflected in the proportion of recreational or land-based debris which accumulates. Months of higher debris accumulation rates were not correlated with increased numbers of cruise ships visiting Halifax Harbour during the same month, with significantly less debris actually collected during the months of highest vessel numbers ($p = 0.016$) (Fig. 4). The highest accumulation rates occurred in May, while the lowest rates occurred in September. The mass of debris was weakly related to the number of items collected ($r^2 = 0.68$), except for September, when a single intact glass bottle was found adding significantly to that sample, despite there being fewer items collected (Fig. 4).

Relative Exposure Index

Black Rock Beach faces northeast, but the prevailing winds are from the south or southwest during summer (Fig. 5). During May the wind blew from the east for more than 170 h and the mean wind direction was from the northeast. Only April, May and June had significant winds blowing from the east or northeast and REI values were highest for these months. REI values for all four wind categories between north to east (0–90°) for April,

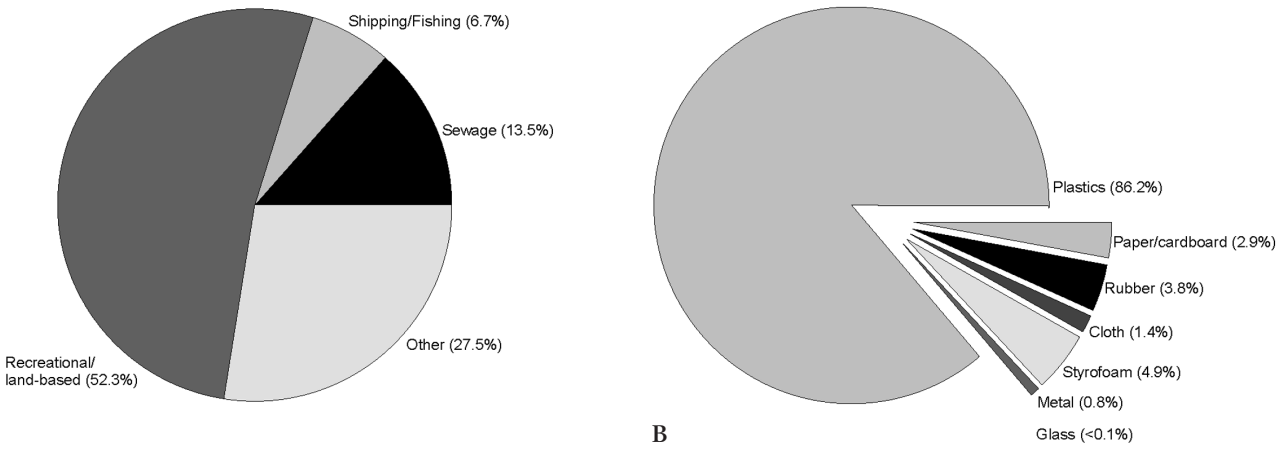

Fig. 2. (A) Sources of debris (%) and (B) proportion of debris (%) at Black Rock Beach, Halifax Harbour.

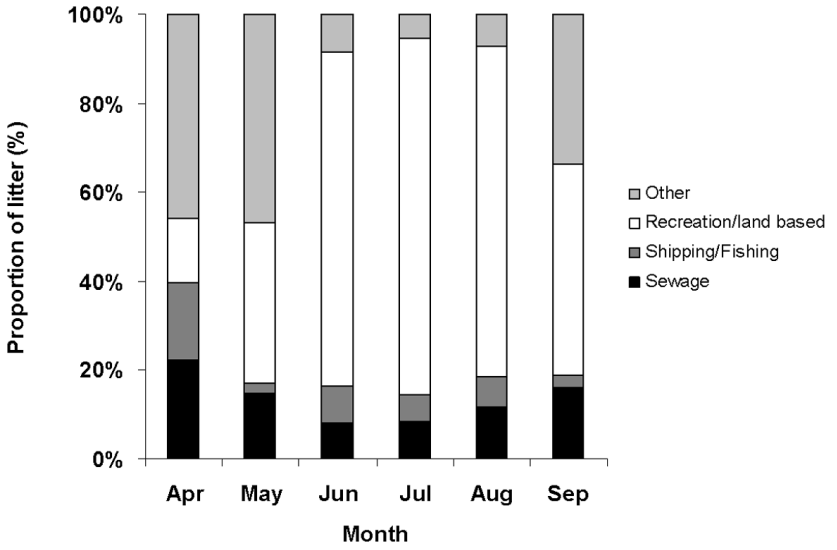

Fig. 3. Proportion (%) of litter by origin each month at Black Rock Beach.

May, June, July, August and September were 10, 25, 10, 2, 0.5 and 2, respectively. There was a strong correlation between REI and total number of debris items accumulating on Black Rock Beach for all months between April to September (p <0.05) (Fig. 6).

