



The status of dwarf carnivores on Cozumel Island, Mexico

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Abstract. Cozumel Island in the Mexican Caribbean is inhabited by four carnivores, of which two, the Cozumel coati *Nasua nelsoni* and pygmy raccoon *Procyon pygmaeus*, are endemic species. The taxonomic status of a third carnivore, a dwarf gray fox *Urocyon cinereoargenteus*, is undetermined, but may deserve subspecific or species-level recognition. The fourth species, the kinkajou (*Potos flavus*), may be a recent introduction. We review the status of these carnivores, report our field observations and results of line transect and trapping efforts, discuss current threats to these taxa, and make recommendations for their conservation. A population density of 0.43 ± 0.27 coatis/km², and a total island population size of 150 ± 95 individuals, was estimated from 386 km of line transects in 1994–1995. Intensive trapping efforts (1479 trap-nights) in 2001 at multiple localities were unsuccessful. Pygmy raccoons were observed in the mangrove and coastal wetland areas of the island and in 2001 we captured 11 individuals with the same sampling efforts as for coatis (8.8 raccoons/1000 trap-nights). The gray fox is also apparently very rare on the island. While a few observations of the animals have been made (1984, 1994 and 2001), no animals were seen along transects and none were trapped. The primary threats to the persistence of these taxa include introduced congeners, introduced predators, parasite and disease spill-over from exotic animals, habitat fragmentation, hunting and collection as pets, and hurricanes. We suggest that the Cozumel coati, pygmy raccoon, and the Cozumel population of the gray fox be considered as Critically Endangered according to the IUCN classification system. Current conservation actions focusing on Cozumel carnivores are extremely limited. We recommend eradication of introduced species, maintenance of habitat connectivity, *ex situ* conservation programs, explicit public policies on land-use and sustainable development, public awareness campaigns, and continuous scientific research and monitoring.

Introduction

The isolation of island systems and the biogeographic factors that contribute to an island's biota often lead to a high degree of endemism, worthy of conservation

action. Although many islands contain endemic forms, Cozumel Island is unique because of its high level of vertebrate endemism. Cozumel contains a total of 25 endemic taxa: three species and three subspecies of mammals, three species and 15 subspecies of birds, and one lizard species (Wilson and Reeder 1993; Howell and Webb 1995; Taylor and Cooley 1995; American Ornithologist Union 1998). As is the trend for island fauna (Foster 1964; Case 1978; Heaney 1978; Lomolino 1985; Anderson and Handley 2002), Cozumel is home to a number of mammals and birds that are smaller than their mainland counterparts. Examples of dwarfed taxa on Cozumel include the Cozumel coati (*Nasua nelsoni*), pygmy raccoon (*Procyon pygmaeus*), gray fox (*Urocyon cinereoargenteus*), Cozumel collared peccary (*Pecari tajacu nanus*), Cozumel Curassow (*Crax rubra griscoi*), and the Cozumel Thrasher (*Toxostoma guttatum*). These island taxa are all of conservation concern.

There are four carnivore species on Cozumel including two procyonids endemic to the island: the Cozumel coati and the pygmy raccoon. Both taxa are listed by the World Conservation Union (IUCN) and Mexico as endangered (Hilton-Taylor 2000; SEMARNAT, Secretaría de Medio Ambiente y Recursos Naturales 2002). In addition, the gray fox, and a third procyonid, the kinkajou, have been recorded on the island. Little published information exists on the status and abundance of Cozumel's carnivores beyond a brief raccoon survey carried out in the 1980s (Navarro and Suárez 1989). This survey occurred prior to hurricane Gilbert (category 5 on the Saffir–Simpson scale), which caused severe damage to Cozumel, and the authors emphasized their concern about the hurricane and its influence on the survival of both raccoons and coatis. Since Navarro and Suárez's survey, however, no field studies of these taxa have been carried out and little formal conservation action has been implemented to ensure their protection.

As part of an ongoing study on the ecology, evolution and conservation of Cozumel endemic vertebrate fauna (Martínez-Meyer et al. 1998; Martínez-Morales 1999; Martínez-Morales and Cuarón 1999), we conducted fieldwork on the island between September 1994 and June 1995, made brief surveys in 1999 and 2000, and started a second phase of research in May 2001. Our work to date suggests immediate conservation concerns. Here, we briefly review the taxonomy and status of the Cozumel carnivores, we report our findings and reexamine the observations of Navarro and Suárez (1989) and finally, we discuss threats to the conservation of Cozumel's carnivores and recommend management actions.

