

ERADICATION OF NON-NATIVE MAMMALS AND THE STATUS OF INSULAR
MAMMALS ON THE CALIFORNIA CHANNEL ISLANDS, USA, AND PACIFIC
BAJA CALIFORNIA PENINSULA ISLANDS, MEXICO

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ABSTRACT—The California Channel Islands, USA, and Pacific Baja California Peninsula Islands, Mexico (hereafter referred to as the California islands), are known for their high levels of biodiversity and globally important colonies of seabirds. We document the history, impacts, and management of non-native mammals and summarize the current status of native, non-volant mammals on the California islands. Of the 26 species of native mammals on the California islands, including 6 species and 41 subspecies that are endemic, ≥ 10 populations have suffered extirpation or global extinction. All recent extirpations and extinctions resulted directly from non-native mammalian predators or indirectly via habitat degradation by non-native herbivores. In light of the devastating effects non-native mammals have had on the native insular biotas of the California islands, a variety of organizations have collaborated to eradicate 44 populations of non-native mammals from 19 California islands. Documentation of impacts of non-native mammals and timely implementation of successful eradication efforts are essential to the conservation of these and other insular ecosystems.

RESUMEN—Las California Channel Islands, USA, y la islas del Pacífico de Baja California (en adelante islas de California) son conocidas por sus altos niveles de biodiversidad y mundialmente importantes colonias de aves marinas. Documentamos la historia, impactos y manejo de los mamíferos introducidos y reportamos el estado actual de los mamíferos nativos no voladores en las islas de California. De las 26 especies de mamíferos nativos de las islas de California, incluyendo 6 especies y 41 subespecies endémicas, ≥ 10 poblaciones han sufrido de extinción local o global. Todas las extirpaciones y extinciones recientes resultaron directamente de depredadores mamíferos introducidos o indirectamente por la modificación de hábitat causada por herbívoros introducidos. En vista de los efectos devastadores que los mamíferos introducidos han tenido en las biotas nativas insulares de las islas de California, una variedad de organizaciones ha colaborado y ha erradicado 44 poblaciones de los mamíferos no nativos de 19 islas de California. La documentación de estos efectos y la implementación oportuna de los esfuerzos de erradicación son esenciales para la conservación de estos ecosistemas y los de otras islas.

Islands frequently harbor endemic biodiversity and thus are critical for conservation of biodiversity. Yet nowhere but on islands is extinction so prevalent (Groombridge et al., 1992; MacPhee

and Flemming, 1999). Non-native mammals are responsible for the majority of those extinctions (Atkinson, 1989; Towns et al., 2006). Two archipelagos, the California Channel Islands,

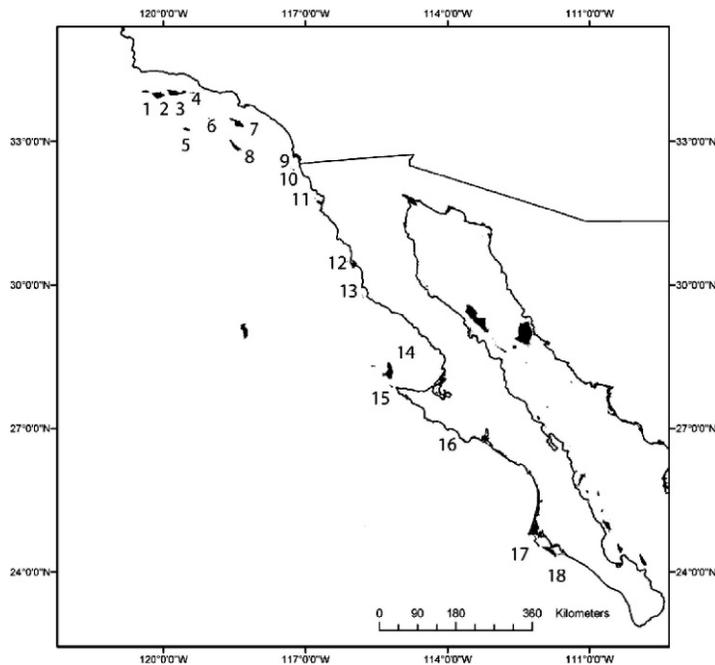


FIG. 1—California islands (California Channel Islands, USA, and Pacific Baja California Peninsula Islands, Mexico) with native mammals present are 1) San Miguel, 2) Santa Rosa, 3) Santa Cruz, 4) Anacapa, 5) San Nicolas, 6) Santa Barbara, 7) San Catalina, 8) San Clemente, 9) Coronado North, 10) Coronado South, 11) Todos Santos South, 12) San Martin, 13) San Jerónimo, 14) Cedros, 15) Natividad, 16) San Roque, 17) Magdalena, and 18) Santa Margarita.

