The role of resuspension in enterococci distribution in water at an urban beach

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Abstract This study investigated the process and effects of bacterial resuspension on microbiological water quality in a small urban embayment. Water and sediments were sampled for enterococci at a small urban bay, on both irregular and intensive time scales, with a focus on the potential sources of faecal contamination to the system. Distribution of enterococci in sediments was influenced by the location and microbiological quality of major sources of enterococci to the embayment. Stream and storm water contributed the greatest numbers of enterococci and, consequently, high numbers of enterococci were found in both water and sediments surrounding discharge points for these sources. To investigate bacterial resuspension, water samples were collected from within the surf zone (at water depths of 1–1.5 m) as a wave crest passed. Two samples were collected simultaneously at each sampling location at 10 cm above the seabed and 10 cm below the water surface. Samples were analysed for enterococci and data compared with bacterial numbers in adjacent sediments as well as in stream and storm water sources. Vertical distribution data for enterococci in the water column revealed evidence of spatial and temporal variability in bacterial resuspension and the role of wave action was demonstrated. Bacterial resuspension under waves was directly related to weather and wave conditions. The resuspension of enterococci was not detected beyond the surf zone suggesting that wave action was the main cause of resuspension at the study site.

Keywords Indicator bacteria; sediment; storm water; water quality; wave action

Introduction

Resuspension of microbial contaminants from near-shore marine sediments is one of the factors which may contribute to elevation of bacterial numbers in recreational water. Resuspension is a process whereby the layer of sediments that have settled to the seabed are entrained and transported upward into the water column for a period of time (Churchill et al., 1994). The process is usually cyclic as sediments are alternatively settled and resuspended. Past research has indicated that levels of indicator bacteria were higher in the shallow water close to shore compared with the deeper offshore zone (McBride et al., 1998). This is significant because contact recreation is most common in the shallow waters of the near-shore zone and greater numbers of immunologically susceptible people, such as young children, are exposed in this area of the beach. Aerosols are also created by the shoaling and breaking of waves in the near-shore zone and by the actions of humans (McBride et al., 1998). These aerosols can carry pathogens that may be inhaled by beach users. These factors together show that recreation in shallow waters poses a higher risk to swimmers from the intake of indicator bacteria and associated pathogens.

There are numerous possible sources of faecal bacteria to a beach system with streams and storm water draining developed catchments often contributing significant numbers of indicator bacteria. Rainfall has been shown to increase bacterial numbers in streams and storm water resulting in a corresponding increase in near-shore beach water. Some of the bacteria in the near-shore zone will settle into bed sediments either attached to sediment particles or as separate cells (Plummer et al., 1987). The resuspension of sediment from the seabed is a complex process caused by a variety of mechanisms such as wave action,
currents and human activity. Many studies have shown that the main mechanism for resuspension within most beach systems is the action of waves (Sleath, 1984; Schoellhamer, 1995; Beach and Sternberg, 1996); however, few studies have addressed this outside of estuarine environments. Wave action operates at all beaches but with varied levels of energy. Even waves at low energy beaches have the ability to resuspend sediments and associated material, including bacteria, particularly during periods of strong sustained winds (Schoellhamer, 1995; Komar, 1998). Such resuspension of bacteria by wave action would lead to increased bacterial levels in the water column where they may come into contact with human water users (Pommepuy et al., 1992; Irvine and Pettibone, 1993; Gillespie, 1999).

The purpose of this research was to assess the distribution and resuspension of the faecal indicator bacteria, enterococci, in a small urban beach system influenced by both stream and storm water. Source and distribution of bacteria in water and sediment samples were investigated for both fresh and marine components of the beach system. Resuspension was assessed by simultaneously sampling water close to the seabed and close to the water surface for multiple wave crests.

