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Challenges and Priorities for Seabird Conservation in Northwestern Mexico

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Abstract.—In Northwestern Mexico, approximately 40 breeding species of seabirds have been reported, with several threats (e.g., invasive species introduction and habitat loss) affecting the viability of their populations. As such, it is necessary to take action for their protection. To prioritize conservation activities, 119 reports (governamental agency monitoring programs, grey literature, and scientific literature) were analyzed for research and monitoring results from 1922-2018 (93 of 119 published after 1990) and ranked the different islands (91 sites, including archipelagos with multiple islands) based on their breeding seabird communities (35 species in 11 seabird families, including 7 endemic breeders). For the ranking exercise, three criteria were considered: conservation category, preferred habitat, and foraging guild for each species. Taking into consideration the breeding species on each island, an index to rank the islands was created. Ten islands or archipelagos have high conservation priority (index score > 10 = high priority; mean index = 4.7, median = 5.0, max = 17.9, n = 91), and the most important are: Revillagigedo and San Benito archipelagos, Coronado, San Lorenzo, and Natividad Islands. It is necessary to use new tools and techniques to determine populations' sizes and trends and to create a baseline to compare with future studies. Furthermore, many of the species breeding or feeding in the Mexican Economic Exclusive Zone migrate to other latitudes, elevating the conservation problem to an international scale. *Received 13 June 2019, accepted 9 December 2019.*

Key words.—conservation indices, endemics, fisheries, foraging areas, invasive species, pelagic, seabirds.

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Pelagic marine birds (seabirds) are characterized by a life cycle with a non-reproductive period in oceanic open waters, traveling far and wide in search for food, and concentration of large numbers on islands used for colony formation and reproduction (Schreiber and Burger 2002). Given the number of seabirds that breed or feed within Mexico's Economic Exclusive Zone (EEZ), the country occupies the third place worldwide in species richness and the second by number of endemics, making Mexico one of the most important in seabird richness and abundance (109 species total, 25 breeding in the EEZ according to Croxall *et al.* 2012). These characteristics are the result of the long shoreline and more than 3,000 islands within the Mexican EEZ. Given the irregularity of visits to islands with seabird colonies, the numbers could be underesti-

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mated, emphasizing the need for further basic research. Furthermore, Mexico is located on a transition zone between the Nearctic and Neotropical biogeographical regions (Morrone 2002; Rojas-Soto *et al.* 2003; Morrone 2006). In response to Mexico's great ecological diversity, Mexico is a member of the Convention for Biological Diversity and the Convention on Fishing and Conservation of Living Resources of the High Seas of 1958, and thus has a responsibility to protect and improve the conservation status of its biological richness. To achieve this, it is necessary to have a solid scientific baseline that allows for the planning and implementation of conservation strategies and actions.

The importance of the Mexican territorial waters for seabirds implies a high responsibility; these birds must be protected with the available legal instruments and the implementation of better laws in the future. On most Mexican islands where seabirds are known to breed, studies and management plans aim to protect them (Anderson 1980; Everett and Anderson 1991; Velarde and Anderson 1994; CONANP 2001, 2005, 2014). However, there is still a need to protect and manage the feeding grounds. For species such as Procellariiformes, it means areas of thousands of square kilometers (Guerrero Madriles 2007). Frequently, these feeding grounds are also used as commercial fishing areas, underscoring the need to manage and protect areas of overlap.

Long-term studies of seabird colonies are important beyond the understanding of species population dynamics. For example, the work carried out for more than 30 years on the seabird community on Isla Rasa, in the Gulf of California, has allowed understanding of the ecology and fisheries in the Gulf of California. Velarde *et al.* (2004) developed two statistical models that use local oceanographic conditions and seabird breeding success and feeding to predict total catch and catch per unit effort (CPUE) of Pacific sardine (*Sardinops sagax*) in the central region of the Gulf of California. Results show that seabird breeding ecology is linked to local and global oceanographic conditions, and preditions indicate that in case of low CPUE the fishing fleet could incur financial losses (Velarde *et al.* 2004; Velarde *et al.* 2013; Velarde *et al.* 2015).

The breeding season of seabirds is a critical moment in their life cycle. They usually breed in colonies on islands without native predators. During this period, breeding birds change from a disperse foraging to a central foraging strategy (Quintana *et al.* 2011). The geographic range of this change is determined by flight capacity of the parents and chick-feeding needs. These conditions, combined with oceanographic productivity, determine foraging sites (Schreiber and Burger 2002). Based on factors mentioned before, it is possible to predict an Ashmole's halo, whose size will be determined by seabird capacity to exploit local productivity and sustainable population size (Gaston *et al.* 2007). On the surface covered by these halos, there is a high probability of competition with different fisheries. Given these circumstances, well-defined pelagic areas should be protected to minimize seabird loss, while at the same time maintaining a sustainable fishery.

In the northwestern Mexican states of Colima, Jalisco, Nayarit, Sinaloa, Sonora, Baja California, and Baja California Sur, there are some 40 breeding seabird species (Everett and Anderson 1991; Erickson and Howell 2001; Howell 2001). Given that several species such as boobies, pelagic cormorants, shearwaters, and murrelets nest on difficult to access sites such as cliffs and burrows, and other species have nocturnal habits, it is difficult to obtain reliable information on presence, population size, and population trends. Therefore, the real number of species and individuals present in the area could be higher if search effort was increased and more detailed monitoring were to be done using new technologies and detection methods, i.e. drone counts as proposed by Alberes-Barajas *et al.* (2018) for burrowing species and acoustic monitoring as proposed by Oppel *et al.* (2014).

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Summarizing existing information is a key first step to achieve an optimal prioritization of research, management, and conservation activities needed for seabird conservation. Even if it is generally accepted that there is a lack of information, to date, existent information has not been compiled and summarized. Without the creation of a hierarchical summary, we cannot establish what needs to be done for seabird conservation. Currently, a high proportion of the information on the population status of Mexican seabirds is in grey literature and usually of poor quality, or in the management plans of the different protected areas where the seabirds breed, and not easily accessible. Conservation of seabirds and their critical habitats is not feasible with current knowledge of populations and population trends. The objective of this work is to analyze existing information in order to rank islands based on the conservation status of the seabirds, identify action opportunities, and focus efforts and resources on priority areas, and consequentially, priority species.