USA, and the Pacific Baja California Peninsula Islands, Mexico (hereafter referred to as the California islands), are known for their high levels of biodiversity and globally important colonies of seabirds (Fig. 1). Introduction of non-native mammals has severely impacted those island ecosystems, particularly populations of native seabirds and non-volant mammals. Fortunately, with techniques pioneered over the past few decades in New Zealand and elsewhere, non-native mammals can be routinely removed from islands (Veitch and Clout, 2002; Donlan et al., 2003b; Donlan, in press). Over the past 20 years, there have been a number of successful eradications of non-native mammals on the California islands, resulting in significant conservation benefits. Here, we review those removal campaigns with a focus on the conservation status of non-volant mammals on the islands.

STUDY AREA AND METHODS—The California Channel Islands extend from Point Conception, California, to the USA-Mexico border, and the Pacific Baja California Islands, Mexico, include all coastal islands from the USA-Mexico border south to Santa Margarita Island

(Fig. 1). We used historic and current records of the distribution of native and non-native mammals from the published and gray literature, as well as a regional conservation database to assess impacts of non-native mammals on the California islands (Donlan et al., 2000). Only islands with native non-volant mammals are addressed here. Guadalupe Island, Mexico, which lacks native mammals and where goats recently have been removed is discussed elsewhere (Keitt et al., 2005; Santos del Prado and Peters, 2006).

RESULTS AND DISCUSSION—Of the 26 species of native mammals on the California islands, including 6 species and 41 subspecies that are endemic, ≥ 10 populations have been extirpated or are extinct (Table 1). Seven extinctions of insular mammals occurred in the late Pleistocene or early Holocene, including the dwarf mammoth (*Mammuthus exilis*; Table 1; Guthrie, 1993; Agenbroad, 2003). While their causes of extinction are unclear, all were coincidental with arrival of Native Americans to the Channel Islands (12,020–10,700 years ago; Orr, 1968). Recent extinctions and extirpations are attributed either directly or indirectly to impacts of non-native mammals (Table 1).

TABLE 1.—Status of non-volant mammals on the California islands (California Channel Islands, USA, and Pacific Baja California Peninsula Islands, Mexico). Classification status follows La Norma Oficial Mexicana (Alvarez-Castaneda and Patton, 1999) or United States Fish and Wildlife Service (E = extinct; EN = endangered; T = threatened; S = special protection) and IUCN Red List (CR = critically endangered; E = endangered; LR/nt = lower risk/near threatened).

Island	Taxon	Status	Cause of decline	Date of extinction	Reference
<i>California Channel Islands</i>					
San Miguel	<i>Mammuthus exilis</i> ^a	E	unknown	11,030 years ago	L. D. Agenbroad, pers. comm.
	<i>Microtus</i>	E	unknown	11,000 years ago	Guthrie, 1993
	<i>Peromyscus maniculatus streatori</i>	E	unknown	8,000 years ago	Guthrie, 1993; Walker, 1980
	<i>Peromyscus nesodytes</i>	E	unknown	late 1800s (?)	Walker, 1980
	<i>Spilogale gracilis</i> ^b	E	unknown	1,000 years ago – 1800s	Guthrie, 1993
	<i>Sorex ornatus cf. vailletii</i> ^c	E	unknown		
Santa Rosa	<i>Urocyon littoralis littoralis</i> ^d	EN, CR	pigs, multiple factors		Roemer et al., 2002, 2004
	<i>Mammuthus exilis</i> ^a	E	unknown	11,030 years ago	L. D. Agenbroad, pers. comm.
	<i>Peromyscus nesodytes</i>	E	unknown	late Pleistocene	White, 1966
	<i>Peromyscus maniculatus santarosae</i>				
	<i>Spilogale gracilis amphiala</i>				
Santa Cruz	<i>Urocyon littoralis santarosae</i> ^d	EN, CR	pigs, multiple factors		Roemer et al., 2002, 2004
	<i>Mammuthus exilis</i> ^a	E	unknown	11,030 years ago	L. D. Agenbroad, pers. comm.
	<i>Peromyscus maniculatus santarosae</i>				
	<i>Reithrodontomys megalotis santarosae</i>				
	<i>Spilogale gracilis amphiala</i>				
Anacapa	<i>Urocyon littoralis santarosae</i>	EN, CR	pigs	late Pleistocene	Roemer et al., 2002, 2004
	<i>Peromyscus aryzapahensis</i>	E	unknown		White, 1966
	<i>Peromyscus maniculatus anacapa</i>	LR/nt			
	<i>Peromyscus maniculatus exterus</i>				
	<i>Urocyon littoralis didkeyi</i>				
San Nicolas	<i>Peromyscus maniculatus ebusus</i>	EN, CR			
	<i>Peromyscus maniculatus catalinae</i>	EN, CR			
	<i>Reithrodontomys megalotis catalinae</i>	T	multiple factors, cats		Williams, 1983; P. W. Collins and T. D. Martin, in litt.
	<i>Sorex ornatus vailletii</i> ^e				
	<i>Spermophilus beecheyi nesioticus</i>				
San Clemente	<i>Urocyon littoralis catalinae</i>	EN, CR	disease		Roemer et al., 2002, 2004
	<i>Peromyscus maniculatus clementis</i>	LR/nt			von Bloeker, 1967
	<i>Reithrodontomys megalotis longicaudus</i>	EN, CR	multiple factors		Roemer et al., 2002, 2004
	<i>Urocyon littoralis clementae</i>				