Study area

Cozumel Island (ca. 490 km²), located 17.5 km off the northeast coast of Quintana Roo, Mexico, is the largest island off the Yucatán Peninsula. The island is separated from the mainland by the Cozumel Channel; its depth eliminates the possibility of an earlier land bridge and justifies the classification of the island as oceanic (Davidson 1975; Weidie 1985). In 2000, close to 90% of Cozumel Island was covered by native vegetation (Romero-Nájera and Cuarón, unpublished data). The

dominant vegetation types are tropical semi-deciduous forest, low tropical deciduous forest, mangrove forest, swamps and coastal vegetation.

As is the case with many areas in the Caribbean Sea, Cozumel is frequently struck by hurricanes. At least one major hurricane has hit the island every decade (Martínez-Morales 1996). The most recent hurricanes were Gilbert (1988), one of the strongest hurricanes ever recorded, and Roxanne (1995). Hurricanes are probably one of the most important ecological factors affecting the structure and composition of the island's vegetation.

The human population on Cozumel is about 65 000 people, most of whom live in San Miguel, one of the two towns on the island. The main economic activity is tourism, which is concentrated on the western coast. Agriculture, while important in the past, is now of minor importance.

Species accounts and status review

Nasua nelsoni Merriam, 1901

The Cozumel coati *N. nelsoni* (*N. thersites* Thomas (1901) is a synonym) has historically been considered a distinct species because it is strikingly smaller in both body size and cranium size than *N. narica* (Merriam 1901). Hall (1981) gave the total length of *N. nelsoni* as 785 mm ($n = 3$ males) and 744 mm ($n = 4$ females). These values are about 62–72% of the total length of animals measured in Arizona, western Mexico and Panama (Gompper 1996; Valenzuela 1998). Jones and Lawlor (1965) also retained *N. nelsoni* as a separate species based on its reduced size relative to *N. narica yucatanica* of the adjacent mainland. Glatston (1994) accepted *N. nelsoni* as a separate species, but indicated that some researchers believe the population may have been introduced to Cozumel by the ancient Mayans. This latter contention, however, has not been based on tangible evidence that we are aware of.

In contrast, Decker (1991) contends that the taxonomic status of the Cozumel coati is controversial because original descriptions were based on a small number of highly variable features. Decker compared island and mainland coatis and concluded that, based on morphological features, the Cozumel coati deserves only subspecific status (*N. narica nelsoni*). As Decker notes, however, five of the six specimens of *N. nelsoni* used in her study were collected from the same locality at the same time and may derive from a single family unit. A larger, more representative sample of individuals across the island should be considered before conclusions can be made based on the differences in morphology between the two taxa. It is clear that additional study of the systematics of this taxon is needed. Following the precautionary principle, we suggest that until more robust data is available, the Cozumel coati should be considered a distinct species.

The presence of coatis on Cozumel Island dates back at least to ancient Mayan civilization times. An archaeological study of animal use by Cozumel Maya reported the excavation of *N. nelsoni* bones from sites dated between the years 100 and 1500 AD (Hamblin 1984). These archaeological excavations show that

Table 1. Number of bones and minimum number of individuals of carnivore species excavated from 10 archaeological sites (100–1500 AD) on Cozumel Island, Mexico (data from Hamblin 1984).

Species	Number of bones	Minimum number of individuals
Coati	608	88
Large procyonid: coati	17	6
Raccoon	19	13
Raccoon/coati	22	12
Gray fox	530	48
Kinkajou	0	0

Cozumel coatis were extremely widespread and relatively abundant; a large number of coati remains were found in several sites on the island (Table 1). These coati remains were consistent with the description of *N. nelsoni* (smaller size, smaller teeth, and a more delicate construction than *N. narica*), but due to the absence of comparative material, identification was not corroborated (Hamblin 1984).

