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Climate Patterns Governing the Presence and Permanence of Salmonellae in Coastal Areas of Bahia de Todos Santos, Mexico[▽]

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Despite the importance of salmonellae as one of the major causes of food-borne infections worldwide, data regarding the presence of these organisms in the environment are limited. We investigated the presence of *Salmonella* spp. in Bahia de Todos Santos (Baja California, Mexico) and evaluated the environmental factors that affect the occurrence of *Salmonella* spp. in this arid region. A total of 1,331 samples collected from 21 sites along the coast during a period of 3 years were analyzed for *Salmonella* spp. Geographical and seasonal distribution of *Salmonella* spp. was evaluated in association with environmental parameters and with human infections in the area. The incidence of *Salmonella* bacteria throughout the study was 4.8%, with the highest incidence detected in wastewater (16.2%), followed by stream water (10.6%), mollusks (7.4%), and seawater (2.3%). Twenty different serotypes were identified among the 64 *Salmonella* isolates. The dominant serotype was Typhimurium (23.4%), followed by Vejle (6.2%). The presence of *Salmonella* spp. in coastal areas was mostly confined to rainy periods and areas of stream discharges, and runoff was identified as the predominant factor influencing the transport of *Salmonella* bacteria from source points to the sea via streams. Isolation of *Salmonella* spp. was negatively and significantly associated with temperature, probably because of the effect of solar radiation in the decline of permanence of *Salmonella* bacteria. Conversely, human infections prevailed during the warmest months and were negatively correlated with the presence of *Salmonella* spp. in the marine environment.

Salmonellae are one of the major causes of food-borne infections worldwide, associated with the ingestion of contaminated water or food of animal origin. *Salmonella* comprises more than 2,500 different serotypes included in the Kauffmann-White scheme (27), most of them belonging to *Salmonella enterica* subspecies *enterica*. Although all the serotypes are considered potentially pathogenic, only 50 serotypes are dominantly isolated from humans or animals, while the pathogenicity of most of the other infrequent serotypes isolated from the environmental or from clinical sources remains undefined (28). The results of large numbers of studies covering all the biological and epidemiological aspects of the dominant serotypes isolated from humans or animals also contrast with the limited data available regarding the distribution and characteristics of the serotypes present in the environment. This information is essential in assessing the roles of nonhost habitats in the transmission of *Salmonella enterica* and as natural reservoirs for this organism. The capacity of *Salmonella* bacteria to survive in the environment has been suggested as a critical step in the *Salmonella* life cycle, increasing the probability of colonizing new hosts (31).

Salmonella bacteria have been detected in a wide range of environments, such as water (1, 26), sewage effluents (21), and soil, where they can survive for long periods (6). The marine environment has traditionally been considered an adverse habitat for the survival of *Salmonella* spp., according to the low risk of food-borne illness for this pathogen in association with marine products (24). Nevertheless, *Salmonella* spp. are commonly isolated from seawater and seafood (1, 3, 10, 11, 19, 26, 30). Detection of enteric bacteria in coastal waters has been linked to periods of sporadic torrential rain discharge, whereby the contamination is transported from the source points to the sea via river water (1, 8, 20, 25). This relationship has been well established in temperate and tropical regions with climates characterized by long periods of heavy rainfall (23). However, there is a complete lack of information about the occurrence of *Salmonella* bacteria in the coastal areas of dry regions of the world with scarce rains and warm temperatures and where other variables may modulate the presence and permanence of this pathogen in the sea.

In order to assess the dynamics of contamination of *Salmonella* spp. in arid regions, we conducted a study of the presence of these organisms along the coast of Bahia de Todos Santos (Todos Santos Bay) in Mexico, a country with high rates of reported cases of *Salmonella* infections (9). Bahia de Todos Santos is located on the Pacific coast of Baja California and is influenced by cold seawater currents that contrast with the elevated temperatures inland. The climatic pattern is notably different from other previously investigated warm areas of the world, such as tropical regions, where the presence of rain and warm seawater provide different environmental conditions for the presence of *Salmonella* spp. The aim of the present study was to evaluate the environmental factors that influence the pattern of contamination of *Salmonella* bacteria in the marine environment in a region with high temperatures and scarce rainfall and characterized by the presence of cold seawater, evaluating additionally the association between the pattern of

