Disturbance hotspots and their impact on shorebird abundance for Mexico to Chile, 2016–2023

Summary Report

To

Point Blue Conservation Science

By

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INTRODUCTION

The Pacific Coast of the Americas supports entire populations of neotropical migratory shorebird species during winter and migration. Shorebirds migrate bi-annually between their breeding grounds in the northern part of the continent and the wintering grounds in Mexico, Central, and South America. They have no option but to congregate at a few places to spend the winter or to rest and recuperate during their migration, and are thus reliant upon a network of coastal and interior wetland ecosystems.

Analyses of population trends indicates that 30% of these shorebird species have declined significantly in recent decades. Although the causes or mechanisms of such population declines are not known, it is presumed that the causes are widespread, as several different species are involved and especially those with broad winter distribution. The probable causes of their population declines include climate change, pollution, human disturbance, predation risk, and habitat loss and degradation.

Potential disturbance from human activities has been identified by the Pacific Americas Shorebird Conservation Strategy (PASCS; Senner *et al*. 2016), shorebird researchers, and land managers as one of the most important threats facing shorebirds along the Pacific Flyway. Human disturbance of shorebirds is defined as "a human activity that causes an individual or group of shorebirds to alter their normal behavior, leading to an additional energy expenditure by the birds. It disrupts or prevents shorebirds from effectively using important habitats and from conducting the activities of their annual cycle that would occur in the absence of humans. Productivity and survival rates may also be reduced" (Mengak and Dayer 2020).

The human disturbance hypothesis (Reiter *et al*. 2020) postulates that the disturbance caused by human activities reduces the time available for shorebirds to accumulate fat for winter survival and migration. As a result, shorebirds will take longer to acquire fat or are forced to move into habitats of lesser quality, where they can forage without being disturbed. The disturbance can also provoke an increase in energy expenditure for the extra time on flight. For example, for Sanderling (*Calidris alba*) the time spent feeding is less in the presence of people, since they invest energy in run or fly due to human activities (Burger and Gochfeld 1991). Ultimately the hypothesis predicts that shorebird abundance should be lower in sites that have higher rates of human disturbance (Mengak *et al.* 2019). A previous localized study in Ensenada de la Paz, Mexico indicated that shorebird abundance during migration and over-winter may be significantly lower at places with higher rates of human disturbance (Palacios *et al*. 2022). More recently, Heredia-Morales *et al*. (2024) found that during migration shorebird abundance is negatively associated with human disturbance in Bahía Todos Santos, Mexico.

The Migratory Shorebird Project (MSP; Reiter *et al*. 2020) offers the opportunity to make a diagnosis of the importance of human disturbance at local, regional, and international scales, because it is the largest coordinated survey ever of wintering shorebirds on the Pacific Coast of the Americas. The MSP was initiated in 2011 and is a cooperative effort of conservation science organizations and agencies led by Point Blue Conservation Science. One of the goals of the Migratory Shorebird Project is to evaluate the principal factors that are influencing shorebird populations and make science-based recommendations and act to conserve and protect shorebirds and wetlands from the flyway to the site level. The Migratory Shorebird Project has been collecting data on disturbance since 2016 to the present to better understand its impact on shorebirds.

Palacios and Reiter (2020) summarized disturbance data from the Migratory Shorebird Project from Mexico to Chile for the period of 2016 to 2019. The most common sources of potential disturbance across MSP sites were people recreating at the beach, dogs, and fishermen; and the rate of potential human disturbances was highest in Chile, Peru, Ecuador, El Salvador, and Mexico (particularly the Baja California peninsula). Overall, 12 of 84 sites in the MSP network had potential human disturbance in >50% of surveyed units. Now, we want to ask whether the impact of potential human disturbances on shorebird abundance is consistent across sites from Mexico to Chile. In order to address this research question, we first needed to assess the data available and identify disturbance hotspots for Mexico to Chile based on the information collected, compiled and analyzed from our shorebird population monitoring and research.

In this summary report, we analyzed the Migratory Shorebird Project data to assess which surveyed sites in the network across Latin America have the most human disturbance. We used data collected annually from 2016 through 2023 to characterize the disturbance landscape and to identify hotspots of potential disturbance. We followed the analytical approach of Palacios et al. (2022) to quantify the impact of potential human disturbance on shorebird abundance while accounting for habitat differences and differences in natural disturbance rates (e.g., predators). Because we have a relatively large data set, we also tried to differentiate the impact of various types of potential human disturbances (e.g., dogs vs. persons vs. vehicles). We will use these analyses to determine which sites are experiencing the biggest impacts and what conservation actions are needed given the predominant local disturbances

This information is essential to develop management actions for the conservation of shorebirds and their habitats in the Pacific Flyway of the Americas.

METHODOLOGY

Since the winter of 2011 a standardized shorebird monitoring protocol has been developed and currently has been implemented in 13 countries along the Pacific coast of the Americas as part of the MSP. In 2016 MSP partners from Mexico to Chile added a component of disturbance monitoring to MSP surveys. This standardized monitoring protocol is a spatial cross-sectional design, in which a number of sampling units were established at each survey site. Sampling units are well defined areas delimited by a polygon on the map of each site (Fig. 1). Each sampling unit is an area where shorebird surveys are conducted annually. Additional information on human disturbance, predators, and other habitat variables such as vegetation, tides, and environmental parameters are also measured. Specifically, for disturbance we recorded the number of potential human causes of disturbance (people, vehicles, dogs, watercraft, and aircraft) observed during the time we are surveying shorebirds. The standardization of the monitoring protocol along the Pacific Flyway allows the analysis of trends in distribution and magnitude of disturbance at the local and regional scale.

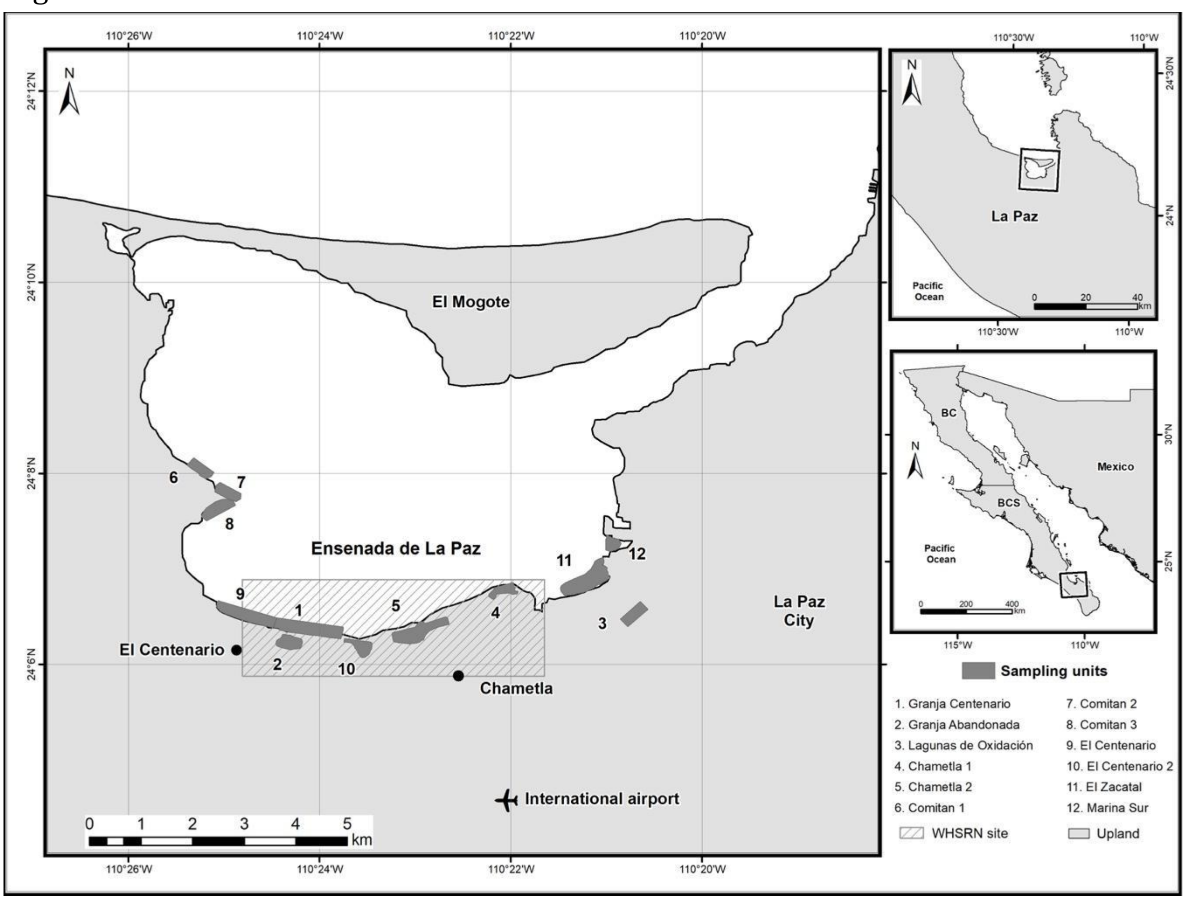

Figure 1. Examples of sampling units for shorebird and human disturbance surveys at one monitoring site (Ensenada de La Paz, Baja California Sur, Mexico).