**Materials and methods**

**Study site description**

A small pocket beach located between two large, clifffed headlands on the east coast of the North Shore City, Auckland, New Zealand was chosen for the study. The bay has a U-shaped steep sided valley that is a completely developed urban area. A small, slow-flowing stream runs through the catchment and discharges to the beach along with a small local storm water drain. The beach is small, approximately 300 m wide, with about 100 m of sand exposed at low tide. The beach is a low-energy system, with small wave heights and a narrow surf zone under normal conditions. Microbiological data for the two years prior to the study showed that the median enterococci count was low (8 and 4.5 CFU/100 mL) with occasionally higher, unexplained results of up to 236 CFU/100 mL.

**Enumeration of enterococci**

Enterococci were enumerated from water, without dilution, using the standard membrane filter method with mE and EIA selective media (APHA, 1992). All counts were the result of three replicate analyses and were expressed as CFU/100 mL water. Sediment was diluted to an appropriate level (generally 1:8) using phosphate buffer plus magnesium (WHO, 1982). This mixture was agitated for 2 min in a sterile bag (Seward Stomacher 400 laboratory blender), left to stand for 5 min and the supernatant used for enterococci analysis as above. Enterococci numbers were calculated using the dilution factor and the sediment dry weight. Results were expressed as CFU/100 g dry weight (DW) sediment.

**Experimental equipment**

*Water sampling.* A special sampling device was designed to allow collection of two or more water samples simultaneously from different heights above the seabed. It consisted of a hand-operated bilge pump and two-way splitter attached to a wooden base. Sterile tubing (approximately 1 m) was fitted to the splitters and the intake end attached to a 1.5 m long sampling rod at appropriate heights for each sampling event. Sterile, 500 mL plastic bottles, for sample collection, were inserted into the tubing between the splitter and the intake as shown in Figure 1. The multiple intake water sampler was used to sample water from successive wave crests. The sampling rod was stabilised by inserting it vertically into sediments just beyond the wave break point. The tubing was aligned so that the open ends were facing into the direction of flow and heights were adjusted so that water was sampled...
from approximately 10 cm above the seabed and 10 cm below the water surface. The pump was then operated as successive wave crests passed the sampler until the sampling bottles were almost full. The samples were then stored at 4°C and transported to the laboratory for analysis within 6 h of collection.

**Sediment sampling.** Exposed sediment samples were collected from above the water line using sterile open-ended 50 mL syringes. These were used to scoop the top 3–5 cm layer of sediments from selected sampling sites. Samples were then aseptically transferred to sterile bags for transportation to the laboratory. Shallow water sediment samples (water depths of 0.2–1.0 m) were collected with 50 mL sterile syringes attached to a 2 m long aluminium pole that was used to scoop sediments into the open syringe. Sediments were sampled from beneath water at 1.0–2.5 m depth using a purpose-built scoop sampler. It consisted of an aluminium box, cut open at one end at a 45° angle, and welded to a 2.5 m long aluminium handle. The sampler was operated from a small boat and enabled sampling of sediments up to 120 m offshore from the low tide water level. The sampler was sterilised between samples by flaming with ethanol. Samples were taken using a slow scooping motion to remove a layer of sediment approximately 5–10 cm thick. The sampler was brought to the surface on an angle so that the top layer of fine, easily suspended particles was trapped in the sampler. The sediment was transferred from the scoop to a sterile bag for transportation.

**Results**

Overviews of the results of enterococci analysis of water and sediment obtained for this study (samples collected January–October, 1999) are shown in Figure 2.

The stream and, to a lesser extent, the storm water were shown to be a significant source of enterococci in the bay. High numbers of enterococci in stream water led to the elevation of these bacteria in receiving water surrounding the discharge zone. The average level of enterococci found in the stream receiving water (90–115 CFU/100 mL) was significantly
higher than in those sampling points away from major source inputs (14 CFU/100 mL) (Figure 2). Elevated enterococci numbers in seawater around source discharge areas were also reflected in sediment samples with the greatest enterococci load in sediments adjacent to the stream input (Figure 2).