Mainland coatis (*N. narica*) tend to be relatively abundant in Mesoamerica and sometimes are successful even in disturbed areas (Gompper 1997; Valenzuela 1998; Carrillo et al. 2000; Escamilla et al. 2000). In contrast, we have obtained only a handful of coati records on Cozumel (Figure 1). In 1999, a park employee at San Gervasio Archaeological Site indicated that a coati band was occasionally observed near the ruins. During 2001, we saw two coatis in a deciduous forest coastal area in Refugio Estatal de Flora y Fauna Laguna de Colombia (popularly known as Punta Sur Park), in the south of the island, the same locality where Navarro and Suárez (1989) captured a coati. Additionally, biologists from that park reported seeing a coati nest in June 2001. Old Cozumel native residents generally agree that the coati is currently very rare, but was much more abundant in the past, particularly before hurricane Gilbert.

During 1994–1995 we used diurnal line transect sampling (Buckland et al. 1993) to assess the population of large bird and mammal species on Cozumel (Martínez-Morales 1999; Martínez-Morales and Cuarón, unpublished data). In total we had a sampling effort of 386 km of walked transects, covering 10 different routes (2.1–5.8 km long) in representative parts of the island (Figure 1). We had a coati encounter rate of 0.05 ± 0.03 (mean \pm SE) individuals/10 km. Sightings were of single individuals within tropical semi-deciduous forest. Based on distance sampling theory (Buckland et al. 1993), and using computer program Distance 3.5 (Thomas et al. 1998), we estimated a density of 0.43 ± 0.27 individuals/km². Assuming that coatis are present throughout Cozumel tropical forests, we estimate a population of 150 ± 95 individuals. Given the small sample size (two individuals seen during transect survey), these estimates should be considered preliminary. Intensive trapping efforts conducted from July to September 2001 in five separate locations on the island, including mangrove forest, low tropical deciduous forest and tropical semi-deciduous forest, confirm the grim status of the taxon; not a single coati was captured in 1479 trap-days. Clearly, the Cozumel coati is extremely rare. Yet, the occasional capture of juvenile individuals (see below) and the finding of an active coati nest indicate a small breeding population.

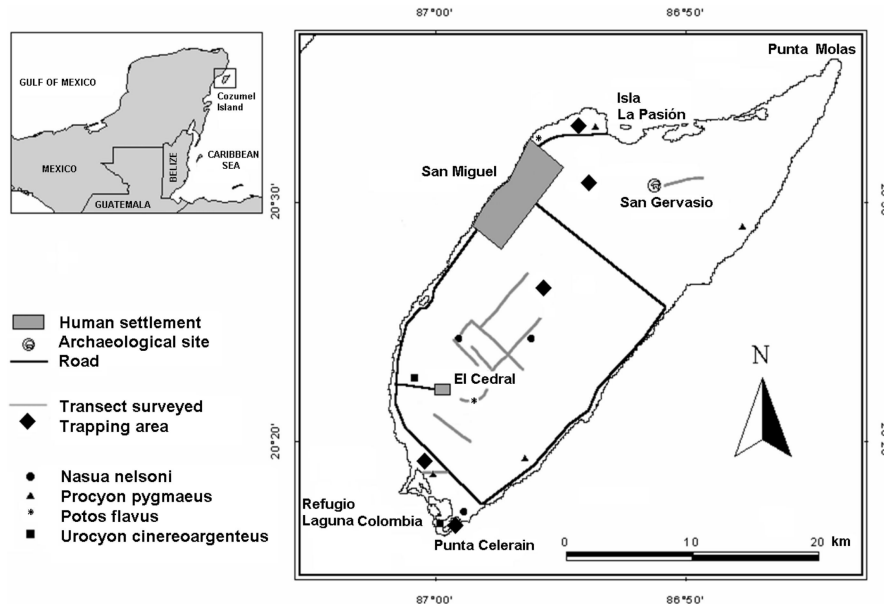


Figure 1. Map of Cozumel Island, showing the localities where records of native carnivores were obtained, and where trapping and transect surveys were conducted. Main sites mentioned in the text are indicated.