Although shorebird counts as part of the Migratory Shorebird Project started in the winter of 2011, concurrent assessments of shorebird abundance and human disturbance were not incorporated until 2016. Since then, assessments have been conducted in 11 Pacific Flyway countries, from Mexico to Chile. Mexico was subdivided into two regions, Baja California peninsula and mainland Mexico, because the number of sites and observation effort has been greater than in other countries. The number of years over which monitoring of disturbance has occurred is variable in each country, but all evaluations have been carried out during winter (December – February) and following the same protocol. The survey effort as measured by number of sites, number of sampling units during the study period, total observation time and average of the observation time spent in each sampling unit is significant but variable between countries (Table 1).

Table 1. Observation effort at each country to document human disturbance and aerial predators along the Pacific Flyway, as part of the Migratory Shorebird Project, during winters of 2016 through 2023. Total number of sampling units include all units surveyed during the study period for each country or region. Total number of sampling units are sampling unit per year.

Country (period)	Sites	Total No. of sampling units	Total observation time (min)	Mean observation time at a unit
Baja California Peninsula (2016-2023)	12	1,285	24,604	19.3
Mainland Mexico (2016-2023)	23	1,103	35,349	32.1
Guatemala (2019-2023)	17	287	8,213	29.0
Honduras (2017-2023)	1	115	9,327	81.1
El Salvador (2017-2023)	4	211	11,586	51.1
Nicaragua (2016-2023)	25	271	21,836	81.0
Costa Rica (2018-2022)	7	141	1,124	8.0
Panama (2016-2023)	5	177	7,951	45.0
Colombia (2016-2023)	11	544	13,055	24.0
Ecuador (2016-2023)	6	385	17,222	44.7

Peru (2016-2023)	10	329	21,492	65.0
Chile (2017-2023)	7	395	6,033	15.2
TOTAL	**128**	**5,243**	**177,792**	**41.3**

Data Analyses

We used generalized linear mixed models (GLMM; Zuur et al. 2009) to investigate associations between the count of shorebirds in each sampling unit and potential human disturbance (events/minute). The unit of replication was shorebird count in a single sampling unit on a single visit. The area (ha) of the sampling unit was included in the model as an offset term to control for varying sized sampling areas among replicates. We included sampling units as a random effect in our models to account for correlation in repeated shorebird counts of the same unit. We assumed a zero-inflated negative binomial distribution given the excess of zero counts in the dataset. The response variable for assessing disturbance impacts on abundance included the total count of all shorebirds combined. We estimated the impact of potential disturbance on shorebird abundance based on the expected percent change in bird abundance in a sampling unit with the mean amount of potential human disturbance rate, compared with a sampling unit with no human disturbance. It was expressed as: Percent of change = (EXP(beta)"1) *100 by rate of disturbance.

These models accounted for other variables that could influence shorebird abundance, such as the percentage of flooded area, but they were not the question of interest. We considered variables significant when the 95% confidence intervals (CI) of their parameter estimates did not overlap with 0. We used the R studio programming environment version 1.3.1073 (R Core Team 2019) and the glmmTMB package (Brooks *et al*. 2017) for the analyses.

Based on data from the last eight years of the Migratory Shorebird Project, for the period 2016-2023, quantitative analyses were carried out at the local (disturbance hotspots sites), regional (Mexico, Central America, and South America) and global levels (Pacific Flyway).

For the local-level analysis, 11 sites that were hotspots in disturbance were selected, that is, those sites with the highest percentage of sampling units with disturbance, of the total units with disturbance in the entire country or region. In Mexico there were five hotspots: Estero de Punta Banda, Bahía Magdalena, and Ensenada de La Paz, in the Baja California peninsula; and Valle de Mexicali, and Marismas Nacionales, in continental Mexico (Fig. 2). Only for one site (Valle de Mexicali) was it not possible to carry out the analysis, because the type of agricultural habitat is not comparable with the other sites. The other six hotspots were: Sipacate, La Libertad, Estero Real, and

Jiquilisco-Jaltepeque in Central America (Fig. 3); in addition to Ite, and Valparaíso in South America (Fig. 4). For the Jiquilisco-Jaltepeque site, it was not possible to perform the analysis due to the overdispersion of the disturbance data.
The regional level included three regions, Mexico, Central America, and South America; while the global analysis was performed for the entire Pacific Migratory Corridor.

For the global analysis, disturbance events caused by the three most frequent disturbance agents: people, vehicles, and dogs, were separated for all sites in the Pacific Flyway. Thus, the impact of disturbance by people, by vehicles, and by dogs on shorebird abundance was analyzed separately throughout the entire Pacific Flyway. For each of the three agents (people, vehicles, and dogs) two models were included: 1) a model that included only those observations with disturbance by the agent (e.g., people); and 2) a second model that also included those observations with zero disturbance for the same units. For the example of people, these were observations with and without disturbance by people in the same units. It was similar for the case of dogs and vehicles. There were six models in total. The number of sites, sampling units, and events included in each model are shown in Table 2.
The formula for each model was as follows:
Shorebird count ~ DistrbAntroAgent + pinund + (1 | Sitio/Unidad) + (1 |year2) + offset (lha)

Each model included: rate of disturbance by agent (people, vehicles, dogs), percentage of flooded area, the random effect of site and nested units, the random effect of year, and area of sampling units as an offset term.

Table 2. Total number of sites, plots, and events for each agent of disturbance (any human factor that may trigger a distribution or behavioral change in shorebirds, e.g., people, vehicles, dogs) documented along the Pacific Flyway, during the period 2016-2023.

Agent	Sites	Plots	Events
People only	63	404	1360
People and no disturbance	63	899	1360
Vehicles only	30	215	651
Vehicles and no disturbance	30	586	651
Dogs only	54	273	366
Dogs and no disturbance	54	782	366

RESULTS

Between 2016 and 2023, 128 sites and a total of 5,243 sampling units were surveyed along the Pacific Flyway between Mexico and Chile. The total effort was 2,963 hours of observation and the average time invested in each sampling unit was 41.3 minutes (Table 1).

Overall, the incidence of disturbance, that is, the proportion of sampling units with some type of potential disturbance was 16%. Although it varied from 0% in Costa Rica to 28% in Guatemala (Table 3). The presence of aerial predators in a sampling unit was considered as natural or background disturbance, although it can also be considered as a risk of predation. In all countries, the proportion of sampling units with the presence of aerial predators was less than the proportion of units with some type of human disturbance, except in Honduras and Panama, where aerial predators were predominant over human disturbance. In Honduras, 17% of the units recorded the presence of aerial predators, including Zone-tailed Hawk (*Buteo albonotatus*), Roadside Hawk (*Rupornis magnirostris*), Peregrine Falcon (*Falco peregrinus*), and Merlin (*F. columbarius*) In Panama, 3% of the units had *F. peregrinus*. The highest proportions of sampling units with aerial predators occurred in Honduras (17%), Baja California peninsula (12%), El Salvador (9%), mainland Mexico (8%), and then Chile (6%), Panama and Peru (3%), Guatemala and Nicaragua (2%). The presence of raptors in Costa Rica, Colombia, and Ecuador, was rare or did not occur (Table 3).

Table 3. Number of sampling units and proportion of sampling units with disturbance and aerial predators along the Pacific Flyway during the period of 2016 through 2023.

Country (period)	Total No. of sampling units	No. of units with disturbance	% of units with disturbance	% of units with raptors
Baja California Peninsula (2016-2023)	1,285	321	25	12
Mainland Mexico (2016-2023)	1,103	140	13	8
Guatemala (2019-2023)	287	81	28	2
Honduras (2017-2023)	115	11	10	17
El Salvador (2017-2023)	211	46	22	9
Nicaragua	271	37	14	2

(2016-2023)				
Costa Rica (2018-2022)	141	0	0	0
Panama (2016-2023)	177	1	1	3
Colombia (2016-2023)	544	41	8	1
Ecuador (2016-2023)	385	22	6	1
Peru (2016-2023)	329	77	23	3
Chile (2017-2023)	395	59	15	6

During the Migratory Shorebird Project surveys, we documented a total of 19 disturbance activities or types of disturbance (Table 4). Dogs, people, and motorcycles occurred at 10 out of 11 countries, and along with boats and livestock were the most frequent disturbance types. Those sites located in the Baja California peninsula, mainland Mexico, Chile, and Guatemala had the most diverse types of disturbance, then El Salvador, Nicaragua, Peru, Honduras, Colombia, and Ecuador. Panama had only one type of disturbance. The 19 types of disturbance were categorized into six disturbance type categories (Table 4 and 5). Throughout the range, a total of 836 units had human disturbance. Among these units, the most frequent human disturbance type was the presence of people (53%) (including fishermen, farmers, and general users), followed by motorized vehicles (48%), dogs (16%) (leashed and unleashed), others (13%) (including presence of fishing and aquaculture camps, road traffic, shooting, explosives, bicycles, and drones), livestock (7%) (including cows, horses, and pigs), and aircraft (1%) (including airplane, light aircraft, helicopter, and model aircraft) (Table 5).

