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PRIORITIZING RESTORATION ACTIONS FOR THE ISLANDS OF MEXICO

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Abstract.—Science-based planning and prioritization can help achieve greater return on investment of limited conservation funds. We conducted a GIS-based multicriteria decision analysis to prioritize efforts to eradicate populations of invasive alien species that threaten native biota on the islands of Mexico. We evaluated 29 Mexican islands with documented presence of invasive mammals and characterized the following attributes of each island: presence of endemic taxa, presence of threatened species, presence of important seabird nesting areas, species richness, likelihood of reinvasion, eradication feasibility, and economic cost. We categorized the islands into 4 priority categories for eradication action. The highest priority islands where eradication efforts are feasible are Socorro, Espíritu Santo, María Cleofas, and María Magdalena islands, where eradication of 11 invasive mammal populations could advance the restoration of an additional 35,813 ha, thereby reducing the extinction risk of approximately 80 endemic taxa.

Resumen.—La planeación sistemática y priorización es fundamental para lograr mayor eficiencia de inversión de fondos limitados para la conservación. Se aplicó un análisis multicriterio por medio de Sistemas de Información Geográfica para priorizar esfuerzos de erradicación de poblaciones de especies invasoras que amenazan la biota de las islas mexicanas. Se evaluaron 29 islas con presencia de mamíferos invasores, para lo cual se caracterizaron los siguientes atributos de cada isla: presencia de especies endémicas, presencia de especies amenazadas, presencia de sitios importantes de anidación de aves marinas, riqueza de especies, probabilidades de reinvasión, factibilidad de erradicación y el costo de su ejecución. Se clasificaron las islas en 4 categorías de prioridad de erradicación. Las islas con mayor prioridad donde la erradicación es factible son Socorro, Espíritu Santo, María Cleofas y María Magdalena, donde erradicando 11 poblaciones especies invasoras se restaurarían 35,813 ha, reduciendo el riesgo de extinción de 80 especies endémicas.

Rigorous science-based planning is important in prioritizing investments of limited conservation resources, especially in the face of high global extinction rates (Myers et al. 2000, Balmford et al. 2003). Islands are renowned hotspots of endemism and extinction (Mulongoy et al. 2006, Kier et al. 2009). Invasive alien species pose the greatest threat to insular biodiversity (Reaser 2007). Though eradication programs can be an efficient and effective means of reducing extinction risk on islands (Howald et al. 2007), limited funding demands careful prioritization among islands to ensure the highest conservation return on investment (Januchowski-Hartley et al. 2011).

In Mexico, 149 islands compose only 0.2% of the country's land surface but host 8% of all Mexican vertebrate and plant species (Aguirre-Muñoz et al. 2008). Approximately 300 species are endemic to Mexican islands, 10% of which are considered vulnerable per the endangered species list of Mexico, the NOM-059-SEMARNAT-2001 (CONABIO 2007). Eighteen percent of all currently threatened birds and mammals are insular species (Aguirre-Muñoz et al. 2008). Invasive alien species have been implicated as the cause of extinction for 16 vertebrate species from Mexican islands (Aguirre-Muñoz et al. 2011a). Islands also support the livelihood of 0.6% of Mexico's population (INEGI 2012), through myriad economic and social values, including lobster, abalone, and tuna fisheries in the rich surrounding waters. Many seabirds and pinnipeds also use the Mexican islands as breeding and resting sites.

Considerable progress has been made in recent years to eradicate invasive mammal species from Mexican islands. As of April 2014, fifty-five invasive mammal populations of 11 species have been eradicated from 35 Mexican islands. These eradications have contributed to the restoration of over 50,815 ha and the protection of approximately 134 endemic plant species, 117 endemic vertebrates, and 220 populations of seabirds (Table 1;

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TABLE 1. Mexican islands with successful eradication projects.