Discussion

There has been an increasing number of marine debris surveys around the world over the last two decades and they show that beach debris accumulation is a growing problem worldwide (Derraik 2002), causing pollution and aesthetic impacts on beaches (Somerville et al. 2003), loss of tourism revenue (Silva-Iñiguez and Fischer 2003) and threats to global biodiversity through invasions of alien species on plastic debris (Barnes 2002). The majority of debris in this survey comprised of plastic material (86%) and compares with other studies along the east coast of North America, where the majority of marine debris is plastic items (Table 1). Although plastic fragments will progressively disappear through degradation and oxidative ageing, they remain an unnecessary contaminant of beaches and provide evidence of persistent oceanic litter (Gregory 1983; Pruter 1987).

The most common items found were generated mainly by the recreational and land-based use of Point Pleasant Park and SRD from sewage disposal practices of the municipality. Surprisingly, marine litter from

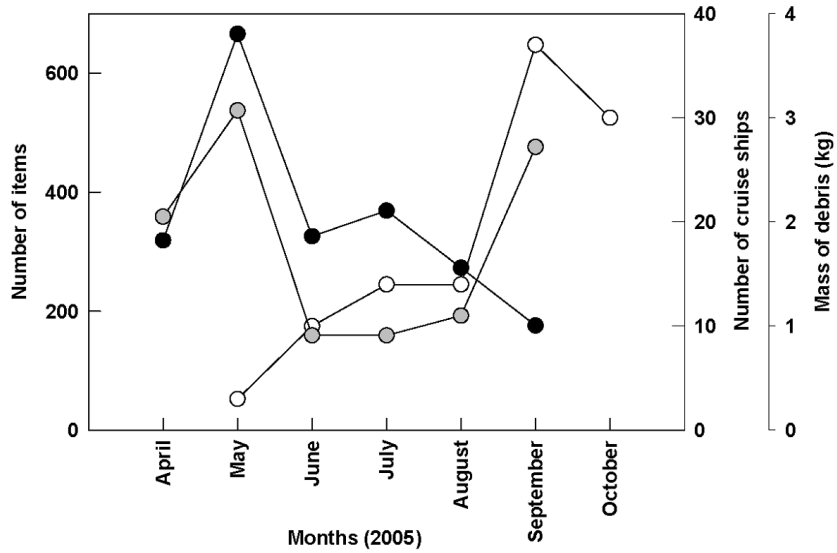

Fig. 4. Monthly comparison of numbers of cruise ships (○), total number of marine debris items (●) and mass of debris items (grey circles) accumulating on Black Rock Beach.

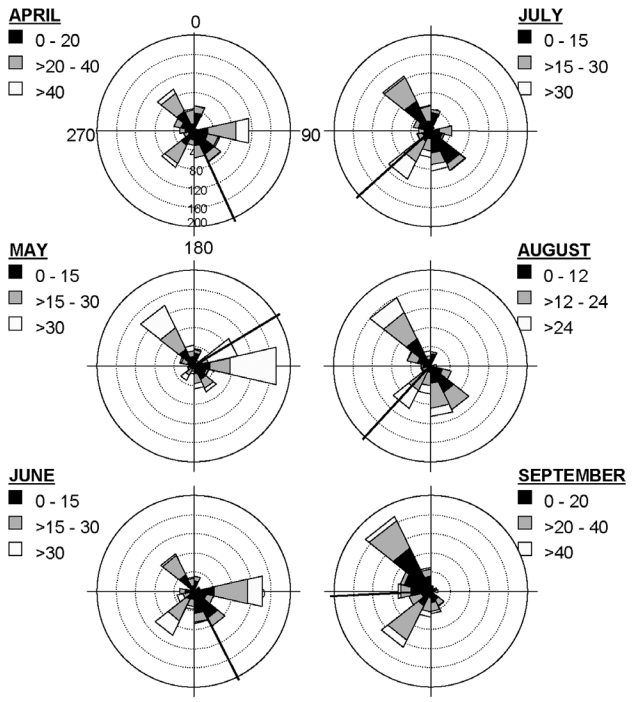

Fig. 5. Monthly stacked wind roses showing wind speed strength categories (km h^{-1}), and duration (h) from each direction for a weather station at McNabs Island. Single solid line indicates overall mean wind direction for each month. Data for 2005 was gathered by Environment Canada (2005).

shipping activities was low, despite industrial activity around the harbour, the presence of an extensive military fleet and the shipping activities of the busiest seaport in eastern Canada (Ross et al. 1991). In a previous study, Ross et al. (1991) showed that 62% of the total litter in Halifax Harbour originated from recreation and land-based sources, instead of the anticipated shipping activities of the seaport.

In contrast to other studies (Walker et al. 1997; Convey et al. 2002), an inverse relationship between the number of cruise ships in Halifax Harbour and the rate of accumulation at Black Rock Beach was observed. This result may reflect other seasonal factors such as current and wind speed, rather than the volume of shipping traffic in the harbour, although the actual relationship between the rates of disposal at sea and accumulation at Black Rock Beach remains unclear. Likewise, in a study by Otley and Ingham (2003) in the Falkland Islands, less debris was found, despite the presence of more vessels in the area. These results are encouraging as they indicate that despite the high volume of shipping traffic in the harbour, their contribution to the marine debris problem is small, suggesting that dumping of floating waste near or in the harbour, either intentionally or accidentally occurs infrequently. However, not all vessels adhere to MARPOL regulations, as a number of successful prosecutions against vessels dumping oil in the harbour by the Halifax Port Authority have taken place recently (DFO 2005).