METHODS

The geographic scope of this study is focused on northwestern Mexico, including the northernmost extent of the Gulf of California and adjacent Pacific Ocean west of the Baja Peninsula (Figs. 1 and 2 show the northern and southern halves of the Gulf of California, respectively), and south to islands in the Pacific Ocean immediately south of the Baja Peninsula (Fig. 3). We conducted a comprehensive literature search on northwestern Mexico seabirds, including published and indexed as well as grey literature (thesis and internal reports) searchable by different means, with search terms including each species' scientific name. We included the databases of Google Scholar and Web of Science, scientific articles, reports, management plans from federal websites, and breeding sites reports on eBird. We created tables that summarized species breeding in the area and important characteristics for prioritization of the islands (Appendix 1). As most of the literature does not report abundance, we only compiled seabird presence/absence data. We selected papers with seabird records present within the study area (Appendix 1). The timeline spanned 97 years, from 1922 to 2019, and we considered 11 families (see Appendix 1): Diomedeidae (two species), Procellariidae (three species), Hydrobatidae (four species), Fregatidae (two species), Phaethontidae (three species), Sulidae (five species), Pelecanidae (one species), Phalacrocoracidae (four species), Laridae (five gull species; terns were not included due

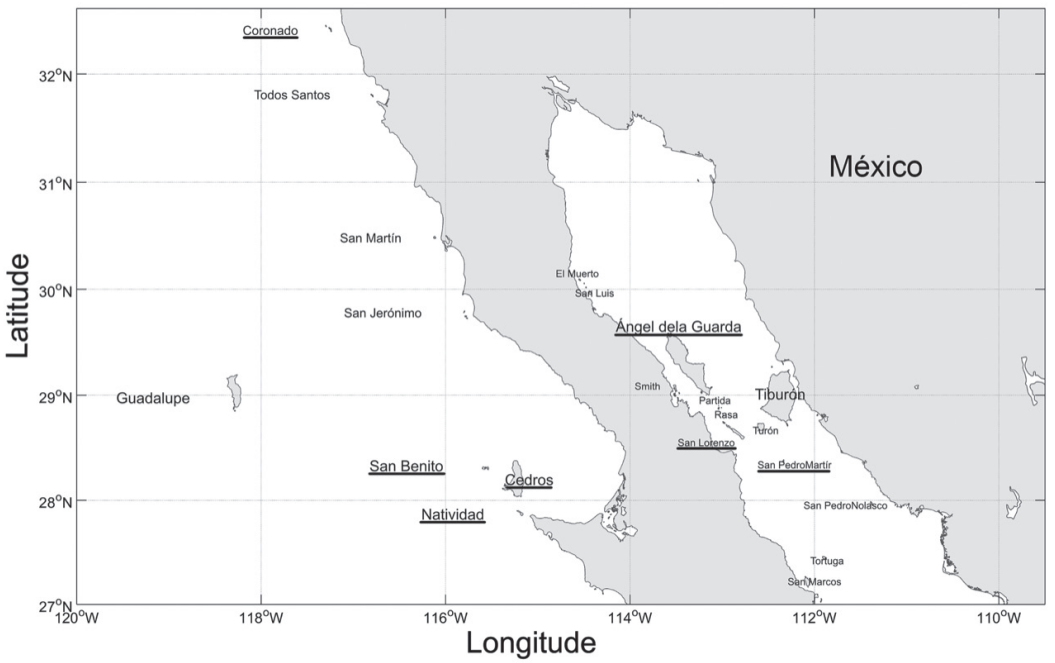


Figure 1. Map of the northern portion of study area in northwestern Mexico, showing seabird colony islands in the northern Gulf of California and the Pacific, where most of the islands with colonies are concentrated. Islands with conservation Priority Index score >10 are underlined.

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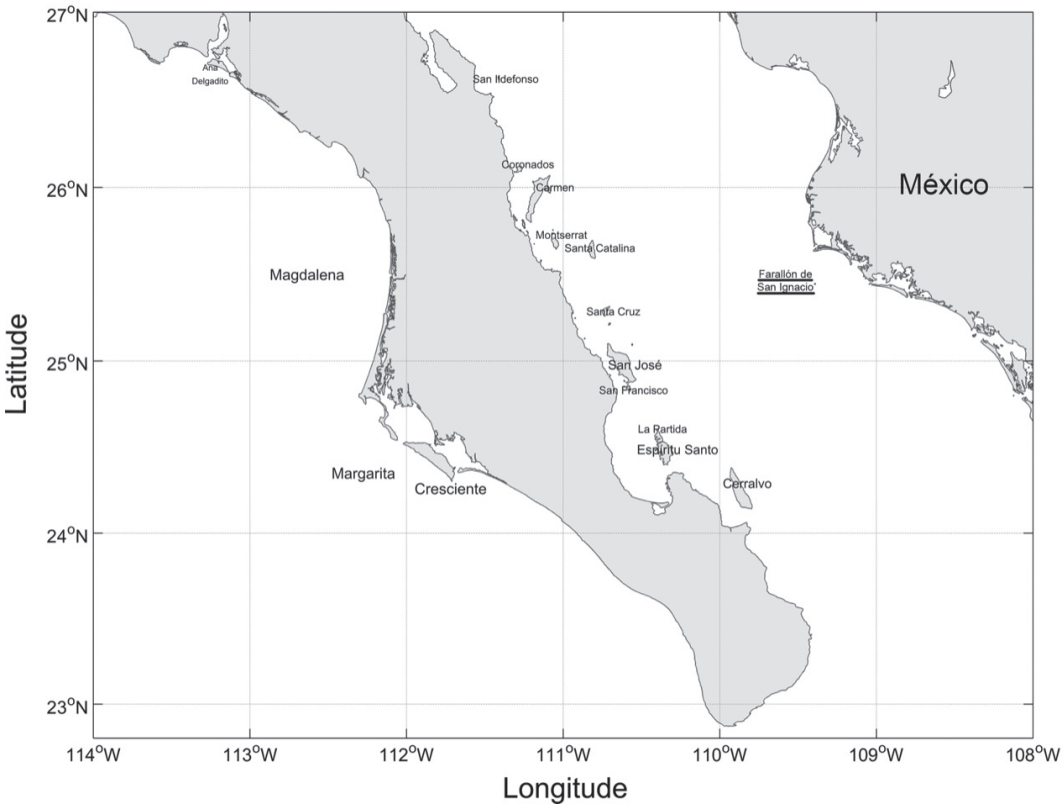