	Island	Area (ha)	Species removed	Eradication date	Methods
Pacific Ocean	Asunción	41	Cat	1995	Trap
	Clarión	1958	Sheep, pig	2002	Hunt
	Coronado Norte	37	Cat	1995–1996	Trap
	Coronado Sur	126	Cat, goat, donkey	2003	Trap, hunt
	Guadalupe	24,171	Rabbit, donkey	2002	Live removal
	Guadalupe		Horse	2004	Live removal
	Guadalupe		Goat	2003–2006	Live removal, trap, hunt, telemetry
	Guadalupe		Dog	2007	Live removal, trap, hunt
	Guadalupe		Goat, sheep	1997	Live removal
	Natividad	736	Cat	1998–2000	Trap, hunt, live removal
	Natividad		Dog	2001	Live removal
	San Benito Este	146	Rabbit	1999	Trap and hunt
	San Benito Medio	45	Rabbit	1998	Trap and hunt
	San Benito Oeste	364	Rabbit, goat	1998	Trap and hunt
			Donkey	2005	Live removal
			Cactus mouse	2013	Aerial broadcast
	San Jerónimo	48	Cat	1999	Trap and hunt
	San Martín	265	Cat	1999	Trap and hunt
	San Roque	35	Cat	1995	Trap
	San Roque		Ship rat	1995	Bait stations
	Socorro	13,033	Sheep	2010	Hunt and telemetry
	Todos Santos Norte	34	Cat, rabbit	1999–2000	Trap and hunt
	Todos Santos Norte		Donkey	2004	Live removal
	Todos Santos Sur	89	Cat	1997–1998 1999–2004	Trap and hunt
	Todos Santos Sur		Rabbit	1997	Trap and hunt
Gulf of California	Coronados	715	Cat	1998–1999	Trap
	Danzante	412	Cat	2000	Trap
	Estanque	82	Cat	1999	Trap and hunt
	Farallón de San Ignacio	17	Ship rat	2007	Aerial broadcast
	Isabel	80	Cat	1995–1998	Trap, hunt & bait stations
	Isabel		Ship rat	2009	Aerial broadcast
	Mejia	245	Cat	1999–2001	Trap and hunt
	Montserrat	1886	Cat	2000–2001, 2003	Trap and hunt
	Partida Sur	1533	Cat	2000	Live removal
	Rasa	57	Ship rat, house mouse	1995–1996	Bait stations
	San Jorge Este	9	Ship rat	2000–2002	Bait stations
	San Jorge Medio	41	Ship rat	2000–2002	Bait stations
	San Jorge Oeste	7	Ship rat	2000–2002	Bait stations
	San Francisquito	374	Cat	2000	Trap and hunt
			Goat	1999	Hunt
	San Pedro Mártir	267	Ship rat	2007	Aerial broadcast
	Santa Catalina	3890	Cat	2002–2004	Trap and hunt
Caribbean	Pérez	11	Ship rat	2011	Hand broadcast
	Muertos	15.6	House mouse	2011	Hand broadcast
	Pájaros	2.3	House mouse	2011	Hand broadcast
	Cayo Norte Mayor	28.8	Ship rat	2012	Aerial broadcast
	Cayo Norte Menor	14.6	Ship rat	2012	Aerial broadcast
TOTALS	35 islands	50,815	55 eradications		

Aguirre-Muñoz et al. 2011b). Technological and methodological advances, such as aerial hunting and aerial baiting, have been used on the Mexican islands and have improved efficiency of eradication programs and delivered important conservation benefits (Aguirre-Muñoz et al. 2009). Despite this progress, there are still 36 Mexican islands with one or