TABLE 1—Continued.

Island	Taxon	Status	Cause of decline	Date of extinction	Reference
<i>Pacific Baja California Peninsula Islands</i>					
Coronados	<i>Peromyscus maniculatus assimilis</i>	E, EN	cats	1950 to present	Donlan et al., 2000; Mellink, 1992
Todos Santos	<i>Neotoma anthonyi</i>	T			Mellink, 1992
	<i>Peromyscus maniculatus dubius^f</i>	EN	cats	1950 to present	Cortes-Calva et al., 2001
San Martín	<i>Neotoma martinensis^g</i>	T			
	<i>Notiosorex craxfordi craxfordi</i>	T			
	<i>Peromyscus maniculatus exiguus</i>	T			
San Jerónimo	<i>Peromyscus maniculatus geronimensis</i>	T			Tershy et al., 2002
Cedros	<i>Chaetodipus fallax anthonyi</i>	T			Tershy et al., 2002
	<i>Neotoma bryanti</i>	EN			
	<i>Odocoileus hemionus cerrosensis</i>	EN			Mellink, 1992
	<i>Peromyscus eremicus cedrosensis</i>	T			Mellink, 1992
	<i>Sylvilagus bachmani cerrosensis</i>	S			
Natividad	<i>Peromyscus maniculatus dorsalis</i>	T			
San Roque	<i>Peromyscus maniculatus cinerithus^h</i>	T	cats/rats	1950 to present	Alvarez-Castañeda and Cortes-Calva, 1996; Donlan et al., 2000
Magdalena	<i>Canis latrans peninsulæ</i>				
	<i>Chaetodipus arenarius albulus</i>	T			
	<i>Chaetodipus spinatus magdalena</i>				
	<i>Lepus californicus magdalena</i>	S			
	<i>Lynx rufus peninsularis</i>				
	<i>Neotoma lepida pretiosa</i>				
	<i>Peromyscus maniculatus magdalena</i>	T			
	<i>Thomomys bottae magdalena</i>				
Santa Margarita	<i>Chaetodipus arenarius ammophilus</i>	T			
	<i>Chaetodipus spinatus margaritæ</i>	T			
	<i>Dipodomys merriami margaritæ</i>	EN, CR			
	<i>Lepus californicus magalena</i>	S			
	<i>Lynx rufus peninsularis</i>				
	<i>Neotoma lepida pretiosa</i>				
	<i>Peromyscus eremicus polyptolus</i>	T			
	<i>Peromyscus maniculatus margaritæ</i>	T			

^a Estimated date of extinction on all three islands are based on the youngest radiocarbon date of pooled specimens.

^b Based on a fossil cranium and unpublished field notes of trapped skunks ~1893.

^c Abundant in the fossil record; may have gone extinct sometime in the 19th century due to land transformation from overgrazing by introduced sheep.

TABLE 1—Continued.

^d Reintroduced from captive-bred populations.
^e Was considered most likely extinct, but a recent intensive survey conducted by the Catalina Island Conservancy in 2003 yielded three captures in 3,638 trap nights.
^f Abundant on the island (Mellink, 1992; C. J. Donlan, unpublished data).
^g Likely extinct (Alvarez-Castañeda and Patton, 1999; A. Samaniego, unpublished data).
^h Likely extinct (Alvarez-Castañeda and Cortes Calva, 1996; A. Samaniego, unpublished data).