Figure 2. Map of the central portion of study area in northwestern Mexico, showing seabird colony islands in the central Gulf of California and the Pacific. Islands with conservation Priority Index score >10 are underlined.

to their more coastal occurrence rather than pelagic), Alcidae (five species) and, exceptionally, Accipitridae (one species).

The species endemic to the area are (scientific names of birds in Appendix 1): Black-vented and Townsend's shearwaters (Ainley *et al.* 1997), Heermann's and Yellow-footed gulls (Patten 1996), Least Storm-petrel (Howell and Webb 1995), and Guadalupe and Craveri's murrelets (Anderson 1983). The shearwaters breed mainly in the Mexican Pacific islands; 95% of the Black-vented Shearwater population breeds on Natividad Island, and Townsend's Shearwater breeds on Socorro and Clarion islands of the Revillagigedo Archipelago (Martínez-Gómez and Jacobsen 2004; Ortiz-Pulido *et al.* 2016). Yellow-footed Gull breeds only in the Gulf of California. Least Storm-petrel is distributed both on the Pacific and the Gulf of California, as well as the murrelets, with Guadalupe Murrelet presenting a more northern distribution in the Pacific.

We focused on information regarding population status and trends of species nesting on islands (Table 1) according to international (IUCN RedList 2018) and national parameters (NOM-059 2010 [DOF 2010]), where categories of distribution, conservation status, and ecological characterization of habitat use are explained: foraging habitat = pelagic or coastal; nesting habitat = plain surfaces, burrows, cliffs (external), crevices, or vegetation/mangroves; and guild = piscivorous, planktivorous, or generalist (Table 1). With this information, we used species richness, foraging habitat, and foraging guild to create indices of seabird biodiversity ("habitat index" and "guild index") for each island or archipelago.

To assign a weight to each category, we considered relative community composition in terms of foraging habitat preferences and foraging guilds of the species that were part of that community, constructing an additive and cumulative scale. We assigned pelagic habitat a value of two and coastal habitat a value of one. We gave pelagic habitat a higher value because most islands in the study have a decreed protected area around them, giving some measure of protection to species that forage in coastal areas. On the other hand, pelagic species usually feed in pelagic zones, far from the protected areas. We based feeding preference categories on species trophic level in the food web: piscivorous = 3, planktivorous = 2, and generalists = 1. We assigned generalists a lower value, as we do not consider them a priority concern due to their plasticity allowing them to better cope with moderate changes. To calculate the habiat index scores for an island, we multiplied the category score (coastal = 1, pelagic = 2) by the number of species for each category, summed the products, and divided this by the number of species in the colony (Table 2). We did likewise to calculate the guild index (Table 2).

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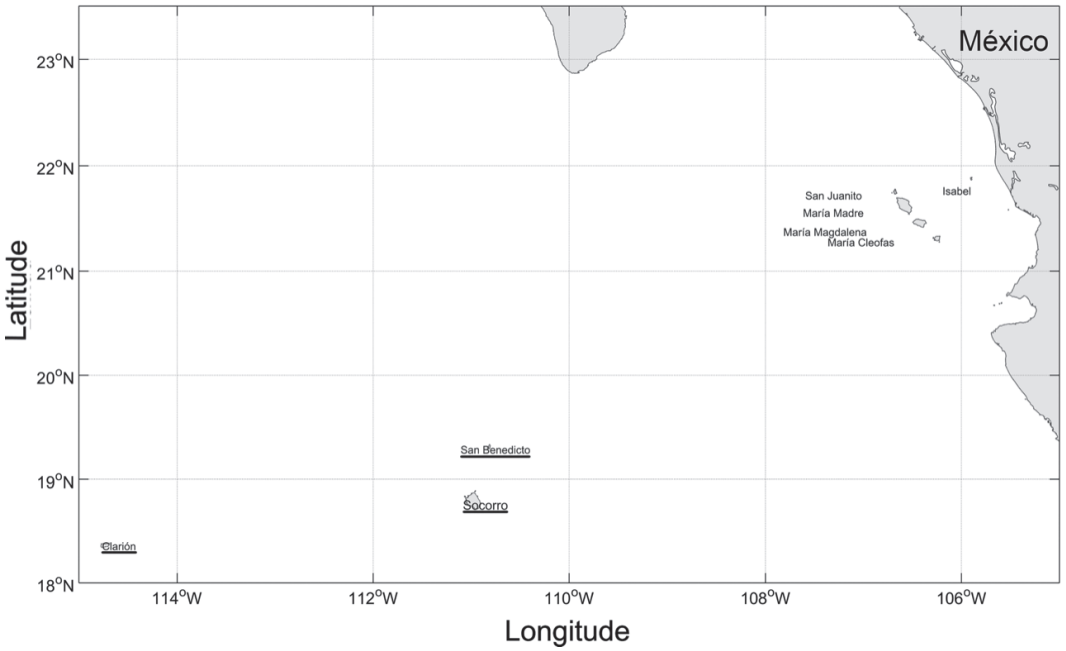


Figure 3. Map of the southern portion of study area in northwestern Mexico, showing seabird colony islands in the Pacific, south of the Baja Peninsula (tip of peninsula visible at top center of map). Islands with conservation Priority Index score >10 are underlined.