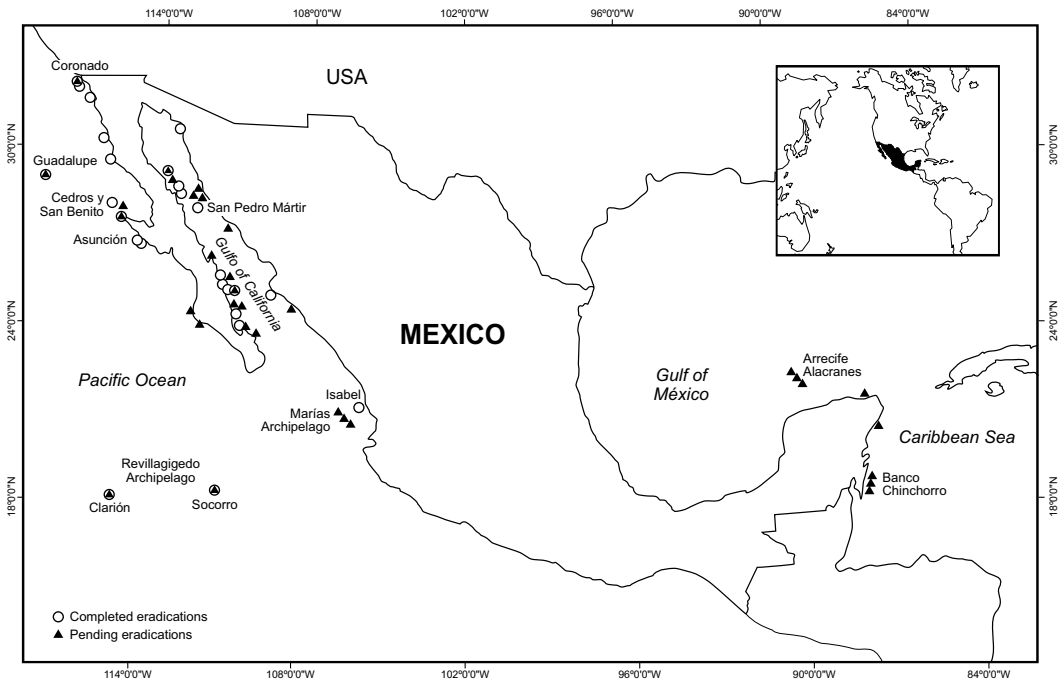

Fig. 1. Completed and pending eradications in Mexican islands.

more known infestations of invasive alien mammal species (Aguirre Muñoz et al. 2011b; Fig. 1). In this paper, we describe a multicriteria decision analysis to prioritize eradication efforts among those islands. Multicriteria decision-making techniques are helpful in conservation planning because they can account for various, sometimes conflicting inputs and can enhance the transparency of decisions (Malczewski 1999, Laskar 2003).

METHODS

To prioritize islands for restoration, we first defined the set of attributes used to rank islands. These included island size (surface area), distance from mainland, species richness, presence of endemic taxa, presence of threatened species, land use, presence of human population, likelihood of reinvasion, feasibility of successful eradication (e.g., given current technologies), and estimated economic cost (based on past eradication expenditures). We populated a database of those attributes for each of the 36 islands with invasive mammal species. Data were insufficient for 7 islands, so our prioritization analysis was based on 29 islands (Table 2).

Using expert input from conservation practitioners from the Mexican NGO Grupo de Ecología y Conservación de Islas, we developed decision rules (Table 3) and used the rank sum method (Malczewski 1999) to assign weights to attributes. Our schema prioritized islands with the highest presence of endemic taxa, followed by presence of important seabird nesting areas, highest number of species enumerated on the endangered species list, and highest species richness. We analyzed our data using the weighted linear combination procedure (Malczewski 2000) with ArcGIS 10 software (ESRI).

We conducted 3 different multicriteria analyses. We compared (1) outputs based only in biological considerations (e.g., island biodiversity value, including data from endemism, species richness, protected species, and important seabird areas); (2) outputs based only on "strategic" feasibility considerations (e.g., economic cost, feasibility of eradication, and probability of reinvasion); and (3) outputs based on the combination of both biological and strategic values. These analyses provided a comparison of islands where eradication campaigns could be implemented somewhat

TABLE 2. Input information for the decision analysis.

