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Baseline

The relationship between environmental parameters and microbial water quality at two Costa Rican beaches from 2002 to 2017

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ABSTRACT

Environmental conditions influence fecal indicator bacteria (FIB) levels, which are routinely used to characterize recreational water quality. This study examined 15 years of environmental and FIB data at Puntarenas and Jacó beach, Costa Rica. FIB relationships with sea level, wave height, precipitation, direct normal irradiance (DNI), wind, and turbidity were analyzed. Pearson's correlations identified lags between 24 and 96 h among environmental parameters and FIB. Multiple linear regression models composed of environmental parameters explained 24% and 27% of fecal coliforms and enterococci variability in Jacó, respectively. Puntarenas's models explained 17–26% of fecal coliforms and 12–18% enterococci variability. Precipitation, sea level anomalies, and wave height most frequently explained FIB variability. Hypothesis testing often identified significant differences in precipitation, wave height, daily sea level anomalies, and maximum sea level 24 h prior between days with and without FIB threshold exceedance. Unexpected FIB interactions with DNI, sea level, and turbidity highlight the importance of future investigations.

Microbial indicators, such as fecal indicator bacteria (FIB), are used worldwide to identify contaminated waters that are unsafe for swimming (WHO, 2003) because of the health and economic burdens associated with recreating in them (Shuval, 2003). Recreational microbial water quality criteria vary by country, with respect to the FIB utilized and the characterization of safe and unsafe concentrations (WHO, 2003). Both fecal coliforms (FC) and enterococci (ENT) are common FIB for coastal waters. They are excreted in the feces of all warm and some cold-blooded organisms and are also found in extraintestinal, environmental reservoirs unrelated to fecal pollution (*e.g.*, soil, aquatic vegetation), which can misrepresent the presence of fecal pollution and subsequent risk to swimmers (Badgley et al., 2011; Feng et al., 2013). Sanitation infrastructure and other human activities can greatly influence FIB concentrations (Byappanahalli et al., 2012).

Environmental parameters can directly and indirectly influence FIB concentrations through a variety of mechanisms, including the movement of fecal pollution into surface waters, resuspension of extraintestinal FIB reservoirs, affect FIB decay and replication rates, among others (Byappanahalli et al., 2012; Cha et al., 2016; Chenier et al., 2012; Enns et al., 2012; Laureano-Rosario et al., 2017; Leight and Hood, 2018; Rochelle-Newall et al., 2015; Santiago-Rodriguez et al., 2012). Previous studies identified the following environmental parameters as correlated with FIB: precipitation, wind, solar irradiance, currents, tidal cycle, sea level, wave energy, as well as water temperature and turbidity (Ackerman and Weisberg, 2003; Boehm et al., 2009a; Byappanahalli et al., 2012; González-Fernández et al., 2020; Laureano-Rosario et al., 2017; Maraccini et al., 2016; Rippy et al., 2013). Storm and tidal surges, which increase sea level and can cause flooding, are often related to increased

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FIB concentrations because they can facilitate the movement of FIB from land and groundwater into coastal waters (Quach et al., 2016). Relationships between FIB and environmental conditions are location-specific (Aragones et al., 2016; Partyka et al., 2018; Wu et al., 2017), and continued monitoring is important to understand beach-specific dynamics (Islam et al., 2017; Laureano-Rosario et al., 2017; Verhougstraete et al., 2020).

The World Health Organization (WHO) Guidelines for safe recreational water environments recommend a simplified framework for assessing recreational waters, which considers use, sanitary inspections, water quality monitoring, as well as the predicable conditions that cause water quality deterioration (WHO, 2003). To date, the environmental conditions associated with poor microbial water quality are not identified for Costa Rica, and studies are lacking in the tropics (Verhougstraete et al., 2020). To understand the environmental conditions that contribute to poor water quality, this study investigated the relationship between FC and ENT and the following environmental parameters over 15 years (2002–2017) for two popular Costa Rican beaches: precipitation, direct normal irradiance (DNI), wind, turbidity, wave height, and sea level. To achieve this objective, this study (1) identified significantly correlated, location-specific time lags between environmental parameters and FIB, (2) evaluated the influence of environmental parameters on FIB in coastal waters using Multiple Linear Regressions (MLR) by identifying the most parsimonious models through redundancy analysis that minimized Akaike Information Criterion (RDA-AIC), (3) categorized and assessed differences in the ranges of environmental factors between days identified as safe or unsafe for swimming per FIB concentrations, and (4) evaluated the occurrence of storm and tidal surges on days categorized as safe and unsafe for swimming days.