We added IUCN information to the model by assigning a higher weight to more threatened species. We assigned a score of five to Critically Endangered species, three to Endangered, two to Vulnerable, one to Near Threatened, and 0.5 to Least Concern species. The sum of the scores for species on each island defined a "Conservation Index" (category for each species in Table 1, Conservation Index scores in Table 2). As a result, islands with Critically Endangered or Vulnerable species have a higher conservation priority. By adding up the three indices of habitat, guild and conservation status, we obtained a general index to classify the island by priority (Priority Index). Islands with 10 to 20 points are considered high priority; between 5 and 10, medium; and below five, low (Table 2). We included both individual islands and island complexes (archipelagos).

We collated all information to develop a Strategic Action Plan that will guide projects ranging from basic to applied science to support conservation policies to protect seabirds in northwestern Mexico. We also looked for academic institutions and NGOs with active projects focused on seabird ecology and conservation. Finally, we searched for information about logistics and infrastructure for each island, a must to consider when planning fieldwork. Active projects and logistics were not considered in the Priority Index calculation. We used information including (1) the species breeding on different islands, (2) population trends, conservation status and ecological characterization in terms of habitat use and guild, and (3) the biodiversity index for each island or archipelago (see Appendix 1, Table 1, and Table 2) to create two integrative tables.

RESULTS

We consulted 119 papers or reports plus management plans for protected areas within the distributions of the seabird species under study. Beginning in 1990, there was a significant increase in the number of publications (93 of the 119 were published after that year). However, the lack of accessibility of documents produced before the digital era could produce a bias.

Northwestern Mexico is the most important area for seabirds within the Mexican territory (Tershy *et al.* 2002). The presence of oceanic islands, such as Revillagigedo Archipelago and Guadalupe Island and several islands in the northern half of the Gulf of California, are excellent breeding grounds for multiple species of seabirds, including several endemics. We must highlight, among others, Townsend's and Black-vented shearwaters, Leach's Storm-petrel, Laysan and Black-footed albatrosses, Brown Pelican, Elegant Tern (*Thalasseus elegans*, although terns were not included in the analyses), and Heermann's and Yellow-footed gulls, as they

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Table 1. Population status and trends of seabirds in northwestern Mexico, according to international (IUCN RedList 2018) and national parameters (NOM-059 2010 [DOF 2010]), where the categories of distribution, conservation status, guild, and ecological characterization of habitat use are explained. Pop trend: = stable; + increase; - decrease; ? unknown. IUCN status: CR=Critically Endangered; EN=Endagered; VU=Vulnerable; NT=Near Threatened; LC=Least Concern. Distribution "NOM distrib": noE=non-endemic; E=endemic. National conservation status "NOM Cat": T=threatened; E=extinction risk; Pr=subject to special protection. Guild: Pisc=piscivorous; Plnk=planktivorous; Gen=generalist. Foraging habitat "hab": Pe=pelagic; C=coastal. Nesting habitat "nest": S=plain surfaces; B=burrows , Cl=cliffs (external); Cr=crevices; V=vegetation/mangroves.

Family	Species	Scientific Name	Code	Pop trend	IUCN	NOM distrib	NOM cat	Guild	Hab	nest	Number of sites
Diomedeidae	Laysan Albatross	*Phoebastria immutabilis*	LAAL	=	NT	noE	T	Pisc	Pe	S	2
	Black-footed Albatross	*Phoebastria nigripes*	BFAL	+	NT	noE	T	Pisc	Pe	S	1
Procellariidae	Wedge-tailed Shearwater	*Ardenna pacifica*	WTSH	-	LC	noE	T	Pisc	Pe	B	1
	Black-vented Shearwater	*Puffinus opisthomelas*	BVSH	?	NT	noE	E	Pisc	C	B	5
	Townsend's Shearwater	*Puffinus auricularis*	TOSH	-	CR	E	E	Pisc	Pe	B	1
Hydrobatidae	Leach's Storm-petrel	*Hydrobates leucorhous*	LESP	=	VU	noE	E	Pisc	Pe	B	6
	Black Storm-petrel	*Hydrobates melania*	BLSP	-	LC	noE	T	Pisc	Pe	Cr	8
	Ashy Storm-petrel	*Hydrobates homochroa*	ASSP	-	EN	noE	E	Plnk	Pe	Cr	1
	Least Storm-petrel	*Hydrobates microsoma*	LTSP	-	LC	noE	T	Plnk	Pe	Cr	17
Fregatidae	Magnificent Frigatebird	*Fregata magnificens*	MAFR	+	LC			Pisc	C	V	10
	Great Frigatebird	*Fregata minor*	GRFR	-	LC			Pisc	C	V	1
Phaethontidae	White-tailed Tropicbird	*Phaethon lepturus*	WTTR	-	LC			Pisc	Pe	B/Cl	4
	Red-billed Tropicbird	*Phaethon aethereus*	RBTR	-	LC	noE	T	Pisc	Pe	B/Cl	7
	Red-tailed Tropicbird	*Phaethon rubricauda*	RTTR	=	LC			Pisc	Pe	B/Cl	1
Sulidae	Red-footed Booby	*Sula sula*	RFBO	-	LC	—	T	Pisc	Pe/C	S/Cl	2
	Brown Booby	*Sula leucogaster*	BRBO	-	LC			Pisc	Pe/C	S/Cl	12
	Blue-footed Booby	*Sula nebouxii*	BFBO	=	LC	—	Pr	Pisc	Pe/C	S/Cl	16
	Masked Booby	*Sula dactylatra*	MABO	-	LC			Pisc	Pe/C	S/Cl	1
	Nazca Booby	*Sula granti*	NABO	-	LC			Pisc	Pe/C	S/Cl	1
Pelecanidae	Brown Pelican	*Pelecanus occidentalis*	BRPE	+	LC	noE	T	Pisc	C	S	27
Phalacrocoracidae	Neotropic Cormorant	*Phalacrocorax brasillianus*	NECO	+	LC			Pisc	C	S/Cl	2
	Pelagic Cormorant	*Phalacrocorax pelagicus*	PECO	-	LC			Pisc	C	Cl	2
	Brandt's Cormorant	*Phalacrocorax penicillatus*	BRCO	-	LC			Pisc	C	S/Cl	19
	Double-crested Cormorant	*Phalacrocorax auritus*	DCCO	+	LC			Pisc	C	S/Cl	20
Laridae	Heermann's Gull	*Larus heermanni*	HEGU	+	NT	noE	Pr	Pisc	C	S	11
	Laughing Gull	*Leucophaeus atricilla*	LAGU	+	LC			Pisc	C	S	3