Island	Surf (ha)	DM (km)	SR	E	PS	IS	PA	IBA	HP
CS	122	13	78	11	18	a,d	N	Y	8
Gupe	24,171	260	342	38	13	a,c	Y	Y	92
SBO	364	145	82	13	11	g	N	Y	70
Ced	35,674	100	140	13	44	a,b,c,d,e,f	N	Y	1339
Nat	728	9.3	80	7	6	i	Y	Y	302
Mag	29,099	7.7	41	6	13	a,c,d,f	N	N	350
SM	21,761	3	55	6	24	c,d,e,f,h,i	N	Y	415
Gran	26	75	12	6	4	b	Y	N	0
Mej	244	76	40	5	4	a,b	Y	N	0
AG	93,604	30	252	15	22	a,b,c	Y	Y	0
SE	4072	54	163	7	12	b	Y	N	0
Alc	47	1.4	110	2	14	a	Y	N	0
ER	232	1	72	0	7	a,b	N	Y	0
Sal	2000	1	159	0	12	a,b	N	Y	0
Smarc	3007	15	190	13	23	c,e,i	Y	Y	394
Car	15,100	7	231	10	24	a,b,c,d,e	Y	Y	0
SD	100	90	88	3	3	e	Y	N	0
SJ	19,400	82	311	9	43	c,e,f	Y	Y	46
ES	11,200	25	328	11	60	c,e	Y	Y	0
Cer	16,000	15	198	12	15	c,e	Y	Y	0
SC	4300	52	168	13	13	a	Y	Y	0
MC	2730	132	562	25	38	b,c,e	Y	Y	0
Mmag	8677	132	572	25	38	b,c,e,j	Y	Y	0
Mmad	14,787	132	575	25	38	c,e,h,k,l	Y	Y	3980
Soc	13,206	690	351	53	24	a,c	Y	Y	30
Clar	1980	1000	310	26	19	k	Y	Y	30
CC	611	30	185	2	10	b,c	Y	N	50
Coz	60,000	16	402	26	56	a,b	Y	Y	77,326
Muj	8673	6	64	0	8	b	Y	N	12,624

COLUMN HEADS
DM = Distance to mainland
SR = Species richness
E = Endemisms
PS = Protected species
IS = Invasive species
PA = Protected area (Y/N)
IBA = Important bird area (Y/N)
HP = Human population

ISLANDS
CS = Coronado Sur
Gupe = Guadalupe
SBO = San Benito Oeste
Ced = Cedros
Nat = Natividad
Mag = Magdalena
SM = Santa Margarita
Gran = Granito
Mej = Mejía
AG = Ángel de la Guarda
SE = San Esteban
Alc = Alcatraz
ER = El Rancho
Sal = Saliaca
Smarc = San Marcos
Car = Carmen
SD = San Diego
SJ = San José
ES = Espíritu Santo
Cer = Cerralvo
SC = Santa Catalina
MC = María Cleofas
Mmag = María Magdalena
Mmad = María Madre
Soc = Socorro
Clar = Clarión
Coz = Cozumel
Muj = Mujeres

INVASIVE SPECIES
a = house mouse
b = ship rat
c = cat
d = dog
e = goat
f = donkey
g = cactus mouse
h = horse
i = antelope squirrel
j = white-tailed deer
k = rabbit
l = black rat

TABLE 3. Decision rules for prioritization analysis.

Rank	Decision rule
1	The island should have endemic species.
2	The island should be considered an important area for reproduction and nesting of seabirds (IBA) and for reproduction of mammals (AZE).
3	The island should have species listed in some protection category from the Mexican NOM-059 or the IUCN.
4	The island should be high in species richness.
5	The risk of reintroduction of the invasive species should be low.
6	The feasibility of the eradication should be high.
7	The cost of the eradication should be low.