In all countries, except Mexico, the prevailing type of human disturbance was the presence of people in the sampling unit, and then motorized vehicles. In both regions of Mexico, motorized vehicles near the unit was more frequent than the presence of people. The potential disturbance by dogs in a sampling unit was very high in Chile (53% of those sampling units with disturbance), El Salvador (35%), Ecuador (23%), and Peru (22%). Dogs did not occur in Costa Rica and Panama. The presence of livestock was particularly important in the sampling units of southern Peru (47%), then to a lesser extent in mainland Mexico (12%), Nicaragua (11%), and Colombia (10%). Other types of disturbance included the presence of fishing and aquaculture camps (mainly oyster farming), recreational camping, and road traffic near the sampling unit, which were particularly important to the Baja California peninsula (24%) and mainland Mexico (14%) (Table 5).

Table 4. Disturbance types observed in each country along the Pacific Flyway from Mexico to Chile 2016-2023. Dogs include leashed and unleashed dogs; Vehicles include watercraft and all-terrain vehicles; [11] camping infrastructure from fishermen, tourists, aquaculture.

	Country												
Disturbance type	**BaCa[1]**	**Mex[2]**	**Gua[3]**	**Hon[4]**	**ES[5]**	**Nic[6]**	**CR[7]**	**Pan[8]**	**Col[9]**	**Ecu[10]**	**Peru**	**Chile**	**TOTAL**
DOGS	X	X	X	X	X	X			X	X	X	X	10
PEOPLE													
General use	X	X	X	X	X	X			X	X	X	X	10
Farmers	X												1
Fishermen	X	X	X		X	X			X		X	X	8
MOTORIZED VEHICLES													
Vehicles/Trucks	X	X	X		X	X				X	X	X	8
Motorcycle	X	X	X	X	X	X			X	X	X	X	10
Boat	X	X	X	X	X	X			X		X	X	9
Airboat		X											1
AIRCRAFT													
Airplane	X									X			2
Light aircraft	X	X	X										3
Helicopter	X							X				X	3
Model aircraft	X												1
LIVESTOCK	X	X	X	X	X	X			X		X	X	9
OTHERS													
Shooting, explosives	X	X	X	X		X							5
Road traffic	X	X	X										3
Drones	X											X	2
Camps[11]	X											X	2
Dredging		X											1
Saltworks					X								1
Fishing nets												X	1
Bicycles										X			1
TOTAL	**16**	**12**	**10**	**6**	**8**	**8**	**0**	**1**	**6**	**6**	**7**	**11**	

[1] Baja California peninsula, [2] Mainland Mexico, [3] Guatemala, [4] Honduras, [5] El Salvador, [6] Nicaragua, [7] Costa Rica, [8] Panama, [9] Colombia, [10] Ecuador.

Table 5. Number of sampling units by human disturbance type category in each country of the Pacific Flyway, between 2016 and 2023. The percentage of sampling units relative to those sampling units with disturbance is between parentheses (e.g., # with dogs/total sampling units with disturbance*100). A sampling unit can have more than one disturbance type category thus percentages will not always sum to 100.

Country	People	Motorized vehicles	Dogs	Livestoc k	Aircraft	Others
Baja California Peninsula	173(54%)	192(60%)	62(19%)	10(3%)		76(24%)
Mainland Mexico	43(31%)	92(66%)	8(6%)	17(12%)	3(2%)	19(14%)
Guatemala	53(65%)	40(49%)	4(5%)	0	4(5%)	4(5%)
Honduras	7(64%)	4(36%)	1(9%)	1(9%)	0	1(9%)
El Salvador	36(78%)	6(13%)	16(35%)	4(9%)	0	1(2%)
Nicaragua	23(62%)	10(27%)	4(11%)	4(11%)	0	2(5%)
Costa Rica	0	0	0	0	0	0
Panama	0	0	0	0	1(100%)	0
Colombia	25(61%)	17(41%)	7(17%)	4(10%)	0	0
Ecuador	13(59%)	8(36%)	5(23%)	0	1(5%)	1(5%)
Peru	40(52%)	23(30%)	17(22%)	36(47%)	0	1(1%)
Chile	29(49%)	10(17%)	31(53%)	5(8%)	1(2%)	4(7%)

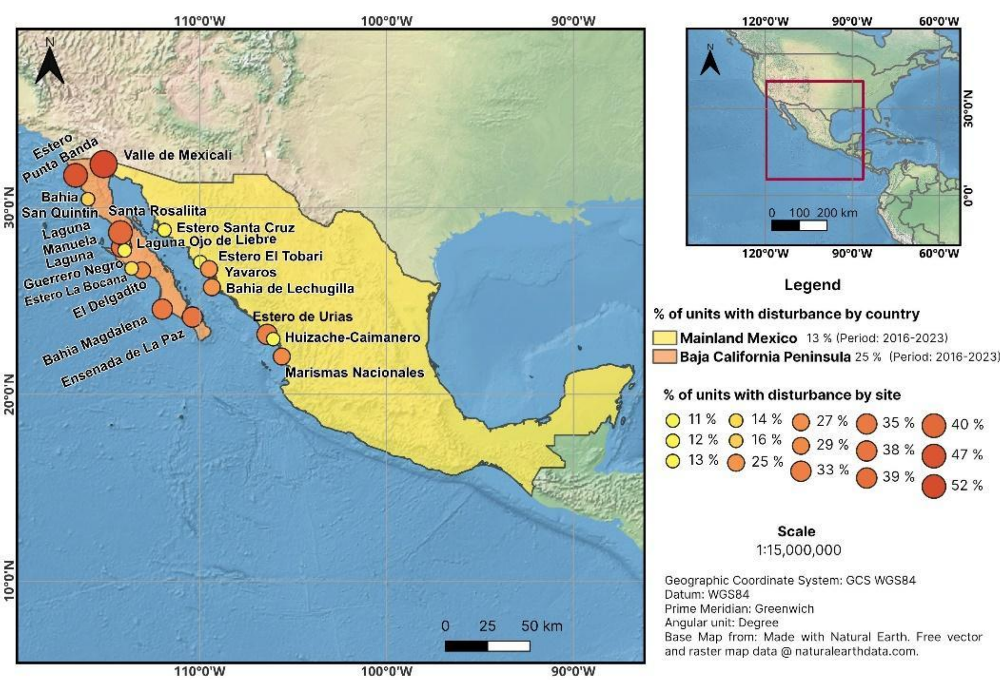

Figure 2. Distribution of human disturbance hotspots in Baja California peninsula and mainland Mexico.

Mexico was the country with the second most disturbance in the entire Pacific Flyway, surpassed only by Guatemala. In Mexico, the Migratory Shorebird Project sites are located in northwestern Mexico and included two regions of which the Baja California peninsula had a disturbance rate almost two times higher than mainland Mexico (Fig. 2). In Baja California peninsula, two sites had the highest proportion of units with disturbance; the agricultural valley of Valle de Mexicali (52%) and the estuary of Estero Punta Banda (47%), both located in the north of the peninsula (Fig. 2). In mainland Mexico, the estuary of Estero de Urias (33%) and the wetlands of Marismas Nacionales (29%) had the highest proportion of units with disturbance (Fig. 2). On a regional scale, the highest proportion of units with disturbance in Baja California occurred in Bahia Magdalena (24%), and in mainland Mexico occurred in Marismas Nacionales (64%). This fact is explained because larger sites such as Bahía Magdalena and Marismas Nacionales have more sampling units than smaller sites, which accounts for a higher percentage of sampling units with disturbance at the regional level (Table 6).