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Table 1. (Continued) Population status and trends of seabirds in northwestern Mexico, according to international (IUCN RedList 2018) and national parameters (NOM-059 2010 [DOF 2010]), where the categories of distribution, conservation status, guild, and ecological characterization of habitat use are explained. Pop trend: = stable; + increase; - decrease; ? unknown. IUCN status: CR=Critically Endangered; EN=Endagered; VU=Vulnerable; NT=Near Threatened; LC=Least Concern. Distribution "NOM distrib": noE=non-endemic; E=endemic. National conservation status "NOM Cat": T=threatened; E=extinction risk; Pr=subject to special protection. Guild: Pisc=piscivorous; Plnk=planktivorous; Gen=generalist. Foraging habitat "hab": Pe=pelagic; C=coastal. Nesting habitat "nest": S=plain surfaces; B=burrows , Cl=cliffs (external); Cr=crevices; V=vegetation/mangroves.

Family	Species	Scientific Name	Code	Pop trend	IUCN	NOM distrib	NOM cat	Guild	Hab	nest	Number of sites
	California Gull	*Larus californicus*	CAGU	-	LC			Pisc	C	S	0
	Yellow-footed Gull	*Larus livens*	YFGU	=	LC	noE	Pr	Gen	C	S	9
	Western Gull	*Larus occidentalis*	WEGU	+	LC			Gen	C	S	12
Alcidae	Scripps's Murrelet	*Synthliboramphus scrippsi*	SCMU	-	VU			Plnk	Pe	B/Cr	6
	Guadalupe Murrelet	*Synthliboramphus hypoleucus*	GUMU	-	EN	noE	E	Plnk	Pe	B/Cr	4
	Craveri's Murrelet	*Synthliboramphus craveri*	CRMU	-	VU	noE	E	Plnk	Pe	B/Cr	21
	Cassin's Auklet	*Ptychoramphus aleuticus*	CAAU	-	NT	E	E	Plnk	Pe	B	9
Accipitridae	Osprey	*Pandion haliaetus*	OSPR	+	LC			Pisc	C	Cl/V	26

are fragile species that have suffered population reductions in the past (Anderson *et al.* 2017; Keitt and Tershy 2003; Martínez-Gómez and Jacobsen 2004; Palacios *et al.* 2003).

We identified many information gaps, especially regarding abundance and temporal variability for the area's species. Protected areas management plans present mostly presence/absence data, very often without providing information on whether the species is resident or migratory or breeds on the island. In several cases, even the presence/absence records were dubious. The most detailed studies have been carried out by academic institutions, mainly from the USA, focused broadly on seabirds in the Gulf of California in general (Anderson *et al.* 1976; Everett and Anderson 1991; Velarde and Anderson 1994; Velarde *et al.* 2005), on specific archipelagos within the Gulf of California (Jehl and Parks 1982; Jehl and Everett 1985; Duberstein *et al.* 2005), and on specific species (Townsend's Shearwater, Jehl 1982; Double-crested Cormorant, Carter *et al.* 1995 and Pfister *et al.* 2005; Laysan Albatross, Pitman *et al.* 2004; Craveri's Murrelet, Hurley and Blinick 2011).

There are other recent studies on particular species, such as: Heermann's Gull (Velarde 1999; Velarde and Ezcurra 2018), Craveri's Murrelet (Velarde *et al.* 2011), and Least Storm-Petrel (Velarde 2000) on Isla Rasa; Brown Pelican in the Midriff Region (Anderson *et al.* 2017); Blue-footed Booby on Isabel Island (Torres *et al.* 2011; Ramos and Drummond 2017; Ancona *et al.* 2018); Townsend's Shearwater on Revillagigedo (Martínez-Gómez and Jacobsen 2004); and Black-vented Shearwater on Natividad Island (Albores-Barajas *et al.* 2016; Albores-Barajas *et al.* 2018; Soldatini *et al.* 2019) and Isla Rasa (Velarde *et al.* 2015b). Other studies have focused on aspects of the ecology of seabirds, such as the predation of larids on Isla Rasa (Velarde 1993) and seabird foraging and fish prey populations (Velarde *et al.* 2004; Velarde *et al.* 2013; Velarde *et al.* 2014; Velarde *et al.* 2015a). These islands and species are certainly important, however these studies cover a minimum of information needs (population size and ecology), although they point in the direction of future research.

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Table 2. Island conservation Priority Index for seabird colony sites in northwestern Mexico with score >10 (index values: mean=4.7, median=5.0, max=17.9, *n*=91; 0<5 low priority, 5<10 medium, and 10<20 high). Score is based on species richness, habitat index, guild index, IUCN conservation status of species nesting on each island or archipelago, and considers island accessibility for research and monitoring (Logistics: 0=nothing; 1=basic facilities; 2=human settlement with basic services). Institutions: CICESE=Center for Scientific Research and Higher Education of Ensenada, INECOL=Mexican National Institute for Ecology, UABCS=Autonomous University of Baja California Sur, UV=University Veracruzana, UNAM=National Autonomous University of Mexico, UG=University of Guadalajara, MPIO=Max Planck Institue for Ornithology, UCD=University of California Davis; NGOs: PNO=Pronatura Nor-Oeste, GECI=Grupo de Ecologia y Conservación de Islas (Islands Ecology and Conservation Group).