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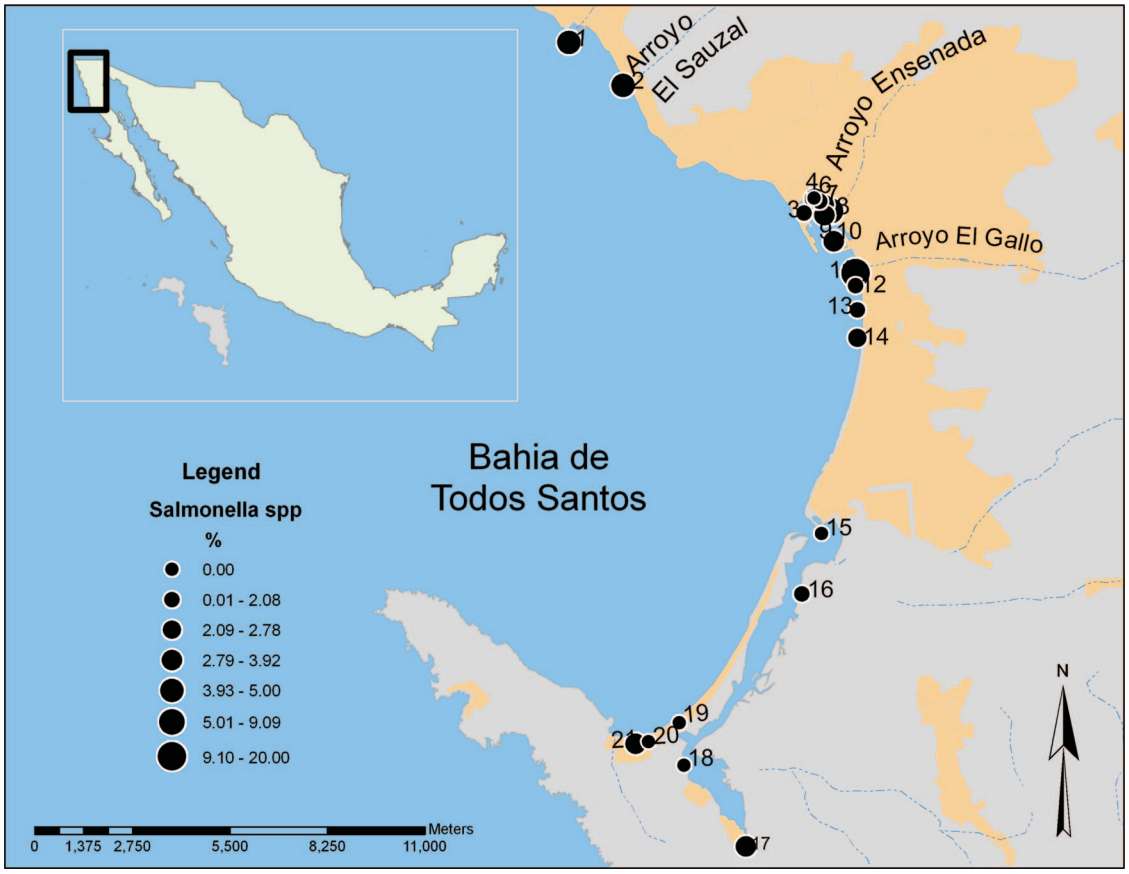

FIG. 1. Area of study and locations of the sampling stations in Bahia de Todos Santos and spatial distribution of presence of *Salmonella* species throughout the study period (2004 to 2006) in the different sampling sites according to GIS results.

contamination and the rates and dynamics of human infections in the area.

MATERIALS AND METHODS

Study area. Bahia de Todos Santos (Todos Santos Bay) is located on the Pacific coast of Baja California (Mexico) and covers an area of approximately 180 km^2 (Fig. 1). The central area of the bay is occupied by the municipality of Ensenada (a population of 413,481 in 2005 [12]). The climate in Bahia de Todos Santos is characteristically temperate and dry, with an average annual temperature of 18°C (a minimum 12.3°C in March and a maximum of 23.8°C in July) and low annual rainfall values of 250 mm (a monthly average of 10 mm). The rainy season is highly variable, although rains are most frequent in the last weeks of fall and during the winter months. Streams flowing into Bahia de Todos Santos are characteristically temporary, with water present only during the rainy periods. However, the El Gallo stream flows throughout the year, owing to a permanent influx of sewage discharge effluents from one of Esenada's primary treatment plants.

Sampling program. A total of 1,331 samples were collected between October 2004 and July 2006 for analysis of *Salmonella* spp. Samples were collected from 21 fixed sites located along the coast of Bahia de Todos Santos (Fig. 1). Sample stations were selected according to their proximities to streams and sewage treatment discharges and the concentration of humans and livestock in the area. Additionally, random samples of mollusks, water discharges, puddles, and wastewater were collected throughout the area to complement the information obtained from the study of the fixed sites.

