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# Wave energy level and geographic setting correlate with Florida beach water quality

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ABSTRACT

Many recreational beaches suffer from elevated levels of microorganisms, resulting in beach advisories and closures due to lack of compliance with Environmental Protection Agency guidelines. We conducted the first statewide beach water quality assessment by analyzing decadal records of fecal indicator bacteria (enterococci and fecal coliform) levels at 262 Florida beaches. The objectives were to depict synoptic patterns of beach water quality exceedance along the entire Florida shoreline and to evaluate their relationships with wave condition and geographic location. Percent exceedances based on enterococci and fecal coliform were negatively correlated with both long-term mean wave energy and beach slope. Also, Gulf of Mexico beaches exceeded the thresholds significantly more than Atlantic Ocean ones, perhaps partially due to the lower wave energy. A possible linkage between wave energy level and water quality is beach sand, a pervasive nonpoint source that tends to harbor more bacteria in the low-wave-energy environment.



## 1. Introduction

In order to reduce waterborne diseases and protect human health at recreational beaches, water quality is routinely monitored through measurements of fecal indicator bacteria (FIB), as epidemiological studies have shown relationships between FIB levels and illness (e.g., Wade et al., 2003; Fleisher et al., 2010; Colford et al., 2012). In addition to traditionally known point sources of FIB such as sewage outfalls (e.g., Cabelli et al., 1982), many studies have identified beach sand as a ubiquitous and diffuse nonpoint source of FIB (e.g., Whitman and Nevers, 2003; Shibata et al., 2004; Yamahara et al., 2007; Halliday and Gast, 2011; Byappanahalli et al., 2012). Among many environmental factors, waves are prevailing physical factors that influence the presence, transport, and distribution of contaminants in the beach environment (Boehm, 2003; Grant et al., 2005; Ge et al., 2012; Feng et al., 2013). At typical open-coast beaches, waves dominate the energetics of the nearshore environment (Komar, 1998). Wave breaking dissipates tremendous amount of energy in the relatively narrow surf zone (Inman et al., 1971), generates eddies (Clark et al., 2012; Feddersen, 2014), drives alongshore currents (Longuet-Higgins, 1970), and significantly increases eddy diffusivity and material mixing (Spydell et al., 2007; Brown et al., 2009). These processes may further affect the transport and dispersion of sediments (e.g., Reniers et al., 2013), pollutants (e.g., Grant et al., 2005), and larvae (e.g., Fujimura et al., 2014). Waves may also induce through-beach transport of bacteria via swash uprush and infiltration into the sand (Russell et al., 2012; Gast et al., 2015).

Florida, known as the Sunshine State, has hundreds of miles of sandy beaches along both Atlantic Ocean and Gulf of Mexico (GoM) coasts. These recreational beaches are important tourism and recreational resources. In 2012, coastal tourism and recreation generated approximately a third million jobs and also contributed $16.4 billion to the state's economy (National Ocean Economics Program, 2014). The Florida Healthy Beaches Program (FHBP), a statewide program administrated by the Florida Department of Health, routinely monitors beach water quality in order to comply with U.S. Environmental Protection Agency (USEPA) regulations (USEPA, 1986, 2012). All 34 coastal counties joined this program in 2000 and began to collect water samples every other week, transitioning in 2002 to sampling on a weekly basis. As a result, a decade-long dataset of continuous FIB observations has been produced across the entire Florida coast.

The unique FHBP water quality dataset allows us, for the first time, to study water quality patterns from a broad perspective, which cannot be achieved by traditional site-specific water quality assessments. To our knowledge, no prior study has analyzed this many beaches (262 beaches in this study), consisting of a variety of hydrologic and geographic features and spanning such a long coastline (approximately 2000 km). The specific objectives of this study are: (1) to provide a

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synoptic and baseline assessment of beach water quality exceedance in the entire state of Florida; and (2) to evaluate relationships between water quality exceedance and two major environmental factors (i.e., wave energy level and geographic distribution).

## 2. Material and methods

### 2.1. Fecal indicator bacteria monitoring data

FIB data were compiled from the archives of the Florida Department of Health. The datasets used in this study spanned nearly a decade, from August 2000 to December 2009, when both enterococci and fecal coliform were monitored. The original database included over 300 beaches; however, only 262 beaches with a minimum of 409 sampling events each (i.e., less than 10% missing samples) were retained for further analyses (see Fig. 1 for beach locations). The same time frame was chosen to collect wave information for corresponding beaches (see Section 2.3).

According to the sampling protocol of the Florida Department of Health, trained personnel from county health departments sampled beach water at waist depth in the morning. Samples were then processed by the standard membrane filtration method and FIB levels were expressed in colony-forming unit per 100 mL (CFU/100 mL). Samples below the detection limit were assigned a value of 0.5 CFU/100 mL, half of the detection limit of 1.0 CFU/100 mL.