Starting in the 1700s, non-native mammals have been introduced to all of the California islands, with the exception of small offshore rocks and islets (Junak et al., 1995; Moran, 1996; Tershy et al., 2002). The most common non-native mammals are sheep (*Ovis aries*), goats (*Capra hircus*), donkeys (*Equus asinus*), pigs (*Sus scrofa*), European rabbits (*Oryctolagus cuniculus*), cats (*Felis catus*), and rats (*Rattus rattus* and *Rattus norvegicus*). Historically many of the California Islands were free of mammalian predators, with the exception of the six Channel Islands that support the endemic island fox (*Urocyon littoralis*) and the three islands that support, or once supported, the endemic island spotted skunk (*Spilogale gracilis amphiala*; Roemer et al., 2004). Non-native predators (cats, rats, or both) were present on most islands and have been implicated as the major driver of extinctions of small mammals (Mellink, 1992; Álvarez-Castañeda and Cortes-Calva, 1996; Donlan et al., 2005). Non-native herbivores (e.g., goats and rabbits) also have had negative impacts on native mammals indirectly via overgrazing, which degrades habitat and reduces availability of food (Coblentz, 1978; Van Vuren and Coblentz, 1987; Mellink, 1993).

Several organizations have collaborated to eradicate 44 populations of non-native mammals from 19 California islands (Table 2). These conservation actions range from the live-removal of a few animals to large-scale eradication efforts. On the Channel Islands, the National Park Service, the United States Navy, and four conservation non-governmental organizations (Catalina Island Conservancy, Institute for Wildlife Studies, The Nature Conservancy, and Island Conservation) have participated in eradication programs (Halvorson, 1994; Keegan et al., 1994; Lombardo and Faulkner, 2000; Schuyler et al., 2002; Howald et al., 2005). On the Pacific Baja California Peninsula Islands, Mexico, eradications have been undertaken by Grupo de Ecología y Conservación de Islas in collaboration with Island Conservation, the Mexican Government (Mexican Office of National Protected Areas of the Secretaría del Medio Ambiente Recursos Naturales, Vizcaíno Biosphere Reserve, and personnel from the Gulf of California Islands Reserve), and local fishing cooperatives (Abulones Cultivados, Busos y Pescadores, Co-operative California de San Ignacio, Pescadores Nacionales de Abúlon—Donlan et al., 2000; Tershy et al., 2002; Wood et al., 2002).

TABLE 2.—The current status of non-native mammals on the California islands with native mammals present (P = present, E = eradicated or population was removed live). Islands are listed north to south.

Island	Dogs	Cats	Rats	Rabbits/ hares	Pigs	Goats	Horse/ donkey	Sheep	Other
<i>California Channel Islands</i>									
San Miguel			P (<i>Rattus rattus</i>)		E		E	E	E (<i>Bos taurus</i>)
Santa Rosa					E		P ^a		P (<i>Odocoileus</i>); P (<i>Cervus elaphus</i>); E (<i>Bos taurus</i>)
Santa Cruz					E		P ^a /E	E	P ¹ (<i>Bos taurus</i>)
Anacapa		E	E (<i>Rattus rattus</i>)	E			E	E	
San Nicolas		P					E	E	
Santa Barbara				E			P	E	
Santa Catalina	P	P	P (<i>Rattus rattus</i> and <i>R. norvegicus</i>)		E	E	P	E	P (<i>Bison bison</i>); P (<i>Odocoileus</i>); P (<i>Antelope cervicapra</i>); E (<i>Bos taurus</i>)
San Clemente		P	P (<i>Rattus rattus</i>)		E	E	E	E	E (<i>Bos taurus</i>); P (<i>Mus musculus</i>); E (<i>Odocoileus</i>)
<i>Pacific Bigia California Peninsula Islands</i>									
Coronado North		E							
Coronado South		E				E	E ^b		
Todos Santos		E		E			E ^b		
North									
Todos Santos		E		E					
South									
San Martin		E							
San Jerónimo		E							
Cedros	P	P	P (<i>Rattus norvegicus</i>)			P	P	E	P (<i>Mus musculus</i>) E (<i>Bos taurus</i>)
Natividad	E ^b	E				E ^b		E ^b	P (<i>Ammospermophilus</i>)
San Roque		E	E (<i>Rattus rattus</i>)						P (<i>Mus musculus</i>)
Magdalena		P							
Santa Margarita									

^a Small domesticated population that currently is not free-roaming.

^b Small populations were removed live in cooperation with island residents and governmental agencies.