This study took place at two beaches on Costa Rica's Pacific coast that are popular tourist attractions: Puntarenas (9.97°N; 84.83°W) and Jacó (9.61°N; 84.63°W; Fig. 1). January through March are the driest months, and rainfall is greatest from May through October. Daily solar irradiance is from around 0500 to 1730 h, and solar noon is at 0900 h. Beach communities in both cities lack improved sanitation infrastructure.

Puntarenas beach is located on a narrow peninsula, protected within the Gulf of Nicoya (Fig. 1). The beach is 13.9 km in length and has low-wave action. Puntarenas's town had a population of 45,157 in 2002, which increased to 49,189 in 2017 (Instituto Nacional de Estadísticas y

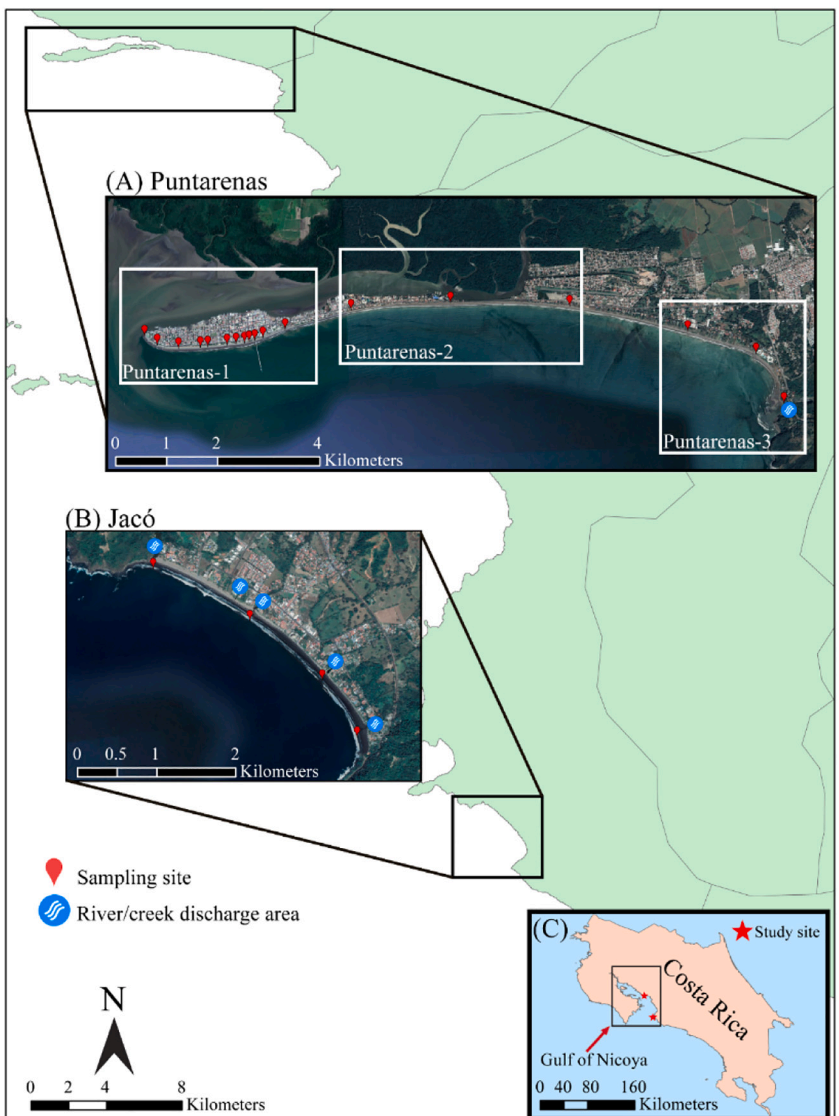

Fig. 1. Map showing the sampling locations (red dots) and river/creek mouths (blue symbols) on the Costa Rican Pacific coast: (A) Puntarenas beach (grouped into three areas) and (B) Jacó beach (one area). Inset map (C) shows the location of both study sites (red stars). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Censos, 2020). Puntarenas beach is located near two water bodies that receive untreated and secondary-treated domestic wastewater: the Puntarenas inlet, located on the northern edge of the peninsula, and the Barranca River, located to the east of the peninsula (Mora Alvarado, 2007).