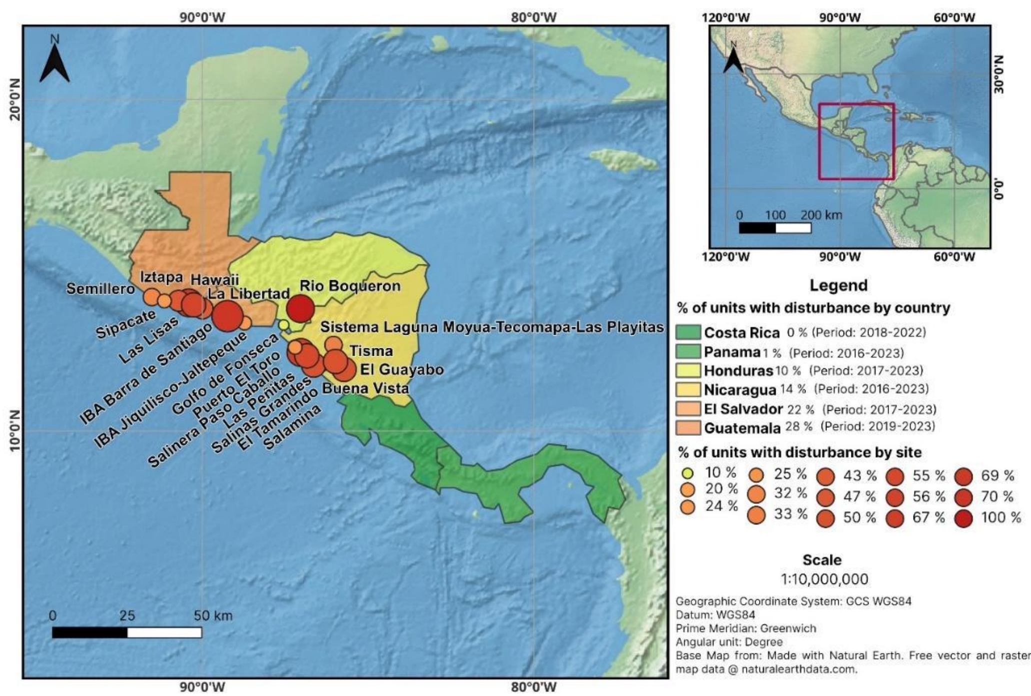

Figure 3. Distribution of human disturbance hotspots in Central America.

The human disturbance rate among countries of Central America increased from south to north. Guatemala (28%) and El Salvador (22%) had the highest rates of disturbance; at least twice higher than the other countries (Fig. 3). Guatemala had three sites with the highest proportion of units with disturbance: Hawaii (69%), Las Lisas (56%), and Iztapa (47%) (Fig. 3), but at the country level, disturbance was concentrated in the large wetlands of Sipacate (49%) (Table 5). El Salvador had two sites with the highest proportion of disturbance: Barra de Santiago (43%) and La

Libertad (70%) (Fig. 3), but at the country level, disturbance was concentrated in the large wetlands of Jiquilisco-Jaltepeque (39%) and La Libertad (35%) (Table 6). Nicaragua had two sites with the highest proportion of units with disturbance: Rio Boqueron (100%) and Las Peñitas (67%) (Fig. 3), while at the country level, the disturbance was concentrated in Las Peñitas (22%) and Delta del Estero Real (19%) (Table 6). To a lesser extent, the disturbance rate in Honduras was 10%, in Panama was 1%, and there was no disturbance in Costa Rica (Fig. 3 and Table 6).

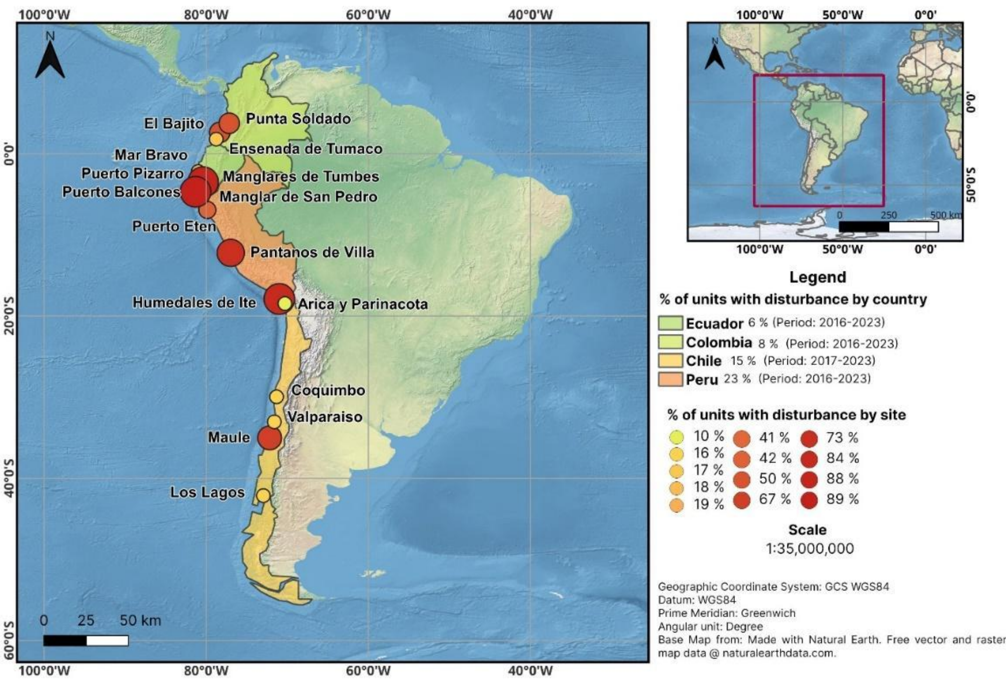

Figure 4. Distribution of human disturbance hotspots in South America.

Among the countries of South America, Peru had the highest rate (23%) of human disturbance (Fig. 4). The disturbance in Peru was concentrated in three sites: Punta Balcones (89%), Punta Pizarro (88%), and Humedales de Ite (84%) (Fig. 4), while at the country level, most of the disturbance was concentrated in Humedales de Ite (35%) (Table 6). Chile was the country with the second highest disturbance rate (15%), and most of the disturbance was concentrated at the mouth of Mataquito river in Maule (67%) (Fig. 4). At the country level, most of the disturbance was concentrated in Valparaiso (37%) (Table 6). Ecuador and Colombia had lower and similar disturbance rates (Fig. 4). At a country level, disturbance in Ecuador was concentrated in Mar Bravo (82%) and in Colombia in Sanquianga (27%) (Table 6).

Table 6. Number of sampling units and occurrence of human disturbance at each site of the Pacific Flyway during 2016-2023. *Proportion (%) of disturbance by country accounts for the spatial distribution of total disturbance at the country scale.

Country (period)	Site	No. of units	No. of units with disturbance	% of disturbance by country *
Baja California Peninsula (2016-2023)	Bahia Magdalena	218	77	24
	Bahia San Quintin	278	44	14
	El Delgadito	48	13	4
	Ensenada de La Paz	86	33	10
	Estero La Bocana	7	1	0
	Estero Punta Banda	72	34	11
	Laguna Guerrero Negro	99	39	12
	Laguna Manuela	55	7	2
	Laguna Ojo de Liebre	190	22	7
	Laguna San Ignacio	161	15	5
	Santa Rosalillita	5	2	1
	Valle de Mexicali	66	34	11
Mainland Mexico (2016-2023)	Agiabampo	71	2	1
	Bahia de Ceuta	55	0	0
	Bahia de Guaymas	24	0	0
	Bahia de Lechuguilla	4	1	1
	Bahia de Lobos	12	0	0
	Bahia de Navachiste	5	0	0
	Bahia de Ohuira	4	0	0
	Bahia Santa Maria	61	2	1
	Cacaxtla	69	4	3
	Canal de Infiernillo	7	0	0
	Delta del Rio Colorado	81	7	5
	Ensenada de Pabellones	48	0	0
	Estero El Cardonal	29	1	1
	Estero El Sargento	19	0	0
	Estero El Tobari	63	7	5
	Estero Santa Cruz	39	5	4
	Estero Tastiota	50	3	2
	Estero de Urias	12	4	3
	Huizache-Caimanero	54	6	4
	Istmo de Tehuantepec	50	1	1
	Marismas Nacionales	314	90	64
	Topolobampo	4	0	0
	Yavaros	28	7	5

Table 6. Continuing.

Guatemala (2019-2023)	Champerico	3	0	0
	Chiquistepeque	4	0	0
	Chulamar	1	0	0
	El Gariton	1	0	0
	Hawaii	13	9	11
	Iztapa	36	17	21
	La Avellana	1	0	0
	Las Lisas	16	9	11
	Manchon Guamuchal	7	0	0
	Monterrico	3	0	0
	Puerto San Jose	1	0	0
	Semillero	19	6	7
	Sipacate	169	40	49
	Tahuexco	5	0	0
	Tecojate	2	0	0
	Tilapa	4	0	0
	Tulate	2	0	0
Honduras (2017-2023)	Golfo de Fonseca	115	11	100
El Salvador (2017-2023)	Golfo de Fonseca	105	9	20
	IBA Barra de Santiago	7	3	7
	IBA Jiquilisco-Jaltepeque	76	18	39
	La Libertad	23	16	35
Nicaragua (2016-2023)	Apacunca	3	0	0
	Apanas	2	0	0
	Arrozales de Sebaco	12	1	3
	Buena Vista	10	2	5
	Carazo	4	0	0
	Delta del Estero Real	154	7	19
	El Guayabo	6	3	8
	El Tamarindo	5	1	3
	Estero Paso Caballos	4	0	0
	Isletas de Granada	1	0	0
	Istmo de Istian	2	0	0
	La Bayona	3	0	0
	Las Peñitas	12	8	22
	Momotombo	1	0	0
	Muelle Los Lirios	2	0	0
	Padre Ramos	4	0	0
	Pueblo Nuevo	6	0	0
	Puerto El Toro	5	1	3
	Puerto Sandino	5	0	0
	Rio Boqueron	1	1	3
	Salamina	2	1	3

Table 6. Continuing.

