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Short Communication

Climate Change and Microbiological Water Quality at California Beaches

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Abstract: Daily microbiological water quality and precipitation data spanning 6 years were collected from monitoring stations at southern California beaches. Daily precipitation projected for the twenty-first century was derived from downscaled CNRM CM3 global climate model. A time series model of *Enterococcus* concentrations that was driven by precipitation, matched the general trend of empirical water quality data; there was a positive association between precipitation and microbiological water contamination ($P < 0.001$). Future projections of precipitation result in a decrease in predicted *Enterococcus* levels through the majority of the twenty-first century. Nevertheless, variability of storminess due to climate change calls for innovative adaptation and surveillance strategies.

Keywords: climate change, *Enterococcus*, gastroenteritis, precipitation, recreational water use

Introduction

California's economy, estimated at USD 46 billion per year, is greatly ocean dependent with nearly 85% of California's residents living and working in coastal counties (California Climate Adaptation Strategy 2009). Well over 500 million California residents and out-of-state tourists visit the coastline every year, many of whom swim or bathe in coastal water itself. In the three most populated southern California counties (Orange, Los Angeles, San Diego), 56 million visitors enter the water annually. There are health risks from bathing in water near large urban areas, however. Exposure to elevated concentrations of bacteria in bathing waters at southern California beaches has been linked with an increased risk of contracting infectious diseases, such as gastroenteritis (Brinks et al. 2008; Dwight et al. 2004; Haile et al. 1999).

Precipitation events in southern California are an important driver for microbiological contamination of coastal water from surface runoff (Dwight et al. 2002, 2011; He and He 2008; Noble et al. 2003). In heavily urbanized areas, rainwater can carry bacteria from numerous sources through stormwater systems, often discharging untreated into coastal water. Public health agencies in California therefore monitor bacterial levels in coastal waters, focusing

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on *Enterococcus*, especially near stormwater discharge points. Uncontained sewage and livestock are the most important sources of enteric bacteria, but intermittent loadings from other sources may also contribute to human disease risk (Brinks et al. 2009).

As the climate of southern California changes through the twenty-first century, precipitation rates will likely change, potentially altering the concentrations of bacteria in coastal waters, and thereby changing the disease burden due to swimming in contaminated water (Semenza and Menne 2009). California has already been affected by climate change, with increasing average air temperatures, rising sea levels, higher intensity, frequency, and duration of heat waves and changes to the hydrological cycle (Barnett et al. 2008; Gershunov et al. 2009). Climate models project that California will become hotter and drier through the twenty-first century, and that southern California will experience a decline in total annual precipitation between 4 and 16% (California Climate Adaptation Strategy 2009). Low- and medium-intensity rain events are expected to decline in number, while some high-intensity events are projected to become more intense (Favre and Gershunov 2009; Groisman et al. 2005; Dettinger 2011). We sought to determine whether changes in precipitation patterns under climate change scenarios result in improved recreational water quality at beaches in southern California?

We derived a linear model of microbiological water contamination (mean *Enterococcus* concentrations for 78 southern California beaches) at the daily timescale (Brinks et al. 2008). Predictor variables in the model were precipitation (gauge data from the vicinity of Huntington Beach, 33.6875°N, 118.0625°W), *Enterococcus* concentrations for each of the 3 days prior to the date modelled, and a categorical variable for month. Generalized least squares was used to estimate model parameters, with an AR(1) covariance structure applied to account for residual autocorrelation, and natural log transformations applied to *Enterococcus* and precipitation data (Table 1). Daily data for 2000–2004 were used for estimation, with data from 2005 used for validation (Fig. 1). The sources of *Enterococcus* data were described previously (Brinks et al. 2008), as was the spatial distribution of contamination (Dwight et al. 2011).

Projected precipitation levels were used to predict daily *Enterococcus* water contamination levels for the region through the twenty-first century. Data were derived from the CNRM CM3 global climate model (Salas-Mélia et al. 2005) under the SRESA2 'business-as-usual' scenario (IPCC 2007) and downscaled to Huntington Beach using bias-corrected constructed analogues (BCCA) (Maurer and Hidalgo 2008).