Analysis for *Salmonella* isolates. Samples were collected in sterile containers and transported to the laboratory under refrigeration. The presence of *Salmonella* spp. was determined according to the ISO 6579:1993 standard method (13). For liquid samples, 100 ml was filtered through 0.45-μm sterile filters (Millipore Corporation, Bedford, MA); filters were added to 225 ml of buffered peptone water (BPW) (Merck, Darmstadt, Germany). For solid samples, 25 g of sample product was added to 225 ml of BPW (Merck), and mixed for 90 s with a Stomacher homogenizer. Inoculated BPW broths were incubated at 37°C for 20 h. Ten milliliters of preenriched cultures was then transferred to 100 ml of selenite cystine broth (Difco, Detroit, MI), 0.1 ml was transferred to 10 ml of RV10 Rappaport-Vassiliadis broth (Difco), and they were incubated at 37°C and 42°C, respectively, for 24 h. Selective enrichments were streaked onto Hektoen enteric agar (Difco), phenol red-brilliant green agar (Difco), and bismuth sulfite agar (Difco) and incubated at 37°C for 24 h (if only slight growth was observed, the plates were reincubated for an additional 24 h). Typical colonies were selected and streaked onto nutrient agar and subjected to initial biochemical screening in triple sugar iron agar (Difco). Cultures showing a reaction typical of *Salmonella* bacteria—an alkaline slant and acid butt, with or without production of H_2S—were confirmed by biochemical tests on an API-20E strip (bioMérieux, Marcy-l'Etoile, France) and PCR analysis by the amplification of 284 bp of the *invA* gene according to the protocol of Malorny et al. (16).

***Salmonella* serotyping.** All *Salmonella* isolates were serotyped by seroagglutination with commercial antisera (Statens Serum Institut, Copenhagen, Denmark). Polyvalent *Salmonella* O and H antisera were used to obtain a presumptive diagnosis, and the definitive antigenic designation was then determined with monovalent antisera.

Environmental parameters. The environmental parameters considered in the study were as follows: temperature, wind, hours of sunshine per day, atmospheric pressure, relative humidity, solar radiation, and rainfall. The daily ambient temperature was taken as the minimum, maximum, and average of the temperature registered in a day. Wind direction was measured as the time in hours that the wind blew in each of the four prevailing quadrants (northwest, northeast, southwest, and southeast) or was measured as no wind (calm). Wind speed was expressed as kilometers per day. Atmospheric pressure was measured in pascals, while relative humidity was expressed as a percentage and solar radiation as Watts per square meter (W/m^2). Rainfall was measured as millimeters of pre-

TABLE 1. Number of samples and incidence of *Salmonella* spp. throughout the period of study per type of sample

Yr	Mo	No. of samples (% positive for *Salmonella* spp.)					Total (%)
		Stream water	Seawater	Sewage water	Mollusks	Puddles	
2004	October	0	1 (0)	14 (0)	0	0	15 (0)
	November	24 (8.3)	69 (0)	4 (0)	11 (0)	0	108 (1.8)
	December	8 (0)	32 (0)	0	8 (0)	0	48 (0)
Total		32 (6.3)	102 (0)	18 (0)	19 (0)	0	171 (1.2)
2005	January	25 (20)	78 (7.7)	3 (60)	6 (16.7)	0	114 (13.2)
	February	12 (0)	31 (0)	3 (0)	2 (0)	0	48 (0)
	March	0	0	0	0	0	0
	April	12 (8.3)	46 (4.3)	1 (100)	0	0	59 (14.8)
	May	3 (0)	16 (0)	0	0	0	19 (0)
	June	20 (5)	90 (2.2)	4 (25)	0	0	114 (3.5)
	July	8 (0)	39 (0)	1 (100)	0	1 (0)	49 (2)
	August	9 (11.1)	60 (3.3)	2 (0)	0	0	71 (4.2)
	September	11 (0)	79 (0)	1 (0)	0	0	91 (0)
	October	13 (7.7)	73 (0)	1 (100)	0	0	87 (2.3)
	November	8 (12.5)	34 (0)	5 (20)	0	0	47 (4.2)
	December	4 (0)	18 (0)	0	4 (0)	0	26 (0)
Total		125 (8)	564 (2.1)	23 (34.8)	12 (8.3)	1 (0)	725 (4.3)
2006	January	8 (50)	33 (0)	4 (25)	0	0	45 (11.1)
	February	14 (7.15)	52 (0)	10 (20)	11 (0)	11 (9.1)	98 (3.1)
	March	12 (16.6)	63 (12.7)	5 (0)	18 (22.2)	2 (0)	100 (14)
	April	9 (22.2)	33 (6)	2 (50)	6 (0)	3 (66.7)	53 (13.2)
	May	7 (28.6)	52 (0)	1 (0)	2 (0)	0	62 (3.2)
	June	6 (0)	46 (0)	2 (0)	0	0	54 (0)
	July	3 (0)	17 (0)	3 (0)	0	0	23 (0)
Total		59 (18.6)	296 (3.4)	27 (11.1)	37 (10.8)	16 (18.75)	435 (7.1)
Total		216 (10.6)	962 (2.3)	68 (16.2)	68 (7.4)	17 (17.6)	1,331 (4.8)