Procyon pygmaeus Merriam, 1901

Merriam (1901) first described the pygmy raccoon as a distinct species from its mainland congener, *Procyon lotor shufeldti*, based on a number of morphological traits. These include being markedly smaller in both body size and cranium size (Merriam 1901). Merriam (1901) described it as very easy to distinguish from *P. lotor* because of its 'broad black throat band and golden yellow tail, short posteriorly expanded and rounded nasals and peculiarities of the teeth'. Goldman (1950) agreed with Merriam's assessment on the distinctiveness of *P. pygmaeus*, and noted that the teeth are remarkably reduced, and that these and other characteristics point to a long period of isolation. Mean total length of two type specimens was 666 mm, about 75% the length of *P. l. shufeldti* (Goldman 1950). Other authors have also examined additional specimens of *P. pygmaeus* and have concurred that the taxon is deserving of specific recognition (Jones and Lawlor 1965; Genoways and Jones 1975). In her archaeological study of animal use by Cozumel Maya, Hamblin (1984) also identified raccoon bones of reduced stature (Table 1).

Navarro and Suárez (1989) recorded the pygmy raccoon as present at a number of sites on Cozumel Island, although the authors suggest that it tends to prefer mangrove stands and sandy soil habitat. Since 1999, we have identified conspicuous evidence of raccoon presence along the unpaved road running northeast from San Miguel and terminating near Isla La Pasión (Figure 1). During 7–11 April 1999 nine

raccoons were observed in this area, including a group of three individuals (likely a mother and two cubs). In July–August 2001 three individuals were seen in this same area. During 2001 we captured and marked 11 specimens (13 total captures in 354 trap-nights) in the mangrove forest along the road. Navarro and Suárez (1989) also reported raccoons in this mangrove region, as well as on the adjacent Isla La Pasión. Most of the sandy island of Isla La Pasión disappeared after Hurricane Gilbert as a result of sand displacement. We did not visit what remains of Isla La Pasión, but local residents indicated that raccoons may still inhabit it.

In 1995 we saw a pygmy raccoon during the day in the mangrove area surrounding Laguna Colombia (currently in Punta Sur Park). Trapping efforts in this area, and at three other localities, during August–September 2001 were fruitless (1125 trap-nights). Overall trapping success in the five localities was 8.8 raccoons/1000 trap-nights. Tracks were, however, observed at several sites in the coastal wetlands along the southeastern (1999) and northeastern (2001) part of the island (Figure 1). No raccoons were observed during line transect sampling (1994–1995; see above), but this was a diurnal effort that did not include mangrove areas, so it is not surprising that no animals were seen. Elsewhere, raccoons are predominantly nocturnal, while coatis tend to be diurnal.

Potos flavus (Schreber, 1774)

No evidence of the kinkajou was found in Cozumel archaeological sites (Hamblin 1984) (Table 1). The species was first recorded on Cozumel in 1995 (Martínez-Meyer et al. 1998). The only known museum specimen is a weathered adult skull found in a tropical semi-deciduous forest 2.6 km east of El Cedral (Figure 1). Interestingly, in comparison to adjacent mainland kinkajous of both sexes, the measurements of this cranium are smaller (91–96%; Martínez-Meyer et al. 1998). Contrary to what is claimed (Martínez-Meyer et al. 1998), there is no evidence to indicate that the kinkajou may be relatively common on Cozumel. We have recorded only two other animals, and we have not discovered an established population. A free ranging animal was seen at a large tree at the parking lot of a non-operating hotel (D. García-Vasco and C. González-Baca, personal communication). An adult male was captured at an unknown location and taken to a local menagerie by the public. Some local inhabitants of Cozumel reported that the species was introduced onto the island, but others believe it may be native.

Urocyon cinereoargenteus (Schreber, 1775)

The Cozumel gray fox is also a dwarf form. It is typically smaller than the mainland subspecies on the Yucatán Peninsula (Merriam 1901; Jones and Lawlor 1965; Hamblin 1984). Merriam (1901) and Jones and Lawlor (1965) based their reports on eyewitness accounts, as they did not capture animals and there are no Cozumel gray fox specimens in museums (Don E. Wilson, *in litt.*). Hamblin (1984) confirmed that the foxes she measured from Cozumel archaeological sites are smaller than

mainland specimens. Although the Cozumel gray fox may represent a distinct taxonomic form, its taxonomic status is undetermined.

Gray foxes were relatively abundant at Mayan archaeological sites on Cozumel (Table 1), but we have seen only a few foxes on the island. In February 1984 an individual was seen walking along a dirt road near El Cedral, and in May 1995 a fox was seen along the road near the lighthouse in Punta Celarain (currently in Punta Sur Park; Figure 1). This animal had darker pelage and looked smaller than mainland foxes. During 2001, we received several reports of observations of a single small ('squirrel-like') fox in Punta Sur Park. No foxes were seen during line transect sampling (1994–1995), and no foxes were captured in 1479 trap-nights (2001).