Jacó beach is a high-wave action, westward-facing beach, influenced directly by the Pacific Ocean (Fig. 1). The beach is 4.2 km long and receives input from five small rivers, which were identified as among the most contaminated in Costa Rica (Badilla-Aguilar and Mora-Alvarado, 2019). Jacó district had a population of 7859 in 2002 and increased to ~16,342 inhabitants in 2017 (Instituto Nacional de Estadísticas y Censos, 2020). Septic tanks and small wastewater treatment plants, which serve specific commercial establishments and condominiums, treat the town's wastewater (Mora Alvarado, 2009). Informal settlements, which lack wastewater treatment, and illegal sewerage connections to the stormwater collection system are prevalent and directly contribute to the discharge of wastewater into the rivers.

In Costa Rica, FC and ENT are routinely measured at popular recreational beaches (Mora Alvarado, 2007). Water quality data for Jacó and Puntarenas beach were obtained from the *Instituto Costarricense de Acueductos y Alcantarillados* (AyA) and included 13 years of ENT data (Jan 2004–Jan 2017) and 15 years of FC data (Jan 2002–Jan 2017). All surface water samples were collected at ~1 m depth, maintained on ice, and processed within 24 h. The multiple-tube fermentation technique was used to determine the most probable number concentrations (MPN/100 mL) for FC (method 9221 E) and ENT (method 9230 B) per Costa Rican regulations (American Public Health Association et al., 2017). Concentrations below the lower limit of quantification and above the upper limit of quantification were substituted as previously described (see Supplementary Material for details; Schang et al., 2016).

Jacó beach was sampled approximately every three months at four locations, while Puntarenas beach was sampled at 23 locations approximately every 1.5 months. Due to the satellite data resolution, FIB data from Jacó beach were combined as one area for analyses given their proximity to each other (Fig. 1). Similarly, FIB data from Puntarenas beach were grouped into three areas based upon their geographic distribution and proximity to pollution sources: Puntarenas-1 ($N = 12$ sites), Puntarenas-2 ($N = 3$ sites), and Puntarenas-3 (also known as Roble beach; $N = 3$ sites) (Fig. 1). For each sampling date and beach area, the geometric mean was calculated for each FIB and were used in all further analyses. Final (combined) sample sizes were as followed: Jacó beach $N_{ENT} = 58$ and $N_{FC} = 64$; Puntarenas-1 $N_{ENT} = 52$ and $N_{FC} = 89$; Puntarenas-2 $N_{ENT} = 17$ and $N_{FC} = 47$; and Puntarenas-3 $N_{ENT} = 48$ and $N_{FC} = 77$. The use of geometric means minimized the effect of outliers, including the censored data substitutions. Overall, less than nine and four daily geometric means were entirely left- and right-censored, respectively, for any given beach grouping.

Precipitation, DNI, wind, and turbidity data were derived from satellites for the study period (see Supplementary Material for details). Subsequently, accumulated precipitation was calculated for different intervals (*i.e.*, 24 to 96 h) before each surface water sampling date. Wind components, zonal (u) and meridional (v), were calculated from daily wind speed and direction. To assess how changes in DNI would influence FIB, daily maximum, minimum, and average DNI were calculated and used in further analyses. Turbidity anomalies, rather than measured values, were used as variables in statistical analyses due to low turbidity values.

Daily sea level (maximum, minimum, and average) and wave height data were obtained from a buoy maintained by the Oceanographic Information Module at the University of Costa Rica's Research Center of Sciences of the Sea (buoy located at 9.5°N, 85.0°W). Sea level anomalies, rather than measured values, were used as variables in statistical analyses due to the inherent periodicity of sea level data. Using the complete time series of all environmental parameters in this study, daily and weekly climatologies and anomalies (turbidity and sea level only) were calculated. All data were average values unless otherwise specified.