cipitation per day. All the variable data except rainfall were obtained from the weather station of the Instituto de Investigaciones Oceanlogicas of the University Autonoma of Baja California, located in Ensenada (116°39′58″W and 31°51′46″N). Rainfall data were provided by the Comision Nacional de Agua and were collected from the weather station of Emilio Lopez Zamora. (116°36′12″W and 31°53′29″N).

Additionally, data for discharges from the sewage treatment plants (liters/s) provided by the Comision Estatal de Servicios Publicos de Ensenada were obtained from the facility of Naranjo-Gallo. This facility discharges its effluents in close proximity to the sea through the El Gallo stream.

Human infections. Information about the number of cases of human nontyphoid and typhoid *Salmonella* spp. infections recorded in Baja California was inferred from the records reported in the weekly *Epidemiological Bulletin* published by the Sistema Unico de Información para la Vigilancia Epidemiológica of the Secretaría de Salud Publica in Mexico (Public Health Department) (5).

Spatial analysis. Results of the analyses were processed with the Geographical Information System (GIS) software, ArcGIS version 9.1, and the extension Spatial Analyst by ESRI. The formats of the data were Shapefile (vector data) and GRID (raster data) by ESRI, and the vector data source was the Instituto Nacional de Estadistica Geografica e Informatica of Mexico (INEGI).

Statistical analysis. The differences in the frequencies of *Salmonella* spp. present at different sites and periods were evaluated by the chi-square and Fisher's exact tests.

The associations between environmental factors and presence of *Salmonella* spp. were initially analyzed by Pearson correlation coefficients with weekly average values of incidence. Relationships between the presence of *Salmonella* spp. and each of the environmental parameters included in the study were initially surveyed by simple logistic regression analysis. Once the significant variables at an individual level were selected, a multiple logistic regression model was then conducted. Predicted probability and odds ratios were estimated by logistic regression analysis. The odds ratio is defined as the predicted change in odds for a unit increase in the corresponding independent variable.

All statistical analyses were carried out with SPSS version 14.0.1 (SPSS Inc.), and the level of significance was set at a P value of <0.05.

RESULTS

The overall incidence of *Salmonella* bacteria in Bahia de Todos Santos throughout the period of study (2004 to 2006) was 4.8%, with a total of 64 positive samples of the 1,331 analyzed (Table 1). The highest incidence of *Salmonella* bacteria was detected in wastewater, with 11 positive samples of the 68 analyzed (16.2%); followed by stream water, with 23 positive samples (10.6%); mollusks, with 5 positive samples (7.4%); and seawater, with 22 positive samples (2.3%). The analysis of a small number of samples of puddle water revealed the presence of *Salmonella* bacteria in 17.6% of the samples. Puddle water, wastewater, and stream water showed a significantly higher incidence of *Salmonella* bacteria than the other groups analyzed ($P < 0.05$).

