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Research article

Effect of beach management policies on recreational water quality

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A B S T R A C T

When beach water monitoring programs identify poor water quality, the causes are frequently unknown. We hypothesize that management policies play an important role in the frequency of fecal indicator bacteria (FIB) exceedances (enterococci and fecal coliform) at recreational beaches. To test this hypothesis we implemented an innovative approach utilizing large amounts of monitoring data ($n > 150{,}000$ measurements per FIB) to determine associations between the frequency of contaminant exceedances and beach management practices. The large FIB database was augmented with results from a survey designed to assess management policies for 316 beaches throughout the state of Florida. The FIB and survey data were analyzed using t-tests, ANOVA, factor analysis, and linear regression. Results show that beach geomorphology (beach type) was highly associated with exceedance of regulatory standards. Low enterococci exceedances were associated with open coast beaches ($n = 211$) that have sparse human densities, no homeless populations, low densities of dogs and birds, bird management policies, low densities of seaweed, beach renourishment, charge access fees, employ lifeguards, without nearby marinas, and those that manage storm water. Factor analysis and a linear regression confirmed beach type as the predominant factor with secondary influences from grooming activities (including seaweed densities and beach renourishment) and beach access (including charging fees, employing lifeguards, and without nearby marinas). Our results were observable primarily because of the very large public FIB database available for analyses; similar approaches can be adopted at other beaches. The findings of this research have important policy implications because the selected beach management practices that were associated with low levels of FIB can be implemented in other parts of the US and around the world to improve recreational beach water quality.

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1. Introduction

Beach water quality monitoring programs include sample collection and laboratory analysis to evaluate levels of fecal indicator bacteria (FIB). When the levels of FIB exceed a set threshold, beach advisories or closures are issued, as these exceedances could indicate a threat to public health. As a result of these programs, a database of long-term FIB monitoring data is created. These databases tend to grow over time resulting in an untapped resource for analysis.

One common goal of these monitoring programs is a desire to reduce the number of beach advisories by identifying and reducing FIB contributions. These sources of FIB to beaches include point sources, such as leaks from sanitary sewers and effluent from wastewater treatment plants. Non-point sources such as storm water runoff (Molina et al., 2014), and humans and animals that frequent beaches (Wright et al., 2009; Elmir et al. 2007, 2009; Converse et al., 2012; Sinigalliano et al., 2013) also contribute FIBs. One of the hypotheses underlying this study is that these sources of FIB, in particular non-point sources, can be controlled through beach management practices, thereby resulting in a reduction of beach advisories. Beach management is defined here as infrastructure and a sequence of policies that are implemented to maintain the recreational and ecological value of a beach.

The state of knowledge related to beach management practices and their influences on recreational water quality includes many major gaps. Studies such as Rippy et al. (2013), Russell et al. (2014), Wu and Jackson, 2016, Feng et al. (2016), and Donahue et al. (2017) have examined some of these issues, but focused on relationships between microbial water quality and physical, chemical, biological, and geomorphological factors. The influence of beach management practices and policies on water quality has not been comprehensively addressed.

Beach grooming studies are underrepresented (Nevers et al., 2016; Whitman et al., 2014; Kinzelman et al., 2003; Verhougstraete and Rose, 2014; Russell et al., 2014); studies that most closely relate to beach grooming, focus on sand erosion and issues of coastal zone management (Sutton-Grier et al., 2015). Studies of birds (Sinigalliano et al., 2013) and some on humans and dogs (Elmir et al., 2009; Wright et al., 2009) have been conducted, but the impact of wildlife and other domesticated animals on recreational water quality is unknown. FIB studies on vehicular traffic; facilities like restrooms and showers; concession stands; solid waste management; and fees to access the beach are not found in the literature. This represents many major gaps in knowledge. The issue of anthropogenic impact, modifications or uses that allow FIBs and pathogens to be introduced into the beach environments, and transport to the beach environment, has also not been well studied.