San Miguel—Historically San Miguel Island (3,865 ha) was home to seven endemic mammals; five are now considered extinct. Three extinctions occurred in the late Pleistocene coincident with arrival and establishment of Native Americans on the Channel Islands; the dwarf mammoth, a vole (*Microtus*), and a deer-mouse (*Peromyscus nesodytes*; Table 1). The latter was replaced by a congener *P. maniculatus streatoris*, possibly introduced by Native Americans (Guthrie, 1993). The ornate shrew (*Sorex ornatus*) is abundant in the fossil record of the island, but may have gone extinct sometime in the 19th century due in part to habitat degradation by non-native sheep (Guthrie, 1993). The island spotted skunk probably went extinct in the late 1800s, perhaps in part due to competition with island foxes (Walker, 1980; Roemer et al., 2002). The San Miguel Island fox (*U. l. littoralis*) was nearly driven to extinction, the decline a result of predation by golden eagles (*Aquila chrysaetos*) whose recent colonization of the northern Channel Islands was facilitated by presence of non-native herbivores on nearby Santa Cruz and Santa Rosa islands (Roemer et al., 2002; Roemer and Donlan, 2004; Coonan et al., 2005). A captive breeding program was established, and currently there are 32 foxes in captivity and 38 foxes in the wild (Coonan et al., 2005; T. J. Coonan, pers. comm.).

San Miguel Island has experienced periodic episodes of vegetal stripping and soil erosion owing to presence of large numbers of non-native herbivores (Johnson, 1980). In the 1860s, there were about 6,000 sheep, 125 cattle (*Bos taurus*), and 25 horses and donkeys on the island; 80% later died of starvation during 3 years of intense drought. Sheep and donkeys were removed by the mid-1960s and mid-1970s, respectively (Erlandson, 2004; Carrion et al., 2007). Black rats (*R. rattus*) were introduced to the island in the mid 1800s and are still present (McChesney and Tershy, 1998).

Santa Rosa—The dwarf mammoth and deer-mouse (*P. nesodytes*) went extinct on Santa Rosa Island (21,853 ha) in the late Pleistocene (Table 1). Three endemic mammals are extant (Table 1). As is the case on San Miguel, the Santa Rosa Island fox (*U. l. santarosae*) is critically endangered due to predation by golden eagles, and a captive breeding program was established in 2000 (Coonan et al., 2005). As of June 2006, there were 42 foxes in captivity and 38 in the wild on Santa Rosa Island (T. J. Coonan, pers. comm.).

In the late 1800s and early 1900s, pigs, cattle (*Bos taurus*), elk (*Cervus elaphus*), and mule deer (*Odocoileus hemionus*) were introduced to the island. Feral pigs were eradicated in 1993 (Lombardo and Faulkner, 2000). In the mid-1990s, there were about 3,000–5,000 cattle, 125–150 horses, 700–800 deer, and 600–1,000 elk (United States Department of the Interior, in litt.). Cattle were removed by 1998 (J. Wagner et al., in litt.), and free-ranging populations of elk, deer, and horses remain.

Santa Cruz—Four endemic subspecies of mammals reside on Santa Cruz Island (24,598 ha; Table 1). Dwarf mammoths also were found there. During February 1994–February 1995, we conducted a total of 3,120 trap nights resulting in three captures of harvest mice (*Reithrodontomys megalotis santacruzae*) and 315 captures of deermice (*P. m. santacruzae*). However, a review of all available trapping data from the island suggests a limited and patchy, but widespread, distribution for the harvest mouse, often at low densities (C. Drost, pers. comm.).

The population of foxes (*U. l. santacruzae*) is critically endangered due to heightened predation by golden eagles as a consequence of apparent competition induced by non-native pigs (Roemer et al., 2002). Currently, there are 81 foxes in captivity and about 200 in the wild (L. Vermeer, pers. comm.). A captive breeding program has been established that has successfully raised young, but captive-reared and released young have not fared well in the face of predation by golden eagles (Courchamp et al., 2003; Roemer et al., 2004). As populations of foxes declined, populations of skunks increased, replacing foxes as the most numerous carnivore on the island (Roemer et al., 2002).

Cattle, horses, pigs, and sheep were introduced to the island in the mid-1800s. The population of sheep reached high densities by the late 1880s and caused widespread ecosystem degradation (Van Vuren and Coblenz, 1987, 1989). Cattle were removed in 1994 (L. Laughlin, pers. comm.). By 1987, the majority of sheep had been removed, and remaining animals were removed in 2000 (Van Vuren, 1992; United States Department of the Interior, 2001). The National Park Service, in collaboration with The Nature Conservancy, have implemented a conservation-recovery strategy for populations of foxes on the northern Channel Islands, which includes captive breeding of foxes, relocation of golden

eagles, reintroduction of bald eagles (*Haliaeetus leucocephalus*), and removal of feral pigs from Santa Cruz (Roemer and Donlan, 2004, 2005).