The incidence of *Salmonella* bacteria in the 171 samples investigated between October and December 2004 was 1.2% (Table 1), which was significantly lower than that of the other years of study. In 2005, *Salmonella* bacteria were detected in 31 samples of the 725 investigated (4.3%), whereas the incidence of *Salmonella* bacteria in 2006 was significantly higher than in other years, with 31 positive samples from a total of 435 samples (7.1%) obtained between January and July. The month

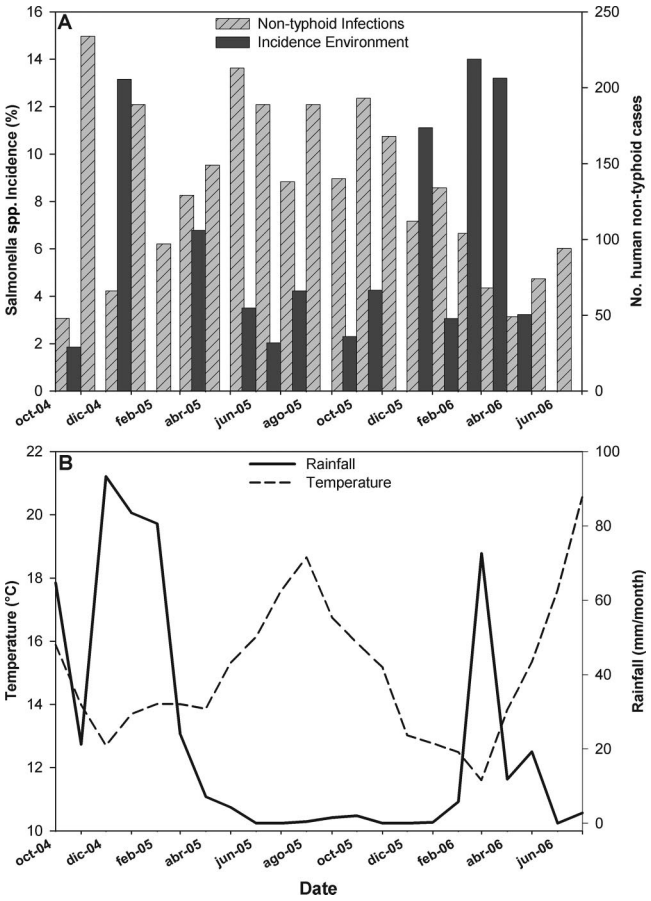

FIG. 2. Monthly distribution of incidence of *Salmonella* species in Bahia de Todos los Santos and human infections of *Salmonella* reported in Baja California throughout the 3-year study (A) and variations in rainfall and temperature throughout the same period (B). oct, October; dic, December; feb, February; abr, April; jun, June; ago, August.

with the highest incidence of *Salmonella* bacteria was April 2005 (Table 1; Fig. 2) when 8 of 59 samples (14.8%) tested positive. Significantly greater differences ($P < 0.05$) were also observed in January 2005 (13.2%) and March 2006 (14%). A high presence of *Salmonella* bacteria (13.2%) was also observed in samples in April 2006, although it was not significantly higher than at other sampling times.

Results obtained from the 21 fixed sample stations located along the coast of Bahia de Todos Santos (Table 2) over the period of study showed a significantly higher incidence ($P < 0.05$) of *Salmonella* bacteria at sites 11 (Arroyo El Gallo) and 8 (Arroyo Ensenada), with 11 (20%) and 5 (9.3%) positive samples, respectively. The site with the second-highest presence of *Salmonella* bacteria was Arroyo Sauzal (sampling station 2), with an incidence of 5% in the 40 samples investigated. An association between the presence of *Salmonella* spp. and areas of stream discharge was also observed by GIS analysis (Fig. 1). *Salmonella* bacteria were detected mostly in close proximity to streams, and the incidence decreased gradually as the distance from the point increased.

Only 45 of the 64 *Salmonella* isolates obtained throughout the study were able to be characterized by serotyping (Table 3). Twenty different serotypes were identified among the 45 isolates. The dominant serotype was *Salmonella enterica* serotype Typhimurium, identified in 15 isolates (23.4%) obtained primarily from stream water samples. The remaining isolates showed highly diverse serovar profiles, with 19 different serotypes determined in 30 isolates. The serotypes Vejle (four isolates), Suberu (three isolates), and Urbana (three isolates) were the most abundant in this group. The 19 untyped isolates showed a rugose phenotype and originated mainly from marine environments.

The rain pattern in Bahia de Todos Santos proved to be highly irregular over the period of study. Rainfall was significantly higher ($P < 0.05$) in 2004 than in 2005 or 2006. The heaviest rains were recorded in October and December 2004, January and February 2005, and March 2006, although the difference was only statistically significant in October 2004. The greatest number of *Salmonella* isolates coincided with the months of highest rainfall (Fig. 2). Temperatures in 2004 were significantly lower than those in 2005 and 2006. The warmest year was 2005, although the temperatures were only significantly higher than those in 2004. The warmest periods occurred between May and October 2005 and in June and July 2006.