The primary objective of this study is to evaluate whether beaches characterized by a set of management policies are associated with lower FIB levels. This work is unique in that it evaluates the understudied areas to fill in some of the gaps and indicates areas of future work. It is innovative by classifying beaches based upon major geomorphological characteristics and then evaluating within these characteristics whether specific conditions and policies used to manage a beach were associated with improved water quality. Since beach management policies are in place for long periods of time, on the order of 10–20 years or more, this study used the entire period of record (15 years) to define a beach's overall average exceedance rate (percentage of time the beach FIB exceeds the regulatory thresholds). This study builds on the work of Feng et al. (2016) and Donahue et al. (2017), by examining the anthropogenic impact on beach water quality due to beach management practices. Earlier studies examined natural and man-made features. This study also evaluated the interaction of these features with new data on beach management practices.

2. Methods

To evaluate beach management policies, a large FIB database was consolidated, corresponding to the entire state of Florida as documented through the Florida Healthy Beaches Program (FHBP). Analysis included the establishment of inclusion criteria, which resulted in 316 beaches for evaluation. Beach type was identified based upon the method of Donahue et al. (2017). The FIB data for each beach were converted to a percent exceedance value to track the fraction of times that the beaches exceeded regulatory guidelines. A beach management survey was developed to collect data on management policies. The results were then compared to FIB data to determine which management condition corresponded to lower bacteria levels. The observed influence of beach morphology determined how each of the responses in the beach management survey were analyzed. For each question within the various categories, the data were analyzed in four groups, 1) all beaches for enterococci, 2) open coast beaches for enterococci, 3) all beaches for fecal coliform, and 4) open coast beaches for fecal coliform. Open coast beaches represented the vast majority of the beach types in Florida ($n = 211$). We also included questions about human and animal densities on a typical Sunday noon and Wednesday noon. Only the results for Sunday are discussed in this paper.

2.1. Analysis of data from the Florida Healthy Beaches Program (FHBP)

The FHBP (Florida Department of Health, 2016) was originally established in August 2000. Through this program FIB data have been collected and reported to the Florida Department of Health (FDOH), which is responsible for maintaining a statewide database. The total number of samples collected through the FHBP for the July 31, 2000 to December 31, 2015 period of record was 189,640 for enterococci and 153,805 for fecal coliform. For a beach to be included for analysis within the current study, the site had to have been included in the FHBP with a minimum of 120 samples during the 15-year period of record (2000-2015). The threshold of 120 was chosen after evaluating the continuity of the records for the beaches in the 100 to 400 sample range, and by also considering input from beach managers concerning their views about the permanency of sites in this range.

A total of 316 beaches from all 34 coastal counties (Fig. 1) met the criteria for inclusion. There were over 50 other sites with fewer than 120 samples and these data were excluded from our analyses. In some cases, extra exploratory samples were collected following a sample that exceeded the “poor” water quality threshold. In our study, we excluded these exploratory samples from the analysis to minimize bias due to extra sampling conducted during periods of high bacteria levels. After excluding the exploratory samples and data for sites with less than 120 samples, the total number of beach monitoring data points utilized for the analysis was 185,225 for enterococci and 151,000 for fecal coliform.

When issuing advisories, both the geometric mean and single sample maximums are considered. From 2000 until 2015, the FDOH has issued beach advisories or closures when single samples exceeded 104 colony forming units (CFU) per 100 ml for enterococci (See supplemental Table S1). Fecal coliform was also measured for beaches in Florida during the majority of the period of study. Fecal coliforms were recommended earlier by the EPA for both freshwater and saltwater (EPA, 2017). From August 2000 through June 2002, closures were issued at 800 CFU/100 mL. This was adjusted to 400 CFU/100 mL, which was in effect from July 2002 until June 2011. After June 2011, fecal coliform was dropped from sampling.

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