The Florida county health departments issue health warnings or advisories when FIB levels exceed a set threshold level based on either geometric mean or single sample analyses (Table 1). Warnings are issued based on fecal coliform measures whereas advisories are issued based on enterococci measures. Given the high variability of the FIB levels observed at Florida beaches, in practice, health advisories and warnings are issued only when two consecutive water samples exceed corresponding single-sample thresholds. However, these resamples after exceedances were excluded from our analyses to eliminate bias towards exceedance events with multiple high FIB levels (Phillips et al., 2011).

**Table 1**
Thresholds for beach warnings and advisories based on fecal coliform and enterococci levels, respectively. The single-sample thresholds are utilized in this study.

| | Fecal coliform[a] (CFU/100 mL) | Enterococci[b] (CFU/100 mL) |
|---|---|---|
| Monthly geometric mean | ≥200 | ≥35 |
| Single-sample threshold | ≥400 | ≥104 |

[a] Source: the Florida Department of Environmental Protection surface water quality criteria.
[b] Source: the USEPA Ambient Water Quality Criteria for Bacteria (1986).

In order to evaluate beach warnings or advisories, each measured FIB level (in CFU/100 mL) was converted to a binary value (either “exceedance” or “non-exceedance”) based on the single-sample thresholds (Table 1). The results for the whole decadal period were then reported as a percent exceedance, representing the percentage of the sampling points within that period exceeding 104 CFU/100 mL for enterococci or 400 CFU/100 mL for fecal coliform. Percent exceedance based on long-term monitoring records is a good metric to evaluate overall water health and water quality of recreational beaches and to conduct statistical comparisons among different groups of beaches.

### 2.2. Beach classifications

The first beach classification is based on the geographic distribution (Fig. 1). The Atlantic beaches are those along the Florida Atlantic coast, from northernmost Nassau County at the Florida–Georgia border through Miami-Dade County. The GoM beaches start from southernmost Monroe County (i.e., Florida Keys), along the concave GoM coastline, and end at Escambia County at the Florida–Alabama border. Note that all beaches of the Florida Keys were categorized under the GoM, consistent with the defined geographic boundary of the GoM (International Hydrographic Organization, 1953).

The second beach classification is based on the wave energy level, depending on the beach location relative to large water bodies and

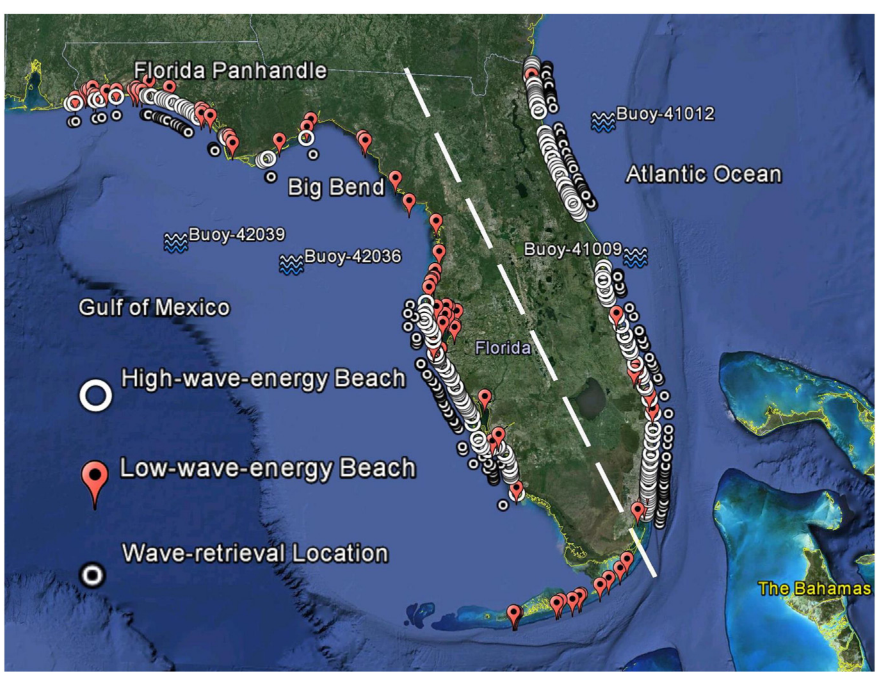


**Fig. 1.** All 262 Florida recreational beaches in this study. Four National Data Buoy Center (NDBC) buoys (for wave observations) are illustrated by wave symbols. Locations of high- and low-wave-energy beaches and wave-retrieval locations (for high-wave-energy beaches) are demonstrated using white circles, red balloons, and black dots. The white dashed line separates Atlantic Ocean and GoM beaches. Big Bend and western Florida Panhandle are identified as water quality hotspots where some recreational beaches frequently exceed enterococci or fecal coliform thresholds. Base map is outputted from Google Earth Pro. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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