Anacapa—Anacapa Island (432 ha) consists of three rocky islets separated by narrow channels. The fossil record reveals a single endemic mammal (*Peromyscus anyapahensis*) that was replaced by another deer mouse (*P. m. anacapa*) in the late Pleistocene (White, 1966). Listed as near threatened by the IUCN, the population of the extant deer mouse has declined compared to the mid-1960s (Collins, 1979). Competition between non-native black rats may have been responsible for the low abundance, including the possible extirpation of mice from the East islet during the 1970s (P.W. Collins et al., in litt.).

Sheep were introduced to the island in the mid-1800s, and cats and hares (*Lepus europaeus*) were introduced in the 1930s; all three populations were removed in the late 1960s (McChesney and Tershy, 1998). Black rats were likely introduced to Anacapa Island during ranching activities, lighthouse construction, or when a steamer ran aground in 1853. In 2002, rats were eradicated (Howald et al., 2005). During the eradication, the endemic deer mouse was protected by staggering the eradication on each of the three islets, and by establishing a captive population (Pergams et al., 2000; Howald et al., 2005). Deer mice have recovered to pre-rat-eradication levels or higher on all three islets (G. R. Howald, pers. comm.).

Santa Barbara—The smallest of the Channel Islands, Santa Barbara Island (326 ha) is home to one native mammal, the endemic Santa Barbara Island deer mouse (*P. m. ehusus*). In the early 1900s, large numbers of sheep and rabbits were introduced to the island, but by 1926 the farming venture failed and sheep were removed (Philbrick, 1972). Rabbits had a devastating impact on the island, including the near extinction of the endemic succulent *Dudleya traskiae* (Philbrick, 1972; Clark and Halvorson, 1987). Rabbits were eradicated in the early 1980s, and while the endemic succulent is recovering, much of the island remains degraded and dominated by bare soil and non-native plants (Halvorson et al., 1988; Donlan et al., 2003a). Recent restoration efforts, including revegetation and erosion control, show some progress but are labor intensive (C. M. D'Antonio et al., in litt.; Chaney and McEachern, 2000).

San Nicolas—Two native mammals inhabit San Nicolas Island (5,411 ha); the endemic San Nicolas Island fox (*U. l. dickeyi*) and San Nicolas Island deer mouse (*P. m. eximius*). The population of foxes is about 400 individuals (G. Smith, pers. comm.), and has been recommended to be listed as vulnerable (Roemer et al., 2004). Currently, because of declines across five islands, San Nicolas harbors the largest population of island foxes. The deer mouse is not well-studied, although it appears common (G. W. Roemer, pers. obser.) and is frequently recorded in scats of foxes (P. W. Collins et al., in litt.). Sheep were introduced to the island in 1857 and reached large populations, causing substantial habitat degradation via overgrazing. The majority of sheep were removed by 1943, and the few remaining animals were removed shortly thereafter (G. Smith, pers. comm.). Feral cats are present on the island and because of their size and diet, may compete with the island fox.

Santa Catalina—Santa Catalina Island (19,400 ha) supports five endemic mammals (Table 1). Severe alteration of habitat from non-native herbivores and predation by feral cats likely contributed to decline and near extinction of the ornate shrew (*S. o. willetti*) and decline of the harvest mouse (*R. m. catalinae*; D. F. Williams, in litt.; P. W. Collins and T. D. Martin, in litt.). The ornate shrew was considered extinct until an intensive survey conducted by the Catalina Island Conservancy in 2003 yielded three captures in 3,638 trap nights (A. J. Aarhus, in litt.). Little is known regarding the harvest mouse; von Bloeker (1967) examined 74 specimens, but the current distribution is unknown.

In 1998, canine distemper virus was introduced to the island, causing an estimated 95% reduction in the population of foxes on eastern Santa Catalina Island (*U. l. catalinae*; Kohlmann et al., 2005). A successful, comprehensive recovery program was initiated and included captive breeding and release, translocation of foxes from the unaffected west end of the island to the affected east end, an island-wide canine distemper vaccination program, and a population viability analysis. The program was a success and about 360 individuals are present on the island (Roemer and Donlan, 2005). While the population was recommended to be listed as Critically Endangered by the IUCN and was listed as Endangered by the United States Fish

and Wildlife Service, its recent recovery warrants a reevaluation (United States Department of the Interior, 2001; Roemer et al., 2004).