		Biodiversity	Habitat Index			Guild Index				Conservation	Active projects		Logistics			
Zone	Islands and Archipelagos (no. of islands)	ecies richness	Number of pelagic taxa	Number of coastal taxa	Community composition index: pelagic spp=2, coastal spp=1	No. Piscivorous species	No. Planktivorous species	No. Generalist species	Guild dominated by species: piscivorous=3, planktivorous=2, generalists=1	IUCN RedList Total Score	Number of projects	Institution	Human presence on island	Transport facilities	Lodging facilities	**Priority Index = habitat+guild+Conservation**
Pacific	Revillagigedo Archipelago (4)	13	5	8	1.4	13	0	0	3.0	13.5	2	INECOL GECI	1	1	1	**17.9**
Pacific	San Benito (3)	13	6	7	1.5	8	4	1	2.5	13.5	1	GECI	1	1	1	**17.5**
Pacific	Coronado (3)	11	5	6	1.5	7	3	1	2.5	11.5	1	GECI	1	0	0	**15.5**
Gulf of California	San Lorenzo Archipelago	13	5	8	1.4	10	2	1	2.7	10	1	UCD	0	2	0	**14.1**
Pacific	Natividad	9	3	6	1.3	5	3	1	2.4	9.5	2	CICESE UABCS GECI	1	2	2	**13.3**
Pacific	Guadalupe + islets	7	4	3	1.6	4	2	1	2.4	9	1	CICESE UABCS MPIO GECI	1	1	1	**13.0**
Gulf of California	Angel de la Guarda	10	5	5	1.5	8	2	0	2.8	8	1	UCD	0	2	0	**12.3**
Gulf of California	San Pedro Martir	10	2	8	1.2	7	2	1	2.6	7	1	UG	0	1	0	**10.8**
Gulf of California	Farrallon de San Ignacio	9	2	7	1.2	6	2	1	2.6	6.5	1	UG	0	1	0	**10.3**
Pacific	Cedros	5	2	3	1.4	2	2	1	2.2	6.5	0		1	2	2	**10.1**

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Ten islands had a Priority Index score > 10 (high conservation priority; Table 2), and Priority Index values ranged from (mean = 4.7, median = 5.0, max = 17.9, n = 91; Table 3). An important element to determine the conservation status of a species is its population trend. We know of the existence of several colonies of seabirds, but in most cases, it is unknown whether the population is increasing, stable, or decreasing. To generate such important information, it is necessary to implement a monitoring program in the medium- and long-term. We summarized the Priority Index calculated from the breeding populations, habitat preference, and guild (Table 3) and we reported the development opportunities in the short-, medium-, and long-term (Table 4).

The Revillagigedo Archipelago sits on top of our list of conservation priorities (Table 3). Townsend's Shearwater breeds here. It is the only seabird species breeding in Mexico considered Critically Endangered by the IUCN (BirdLife International 2015). Historically, this species bred on Socorro, Clarion, and San Benedicto Islands of the archipelago. The long-term monitoring carried out by INECOL (Mexican National Institute for Ecology) has confirmed that the colonies in Socorro and Clarion remain, but the colony on San Benedicto has not reestablished after the eruption of the Barcena volcano (Martínez-Gómez and Jacobsen 2004; Martínez-Gómez *et al.* 2015). It is therefore of utmost importance to continue high-quality monitoring on these two islands and to continue the exploration on San Benedicto to detect any recolonization attempts. Furthermore, the Archipelago is the only breeding ground in Mexico for Black-footed Albatross, Nazca Booby, and Red-tailed Tropicbird. This archipelago is also home to the only subtropical colony in the world of Laysan Albatross, and the only breeding record in Mexico of Common White Tern (*Gigis alba*) (Martinez-Gomez and Matias-Ferrer 2013).

Second on our priority conservation list is San Benito Archipelago. This three-island archipelago hosts more than three million individuals of different species, the highest abundance of seabirds in northwestern Mexico. Among them and particularly important are the species catalogued by the IUCN: Guadalupe Murrelet, Endangered; Scripps's Murrelet, Vulnerable; and Leach's Storm-petrel, Vulnerable.

The Coronado Archipelago is third on our list. It is the southernmost breeding site of Ashy Storm-petrel, cataloged as Endangered by the IUCN. There are also reports of Leach's Storm-petrel nesting on the islands, and it hosts the northernmost breeding sites for Black Storm-petrel and Brown Booby. Additionally, other seabird species are present on the islands; however, there is overlap with the seabird community on San Benito, and the abundance for these species is greater on San Benito.

The San Lorenzo Archipelago is the fourth area on our priority list. Its ranking is due the high number of islands and islets (12), and the number of species the archipelago hosts (13). Furthermore, there are several islands in the archipelago that host important numbers of several seabird species, such as Isla Rasa, where 95% of the global population of Heermann's Gull and Elegant Tern breed. Isla Partida hosts 80% of the global population of Black and Least storm-petrels. There is also a large percentage of the global population of Yellow-footed Gull distributed among several islands within the archipelago, this species breeds in small colonies, usually less than 100 nests, and the global population, estimated at 20,000 pairs by Anderson (1983) is mainly concentrated in the central Gulf of California. An interesting aspect of this archipelago is that it offers an excellent opportunity to carry out population dynamics and metapopulation studies (because data has been collected for a long time there already), both essential for a successful long term conservation plan (Anderson *et al.* 2017).

In fifth priority is Isla Natividad. Despite being close to the San Benito Archipelago, this island is very important, hosting 95% of the world population of Black-vented Shearwater. Recent studies show that the actual population number is much lower (42,090 breeders on average in 2016-2017) than the one estimated previously (76,570 breeders

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Table 3. Ranking of the islands of Northwestern Mexico based on Priority Index score for seabird conservation (listed in order from highest priority to lowest). Pa=Pacific Ocean; GoC=Gulf of California. Priority Index scores: 10<20=High; 5<10=Medium; 0<5=Low (mean=4.7, median=5.0, max=17.9, *n*=91; island scores <4.5 not shown).

