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Effects of bacterial pollution caused by a strong typhoon event and the restoration of a recreational beach: Transitions of fecal bacterial counts and bacterial flora in beach sand

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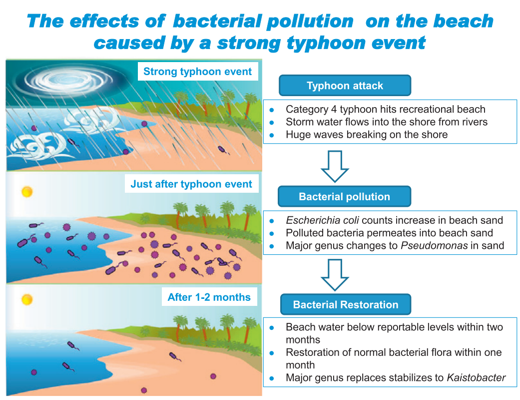
HIGHLIGHTS

- The effects of bacterial pollution caused by a strong typhoon event were monitored.
- Entire bacterial community was investigated using Illumina next-generation sequencing.
- The pollution of the beach water was below reportable levels within 2 months.
- The major genera in the sand were *Pseudomonas*, *Perlucidibaca*, and *Planctomyces* during the typhoon.
- The normal bacterial flora of the surface sand was restored within 1 month.

GRAPHICAL ABSTRACT



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ABSTRACT

To determine the effects of bacteria pollution associated with a strong typhoon event and to assess the restoration of the normal bacterial flora, we used conventional filtration methods and nextgeneration sequencing of 16S rRNA genes to analyze the transition of fecal and total bacterial counts in water and core sand samples collected from a recreational beach. Immediately after the typhoon event, *Escherichia coli* counts increased to 82 CFU/100 g in the surface beach sand. *E. coli* was detected through the surface to sand 85-cm deep at the land side point (10-m land side from the high-water line). However, *E. coli* disappeared within a month from the land side point. The composition of the bacterial flora in the beach sand at the land point was directly influenced by the typhoon event. Pseudomonas was the most prevalent genus throughout the sand layers (0–102-cm deep) during the typhoon event. After 3 months, the population of *Pseudomonas* significantly decreased, and the predominant genus in the surface layer was Kaistobacter, although *Pseudomonas* was the major genus in the 17- to 85-cm layer. When the beach conditions stabilized, the number of pollutant Pseudomonas among the 10 most abundant genera decreased to lower than the limit of detection. The bacterial population of the sand was subsequently restored to the most populous pre-event orders at the land point. A land-side beach, where users directly contact the sand, was significantly affected by bacterial pollution caused by a strong typhoon event. We show here that the normal bacterial flora of the surface sand was restored within 1 month.

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1. Introduction

The water generated from human and manufacturing activities such as agriculture, livestock farms, and aquaculture is discharged from the land through rivers, finally reaching coastal areas (Ding et al., 2015). Coastal areas such as recreational beaches have a high probability of suffering from bacterial pollution (Hernandez et al., 2014), and outbreaks of infectious diseases caused by coastal pollution are considered a significant problem (Meays et al., 2004; Scott et al., 2002; Sunderland et al., 2007). The United States, which prioritizes the public health of waterfront areas, established guidelines for fecal pollution of bathing water of recreational beaches (United States Environmental Protection Agency, 2003). The monitoring of bathing water is performed at least once each week, and certain recreational beaches are closed due to excessive fecal bacterial counts in agreement with the criteria of the guidelines. In the European Union, the regulation of bathing water quality is managed with the European Directive, 2006/7/EC (European Union, 2006). >85% of bathing water sites satisfied the directive's most stringent "excellent" bathing water quality standards in 2016 (European Environment Agency, 2017).

Pollution of bathing water and sand is recognized as a significant risk to public health. For example, fecal bacteria accumulate and survive for long periods in sand, and their concentrations in sand are 10 to 100 times higher than those of bathing water (Haack et al., 2003; Zhang et al., 2015). As a matter of course, there are the beaches which show much less contamination levels for microbiological sand quality (Sabino et al., 2011; Pereira et al., 2013). Pollution of bathing water and sand will be depending on the location and season. The risk of beach users contracting an infectious disease can be strongly associated with the presence of pathogenic bacteria in the sand (Abdelzaher 2011; Bonilla et al., 2007; Fleisher et al., 2010; Heaney et al., 2007; Sinigallino et al., 2010; Solo-Gabriele et al., 2016).

The information and scientific knowledge of bacterial pollution in beach sands are insufficient, and it is therefore difficult to establish guidelines for bacteria in recreational beach sand in countries. In advanced countries included Japan, waste water treatment systems are extensive and contribute significantly to the quality control of waterbodies. Nevertheless, it is difficult to control water pollution when the land is subject to typhoons and torrential rains (Abreu et al., 2016; Beversdorf et al., 2007) there is an extremely high probability that recreational beaches will become polluted as a consequence of such weather events (Badin et al., 2011).

Establishing a management system to ensure the safety of recreational beaches requires information on the effects of bacterial pollution caused by storms as well as on the subsequent environmental remediation. As a model area, we studied the recreational beach facing the Hyuga-nada Sea in the Pacific Ocean bordering the Kyushu District, Japan. To determine the effects of bacterial pollution caused by a strong typhoon event and to assess the subsequent restoration of the beach conditions, we determined the transition of fecal bacterial counts and those of the entire bacterial community in water and core sand samples. For this purpose, we used a conventional membrane filtration method to collect bacteria and Illumina next-generation sequencing to analyze 16S rRNA genes.

2. Materials and methods

2.1. Sampling sites

The Kizaki Beach, which is one of the main surfing beaches in Japan and is situated between the outlets of the Kiyoteke and Kaeda Rivers, was impacted by a strong typhoon event and therefore selected as a model beach for this study (Fig. 1). The covered areas of the Kiyotake and Kaeda Rivers were 166.4 and 538 km^2, respectively, and their corresponding covered lengths were 28.8 and 17.5 km. The target typhoon event was a Category 4 typhoon named GONI that was very strong and large. GONI hit the Kyushu District on August 25, 2015 (Fig. 2). The Kizaki Beach was severely affected by strong winds (26.6 m/s) and torrential rains (74 mm/h). The survey started within 24 h after the typhoon (August 26, 2015) made landfall and continued monthly for 3 months (September 28, 2015, October 29, 2015, and November

Fig. 1. Locations of sampling points on Kizaki Beach, Miyazaki City, Japan. The Kiyoteke and Kaeda Rivers border each end of the beach.