	Salinas Grandes	11	6	16
	Salinera Paso Caballo	4	1	3
	Sistema Laguna Moyua-Tecomapa-Las Playitas	6	2	5
	Tisma	6	3	8
Costa Rica (2018-2022)	Chomes	21	0	0
	Cocorocas Punta Morales	25	0	0
	Colegio Colorado	23	0	0
	Costa Pajaros	12	0	0
	Muelle Colorado	16	0	0
	Puente e' Piedra Colorado	12	0	0
	Santos Colorado	32	0	0
Panama (2016-2023)	Boardwalk at Juan Diaz	20	0	0
	Coste del Este	37	1	100
	Panama Viejo	17	0	0
	Rio Pacora-Rio Chico	85	0	0
	Panama West	18	0	0
Colombia (2016-2023)	Amarales	121	9	22
	Bocagrande	8	0	0
	Bocana del Rio Iscuande	70	1	2
	El Bajito	8	4	10
	Ensenada de Tumaco	6	1	2
	Guascama	101	9	22
	Parque Sanquianga	5	0	0
	Punta Soldado	4	2	5
	Salango	9	0	0
	Sanquianga	118	11	27
	Tapaje	94	4	10
Ecuador (2016-2023)	Caraquez	25	0	0
	Cayapas-Mataje	5	0	0
	El Morro	5	0	0
	Jambeli	124	0	0
	Mar Bravo	94	18	82
	Pacoa	132	4	18
Peru (2016-2023)	Estuario de Virril	54	0	0
	Humedales de Ite	32	27	35
	Manglar de San Pedro	28	5	7
	Manglares de Sechura	9	0	0
	Manglares de Tumbes	17	7	9
	Pantanos de Villa	15	11	14
	Puerto Eten	12	5	7
	Puerto Pizarro	8	7	9
	Punta Balcones	9	8	10

Table 6. Continuing.				
	Reserva Nacional Paracas	145	7	9
Chile (2017-2023)	Arica y Parinacota	20	2	3
	Biobio	71	6	10
	Calbuco	18	1	2
	Coquimbo	80	13	22
	Los Lagos	58	9	15
	Maule	9	6	10
	Valparaiso	139	22	37

Among all countries, there were sites where human disturbance occurred to a lesser extent or did not occur (Table 6). Maps indicating the location of all the sites of the Migratory Shorebird Project included in this analysis are shown in Figs. 5, 6, and 7.

Table 7. Proportion of sampling units with human disturbance at each site of the Pacific Flyway during 2016-2023. An identification number (ID) is given in order to locate each site on the regional maps.

Region	Country	ID	Name of site	% units with disturbance
Baja California peninsula				
	Mexico	1	Bahia Magdalena	35
		2	Bahia San Quintin	16
		3	El Delgadito	27
		4	Ensenada de La Paz	38
		5	Estero La Bocana	14
		6	Estero Punta Banda	47
		7	Laguna Guerrero Negro	39
		8	Laguna Manuela	13
		9	Laguna Ojo de Liebre	12
		10	Laguna San Ignacio	9
		11	Santa Rosalillita	40
		12	Valle de Mexicali	52
Mainland Mexico				
	Mexico	13	Agiabampo	3
		14	Bahia de Ceuta	0
		15	Bahia de Guaymas	0
		16	Bahia de Lechuguilla	25
		17	Bahia de Lobos	0
		18	Bahia de Navachiste	0
		19	Topolobampo	0
		20	Yavaros	25
		21	Bahia de Ohuira	0
		22	Bahia Santa Maria	3

Table 7. Continuing

		23	Cacaxtla	6
		24	Canal de Infiernillo	0
		25	Delta del Río Colorado	9
		26	Ensenada de Pabellones	0
		27	Estero El Cardonal	3
		28	Estero El Sargento	0
		29	Estero El Tobari	11
		30	Estero Santa Cruz	13
		31	Estero Tastiota	6
		32	Estero de Urias	33
		33	Huizache-Caimanero	11
		34	Istmo de Tehuantepec	2
		35	Marismas Nacionales	29
Central America				
	Guatemala	1	Hawaii	69
		2	La Avellana	0
		3	Las Lisas	56
		4	Manchon-Guamuchal	0
		5	Tecojate	0
		6	Champerico	0
		7	Chiquistepeque	0
		8	Chulamar	0
		9	El Gariton	0
		10	Iztapa	47
		11	Monterrico	0
		12	Puerto San José	0
		13	Semillero	32
		14	Sipacate	24
		15	Tahuexco	0
		16	Tilapa	0
		17	Tulate	0
	Honduras	18	Golfo de Fonseca	10
	El Salvador	19	IBA Barra de Santiago	43
		20	IBA Jiquilisco-Jaltepeque	24
		21	La Libertad	70
		22	Golfo de Fonseca	9
	Nicaragua	23	Apacunca	0
		24	Apanas	0
		25	Arrozales de Sebaco	8
		26	Buena Vista	20
		27	Carazo	0
		28	El Guayabo	50
		29	El Tamarindo	20
		30	Estero Paso Caballos	0
		31	Isletas de Granada	0
		32	Istmo de Istian	0

Table 7. Continuing.

	Nicaragua	33	Las Peñitas	67
		34	Momotombo	0
		35	Muelle Los Lirios	0
		36	Padre Ramos	0
		37	Pueblo Nuevo	0
		38	Puerto Sandino	0
		39	Rio Boqueron	100
		40	Salamina	50
		41	Salinas Grandes	55
		42	Sistema Laguna Moyua-Tecomapa-Las Playitas	33
		43	Tisma	50
		44	La Bayona	0
		45	Puerto El Toro	20
		46	Salinera Paso Caballo	25
		47	Delta del Estero Real	5
	Costa Rica	48	Chomes	0
		49	Cocorocas Punta Morales	0
		50	Colegio Colorado	0
		51	Costa Pajaros	0
		52	Muelle Colorado	0
		53	Santos Colorado	0
		54	Puente e' Piedra Colorado	0
	Panama	55	Coste del Este	3
		56	Panama Viejo	0
		57	Rio Pacora-Rio Chico	0
		58	Panama West	0
		59	Boardwalk at Juan Diaz	0
South America				
	Colombia			
		1	Sanquianga	9
		2	Amarales	7
		3	Bocagrande	0
		4	Bocana del Rio Iscuande	1
		5	El Bajito	50
		6	Ensenada de Tumaco	17
		7	Guascama	9
		8	Parque Sanquianga	0
		9	Punta Soldado	50
		10	Salango	0
		11	Tapaje	4
	Ecuador	12	Caraquez	0
		13	Cayapas-Mataje	0
		14	El Morro	0
		15	Jambeli	0
		16	Mar Bravo	19
		17	Pacoa	3

Table 7. Continuing.