Area	Islands and Archipelgos (number of islands)	Priority Index	Notes
Pa	Revillagigedo Archipelago (4)	17.9	Townsend's Shearwater and two albatross species
Pa	San Benito (3)	17.5	High species richness, some threatened. More than 3 million individuals estimated
Pa	Coronado (3)	15.5	Presence of Ashy Storm-petrel
GoC	San Lorenzo Archipelago	14.1	Island complex hosts many species of seabirds including Rasa Island with 90% of two species: Elegant Tern and Herman's Gull
Pa	Natividad	13.3	95% of the world population of Black-vented Shearwater
Pa	Guadalupe + islets	13.0	Growing colony of Laysan Albatross, Guadalupe murrelet colonies and possible presence of Guadalupe Storm-petrel
GoC	Angel de la Guarda	12.3	Craveri's murrelet, black and least storm petrels colonies and other threatened species.
GoC	San Pedro Martir	10.8	Largest Brown Booby colony in the world, and important breeding grounds for Craveri's Murrelet
GoC	Farrallon de San Ignacio	10.3	Important colony for Brown and Blue-footed Boobies, tropicbirds and Least Storm-petrel
Pa	Cedros	10.1	Possible presence of Guadalupe and Scripps's Murrelet
Pa	Todos Santos	9.8	High species richness. Most on the LC category.
GoC	Cerralvo	9.4	
Pa	Asunción	9.2	High species richness. Most on the LC category.
GoC	Rasa	9.2	95% of the world population of two seabird species.
Pa	San Jeronimo	8.7	One of the few islands where both species of murrelet can be found
Pa	Isla Isabel	8.5	Important colonies for Brown and Blue-footed Boobies
Pa	San Martin	8.2	
Pa	San Roque	8.2	
GoC	Espiritu Santo Complex	7.8	
GoC	San José	7.6	
Pa	Marietas (2)	7.5	
GoC	Las Animas	7.5	
Pa	Marias (4)	7.0	
GoC	Salsipuedes	6.7	
GoC	Tiburon	6.6	
GoC	Granito	6.5	
GoC	Piojo	6.5	
GoC	Mejia	6.5	
Pa	Isla Margarita	6.1	Historically hosted the largest colony of Magnificen Frigatebird in the world
GoC	Cabeza de Caballo	6.0	
GoC	Ventana	6.0	

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Table 3. (Continued) Ranking of the islands of Northwestern Mexico based on Priority Index score for seabird conservation (listed in order from highest priority to lowest). Pa=Pacific Ocean; GoC=Gulf of California. Priority Index scores: 10<20=High; 5<10=Medium; 0<5=Low (mean=4.7, median=5.0, max=17.9, *n*=91; island scores <4.5 not shown).

Area	Islands and Archipelgos (number of islands)	Priority Index	Notes
GoC	Bota	6.0	
GoC	Mitlán	6.0	
GoC	La Partida	5.8	
GoC	Idelfonso	5.5	
GoC	Farallon	5.5	
GoC	San Luis (4)	5.5	
Pa	Islas Bahia Magdalena Complex (4)	5.5	
GoC	Coronados	5.5	
GoC	Patos	5.5	
GoC	Smith	5.5	
GoC	Consag	5.5	
GoC	Pájaros (Guasave)	5.5	
GoC	Alcatraz	5.3	
GoC	San Jorge	5.0	
GoC	Tortuga	5.0	
GoC	El Rancho	5.0	
GoC	San Lorenzo	5.0	
GoC	San Ignacio	5.0	
GoC	Monserrat	4.5	
GoC	Danzante	4.5	
GoC	Carmen	4.5	
GoC	San Marcos	4.5	
GoC	Calavera	4.5	
GoC	Gemelito Este	4.5	
GoC	Gemelito Oeste	4.5	
GoC	Jorobado	4.5	
GoC	San Luis	4.5	

Table 4. Strategic action plan for the development of projects including basic and applied research and supporting conservation policies for seabirds in northwestern Mexico. Codes: C=short term 1-2 years; M=medium term 3-4 years; L= long term more than 5 years; √ = in process. Acronyms list: Mon=population abundance and monitoring; Band=Banding of chicks and adults; Isot= stable isotopes analysis; Trend=population trend (3 years of Mon); Dem=demographic studies (5 years of Band); Home=home range determination; IBA=propose a marine Important Bird Area; Dissem=transference of knowledge to stakeholders; Agree=agreements with local communities; NPA=technical support from Natural Protected Areas Personnel.

	Basic research			Applied research			Conservation projects			
	Mon	Band	Isot	Trend	Dem	Home	IBA	Dissem	Agree	NPA
Revillagigedo (4)	C	C	M	M	M	C	M-L	C-M	—	M-L
San Benito (3)	C	C	M	M	M	C	M-L	C-M	C	M-L
Coronado (3)	C	C	M	M	M	C	M-L	C-M	—	M-L
San Lorenzo Archipelago (10)	C	C	M	M	M	C	M-L	C-M	—	M-L
Natividad	√ - C	√ - C	M	M	M	√ - C	C-M	C	C	C-M
Guadalupe and islets	C	C	M	M	M	C	M-L	C-M	C	M-L
San Lorenzo Archipelago	C	C	√	M	M	C	M-L	C-M	—	M-L
San Pedro Mártir	C	C	M	M	M	C	M-L	C-M	—	M-L
Farallón de San Ignacio	C	C	M	M	M	C	M-L	C-M	—	M-L
Cedros	C	C	M	M	M	C	M-L	C-M	C	M-L
Todos Santos	√	M	M	M	M	M	M	M	M	M
Cerralvo	M	M	M	M	M	M	M	M	M	M
Asunción	√	M	M	M	M	M	M	M	M	M
Rasa	√	√	√	M	M	M	M	M	M	M
Isabel	√	M	M	M	M	M	M	M	M	M
San Jerónimo	√	M	M	M	M	M	M	M	M	M
San Martin	√	M	M	M	M	M	M	M	M	M
San Roque	√	M	M	M	M	M	M	M	M	M
Espíritu Santo (5)	C	M	M	M	M	M	M	M	M	M

in 1997) (Albores-Barajas *et al.* 2018), making the conservation of this area even more critical.