Data were analyzed with permutation-based statistics (1000 iterations; $17 \leq N \leq 89$, sample size varied by beach and FIB), which are distribution-free methods previously used to investigate correlations between FIB and environmental conditions for datasets with less than 200 observations (Anderson, 2001; Laureano-Rosario et al., 2017; Legendre and Anderson, 1999; McArdle and Anderson, 2001; Riaz et al., 2016). MATLAB 9.7.0.1190202 (R2019b) and the Fathom toolbox were used for all statistical analyses (Jones, 2015). Prior to all analyses, FIB geometric mean data were ln-transformed and environmental data were standardized (Vittinghoff et al., 2011). To assess how much the environmental parameters explained FIB variability, it was first necessary to identify the strength of time-lagged correlations between explanatory variables (*i.e.*, environmental/oceanographic parameters) and the dependent variable (*i.e.*, FIB) using permutation-based Pearson's correlation analyses for the following time lags (h): 24, 48, 72, and 96 (Laureano-Rosario et al., 2017).

Those time lags with Pearson's correlation coefficients (r) $\geq |0.2|$ were selected for inclusion in downstream analyses, regardless of significance (Schober et al., 2018). FIB geometric means at Jacó and Puntarenas beaches from 2002 to 2017 were most significantly correlated with average wave height, cumulative precipitation, and average sea level anomalies with time correction factors ranging from 24 to 96 h (Tables S1 and S2). For FC, environmental parameters had the highest correlation using a 24 h time lag, except for sea level anomaly, which had correlations with 48 h or 72 h time lags. ENT were most significantly correlated with environmental parameters at time lags of 24 h, except for three parameters with time lags of 48 h and 96 h. The extent of correlation between environmental factors and FIB differed across beach areas.

Nevertheless, when significant correlations were identified, FIB were generally positively correlated with precipitation, wave height, and zonal wind velocity and negatively correlated with DNI, sea level anomalies, and wind speed. Overall, higher FIB were observed with 24-h cumulative precipitation and lower FIB were observed when sea level was higher than average in the previous 24 h. Precipitation is known to increase FIB concentrations through runoff containing animal feces, domestic wastewater, and soils (Paule-Mercado et al., 2016). Rainfall intensity and frequency typically increase as you move from temperate to tropical climates. However, in other regions and climates, other time-lags (*e.g.*, 72- or 96-h) are more important, likely reflecting their specific weather patterns, size of watershed, land use, and coastal morphology (Islam et al., 2017; Kay et al., 2005; Partyka et al., 2018; Ackerman and Weisberg, 2003; Laureano-Rosario et al., 2017). Higher than average sea level would minimize river influence on coastal water quality, which may explain the lower FIB observed given the rivers' chronically poor microbial water quality (Mora Alvarado, 2007, 2009).

To assess the relationship between environmental parameters and FIB variability, RDA-AIC model selection was executed prior to MLR. RDA-AIC model selection is a permutation-based stepwise selection of continuous explanatory variables *via* forward addition minimizing model AIC (Godínez-Domínguez and Freire, 2003). Subsequent MLRs with the selected model were executed using only the time-lagged environmental parameters identified as significantly correlated with FIB concentrations (Laureano-Rosario et al., 2017). For Jacó beach, precipitation, DNI, wave height, sea level anomalies, and zonal wind velocity were analyzed. For Puntarenas beach, the environmental parameters varied slightly by area; precipitation, wave height, wind speed (including both wind components), and sea level anomalies were among those parameters included in the analyses. The RDA-AIC model selection analyses helped identify the optimal environmental parameters that substantially explained variation in both FIB, and only selected those parameters that were not linearly correlated (*i.e.*, multicollinearity). The parameters included were those that showed a Pearson's correlation (r) $\geq |0.2|$.