Table 1. Coefficients and Statistical Results for a Model of *Enterococcus* Concentrations at Southern California Beaches, 2000–2005

Coefficient	Estimate	F	P
Intercept	0.669	429839.4	<0.0001
Precip	0.038	8450.7	<0.0001
Ent-lag1	1.115	19893.9	<0.0001
Ent-lag2	0.041	180.8	<0.0001
Ent-lag3	−0.272	130.8	<0.0001
Month	See below	5.4	<0.0001

Month	Estimate
Jan	Reference
Feb	0.078
Mar	−0.012
Apr	−0.071
May	−0.103
Jun	−0.117
Jul	−0.081
Aug	−0.108
Sep	−0.101
Oct	−0.017
Nov	−0.008
Dec	0.018

Note The region's average *Enterococcus* concentration was modelled, with generalized least squares regression, as a function of precipitation on the day of measurement (Precip), the preceding 3 days' *Enterococcus* concentrations (Ent-lag1/2/3), and the month in which the modelled day occurred (Month)

For the years 2000–2004, observed precipitation was significantly related to measured *Enterococcus* concentration (Fig. 1; Table 1). Statistically modeled and empirical water quality data for the years 2000–2005 matched well (Fig. 1). We computed the annual means for projected *Enterococcus* levels and grouped the data by decade for the twenty-first century (Fig. 2). The model projects a general decrease in contamination over the decades, with increasing variability towards the end of the century.

Climate models project that California's Mediterranean climate will warm, but continue to have wet winters and dry summers, as well as a large amount of variability (California Climate Adaptation Strategy 2009). Despite this

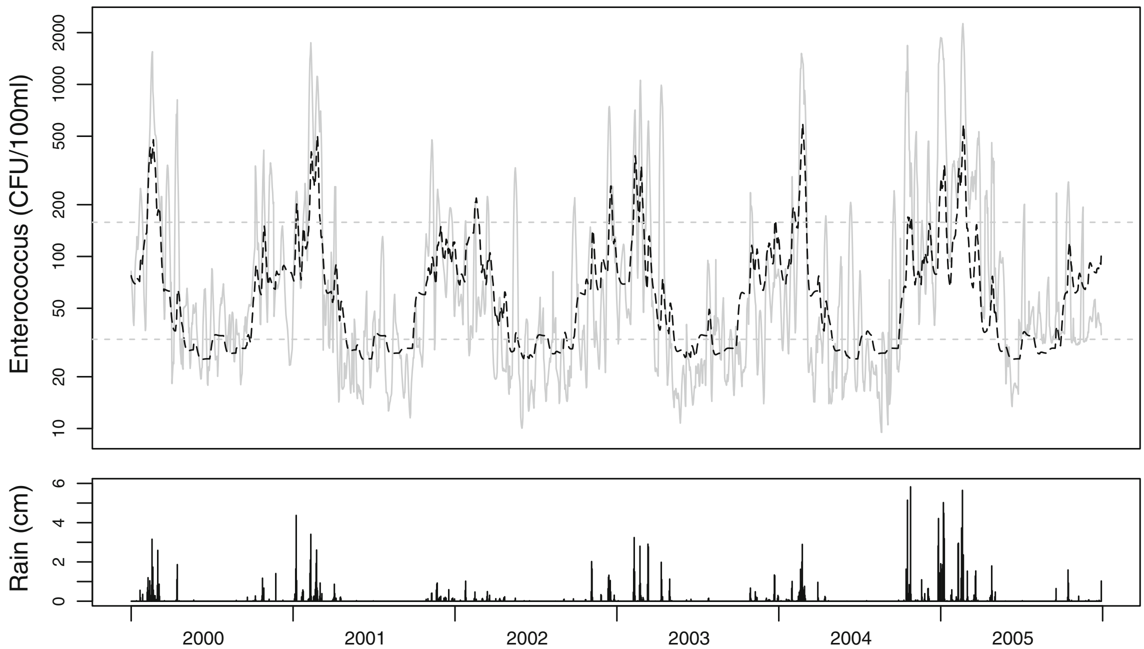

Figure 1. Mean *Enterococcus* concentrations in southern California swimming waters, as derived from measured (*grey*) or modelled (*black dashed*) data sources (*top panel*), and daily rainfall (*bottom panel*) spanning 2000–2005. *Horizontal dashed lines* at 33 and 158 CFU/100 ml reflect the range of *Enterococcus* concentrations most influencing health risk in one prominent model (Kay et al. 1994).