In sixth priority is Isla Guadalupe. This island has the largest Laysan Albatross colony in Mexico. It also hosts breeding Guadalupe Murrelet, Black-vented Shearwater, and Cassin´s Auklet. The only seabird species considered extinct in Mexico, Guadalupe Storm-petrel (*Hydrobates macrodactylus*) used to breed here, no individuals have been observed since the early twentieth century. The possible extinction can be attributed to habitat modification by goats, now extirpated, and the predation by cats present on the whole island. However, to this day, no extensive and exhaustive search has been carried out within the breeding dates reported for the species (BirdLife International 2018).

In seventh priority is Isla Angel de la Guarda Island. This island is important for the Leach's, Black, and Least storm-petrels, as well as Craveri's Murrelet. In eighth priority is Isla San Pedro Mártir, an important breeding site for Blue-footed and Brown boobies, Least Storm-petrel, and Craveri's Murrelet (Tershy and Breese 1997). Other species present include Red-billed Tropicbird, Brown Pelican, and Heermann's and Yellow-footed gulls. In ninth priority is Farallón de San Ignacio. It is one of the most important breeding grounds for Craveri's Murrelet. It is also home to large colonies of Brown and Blue-footed boobies. In tenth place is Isla Cedros. It is a historical breeding ground for the Guadalupe and Scripps's murrelets, which gives its importance. However, recent literature reports breeding attempts or small colonies of Brown Pelican and Double-crested and Brandt´s cormorants, but no large seabird colonies.

Some islands critical to seabirds in Mexico are not included in our list. This is because we did not consider them to be data deficient, where the continuous presence of researchers has helped to detect population trends and ecology and conservation aspects of several seabird species. Such is the

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case of Isla Rasa, where Enriqueta Velarde, from Universidad Veracruzana, has studied seabirds for more than 40 years, Isla Isabel where Hugh Drummond and Roxana Torres from National Autonomous University of Mexico (UNAM) conduct their long term research, and Isla Alcatraz with the long term monitoring work of Prescott College.

DISCUSSION

Many conservation and research efforts have contributed significantly to knowledge about seabirds and their breeding ground in northwestern Mexico. However, in recent decades, the effort and number of published papers decreased notably, and in some cases, we must deal with data older than 20 years. For this reason our results are based on species presence information and not on abundance, given that this kind of information is discontinuous or not updated for most species and most islands considered. Nevertheless, the Priority Index, based on the characteristics of the community and the conservation priorities of the species allowed us to rank the islands as a basis for a seabird conservation strategic plan of northwestern Mexico.

With particular reference to population estimates, many methods used had a very large intrinsic error, as was the case for Black-vented Shearwater on Isla Natividad. At the end of the 1990s, Keitt (2003) estimated a population of more than 100,000 breeding pairs; they used plots to measure density and extrapolated that to the total area where burrows were seemingly present. Recently, with the use of drones, researchers took aerial photographs and built a georeferenced orthomosaic. They then counted each burrow on the orthomosaic, with a detection error of 5.6%. With this method, and considering burrow occupancy, they estimated the population to be ~45,000 breeding pairs, half of what was reported at the end of the 1990s (Albores-Barajas *et al.* 2018). Cats were eradicated on the island between the late 1990s and 2018, therefore a population increase would be expected. When comparing the results from both studies (100,000 vs. 45,000 breeding pairs), the difference is almost certainly due to an error in the earlier extrapolation, leading to a large overestimate. It is also likely that there are biases in population estimates for islands such as San Benito, where the estimates are for more than three million individuals of several species. With the new technologies, it is likely this figure will be a better estimate of actual population numbers.

The research group at INECOL has continuosly monitored the breeding grounds of the Townsend's Shearwater on Socorro Island since 2006 and intermittently monitored areas on Clarion Island. They have also visited San Benedicto Island at different times of the year when Townsend's Shearwater could be breeding. The monitoring of this species has been carried out carefully, without damaging the vegetation surrounding the burrows, to avoid encouraging predation by introduced cats or the native Red-tailed Hawk (*Buteo jamaicensis*).

After identifying priority islands, the next step is to obtain more accurate population estimates for different seabird species, setting the basis for population trends over time. In the mid-term, research should focus on population trends and the influence of environmental variability, disturbance, and human impacts on these trends. This will require capture-mark-recapture data, satellite tracking to identify at-sea distribution, and stable isotope analysis to determine diet and movements outside of the breeding season (Phillips *et al.* 2007; Ramos *et al.* 2009; Suryan and Fischer 2010), although those methods have only recently been applied to seabird research in the study region (Soldatini *et al.* 2019). Together these elements will help the progression and linkage of seabird conservation on land to seabird conservation at sea, including helping researchers understand the environmental variability and dynamics of newly identified marine Important Bird Areas (BirdLife International 2010).

Other priority aspects for conservation are feeding areas and routes seabirds follow to reach these areas daily or during migration. In 1998, 1999, 2000, 2003, and 2006, the Unit-

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ed States National Oceanographic and Atmospheric Administration (NOAA) carried out at-sea transects to estimate abundance and distribution of seabirds. However, the data obtained are not reliable for robust analyses as all transects were done at different places and times of the year, increasing the variability and the error of the estimates, reducing the power of the data analyses (Joyce 2016).

There is a lack of general information on seabirds in northwest Mexico that needs to be filled so that Mexico can fulfill its obligations towards biodiversity conservation, as established in the Convention for Biological Diversity, the Ley General de Vida Silvestre (SEMARNAT 2000), and different international agreements signed to protect the species that use islands in Mexican territorial waters (such as the Convention for Biological Diversity and the Convention on Fishing and Conservation of Living Resources of the High Seas). Furthermore, many species that use the territorial waters nest or disperse towards other latitudes, elevating the issue to the international level. For this reason, conservation of northwest Mexico's seabirds can have broad-reaching impacts. Conflict with fisheries, introduced species, and other human-caused factors continue to threaten seabird populations in northwest Mexico and worldwide. Improving our understanding of seabird population trends and status during all stages of their annual cycle, how environmental factors impact population levels, and how human activity can harm seabirds can help improve laws to protect marine biodiversity.

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APPENDICES

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APPENDIX 1

Seabird species breeding on each island or archipelago in the Gulf of California and Pacific Ocean of northwestern Mexico.

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