Overall, precipitation, wave height, and/or sea level anomalies most frequently explained FIB geometric mean variability. For Jacó beach, 24-h cumulative precipitation was the only parameter that substantially explained FC variability (Table 1). In contrast, 24-h cumulative precipitation and daily average sea level anomalies most substantially explained ENT variability. Different parameters explained FIB variability among the Puntarenas areas, yet daily average sea level anomaly, average wave height, and cumulative precipitation were most frequently identified as variables explaining FIB variability (Table 2). For Puntarenas-1, 24-h daily average wave height and 48-h daily average sea level anomalies best explained FC variability, whereas 24-h daily average meridional wind velocity was identified as the parameter that substantially explained ENT variability. For the Puntarenas-2 area, 24-h daily average wave height was the most influential parameter explaining FC variability, whereas only 24-h cumulative precipitation substantially explained ENT variability. Lastly, at Puntarenas-3, only 24-h cumulative precipitation best explained the FC variability; 96-h daily average sea level anomalies explained the most amount of ENT variability.

Since all areas are located near rivers with poor microbial quality (Mora Alvarado, 2007, 2009), the increased rainfall and/or lower sea level (*i.e.,* negative sea level anomalies) likely increased the influence of the rivers on the beach areas, which increased FIB geometric means. Overall, the environmental variables that had the weakest correlations, or lacked a correlation all together, with FIB geometric means in this study included turbidity, DNI, and winds. Previous studies have identified significant correlations between FIB and the aforementioned parameters (Boehm et al., 2009b; Byappanahalli et al., 2012; Laureano-Rosario et al., 2017; Maraccini et al., 2016; Paule-Mercado et al., 2016; Rochelle-Newall et al., 2015). Thus, future work is needed to assess these relationships *in situ* given the possible lack of data resolution from satellites (Fisher et al., 2018).

To further explore environmental conditions associated with poor microbial water quality, permutation-based student *t*-tests were executed to test the null hypothesis that there was no significant difference between FIB and select environmental parameters on safe *versus* unsafe swimming days (iterations = 1000). For the environmental parameters most commonly used in the models, the previous 24 h of environmental parameter data were binned into two categories: days with and without elevated FIB concentrations, based on Costa Rican FIB thresholds for characterizing safe swimming conditions (Mora Alvarado, 2007). Similarly, the region periodically experiences storm and tidal surges (*La Llena*), which are identified as sea level > 3.2 m (Lizano and Lizano, 2010; Lizano, 1997). Since the use of sea level anomalies removes the periodicity associated with surges, significant differences in the previous 24 h maximum sea level for the days categorized as safe and unsafe for swimming were also evaluated to understand if this daily variability in sea level was associated with exceeding FIB criteria.

The safe and unsafe characterizations were based on each beach/beach areas' FIB geometric mean separately (*e.g.,* values below/above the geometric mean thresholds of 240 FC MPN/100 mL and 35 ENT MPN/100 mL). Based upon the daily ENT and FC geometric means, 40% and 29% of the total days were characterized as unsafe for swimming at Jacó beach, respectively. For Puntarenas beach, the following percentage of days were categorized as unsafe for swimming at Puntarenas-1, Puntarenas-2, and Puntarenas-3, respectively: 33%, 25%, and 27% based on daily ENT geometric means and 57%, 68%, and 27% based on daily FC geometric means.

Overall, days with FIB threshold exceedance were associated with higher 24-h cumulative precipitation, greater wave height, and/or lower negative daily average sea level anomalies. At Jacó beach, days identified as unsafe for swimming based on both FIBs' thresholds showed higher 24-h cumulative precipitation; however, only a significant difference was identified on days based on FC (Fig. S1A). Significantly lower than average sea level (*i.e.,* negative anomalies) was identified 24 h prior to days categorized unsafe for swimming based on both FIBs' thresholds at Jacó beach (Fig. S1B). In Puntarenas-1, swimming days categorized as unsafe by both FIB had lower negative daily average sea level anomalies 24 h prior (Fig. S2A), and days unsafe for swimming per FC had a higher median daily average wave height 24 h prior (Fig. S2B). For Puntarenas-2, higher median daily average wave height and cumulative precipitation were observed 24 h prior to days categorized as unsafe for swimming based on FC and ENT thresholds, respectively (Fig. S3). Based on FC for Puntareans-2, days categorized as unsafe for swimming had significantly higher daily average wave height 24 h prior (Fig. S3A). In Puntarenas-3, only cumulative precipitation and daily average sea level anomalies were significantly different 24 h prior to days categorized as safe and unsafe for swimming, and they followed the same trends previously mentioned (Fig. S4A).

