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Effects of full-scale beach renovation on fecal indicator levels in shoreline sand and water

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ABSTRACT

Recolonization of enterococci, at a non-point source beach known to contain high background levels of bacteria, was studied after a full-scale beach renovation project. The renovation involved importation of new exogenous sand, in addition to infrastructure improvements. The study's objectives were to document changes in sand and water quality and to evaluate the relative contribution of different renovation activities towards these changes. These objectives were addressed: by measuring enterococci levels in the sand and fecal indicator bacteria levels (enterococci and fecal coliform) in the water, by documenting sediment characteristics (mineralogy and biofilm levels), and by estimating changes in observable enterococci loads. Analysis of enterococci levels on surface sand and within sediment depth cores were significantly higher prior to beach renovation (6.3–72 CFU/g for each sampling day) when compared to levels during and after beach renovation (0.8–12 CFU/g) ($P < 0.01$). During the renovation process, sand enterococci levels were frequently below detection limits (<0.1 CFU/g). For water, exceedances in the regulatory thresholds that would trigger a beach advisory decreased by 40% for enterococci and by 90% for fecal coliform. Factors that did not change significantly between pre- and post-renovation included the enterococci loads from animals (approx. 3×10^{11} CFU per month). Factors that were observed to change between pre- and post- renovation activities included: the composition of the beach sand (64% versus 98% quartz, and a significant decrease in biofilm levels) and loads from direct stormwater inputs (reduction of 3×10^{11} CFU per month). Overall, this study supports that beach renovation activities contributed to improved sand and water quality resulting in a 50% decrease of observable

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enterococci loads due to upgrades to the stormwater infrastructure. Of interest was that the change in the sand mineralogy also coincided with changes in biofilm levels. More work is needed to evaluate the relationships between beach sand mineralogy, biofilm characteristics, and the retention of fecal indicator bacteria in sand.

1. Introduction

Beach advisories are issued based upon microbial measures of the water at recreational beaches (U.S. EPA, 1986). Beach sand quality can potentially impact a beach's corresponding water quality (Byappanahalli and Fujioka, 2004; Yamahara et al., 2007; Beversdorf et al., 2007; Imamura et al., 2011; Phillips et al., 2011) and there is reason to believe that sand quality can have human health effects. Heaney et al. (2012) found an association between indicator microbe levels in sand and gastrointestinal (GI) illness and diarrhea among beach goers who dig or bury themselves in sand. An epidemiologic study conducted at Hobie Cat beach, the chosen site for this beach renovation study, showed a relationship between enterococci levels in water and skin illness, but no association with gastrointestinal illness (Fleisher et al., 2010; Sinigalliano et al., 2010; Abdelzaher et al., 2011). The primary source of the enterococci to the water column at this site is the shoreline sand, as evidenced through the numerous studies that have evaluated the spatial and temporal distribution of enterococci at this beach (Shibata et al., 2004; Wright et al., 2011; Enns et al., 2012; Feng et al., 2013). Moreover, the presence of enterococci in the sand has also correlated with pathogens (including yeast, helminthes, and pathogenic bacteria, Shah et al., 2011) further emphasizing the potential public health significance of sand fecal indicator bacteria levels.

A beach renovation project conducted at Hobie Cat Beach has provided the opportunity to evaluate the recolonization of enterococci in newly imported sand and subsequently the impact of a full-scale beach renovation on sand and water quality. Specifically the objectives of this study were to evaluate the impact of beach renovation on sand and water quality and to quantify the change in enterococci loads associated with the beach renovation activities. Although studies have described the impacts of beach renovation on shoreline animals (Steinitz et al., 1998; Grippo et al., 2007) and physical properties of the beach (Park et al., 2009; Bocamazo et al., 2011), this is the first study that documents the changes in sand and water bacterial quality in conjunction with beach renovation activities.

2. Materials and methods

2.1. Site description

Hobie Cat Beach is a 1.6 km strip of beach that consists of the coastal waters lining the Rickenbacker Causeway (Fig. S-1), which connects mainland Miami to Virginia Key (8.7 km distance). Its subtropical climate is characterized by an average ambient temperature of 24.8 °C, and annual average rainfall of 149 cm. Hobie Beach has relatively poor water circulation due to its shallow depth and location within a cove (Zhu et al., 2011). Hobie experiences no point sources of pollution such as sewage outfalls, failing lift stations, cross-connections of sewage with storm drains, or less obvious non-point sources such as septic tanks (Shibata et al., 2004). Primary non-point sources of contamination include humans, birds, and pets, especially dogs, with their major impact previously observed on the sand closest to the shore (Wright et al., 2009). Despite the fact that animals are allowed, dog owners are not required to pick up the dog waste. Hobie has been the site for multiple indicator bacteria studies due to its history of high enterococci levels and beach advisories (e.g., Shibata et al., 2010; Fleisher et al., 2010; Sinigalliano et al., 2010; Abdelzaher et al., 2010). Although usually in compliance with regulatory monitoring criteria, the beach has exceeded the EPA Poor Water Quality Guideline of 104 colony forming units (CFU) per 100 ml approximately 7% of the time on average from 2000 to 2011 (FDOH, 2012). Hobie Cat Beach has been known to have high levels of enterococci in the inter-tidal zone, below the seaweed line (20 ± 10 CFU/g of dry sand), and in the supra-tidal zone, above the seaweed line (300 ± 159 CFU/g of dry sand) (Wright et al., 2011). Fecal coliform has also been documented in the sand within the inter-tidal (8.4 CFU/g dry sand) and supra-tidal zones (1400 CFU/g dry sand) (Shah et al., 2011). Thus the sand at this site (ultimately receiving diffuse bacteria inputs from dogs, humans, and birds) is believed to represent the major source of fecal indicator bacteria to the water column (Wright et al., 2011). Local wind waves occurring at high tides can release a significant amount of enterococci from the sand and potentially cause water quality exceedances (Feng et al., 2013).

2.1.1. Pre-renovation

Hobie Cat Beach is located immediately adjacent to the southwest side of the Rickenbacker Causeway with a parallel local-access paved road (6 m wide) just 13 m from the mean high tide line. Before renovation, the sand above the high tide line was characterized by sparse patches of grass with an increasing gradient of grass density towards the local-access paved road. The lack of designated parking for visitors led to vehicles being parked over the sand/grass on either side of the local-access paved road, with a preference of parking towards the shore side, which lies within a few meters of the intertidal zone (Fig. S-2). Prior to renovation, Hobie Cat Beach had no storm water management infrastructure causing rain runoff to flow from the paved access road directly to the beach through natural ditches that would form after storm events. Trash cans were placed on both sides of the access road with one line of trash bins as close as 5 m to the shore, allowing for rainwater coming in direct contact with the waste to flow into the natural drainage ditches.