TABLE 4. Weights set for the final analysis of biodiversity and strategy combined.

Criterion	Straight rank	Weight	Normalized weight
Endemism	1	7	0.25
Important nesting area	2	6	0.21
Protection category	3	5	0.18
Species richness	4	4	0.14
Reintroduction probability	5	3	0.11
Feasibility of eradication	6	2	0.07
Economic cost of eradication	7	1	0.04
TOTAL	7	28	1.00

TABLE 5. Priority matrix for eradication efforts on Mexican islands based on biodiversity scores and strategy. 1 = higher priority (no shading), 4 = lower priority (darkest shading).

Island	Priority	Biodiversity	Strategy
Socorro	1	1	2
Cozumel		1	4
María Cleofas		2	1
María Magdalena		2	2
Espíritu Santo		3	1
María Madre	2	2	4
Guadalupe		2	4
Clarión		2	2
San José		3	2
San Benito Oeste	3	3	1
Carmen		3	2
Cedros		3	4
Cerralvo		4	2
San Marcos		3	1
Santa Catalina		3	2
San Esteban		4	2
Cayo Centro		4	1
Saliaca		4	2
Coronado		4	1
Angel de la Guarda		3	4
Santa Margarita		3	3
Alcatraz	4	4	1
Natividad		4	2
San Diego		4	1
Magdalena		4	3
El Rancho		4	2
Mujeres		4	4
Mejía		4	1
Granito		4	1

easily with "hotspot" islands where the biodiversity value may be greater.

RESULTS

We categorized 29 islands into 4 priority groups, higher (1) to lower (4) (Table 4). The highest priority set included Socorro, Espíritu Santo, María Cleofas, María Magdalena, and Cozumel islands. The combined area of these islands is 95,813 ha. Thirteen invasive mammal taxa are found on these islands. Removal of those taxa could benefit 115 endemic taxa, 178 imperiled taxa, and numerous seabird nesting colonies.

The "biological" and "strategic" analyses provided very different results (Table 5), showing that more complex islands with higher species richness pose complex challenges to the success of eradication programs and that a few small, simple islands have the potential for successful, yet simply executed eradication programs. The "strategic" priority set are San Marcos, Cayo Centro, Coronado Sur, San Benito Oeste, Alcatraz, San Diego, Mejía, and Granito islands. Only 2 islands coincided in all priority categories: María Cleofas and Espíritu Santo.

DISCUSSION

With this analysis, we provide a recommendation for strategic investment for the restoration of the Mexican Islands (Table 5; Fig. 2). We also provide a framework that can be used to evaluate archipelagos in other regions that may benefit from conservation action. The multicriteria analysis framework we developed provides many advantages, including that it can be adaptive and dynamic and can help improve the transparency and objectivity of decision-making. This sort of regional prioritization framework can also facilitate planning and implementation of eradications in a programmatic and strategic sequence designed to maximize efficiency and reduce investment risk (e.g., Saunders et al. 2011).

Given the importance we placed on endemism and species richness in our weightings, these characteristics prevailed over economic cost, feasibility of eradication, and reinvasion probability. As a consequence, many small islands in our candidate set, for which eradications may be relatively simple (e.g., Alcatraz, San Diego), rank lower in priority than other more diverse and complex islands. Islands in the tropical Pacific and Caribbean were our highest priority, largely based on species richness and endemism; however, eradications on some of these islands may be more difficult due to the presence of native mammals and large human settlements (e.g., Cozumel). We also note that some important seabird nesting colony islands were disadvantaged in our analysis if they were not on an island with high species richness; such was the case of San Benito Island. In cases where eradication of introduced taxa is not logistically or politically feasible, other approaches may be needed, such as invasive species population control or fencing of nesting areas or other sensitive resources.