When sea level periodicity was considered, a clear pattern of higher daily maximum sea level was observed 24 h prior to days categorized as unsafe for swimming based on FIB thresholds at both beaches; albeit, this pattern was not always statistically significant (Fig. S5). The lack of significant differences in daily maximum sea level, at some study sites, on safe and unsafe swimming days suggests that the data set may not have contained enough sea level observations greater than 3.2 m to observe statistical significance. Additionally, tidal- and storm-related

Table 1
The most parsimonious multiple linear regression (MLR) models with the environmental parameters identified by redundancy analysis minimizing the Akaike Information Criterion (AIC) that substantially explained fecal indicator bacteria variability at Jacó beach. The MLR *p*-value is shown at the top of the table, whereas individual *p*-values are shown in the table (α = 0.05).

Variable	b	t-stat	p-value
Fecal coliforms (r^2 = 0.24; $p < 0.05$; AIC = 19.45)			
Intercept	2.87	20.59	0.002
24 h Precipitation	0.63	4.51	0.002
Culturable enterococci (r^2 = 0.27; $p < 0.05$; AIC = −6.70)			
Intercept	2.144	18.783	0.002
24 h Precipitation	0.384	3.319	0.002
Average 72 h Sea level anomaly	−0.356	−3.082	0.002

Table 2
The most parsimonious multiple linear regression (MLR) models with the environmental parameters identified by redundancy analysis minimizing the Akaike Information Criterion (AIC) that substantially explained fecal indicator bacteria variability at Puntarenas beach. The MLR p-value is shown at the top of the table, whereas individual p-values are shown in the table (α = 0.05).

Variable	b	t-stat	p-value
Puntarenas 1			
Fecal coliforms (r^2 = 0.19; MLR p-value < 0.05; AIC = −20.91)			
Intercept	2.676	28.908	0.002
Average 24 h Wave height	0.381	4.088	0.002
Average 48 h Sea level anomaly	−0.250	−2.680	0.002
Culturable enterococci (r^2 = 0.12; MLR p-value < 0.05; AIC = 6.08)			
Intercept	2.184	15.909	0.002
Average 24 h Meridional wind velocity (v)	−0.397	−2.866	0.002
Puntarenas 2			
Fecal coliforms (r^2 = 0.26; MLR p-value < 0.05; AIC = 57.13)			
Intercept	4.082	16.234	0.002
Average 24 h Wave height	1.056	4.156	0.002
Culturable enterococci (r^2 = 0.18; MLR p-value < 0.05; AIC = −20.01)			
Intercept	1.907	14.928	0.002
24 h Precipitation	0.325	2.491	0.002
Puntarenas 3			
Fecal coliforms (r^2 = 0.17; MLR p-value < 0.05; AIC = 19.58)			
Intercept	2.537	20.338	0.002
24 h Precipitation	0.506	4.034	0.002
Culturable enterococci (r^2 = 0.12; MLR p-value < 0.05; AIC = 12.13)			
Intercept	2.135	11.934	0.002
Average 96 h Sea level anomaly	−0.448	−2.474	0.002

surges (sea level > 3.2 m), which in part are caused by local precipitation and sea level, never coincided 24 h prior to FIB monitoring. Future investigations that specifically include surges are needed to fully understand if and how maximum sea level 24 h prior is associated with exceeding FIB thresholds.