Peru	18	Estuario de Virril	0
	19	Humedales de Ite	84
	20	Manglar de San Pedro	18
	21	Manglares de Tumbes	41
	22	Manglares de Sechura	0
	23	Pantanos de Villa	73
	24	Puerto Eten	42
	25	Puerto Pizarro	88
	26	Punta Balcones	89
	27	Reserva Nacional Paracas	5
Chile			
	28	Biobio	8
	29	Maule	67
	30	Arica y Parinacota	10
	31	Calbuco	6
	32	Coquimbo	16
	33	Valparaiso	16
	34	Los Lagos	16

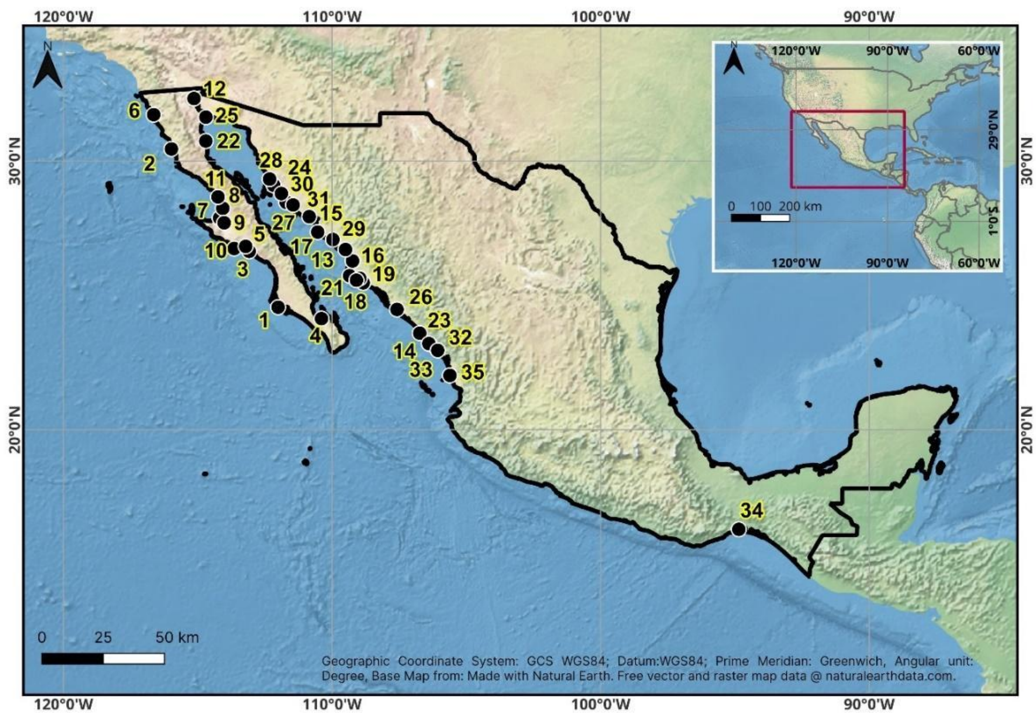

Figure 5. Location of all Migratory Shorebird Project sites in Mexico included in this analysis. See Table 7 for locations names of corresponding numbers in the map

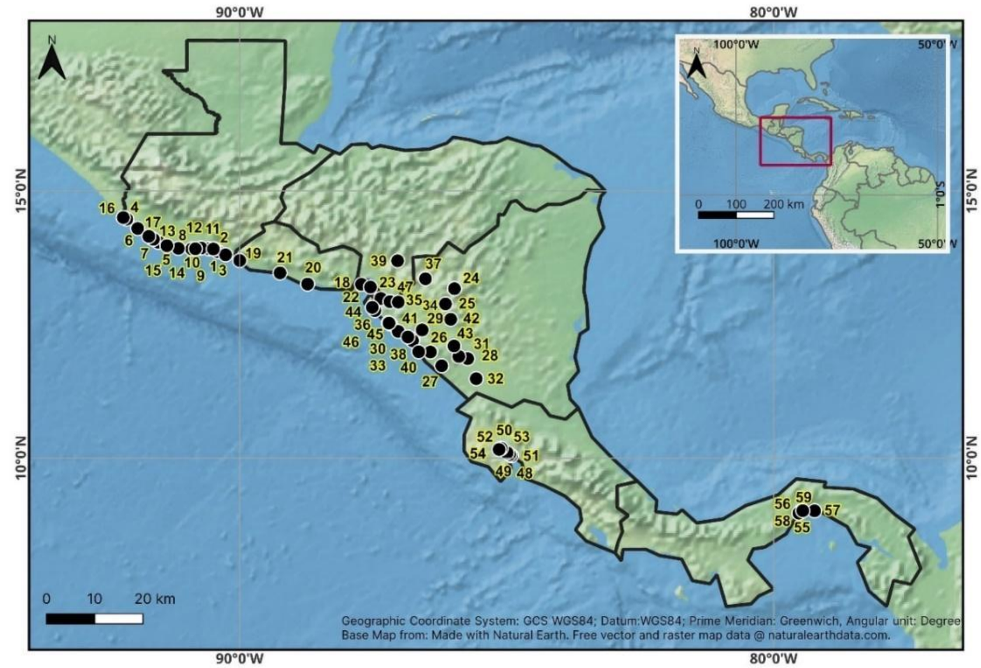

Figure 6. Location of all Migratory Shorebird Project sites in Central America included in this analysis. See Table 7 for locations names of corresponding numbers in the map.

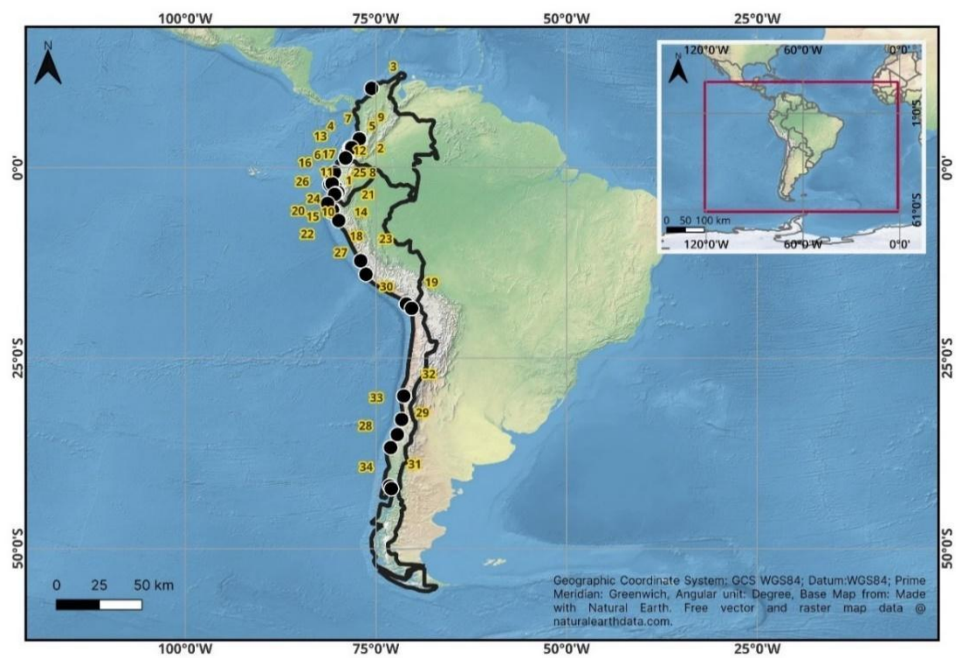

Figure 7. Location of all Migratory Shorebird Project sites in South America included in this analysis. See Table 7 for name of locations of corresponding numbers in the map

Quantitative Analyses

Based on data from the last eight years of the Migratory Shorebird Project, for the period 2016-2023, quantitative analyses were carried out on the impact of human disturbance on the abundance of shorebirds. These analyses were carried out at the local, regional and global levels. The regional level included three regions, Mexico, Central America, and South America; while the global analysis was performed for the entire Pacific Migratory Corridor.

For Mexico, in three of the four sites the impact of the disturbance was negative and significant. The change in abundance in Magdalena Bay was greater than in the Ensenada de La Paz and Marismas Nacionales. In Estero de Punta Banda the influence of the disturbance was also negative, but it was not significant (Fig. 5). In the five sites in Central and South America the impact of the disturbance was negative, but only in one site (Ite, Peru) was it significant (Fig. 6). For all 9 hotspots together, the impact of recreational disturbance was negative and significant. Our model estimated a -3.87% decline in abundance of all shorebirds combined, in a sampling unit with an average amount of potential human disturbance compared to a unit with no disturbance. This percentages indicate the declines in the expected abundance of shorebirds in any given sampling unit with an average amount of potential human disturbance compared with a sampling unit with no potential human disturbance.

According with Heredia-Morales et al. (2024), *Agent of Disturbance* is defined as any human factor that may trigger a distribution or behavioral change in shorebirds (stimuli from human activities, e.g., people, vehicles, dogs). The most frequent agent of disturbance was people, followed by vehicles, and dogs. Potential human disturbance by each agent varied by country, by people it was detected on 31-78% of surveys, by vehicles on 17-66% of surveys, and by dogs on 5-53% of surveys (Table 4). After controlling for sampling effort, habitat conditions, and spatiotemporal variation, five out of six models indicated a significant negative association of shorebird abundance with potential human disturbance (Table 6). Only one out of six models showed no significant effect of potential disturbance.

During Winter, potential human disturbance by people had a significant negative association with total shorebird abundance. Our models estimated a 19.44% decline in abundance of all shorebirds combined, in a sampling unit with an average amount of potential human disturbance by people compared to a unit with no disturbance. A second model that also included those observations with zero disturbance by people to the same units, estimated a 8.71% significant decline in abundance of shorebirds (Table8, Fig. 10). These percentages indicate the declines in the expected abundance of shorebirds in any given sampling unit with an average amount of potential human disturbance by people compared with a sampling unit with no potential human disturbance by people.