Enterococci levels in water reduced as the distance from the source increased. Enterococci numbers in water sampled from approximately 120 m offshore from the mean low water level were <1 CFU/100 mL indicating that enterococci from stream and storm water were either effectively diluted in near shore water or were inactivated. Sediment enterococci numbers also reduced with increasing distance from the source but on most occasions were higher than in the paired water sample (Figure 2). These data suggested that deposition of bacteria was occurring and may have been an important mechanism for removal of bacteria from the water column.

Rainfall had significant impacts on enterococci levels in water and sediment at the bay. Following rainfall, elevated enterococci numbers were detected in the stream and storm water. After a short delay (approximately 2–3 h) enterococci numbers in receiving waters increased adjacent to the sources (data not shown). Elevated enterococci numbers in sediments were observed approximately 1 d after the rainfall event. Figure 3 illustrates the effect of rainfall on enterococci numbers in sediment over four consecutive days with periodic rainfall.

Bacterial resuspension from sediments by wave action was investigated in a number of sampling runs and sampling locations under different environmental conditions. Table 1 shows the results of analysis of the difference between enterococci numbers in near-bed and near-surface water samples from both the near-shore and offshore zones.

Statistical analysis showed that near-bed water samples contained significantly more enterococci than did near-surface water samples (Table 1). A statistically significant difference (P <0.05) was detected in 8/17 paired samples in the near-shore zone. In the offshore zone there were no significant differences between enterococci numbers in near-bed and near-surface samples. This observation may have been due to low sample numbers and low enterococci occurrence (<1 CFU/100 mL). These data demonstrated that wave action could cause bacterial resuspension from the sediments.
Discussion and conclusions

Elevated enterococci numbers in water and sediment surround the main inputs of water from the catchment (stream and storm water) into the bay and were clearly major sources of bacteria to the system. The results indicated that transportation of bacteria offshore appeared to be minimal, with the highest concentrations remaining around the source discharges. While there may have been some transportation along the shoreline to bays north and south of the study site, this appeared to be small and did not influence observations under the conditions studied.

Bacterial resuspension could be detected by analysing water samples collected simultaneously from near the seabed and water surface. Enterococci numbers in near-bed samples were often significantly higher than near-surface samples. This provided evidence to support the occurrence of bacterial resuspension under waves. Resuspension was not always detected in the near-shore zone of the beach. It may be that resuspension associated with wave action occurred almost continuously in this zone and, as such, the extent of and ability to detect resuspension may vary both spatially and temporally. When bacterial numbers were high in the water column (influenced mainly by locality to sources and weather patterns) then detecting resuspension was likely to be difficult because the relative difference in bacterial numbers between water and sediment was low. A similar discrimination problem may have occurred when bacterial numbers in sediment were low and, although bacteria may have been resuspended from the bed, there may not have been enough to cause measurable elevation in near-bed water. Sampling results suggested that resuspension did not occur to detectable levels beyond the surf zone. This was likely to be due to both the lack of wave interaction with bed sediments and low bacterial numbers in sediment in this zone.

Resuspension of enterococci from bed sediments can aid in the redistribution of bacteria throughout a beach system by the release of bacteria into the water column. Bacterial resuspension from sediments by wave action may, on some occasions, be sufficient to cause local health guidelines for water quality to be exceeded.

References


Table 1 P-values obtained from t-tests comparing enterococci numbers in near-surface and near-bed water samples at various sites and dates

<table>
<thead>
<tr>
<th>Sample date</th>
<th>P value for comparison of near-bed and near-surface water samples adjacent to:</th>
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<tr>
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<td>Stream discharge</td>
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<tr>
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<tr>
<td>30 Aug 99</td>
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<tr>
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</table>

(A P-value ≤0.05 is considered a significant difference. Empty cells indicate that samples were not collected. The result (labelled *) from the stream discharge site on 17 September, contained atypical colonies in the near surface water, which may have influenced the analysis.)