Santa Catalina Island has a long history of introductions of mammals, including goats, bison (*Bison bison*), mule deer, pigs, cattle, sheep, and a small herd of black bucks (*Antelope cervicapra*; Schuyler et al., 2002). Both black and Norway rats (*R. norvegicus*) are present. Sheep were removed from the island in the mid-1920s and nearly all goats were removed by 2002; apparently 1–2 females may be left on the extreme east end of the island (Garcelon et al., 2003). Pigs were recently eradicated from the island, with one pig remaining around the town of Avalon (Schuyler et al., 2002; D. Garcelon, pers. comm.)

San Clemente—Two endemic subspecies of mammals are present on San Clemente Island (14,800 ha). Historic data also reveal presence of populations of a western harvest mouse indistinguishable from the mainland subspecies (*R. m. longicaudus*—von Bloecker, 1967). The population of island foxes (*U. l. clementae*) is about 410 adults, which is a 50% reduction over the past 10 years; this subspecies has been recommended to be listed as endangered (Roemer and Wayne, 2003). One factor in the decline may have been unexpected effects from management techniques aimed at protecting the critically endangered San Clemente loggerhead shrike (*Lanius ludovicianus mearnsi*); however, other causes may include widespread alteration of habitat by non-native herbivores and proliferation of exotic grasses (Roemer and Wayne, 2003). The deer-mouse (*P. m. clementis*) and the harvest mouse may be threatened by competition from non-native house mice (*Mus musculus*) and predation by feral cats (Phillips, 1999). The deer-mouse is listed as “near threatened” by IUCN and the status of the harvest mouse is unknown.

Cattle, sheep, goats, pigs, and deer were all introduced to the island during the late-1800s and mid-1900s. Black rats, house mice, and feral cats also are present. Goats were eradicated in 1991 (Keegan et al., 1994). Pigs and deer were eradicated in the 1990s (B. E. Coblenz, pers. comm.).

Los Coronados—The Coronado Islands (173 ha) consist of four islets ~15 km off the USA-Mexico border. The north and south islands are inhabited by an endemic subspecies of deer-mouse (*P. m. assimilis*). While the current status

is unknown, it likely has been adversely affected by feral cats and habitat degradation by goats (Álvarez-Castañeda and Cortes-Calva, 1996) and the recent introduction of house mice (A. Samaniego, unpublished data). Cats were recorded on the south island in 1908 (Wright, 1909) and in the late 1970s on the north island (McChesney and Tershy, 1998). Cats were removed from the north island in 1995 and the south island in 2001 (Wood et al., 2002). Goats and donkeys were removed from the south island in 2003 (Carrion et al., 2007).

Todos Santos—The Todos Santos Islands are two islands (31 and 87 ha). The endemic species of woodrat (*Neotoma anthonyi*) is extinct from the south island due to predation by feral cats (Mellink, 1992; Donlan et al., 2000). The woodrat has not been reported from the north island. The endemic Todos Santos Island deer-mouse (*P. m. dubius*) is listed as threatened, but is abundant on both islands (Mellink, 1992; Donlan et al., 2000; C. J. Donlan, unpublished data). Cats were introduced to the islands sometime between 1910 and 1923 (Howell, 1912; van Denburgh, 1924) and European rabbits in the 1970s (Donlan et al., 2000). Cats and rabbits were removed from the south and north islands in 1997 and 2000, respectively (Wood et al., 2002). Donkeys from the north island were translocated to the mainland (Carrion et al., 2007).

San Martín—San Martín (256 ha) is a small, rugged island located 5 km off the coast of San Quintín, Mexico. Cats were introduced to the island by Japanese abalone fishermen in the early 1900s, and have caused the extinction of the endemic woodrat (*N. martinensis*; Álvarez-Castañeda and Cortes-Calva, 1996). The endemic subspecies of deer-mouse (*P. m. exiguus*) is listed as threatened, and a desert shrew (*Notiosorex crawfordi crawfordi*) is also present. Cats were removed from the island in 1999 (Wood et al., 2002).

San Jerónimo—Located south of Rosario Bay, San Jerónimo Island (48 ha) is a low, rocky island with sparse vegetation. The endemic San Jerónimo Island deer-mouse (*P. m. geronimensis*) is listed as threatened. Cats were introduced sometime before 1970 and eradicated in the early 2000s (Jehl and Bond, 1975; Wood et al., 2002).