Interactions between the daily incidence of *Salmonella* bacteria in Bahia de Todos Santos and the environmental factors were initially examined by correlation analysis (Table 4). The presence of *Salmonella* spp. was positively and significantly correlated ($P < 0.05$) with rainfall 1 and 2 days before sample collection and with the accumulated rainfall during the 3 days

TABLE 2. Number of samples analyzed and *Salmonella* incidence per year and sampling site

Sampling site	No. of samples (% positive for *Salmonella* spp.)			Total	
	2004	2005	2006	No. of samples	No. of samples positive for *Salmonella* spp. (%)
1	7 (0)	30 (6.7)	10 (0)	47	2 (4.3)
2	12 (0)	22 (0)	6 (33.3)	40	2 (5)
3	5 (0)	32 (3.1)	18 (0)	55	1 (1.8)
4	7 (0)	31 (0)	17 (0)	55	0 (0)
5	7 (0)	32 (3.1)	18 (5.6)	57	2 (3.5)
6	7 (0)	23 (0)	18 (5.6)	48	1 (2.1)
7	3 (0)	33 (6.1)	18 (0)	54	2 (3.7)
8	7 (14.3)	32 (9.4)	16 (6.3)	55	5 (9.1)
9	5 (0)	32 (0)	17 (11.8)	54	2 (3.7)
10	5 (0)	32 (6.3)	18 (0)	55	2 (3.6)
11	7 (14.3)	31 (16.1)	17 (29.4)	55	11 (20)
12	7 (0)	31 (3.2)	17 (0)	55	1 (1.8)
13	7 (0)	32 (0)	17 (6)	56	1 (1.8)
14		19 (0)	17 (6)	36	1 (2.8)
15	7 (0)	32 (0)	17 (0)	56	0 (0)
16	6 (0)	31 (3.2)	16 (0)	53	1 (1.9)
17	7 (0)	27 (0)	17 (11.8)	51	2 (4)
18	7 (0)	6 (0)	1 (0)	14	0 (0)
19		23 (0)	18 (0)	41	0 (0)
20	8 (0)	25 (0)	17 (0)	50	0 (0)
21	7 (0)	32 (3.1)	17 (6)	56	2 (3.6)
Other	43 (0)	137 (8.8)	108 (13)	288	26 (9.1)
Total	171 (1.2)	725 (4.3)	435 (7.1)	1,331	64 (4.8)

TABLE 3. Distribution of serotypes among the *Salmonella* isolates obtained throughout the study per type of sample

Serotype	No. of isolates per sample type					Total (%)
	Stream water	Seawater	Sewage water	Mollusks	Puddles	
Typhimurium	9	4	2	0	0	15 (23.4)
Vejle	2	1	1	0	0	4 (6.2)
Suberu	2	1	0	0	0	3 (4.7)
Urbana	3	0	0	0	0	3 (4.7)
Galiema	0	2	0	0	0	2 (3.1)
Othmarschem	1	1	0	0	0	2 (3.1)
Soerenga	1	0	1	0	0	2 (3.1)
Tonev	0	1	0	1	0	2 (3.1)
Amherstiana	0	0	0	0	1	1 (1.6)
Augustenborg	1	0	0	0	0	1 (1.6)
Breda	1	0	0	0	0	1 (1.6)
Bulovka	0	1	0	0	0	1 (1.6)
Coeln	1	0	0	0	0	1 (1.6)
Corvallis	0	0	1	0	0	1 (1.6)
Djugu	1	0	0	0	0	1 (1.6)
Nchanga	0	0	1	0	0	1 (1.6)
Nitra	0	0	1	0	0	1 (1.6)
Stanley	0	1	0	0	0	1 (1.6)
Stanleyville	0	0	1	0	0	1 (1.6)
Winnipeg	0	0	0	1	0	1 (1.6)
Salmonella spp.	1	10	2	3	3	19 (29.7)
Total	23	22	10	5	4	64

prior to sample collection. There was a negative significant association with registered temperatures on the day of collection and the day before the sample collection, whether the maximum, minimum, or averaged values of temperature were considered, along with the relative humidity on the day of the sample collection. The highest significant association was observed with rainfall the day before the sampling day, with a correlation coefficient of 0.349 ($P < 0.01$).

The model obtained by simple logistic regression analysis showed a Nagelkerke r-square value of 0.145 and identified the presence of rain during the 2 days prior to sample collection as the dominant factor in the model, with a highly significant positive effect on the presence of *Salmonella* spp. in Bahia de Todos Santos ($P < 0.00001$, 1 day before; $P < 0.001$, 2 days before). The model also revealed a positive significant association ($P < 0.05$) with winds on the day of the sample collection and a negative relationship with the average temperature on the day of the sample collection.

