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Wildlife, urban inputs, and landscape configuration are responsible for degraded swimming water quality at an embayed beach

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A B S T R A C T

Jeorse Park Beach, on southern Lake Michigan, experiences frequent closures due to high *Escherichia coli* (*E. coli*) levels since regular monitoring was implemented in 2005. During the summer of 2010, contaminant source tracking techniques, such as the conventional microbial and physical surveys and hydrodynamic models, were used to determine the reasons for poor water quality at Jeorse Park. Fecal indicator bacteria (*E. coli*, enterococci) were high throughout the season, with densities ranging from 12–2419 (culturable *E. coli*) and 1–2550 and <1–5831 (culturable and qPCR enterococci, respectively). Genetic markers for human (*Bacteroides* HF183) and gull (*Catellicoccus marimammalium*) fecal contamination were found in 15% and 37% of the samples indicating multiple sources contributing to poor water quality. Nesting colonies of double-crested cormorants (*Phalacrocorax auritus*) have steadily increased since 2005, coinciding with high *E. coli* levels. A hydrodynamic model indicated that limited circulation allows bacteria entering the embayed area to be retained in nearshore areas; and bacterial resuspension from sand and stranded beach wrack during storm events compounds the problem. The integration of hydrodynamics, expanded use of chemical and biological markers, as well as more complex statistical multivariate techniques can improve microbial source tracking, informing management actions to improve recreational water quality. Alterations to embayed structures to improve circulation and reduce nuisance algae as well as growing native plants to retain sand to improve beach morphometry are among some of the restoration strategies under consideration in ongoing multi-agency collaborations.

Introduction

With increased interest and research in recreational water quality over the last few decades (Nevers et al., 2014; U.S. EPA, 1999; WHO, 2003), new insights on the nature of fecal indicator bacteria (FIB) ecology have been developed, primarily focusing on their environmental occurrence and sources, persistence, transport, and population flux in response to biotic and abiotic factors. Extensive research has shown that populations of FIB can survive and grow in a variety of environmental substrates that may then act as a source of FIB to beach water. A few specific examples include (a) riparian systems (soil, sediment, streams) (Bermudez and Hazen, 1988; Byappanahalli et al., 2003; Hardina and Fujioka, 1991; Ishii et al., 2006; Solo-Gabriele et al., 2000), (b) beachshed (sand, sediments, birds, algae) (Alderisio and DeLuca, 1999; Ginsberg et al., 1994; Levesque et al., 1993; Whitman and Nevers, 2003; Whitman et al., 2003) and (c) runoff and river outfalls (Dwight et al., 2002; Nevers and Whitman, 2005; Roll and Fujioka, 1997). Additional sources often include wildlife, river point sources, storm water runoff, or resuspension of previous contamination (Nevers et al., 2014; Whitman et al., 2011). Once these bacteria enter the nearshore water, they are influenced by hydrodynamic forces that result in highly variable distribution, both spatial and temporal, and their survival is affected by ambient factors, such as solar radiation (Boehm et al., 2002; Enns et al., 2012; Ge et al., 2012b; Liu et al., 2006).

These intrinsic and extrinsic biological and physical factors together influence the net bacterial (FIB) densities at a given beach, suggesting that knowing the initial contamination source alone may not be sufficient to eliminate the bacterial problem. Because contamination from anthropogenic sources (e.g., sewage, wastes from domesticated animals) poses the greatest threat to human health (Abdelzaher et al., 2010; Stewart et al., 2008), confirming a human or non-human source and understanding the physical factors that determine FIB concentration and distribution are critical for managing beaches and ascertaining exposure risks. Thus, the primary objective for beach managers is to find the prominent sources of high FIB. High-intensity sampling, analysis of different fecal indicators, empirical and hydrodynamic modeling, and molecular tests to distinguish contamination sources are among the popular microbial source tracking (MST) tools explored in source identification studies (Kinzelman et al., 2012; Nevers and Boehm, 2011; U.S.

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EPA, 2008). In recent years, sanitary surveys that incorporate various physical, chemical, and biological parameters (observed or measured) (U.S. EPA, 2008) have particularly been proven useful when used in con-

(Dorfman and Rosselot, 2011). Aside from routine monitoring during the recreational season (May–September), no systematic studies have been conducted to determine sources contributing to high *E. coli* levels