This analysis can contribute to both the *Estrategia Nacional Sobre Especies Invasoras en México* (National Strategy for Invasive Species in Mexico) and the *Estrategia nacional*

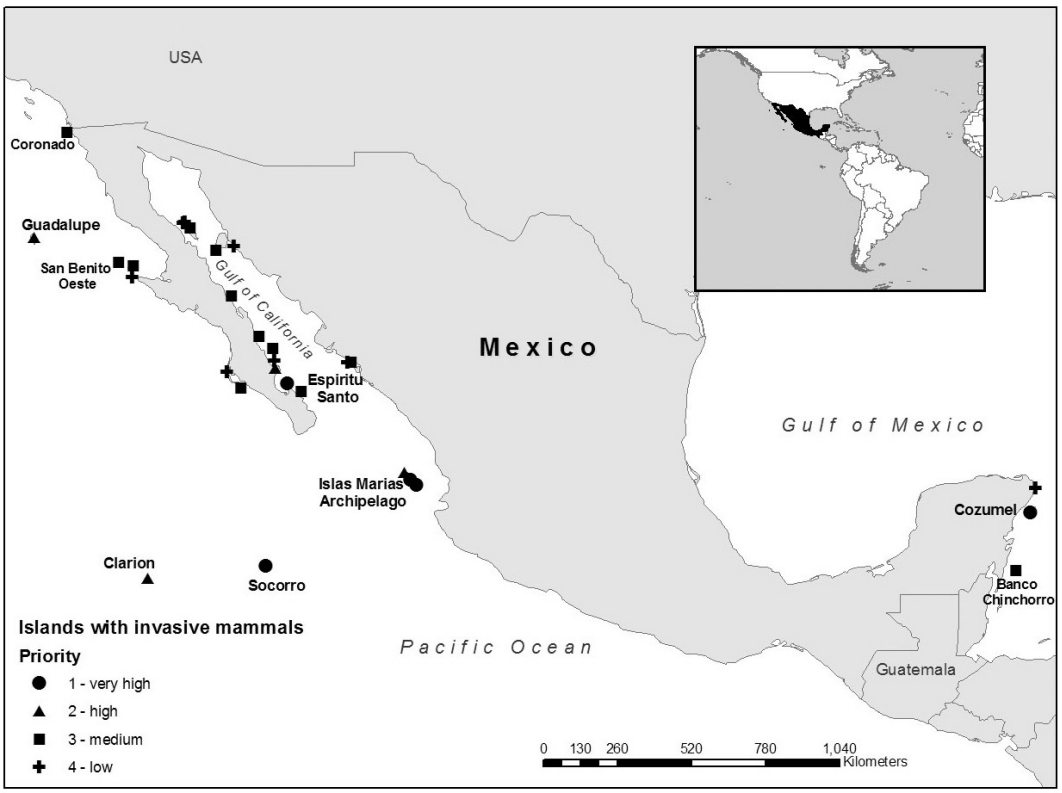

Fig. 2. Priorities for eradication efforts on Mexican islands.

para la Conservación y el Desarrollo Sustentable del Territorio Insular Mexicano (National Strategy for the Conservation and Sustainable Development of the Mexican Insular Territory) by generating information that can inform decision-making to prevent, control, and eradicate invasive species. Indeed, we are hopeful that this database will be used and improved into the future. A priority research need is to improve the database with information regarding native insect and plant taxa and to expand the utility of the database for evaluating eradication priorities of nonmammalian invasive alien species.

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UPDATE

In December 2013, the Grupo de Ecología y Conservación de Islas, A.C., in collaboration with the Mexican government (SEGOB, SEMAR, SEMARNAT, CONANP, CONABIO), and with the support of the National Fish and Wildlife Foundation (NFWF), the Packard Foundation, and the Marisla Foundation, successfully conducted the eradication of a population of invasive mouse (*Peromyscus eremicus*) on San Benito Oeste, one of the islands included in our analysis of priorities.

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