The comparison of the data obtained in this study with the number of cases of human nontyphoid and typhoid *Salmonella* infections recorded in Baja California over the same period showed an inverse relationship between the presence of *Salmonella* spp. in coastal areas and the dynamics of infections in the region (Fig. 2). The weekly incidence of *Salmonella* bacteria in coastal environments was negatively and significantly associated ($P < 0.05$) with the weekly number of nontyphoid and typhoid cases, with correlation coefficients of −0.254 and −0.261, respectively. Human infections prevailed in the warmest months of the year, whereas the presence of *Salmonella* bacteria in the environment was governed primarily by rainy periods during the coldest periods.

TABLE 4. Correlation coefficient values for the presence of *Salmonella* spp. in Bahia de Todos Santos and different environmental parameters

Environmental parameter	Correlation coefficient[a]			
	0	1	2	3
Wind speed	0.194	0.107	0.105	−0.035
Wind direction	0.025	0.067	−0.052	0.009
Temp	−0.315**	−0.310**	−0.287*	−0.164
Maximum temp	−0.309**	−0.332**	−0.278*	−0.172
Minimum temp	−0.306**	−0.268*	−0.163	−0.103
Rainfall	0.167	0.349**	0.279*	0.004
Atmospheric pressure	0.210	0.177	0.023	0.176
Relative humidity	−0.308**	−0.131	−0.076	−0.118
Radiation	0.122	0.091	−0.031	0.035
Sun exposure	−0.036	−0.047	−0.050	−0.053
Sewage flow	0.097	0.207	0.175	0.119

[a] 0, day of sample collection; 1, 1 day before sampling date; 2, 2 days before sampling date; 3, 3 days before sampling date; *, significant correlation at a P value of <0.05; **, significant correlation at a P value of <0.01.

DISCUSSION

The presence of *Salmonella* bacteria is an important public health issue in Mexico, with high rates of infection reported annually. The number of recorded cases varies greatly from one year to the next among different states in the country. In 1994, a total of 100,342 infections were reported in Mexico (111.21 cases per 100,000 people), whereas nearly twice the number of cases were recorded in 1998 (215,155 cases; a rate of 223.53 per 100,000 people) (9). Similar values were obtained between 2003 and 2005, with the number of infections reaching 106,000 cases, an average rate of 102.7 cases per 100,000 people (5). These values are significantly higher than those reported for other parts of the world, such as the United States with 17.7 cases per 100,000 people in 1999 (15), the European Union with 35 cases per 100,000 people in 2006 (7), and New Zealand with 32.3 cases per 100,000 people in 2006 (22). During the same period, the number of infections reported in Baja California was lower than the national rate, although it remained elevated, with a mean value of 70 cases per 100,000 people, which represented 1.8% of all cases reported for the entire country. The low number of cases reported in Baja California, a warm location with scarce rainfall, contrasts with the number of infections recorded in other Mexican states with extreme climates and high temperatures, such as Chihuahua, where incidences of *Salmonella* infection reached 850 cases per 100,000 people, which represents 14% of the total number of cases reported in Mexico (5).

The results obtained in the present study reflect a low incidence of *Salmonella* bacteria in the coastal environments of Bahia Todos los Santos, with an overall value of 4.8% throughout the 22 sampling months. Similar low levels of *Salmonella* presence were obtained in marine samples from regions with similar oceanographic conditions to Baja California and temperate seawater temperatures, such as Galicia (northwest Spain), the United States, and the United Kingdom, which have incidences of 2.4%, 7.4%, and 8%, respectively (2, 20, 30), far from the values obtained in tropical or warm seawater areas where *Salmonella* incidence in seafood can reach up to 20% (10, 11, 19).