Since the frequency, duration, and severity of tidal- and storm-surges, precipitation, and wind events are predicted to increase in Costa Rica and worldwide due to climate change (Ashbolt, 2019; Lizano and Lizano, 2010), it is even more imperative to understand how environmental conditions may influence coastal microbial water quality to mitigate future effects. A maximum of 27% of the FIB variability was explained by environmental variables at Puntarenas and Jacó beach in this study, which is similar to previous studies from Jacó beach and other tropical beaches where models explained less than 50% of FIB variability (Gonzalez and Noble, 2014; Laureano-Rosario et al., 2017; González-Fernández et al., 2020). In this study, domestic wastewater pollution likely explained the remaining FIB variability because both beaches are situated in cities that lack adequate sanitation infrastructure (Mora Alvarado, 2007). It has been previously observed that untreated and undertreated wastewater from septic tanks and wastewater or stormwater collection networks can impact Jacó and Puntarenas beach coastal waters. During the period of this study, resident populations, including informal settlements along rivers and inlets, increased over time and floating populations (*i.e.*, tourists) varied over time (Instituto Nacional de Estadísticas y Censos, 2020); yet, it is unknown how the subsequent variability in wastewater production impacted beach water quality or the health of recreators at these beaches.

It is important to acknowledge that the censored data approach utilized in this study may have influenced the results. However, the use of geometric means likely minimized the influence of the left- and right-censored data substitutions, as previously demonstrated (Laureano-Rosario et al., 2017). Samples sizes also could have influenced the correlations and relationships between environmental parameters and FIB identified in this study ($17 \leq N \leq 89$). Limited sampling can represent challenges when investigating environmental trends in low- and middle-income countries (WHO, 2003). Nevertheless, the permutation-based RDA-AIC approach used here reduced collinearity and minimized the influence of sample size (Anderson et al., 2000; Radersma and Sheldon, 2015). This work shows the need for continued research and the application of appropriate data analyses in data-limited areas to improve our understanding of microbial water quality and the environmental conditions that correlate with its deterioration.

In this study, FC and ENT geometric means rarely classified the same day as unsafe for swimming; these inconsistencies among FIB were previously demonstrated outside the tropics (Noble et al., 2003) and in the tropics (Shibata et al., 2004). FIB do not always correlate with the presence of wastewater-related pathogens due to secondary extra-intestinal sources in the environment and differing decay/replication rates (summarized in Boehm et al., 2009a, Fujioka et al., 2015). The relationship between environmental parameters, wastewater-related pathogens, and microbial indicators can be complex; thus, it is necessary to consider all factors to understand the public health implications of high FIB concentrations (Boehm et al., 2009a; Rochelle-Newall et al., 2015). Future tropical microbial water quality studies should include sanitary assessments as well as reference pathogen and FIB measurements to better understand which FIB appropriately identify high-risk swimming days and the environmental conditions that are correlated with them (Verhougstraete et al., 2020). Understanding the variability and reliability of microbial indicators as they relate to human health risk is essential to help stakeholders target and protect public health (Boehm et al., 2009a; Rochelle-Newall et al., 2015).

Costa Rica currently lacks the necessary laws to define how beaches should be managed considering their microbial water quality. Nevertheless, coastal recreational microbial water quality is regularly characterized as a part of the National Blue Flag Program, promoting the safe use of beaches (Mora Alvarado, 2007). In this study, wastewater infrastructure and water quality monitoring occur under the same agency's oversight, and the region has a reasonable expectation that infrastructural solutions may be funded in the near future. To effectively address how the results of this study can be actioned, attention to local budgetary limitations, regulatory abilities, and environmental conditions is necessary.

CRediT authorship contribution statement

Abdiel E. Laureano-Rosario & Erin M. Symonds: Conceptualization, Methodology, Formal analysis, Visualization, Writing – Original Draft. **Adriana González-Fernández, Darner Mora Alvarado, Pablo Rivera Navarro, & Andrei Badilla-Aguilar**: Fieldwork, Data Compilation (fecal indicator bacteria), Writing – Reviewing & Editing. **Omar G. Lizano R.**: Data Compilation (sea level data), Writing – Reviewing & Editing. **Digna Rueda-Roa and Daniel B. Otis**: Satellite Data Compilation (*e.g.*, turbidity, precipitation) and Wind Components Analyses. **Maryann R. Cairns**: Demographic Data, Writing – Reviewing & Editing. **Valerie J. Harwood and Frank E. Muller-Karger**: Supervision, Resources, Writing – Reviewing & Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2020.111957.

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