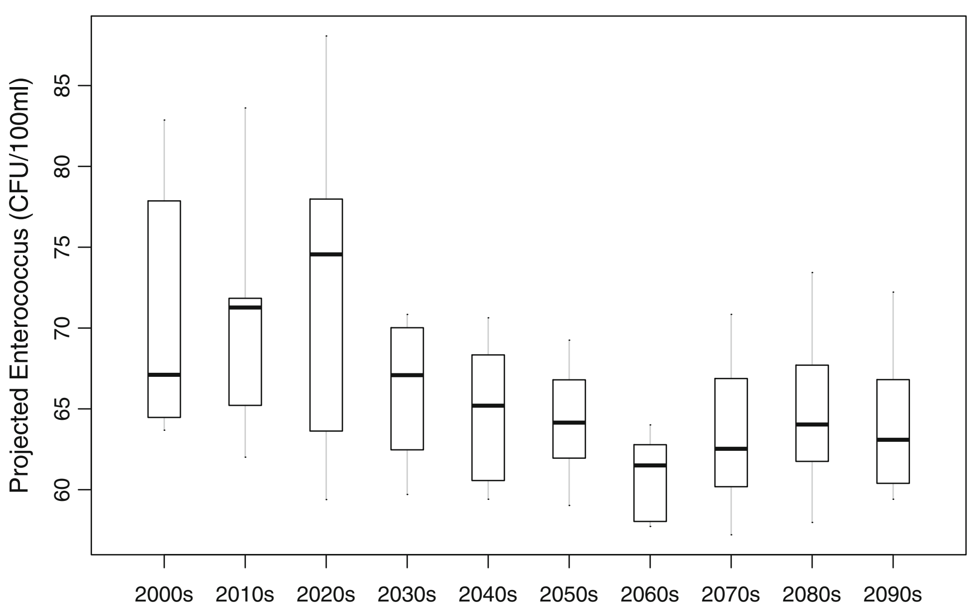

Figure 2. Distribution of projected annual mean *Enterococcus* concentrations, grouped by decade, for southern California swimming waters through the twenty-first century. *Boxes* show the range of annual means for the middle 50% of years, *thick bars* shows the median year, and *whiskers* extend to the most extreme years in the decade.

variability, the climate will become progressively drier; annual precipitation will dry up with a general decrease in frequency of rain events (Figure, web annex) (Favre and Gershunov 2009). The projected decrease of precipitation by 4–16% during this century is expected to mainly occur during the wet season. However, the infectious disease burden peaks during the summer months (June, July and August) when 53% of beach visits occur, in spite of lower *Enterococcus* contamination levels compared to the winter months (Dwight et al. 2007). Moreover, accumulated contamination might flush into coastal waters during the first precipitation of the rainy season, while subsequent rain events will contaminate the beaches less.

A relative decrease in coastal water contamination during this century might have positive implications for the infectious disease burden among recreational water users.

We modelled the disease burden according to two published dose–response relationships using these projected contamination levels (data not shown) (Cabelli et al. 1982; Kay et al. 1994). However, due to the large variance in the empirical water quality and projected precipitation data, and differences in the dose response curves, we concluded that it is currently difficult to accurately predict disease burden. Moreover, the population along the coast is projected to grow disproportionally compared to the rest of the state and reach 32 million people by 2025 (Boesch et al. 2000). The coast will warm less than the inland areas, especially during the summer, and longer warm seasons might draw more individuals to the beaches of southern California (California Climate Adaptation Strategy 2009). A potential decrease in gastrointestinal illnesses based on a decrease in precipitation might be offset by an increase in exposures of a larger population. Since global climate change is to remain with us for the foreseeable future, adaptation strategies need to be developed to address emerging concerns (Semenza et al. 2012). An intriguing approach has been modelled in Portugal by increasing the sewer system storage capacity to minimize the wet weather discharges onto beaches (David and Matos 2005). These models show that storage and advances in physical–chemical treatment of stormwater can significantly reduce overflow volumes. While settling in sedimentation tanks could reduce overflow, microorganism concentrations remained nevertheless high, which could potentially be treated on-line with UV-disinfection (Soyeux et al. 2007). With regard to recreational water use, these strategies call for higher water quality standards accompanied by monitoring, greater water treatment capacity and greater public outreach and education campaigns (Boehm et al. 2009). Furthermore, monitoring meteorological conditions and gathering epidemic intelligence will increasingly be part of public health practice aiming to protect the health of the public (Semenza and Menne 2009). Society will have to accept these adaptive strategies to minimize the negative consequences of global climate change that can interact with a number of other drivers of infectious diseases (Suk and Semenza 2011).

In conclusion, we found a positive association between measured precipitation and observed coastal water contamination in southern California. Our data project a decrease in precipitation frequency over the course of the century with potentially beneficial implications for public health. Nevertheless, the variability of storminess might actually increase in southern California in the twenty-first century (California Climate Adaptation Strategy 2009) which calls for innovative adaptation and surveillance strategies (Lindgren et al. 2012).

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