Isolation of *Salmonella* spp. in the coastal environments of Bahia Todos los Santos was significantly and negatively associated with atmospheric temperature. Conversely, atmospheric temperature was the parameter that modulated human infections during the same period in this area, with cases peaking during the warmer months. The presence of *Salmonella* spp. in this study was associated primarily with rainy periods and confined to areas close to stream discharges. Similar associations between storm-generated flows, torrential rains, and the monsoon season have been reported in previous studies in temperate and tropical regions of the world with frequent rainy periods (1, 2, 10, 14, 19, 25, 29), signaling the washing effect of torrential rains as one of the principal environmental drivers of *Salmonella* contamination in coastal areas (19). According to the pattern observed in Bahia Todos los Santos, the arrival of *Salmonella* spp. into marine environments was predominantly governed by the presence of rains persistent enough to transport the contamination from the original source points to the sea via streams, whereas the permanence of *Salmonella* contamination in coastal areas appears to have been modulated by a combination of oceanographic characteristics and atmospheric conditions related primarily to the effects of sunlight. Bahia Todos los Santos has a semiarid climate with warm temperatures accompanied by rains restricted to only a few days throughout the year that restore water flow along dry streams for short periods. According to the results of the present study, *Salmonella* spp. were only detected if rain occurred on the days prior to sampling and the presence of *Salmonella* spp. was especially marked if rainy conditions prevailed for several consecutive days. Alternatively, the occurrence of rain on the day of the sample collection alone did not have any effect on the detection of *Salmonella* species.

Once the contamination reached the sea, the presence of *Salmonella* spp. was affected mainly by atmospheric conditions on the day of the sample collection, primarily recorded temperatures and winds. In contrast to observations for human infection, high temperatures in the Bahia Todos los Santos had a negative effect on the occurrence of *Salmonella* spp., which may be linked to the effect of sunlight on the survival of bacteria. In Mexico, solar radiation reaches maximum values in the northwestern states, with annual average values for Baja California ranging from 6 to 7 kWh/m^2/day. The incoming fresh water from streams characteristically spreads to the sea surface because of its lower density, thereby exposing the bacteria trapped in the water to the direct deleterious effect of solar radiation. A similar association may be suggested for the favorable effect of the wind on the same sampling day, since the presence of strong winds causes turbulence and waves on the sea surface that reduce the penetration of sunlight and its bactericidal effect. Additionally, seawater temperature may play a secondary role in the long-term survival rate of *Salmonella* bacteria. The presence of cold waters may reduce the permanence of *Salmonella* spp. in the marine environment, while warm waters together with high levels of organic matter—i.e., typical conditions in tropical coastal areas—may contribute to a more appropriate habitat for an increased survival of bacteria, as reflected in the disparate incidence of *Salmonella* spp. described in diverse studies in temperate and tropical regions (2, 10, 11, 20, 30).

Previous studies of the presence of *Salmonella* spp. in marine environments characteristically identified a maximum of 20 different serovars, independent of the number of samples processed or strains isolated (18). Serovar Typhimurium has been shown to be the most common clinically significant serovar isolated from marine samples in different parts of the world (1, 3, 20, 26, 30), probably because of its enhanced capacity for adaptation and survival in saline environments (1). A similar pattern was also observed in the present investigation, with 20 serovars identified among the *Salmonella* isolates and a clear dominance of serovar Typhimurium among the strains recovered. Serovar Typhimurium is the most common serovar isolated from human sources in Mexico (9, 32) and also predominates in animals and in meat products (32). The different seasonal relationship between human infections and *Salmonella* contamination observed in Bahia Todos los Santos may suggest a nonhuman origin for the *Salmonella* serovar Typhimurium contamination detected in coastal areas. There is significant livestock production in the area surrounding Bahia Todos los Santos, and there are several ranches located in the vicinity. The rainfall that occurs after long periods of drought probably carries animal waste from source points to streams and finally to the sea. These results contrast with data from previous studies carried out in the United States and Spain (2, 20), in which a different serotype dominance was reported in marine environments and humans. Whereas the serovars Typhimurium and Enteritidis are the major serotypes isolated from humans in both countries (4, 20), serovar Newport prevailed in oysters collected in the United States, and serovar Senftenberg prevailed in shellfish from northwest Spain. This distinctive pattern may be related to the relative epidemiological or zoonotic importance of these serovars in the regions investigated and may have biased the serotype distribution present in the sea (17).

In conclusion, rain has shown to be the distinctive factor influencing the transport of *Salmonella* contamination from source points to the sea in the arid region of Baja California. A similar pattern has been described for both rainy temperate and tropical regions of the world, signaling runoff as a universal environmental driver for the presence of *Salmonella* spp. in the marine environment. Furthermore, the intense sunlight prevailing in Bahia Todos los Santos emerges as a critical variable for the drastic reduction of the permanence of *Salmonella* spp. in the sea. The integration of the major environmental factors governing the dynamics of contamination of *Salmonella* spp. in the sea in the surveillance programs of coastal areas and shellfish may greatly contribute to the development of improved and more operative risk management systems.

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