Cedros—Cedros Island is the largest (34,828 ha) and most diverse island off the

northern Pacific coast of Mexico. Cedros supports five endemic mammals (Table 1). The black-tailed deer (*O. h. cerrosensis*) and woodrat (*N. bryanti*) are listed as endangered by the IUCN. Populations of the brush rabbit (*Sylvilagus bachmani cerrosensis*) and pocket mouse (*Chaetodipus fallax anthonyi*) appear to be small, and feral cats and dogs have been observed preying on rodents (Mellink, 1993).

Whalers arrived on Cedros in the mid-1800s and brought goats as a source of meat (Mellink, 1993). By the end of that century, Norway rats, house mice, cats, and donkeys had established feral populations on the island (Bryant, 1886; Slevin, 1923; Mellink, 1993). Cattle, sheep, and dogs were introduced in the 1940s (Mellink, 1993).

Natividad—Natividad Island (728 ha) is located 9 km off the Vizcaíno Peninsula; the endemic Natividad Island deer mouse (*P. m. dorsalis*) is the only native mammal. Cats and dogs were introduced to the island about 1920 (Bancroft, 1927). In 1996, white-tailed antelope squirrels (*Ammospermophilus leucurus*) were introduced to the island, followed by goats and sheep in 1997 (Donlan et al., 2000). Later that year, goats and sheep were translocated to the mainland (Donlan and Keitt, 1999; Tershy et al., 2002). In the following 2 years, cats were removed (Wood et al., 2002). Most dogs have been removed from the island, and only a few pets remain in the fishing village.

San Roque—San Roque Island is a small (37 ha), rocky island off the Vizcaíno Peninsula. The only native mammal on the island, an endemic deer mouse (*P. m. cineritius*), is presumed to have gone extinct sometime before 1960 as a result of alteration of habitat, competition from rats, and predation by cats. The mouse was declared extinct in early 1994 after periodic extensive trapping efforts (Álvarez-Castañeda and Cortes-Calva, 1996). Arrival of cargo ships in the 1940s brought rats to the island, and cats were introduced in the 1970s. Efforts to eradicate cats began in the late 1980s, and cats and rats were eradicated in 1994 (Tershy et al., 2002; Wood et al., 2002).

Magdalena—Due to its proximity to the Baja California Peninsula, many native mammals occur on Magdalena Island (28,711 ha; Table 1), including four endemic subspecies; the Magdalena Island pocket gopher (*Thomomys bottae magdalenae*), two pocket mice, (*C. arenarius albus*, *C. spinatus magdalenae*), and the Magda-

lena Island black-tailed jack rabbit (*Lepus californicus magdalenae*). Little is known about status of the native mammals or the presence of non-native mammals on the island; feral cats are present (Table 2).

Santa Margarita—Santa Margarita Island (21,761 ha) lies immediately south of Magdalena Island. With the exception of bobcats and a woodrat, all native mammals present are endemic subspecies; two species of pocket mice (*C. a. ammophilus* and *C. s. margaritae*), the Santa Margarita Island kangaroo rat (*Dipodomys merriami margaritae*), Santa Margarita Island black-tailed jackrabbit (*L. c. magdalenae*), and two deer mice (*P. e. polyphilius* and *P. m. margaritae*). Cats are suspected on the island, and all native endemic mammals are considered threatened by the Mexican government.

CONCLUSIONS—The California islands harbor a unique and largely endemic mammalian fauna. Like all island ecosystems, the California islands are acutely vulnerable to anthropogenic disturbance, particularly the impact of non-native mammals. Since arrival of humans on the islands, non-native mammals have caused the decline of many native mammals via predation and the indirect effects of habitat degradation and changes in the food web. Twelve populations of native mammals are likely extinct or extirpated (Table 1). Fortunately, techniques to remove non-native mammals from islands have proved successful and have helped to safeguard many of the remaining insular populations. Removing remaining non-native mammals from the California islands is essential to restoration and recovery of these fragile ecosystems—removals should be conducted whenever possible and measures taken to prevent future non-native introductions should be of equal importance. Experimental reintroductions to replace extirpated populations should also be considered (Jones, 2002). Research and conservation action is sorely needed with respect to control and eradication of non-native plants and invertebrates.

The status of native mammal populations remain unknown on many of the California islands. Similar to a recent effort in the Gulf of California, Mexico (Álvarez-Castañeda and Ortega-Rubio, 2003), intensive, systematic surveys and monitoring efforts are needed on some islands. Continuing removal efforts and prevent-

ing future introductions of non-native mammals, combined with heightened research and education, will aid immensely in protecting the unique ecosystems of the California islands.

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