Overall, the REI values were low and Black Rock Beach could be classified as relatively low-energy according to Shafer and Streever (2000). However, the REI value for May was highest at 25, which corresponded with the greatest number of debris items collected that month. During May the wind blew from the east for more than 170 h and the mean wind direction was from the northeast, precisely the orientation of the beach. Recreational litter during May comprised only 36%, as visitor numbers to the park during spring are low due to the inclement weather. Throughout the summer months visitor numbers to the park increase and this is reflected in the increasing proportion of recreational or land-based debris which accumulates. The fetch distances from the east or northeast that could transport debris onto the beach, are low due to close proximity of McNabs Island and Dartmouth on the opposite shore of the harbour. A possible explanation for the high numbers of debris items may be the strong easterlies during May which may contribute to longer residence times on the beach and the introduction of new material from offshore sources. The proportion of SRD during the summer shows no seasonality as sewage outflow from the city would be expected to remain fairly constant. Indeed, there are two sewage outflow pipes located within 2 km of the study site, e.g., located in the Northwest Arm and along the harbourfront in downtown.

The relatively high accumulation rate of debris on Black Rock Beach is, however, a cause for concern, as it indicates that recreational users of the park are the primary culprits, followed by the potentially hazardous wastes from SRDs, with Halifax continuing to use the harbour as a sewage dump. Other cities in Canada, such as Whistler, British Columbia, and Calgary, Alberta, have

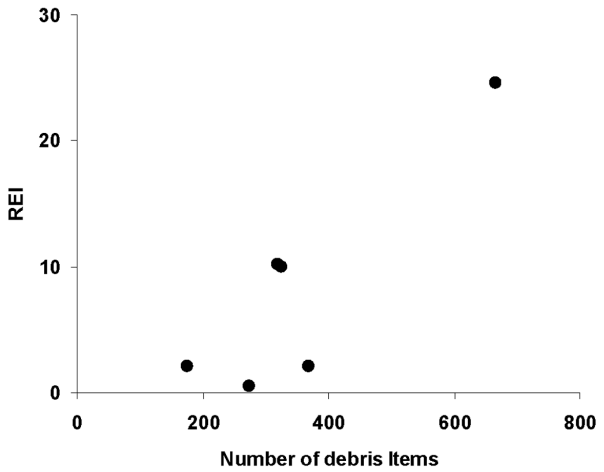

Fig. 6. Relationship between relative exposure index (REI) and total number of debris items accumulating on Black Rock Beach for all months between April to September (p <0.05).

TABLE 1. Proportion (%) of plastics (based on total number of items) in marine debris collected at different locations along the east coast of North America[a]

Location	*Type of litter survey*	*Percentage of debris items represented by plastics*	*Source*
Black Rock Beach, Halifax Harbour	Beach/harbour	86	This study
Sable Island, Nova Scotia, Canada	Beach	92	Lucas (1992)
National Parks in U.S.A.	Beach	88	Manski et al. (1991)
Cape Cod, U.S.A.	Beach/harbour	90	Ribic et al. (1997)
4 North Atlantic Harbours, U.S.A.	Harbour	73–92	Ribic et al. (1997)
Island Beach State Park, New Jersey, U.S.A.	Beach	73	Ribic (1998)
Halifax Harbour, Canada	Beach(es)	54	Ross et al. (1991)

[a]Adapted from Derraik (2002).

world-class tertiary sewage treatment plants that reduce sewage to clear effluent and compost that is safe enough to use as fertilizer (Wristen 1999; MacQueen 2005). For several decades Halifax Regional Municipality (HRM) has been discussing, planning and carrying out environmental impact assessments for providing a new sewage treatment facility for the city and finally, in 2003, officially signed agreements for the design, construction and commissioning of three new sewage treatment plants (STPs).

It is suggested that a significant reduction in marine debris at recreational beaches may arise from improved education of the public by local government and future improvements and upgrades to the HRM sewage disposal system that may eventually help attract a diversity of native marine species back into the harbour and reopening shellfish areas, that could produce up to $19 million in revenues (Wilson 2000). Currently, shellfish harvesting is closed in Halifax Harbour due to bacteriological contamination, resulting in lost revenues (Wristen 1999). The aesthetic improvements in the downtown waterfront area, the reopening of affected Halifax beaches, and projected increases in water-based tourism, including water tours and cruises, sailing, windsurfing and canoe rentals, will all boost metro tourism.

Recommendations

1. Improve public awareness of the environmental and aesthetic implications of careless disposal of recreational litter in public sites around Halifax Harbour and particularly in Point Pleasant Park by HRM.
2. Repeat surveys at Black Rock Beach during the summer season once construction of three new STPs is complete.

Acknowledgements

We acknowledge Art Sampson, HRM works supervisor at Point Pleasant Park, and Stewart MacMillan, HRM parkland planner, for permission to conduct this survey. We wish to thank Mary Kate Archibald for help with REI calculations.

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Received: December 14, 2005; accepted: May 8, 2006.