Potential human disturbance by vehicles had a significant negative association with total shorebird abundance. Our models estimated a 15.52% decline in abundance of all shorebirds combined, in a sampling unit with an average amount of potential human disturbance by vehicles compared to a unit with no disturbance. A second model that also included those observations with zero disturbance by vehicles to the same units, estimated a 5.68% decline in abundance of shorebirds, but it was not significant (Table 8, Fig. 10). These percentages indicate the declines in the expected abundance of shorebirds in any given sampling unit with an average amount of potential human disturbance by vehicles compared with a sampling unit with no potential human disturbance by vehicles.

Potential human disturbance by dogs had a significant negative association with total shorebird abundance. Our models estimated a 20.05% decline in abundance of all shorebirds combined, in a sampling unit with an average amount of potential human disturbance by dogs compared to a unit with no disturbance. A second model that also included those observations with zero disturbance by dogs to the same units, estimated a significant 7.04% decline in abundance of shorebirds (Table 8, Fig. 10). These percentages indicate the declines in the expected abundance of shorebirds in any given sampling unit with an average amount of potential human disturbance by dogs compared with a sampling unit with no potential human disturbance by dogs.

Table 8. Total number of sites, plots, and events for each agent of disturbance (any human factor that may trigger a distribution or behavioral change in shorebirds, e.g., people, vehicles, dogs) along the Pacific Flyway, during the period 2016-2023.

Agent	Sites	Plots	Events	% Change	Significance
People only	63	404	1360	-19.44	Yes
People and no disturbance	63	899	1360	-8.71	Yes
Vehicles only	30	215	651	-15.52	Yes (0.1)
Vehicles and no disturbance	30	586	651	-5.68	NS
Dogs only	54	273	366	-20.05	Yes
Dogs and no disturbance	54	782	366	-7.04	Yes

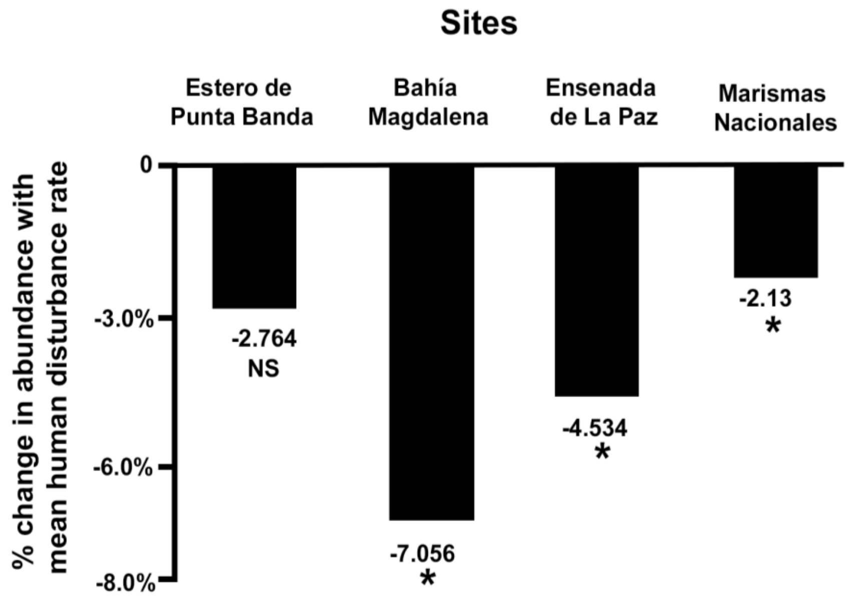

Figure 8. Impact of potential disturbance on shorebird abundance for four hotspots sites in Mexico. Numbers below bars show the expected percent change in bird abundance in a sampling unit with the mean amount of potential human disturbance rate compared with a sampling unit with no human disturbance. Percent of change = (EXP(beta)"1)*100 by rate of disturbance. * indicates significance (0.05); NS = Not Significant.

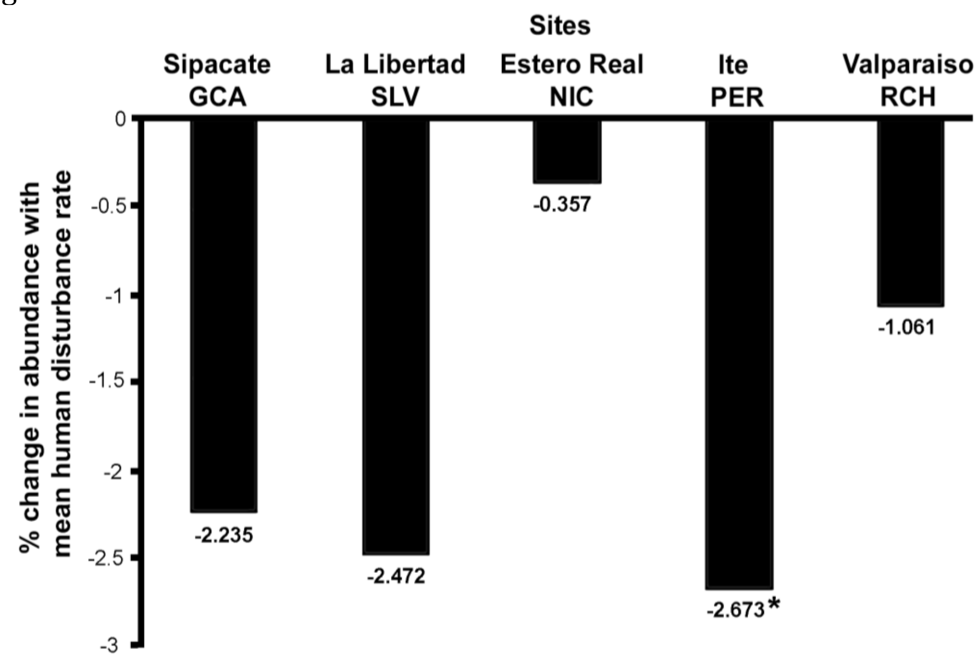

Figure 9. Impact of potential disturbance on shorebird abundance for five hotspots sites in Central America and South America. Numbers below bars show the expected percent change in bird abundance in a sampling unit with the mean amount of potential human disturbance rate compared with a sampling unit with no human disturbance. Percent of change = (EXP(beta)"1)*100 by rate of disturbance. * indicates significance (0.05).

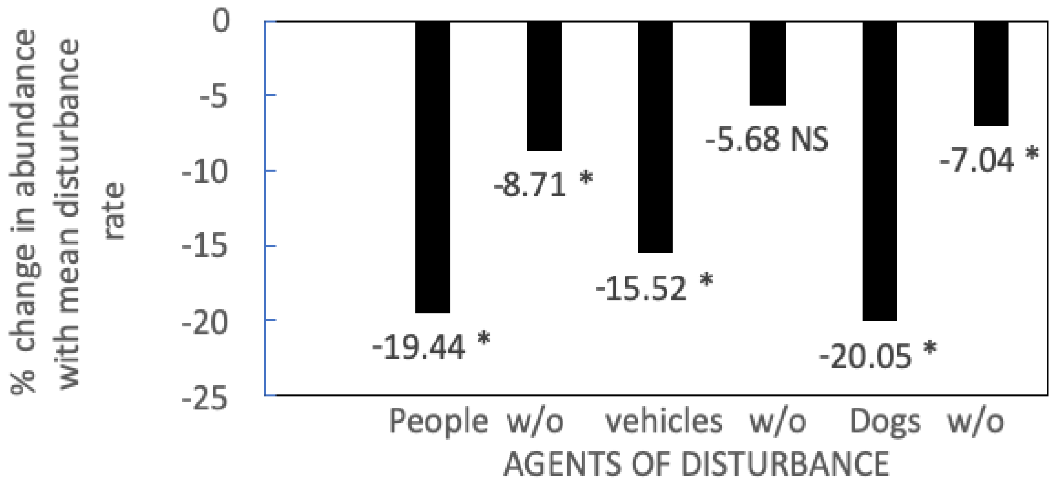

Figure 10. Impact of potential disturbance on shorebird abundance by People, Vehicles, and Dogs on the Pacific Flyway. Numbers below bars show the expected percent change in bird abundance in a sampling unit with the mean amount of potential human disturbance rate compared with a sampling unit with no human disturbance. Percent of change = (EXP(beta)"1)*100 by rate of disturbance. * indicates significance (0.05). w/o includes the total number of sampling units with disturbance by the specific agent plus zero disturbance at the same sampling units.

DISCUSSION

We provide a landscape assessment of shorebird disturbance hotspots along the Pacific Flyway. Also, an overview of the most frequent types of human disturbance, as well as the incidence and spatial distribution of human disturbance on a broad-scale throughout the Pacific Flyway and in each country from Mexico to Chile, for the period 2016 through 2023. Data collected by the Migratory Shorebird Project allowed analysis of critical disturbance hotspots in coastal wetlands important to neotropical migratory shorebirds. No latitudinal gradient was found for the rate or incidence of human disturbance along the Pacific Flyway. The four countries with most disturbance were widely distributed along the spatial range of this analysis (Mexico, Guatemala, El Salvador, and Peru) (Figs. 2, 3, and 4).

Migratory shorebirds are distributed in very low densities in their breeding grounds, but during the non-breeding period they congregate at very high densities in just a few places along the Pacific Americas Flyway, and are thus more vulnerable to human activities that may disturb the normal activities of shorebirds, such as foraging and resting. The rate of disturbance at the Flyway level was 16%, but at the country level this rate was up to 28% in Guatemala. Importantly, Guatemala had the highest rate of all countries and it is the country with less time of surveys, from 2019 to 2023. At the site level, however, in all countries most of the disturbance was concentrated only in one or two sites of the country.

The occurrence of aerial predators (i.e. percentage of sampling units with raptors) on the Pacific Flyway between Mexico and Chile was considered as an index of natural or background disturbance. This index was lower than human disturbance in most countries, which makes human disturbance a more important threat than aerial predators in the region. Only two countries (Honduras and Panama) with very low human disturbance, had a higher natural disturbance. Many of the sites in the 12 countries included in this assessment are major wintering areas for several species of shorebirds that breed in the Nearctic, and therefore, are included in the Western Hemispheric Shorebird Reserve Network. At the same time, at current growth rates, the human population in Latin America will double in the next 30 years, and the rest of the natural areas that remain unchanged will be reduced considerably and human disturbance will likely increase. The health of each of these wetlands is vital to the well-being and prosperity of the people and their natural resources, and migratory birds. Environmental awareness among residents to demonstrate this connection between people and shorebirds is badly needed, thereby increasing support for the conservation of their natural resources. Since human disturbance can be related to habitat degradation, the results generated in this analysis can provide benchmarks for assessing the environmental quality of wintering areas relative to other areas located along the Pacific Flyway, and to identify priority wetlands to try to limit disturbance and buffer areas against degradation.

Our quantitative analyses showed that people, vehicles, and dogs were the most common agents of disturbance, as has been reported elsewhere (Tarr et al. 2010; Schlacher et al. 2013). We found that non-breeding shorebirds abundance showed variation in their responses towards different agents of disturbance, reacting stronger (i.e., more change in abundance) towards dogs and people than to vehicles. Dogs are a disturbance agent that is commonly found in shorebird habitats (Lafferty 2001; Murchison et al. 2016; Ramli and Norazlimi 2017; Gómez-Serrano 2020), and even the presence of dogs with groups of people has shown an additive effect (Gómez-Serrano 2020; Murchison et al. 2016), which it indicates that dogs and people have greater disturbance effect together than when they occur separately. Glover et al. (2011) found experimentally that the approach of a person walking with a dog evoked an avoidance flight at a greater distance than that of a person walking alone.

Our results suggest that a management strategy to mitigate human disturbance in the Pacific Flyway should include policies to reduce the risk of disturbance from dogs accompanying people. Leashes for domestic dogs can markedly reduce the likelihood of disturbance to shorebirds (Lafferty 2001).

A management strategy to mitigate human disturbance in those hotspots documented in this study should also include policies to ban the use of vehicles on the sandy beach and mudflats, reducing the risk of disturbance. The potential conflict between recreationists and shorebirds could be reduced by a public awareness program through the installation of educational materials at each beach access and production of leaflets and other materials by local environmental NGOs with information on shorebirds species, their habitats and the main threats they face.

To reverse the declines in migratory shorebirds requires mitigating threats to their populations across their full annual cycle. However, shorebirds spend the majority of their lives on non-breeding grounds and thus threats during the non-breeding season may be particularly important at driving key demographic parameters for shorebirds (e.g. annual survival; Hitchcock & Gratto-Trevor 1997). Our study suggests that non-breeding sites with higher potential human disturbance will have fewer shorebirds. Given our general inference of a negative impact of human disturbance is consistent with other studies (Palacios et al. 2022, Drever et al. 2016), we recommend that future studies should evaluate the demographic impacts and ultimately population impacts of human disturbance on migratory shorebirds.

LITERATURE CITED

Brooks, M. E., K. Kristensen, K. J. van Benthem, A. Magnusson, C. W. Berg, A. Nielsen, H. J. Skaug, M. M€achler and B. M. Bolker. 2017. glmmTMB balances speed and flexibility among packages for zero- inflated generalized linear mixed modeling. The R Journal 9: 378–400. doi:10.32614/RJ-2017-066

Burger, J., and M. Gochfeld. 1991. Human activity influence and diurnal and nocturnal foraging of Sanderlings (*Calidris alba*). Condor 93: 259–265.

Drever, M. C., B. A. Beasley, Y. Zharikov, M. J. F. Lemon, P. G. Levesque, M. D. Boyd and A. Dorst. 2016. Monitoring migrating shorebirds at the Tofino Mudflats in British Columbia, Canada: is disturbance a con- cern? Waterbirds 39: 125–135. doi:10.1675/063.039. 0203

Heredia-Morales, A., E. Palacios, and M. Reiter. 2024. Evaluating the response of nonbreeding shorebirds to rate and agents of human disturbance. Waterbirds 47: 1-11.

Hitchcock, C. L. and C. Gratto-Trevor. 1997. Diagnosing a shorebird local population decline with a stage- structured population model. Ecology 78: 522–534. doi:10.2307/2266027

Glover, H. K., M. A. Weston, G. S. Maguire, K. K. Miller and B. A. Christie. 2011. Towards ecologically meaningful and socially acceptable buffers: response distances of shorebirds in Victoria, Australia, to human disturbance. Landscape and Urban Planning 103: 326–334. doi:10.1016/j.landurbplan.2011.08.006

Gómez-Serrano, M. A. 2020. Four-legged foes: dogs disturb nesting plovers more than people do on tourist beaches. Ibis 163: 338–352. doi:10.1111/ibi.12879

Lafferty, K. D. 2001. Disturbance to wintering western snowy plovers. Biological Conservation 101: 315–325. doi:10.1016/S0006-3207(01)00075-1

Mengak, L., A. A. Dayer, R. Longenecker, and C. S. Spiegel. 2019. Guidance and Best Practices for Evaluating and Managing Human Disturbances to Migrating Shorebirds on Coastal Lands in the Northeastern United States. U.S. Fish and Wildlife Service.

Mengak, L., and A. A. Dayer. 2020. Defining human disturbance to shorebirds using manager and scientist input. Environmental Management 65: 62–73.

Murchison, C. R., Y. Zharikov and E. Nol. 2016. Human activity and habitat characteristics influence shore- bird habitat use and behavior at a Vancouver Island migratory stopover site. Environmental Management 58: 386–398. doi:10.1007/s00267-016-0727-x

Palacios, E., Vargas, J., Fernandez, G., and M. Reiter. 2022. Impact of human disturbance on the abundance of nonbreeding shorebirds in a subtropical wetland. Biotropica 54: 1160–1169.

Ramli, R. and N. A. Norazlimi. 2017. The effects of disturbance on the abundance and foraging behaviour of shorebirds and waterbirds in the tropical mudflat areas. Sains Malaysiana, 46: 365–372. doi:10.17576/ jsm-2017-4603-02

Reiter, M. E., E. Palacios, D. Eusse-Gonzalez, R. Johnston, P. Davidson, D. W. Bradley, R. Clay, K. M. Strum, J. Chu, B. A. Barbaree, C. M. Hickey, D. B. Lank, R. C. Ydenberg, M. Drever, and R. Butler. 2020. A monitoring framework for assessing threats to nonbreeding shorebirds on the Pacific Coast of the Americas. *Avian Conservation and Ecology* XX(YY):ZZ. [Online]: https://shorturl.at/FWgWC

Schlacher, T. A., T. Nielsen and M. A. Weston. 2013. Human recreation alters behavior profiles of non- breeding birds on open-coast sandy shores. Estuarine, Coastal and Shelf Science 118: 31–42. doi:10.1016/j. ecss.2012.12.016.

Senner, S. E., B. A. Andres and H. R. Gates (Eds.). 2016. *Pacific Americas shorebird conservation strategy*. National Audubon Society, New York, New York, USA. [Online] URL: http://www.shorebirdplan.org

Tarr, N. M., T. R. Simons and K. H. Pollock. 2010. An experimental assessment of vehicle disturbance effects on migratory shorebirds. Journal of Wildlife Management 74: 1776–1783. doi:10.2193/2009-105

Zuur, A., E. N. Ieno, N. J. Walker, A. A. Saveliev and G. M. Smith. 2009. Mixed effects models and extensions in ecology with R: statistics for biology and health. Springer, Berlin, Germany.