Conservation threats

We have identified six main threats to the Cozumel carnivores: introduced congeners (genetic introgression), introduced predators, parasite and disease spill-over from exotic animals, habitat fragmentation, hunting and collection of carnivores as pets, and hurricanes. Additional potential threats include overexploitation of underground freshwater, disturbance associated with an expanding human population and increasing touristic development.

Introduced congeners

Pet coatis and a captive kinkajou from the mainland have been observed on Cozumel and could become sources of genetic introgression. The mainland coati is the most common wild mammal species used as a pet in southern Mexico, and the gray fox, raccoon, and kinkajou are among the top 10 species captured to be kept as pets (Cuarón 1997). We know of 12 mainland coatis in captivity on the island, although it is very likely that there are more. Since at least May 2001, a young female coati believed to be from Cozumel lived together with four mainland coatis in Punta Sur Park. By September 2001 one of these mainland coatis disappeared. These coatis roamed free in the administrative area of the park, but by December 2001 the remaining four animals had been placed together in an enclosure. In May 2002 the female Cozumel coati gave birth to four hybrid cubs, although one cub died immediately after birth. A mainland female coati also gave birth to four cubs. As of August 2002 only one hybrid cub remained in the enclosure. We were informed by park authorities that the remaining cubs had died, but there are reports that the infants may have been given away to park employees. We are not aware of the presence of any mainland raccoons or gray foxes on the island.

Introduced predators

Boa constrictor is thought to have been introduced on Cozumel in 1971, and now is a concern for the conservation of several endemic and other native terrestrial vertebrates of the island (Martínez-Morales and Cuarón 1999). This species is also

of concern for the conservation of carnivores, as large boas are certainly capable of killing adult carnivores (Janzen 1970). Domestic or feral dogs could also be a problem as predators or marauders of Cozumel carnivores. Managers have observed coatis being chased by feral dogs in Punta Sur Park.

Parasite and disease spill-over from exotic animals

The movement of parasites and diseases from domestic and exotic animals into populations of wild animals has recently been identified as an important conservation issue (Daszak et al. 2000) and this appears especially true for carnivores (Funk et al. 2001). In 1999 and 2001 we observed a population of feral dogs infected with mange at Cozumel's primary garbage dump in the southeastern part of the island. This dump is adjacent to regions where both raccoon and dog tracks were observed, and there is continuous suitable habitat between the dump and both the southern and northern parts of the island where native carnivore populations exist. Thus, infectious disease outbreaks such as mange, rabies, and canine distemper in the dog population could spill over into the native carnivore populations. The size of feral cat populations on Cozumel is unclear, but a recent localized coati population decline in western Mexico due to a notoedric mange epizootic (Valenzuela et al. 2000) indicates that diseases harbored by domestic cats could also be a concern. Because Cozumel carnivores have presumably been isolated from mainland parasites and diseases for a long time, they may be particularly vulnerable to novel pathogens introduced by domestic animals and mainland wild species.

Habitat fragmentation

Habitat loss is not a current conservation threat on Cozumel Island, as land-cover changes have remained within reasonable limits (Figure 2). Urban growth in San Miguel and developments for tourism have occurred in localized areas on the coastline of western Cozumel. Habitat fragmentation, however, remains a critical issue on Cozumel. Particularly worrisome is the road that bisects the island along a northwest-southeast axis and the subsequent development occurring there. Development along this road effectively splits the island into two regions, with reduced opportunities for wildlife movement between the areas. There are still three areas where connectivity between both sides of the road remains, one of which is being affected by the expansion of San Miguel's urban area (Figure 2).

Hunting and collection of Cozumel carnivores as pets

The impact of hunting and collecting Cozumel carnivores as pets is unclear. Navarro and Suárez (1989) reported that the raccoon was often hunted or poisoned to protect agricultural crops. However, agriculture is now an activity of lesser importance due to a shift to tourism. Navarro and Suárez (1989) also observed signs of hunting on Isla La Pasión. Hunting on Cozumel has declined and is now illegal on the island, but it still occurs and is mainly directed toward curassows, peccaries and armadillos

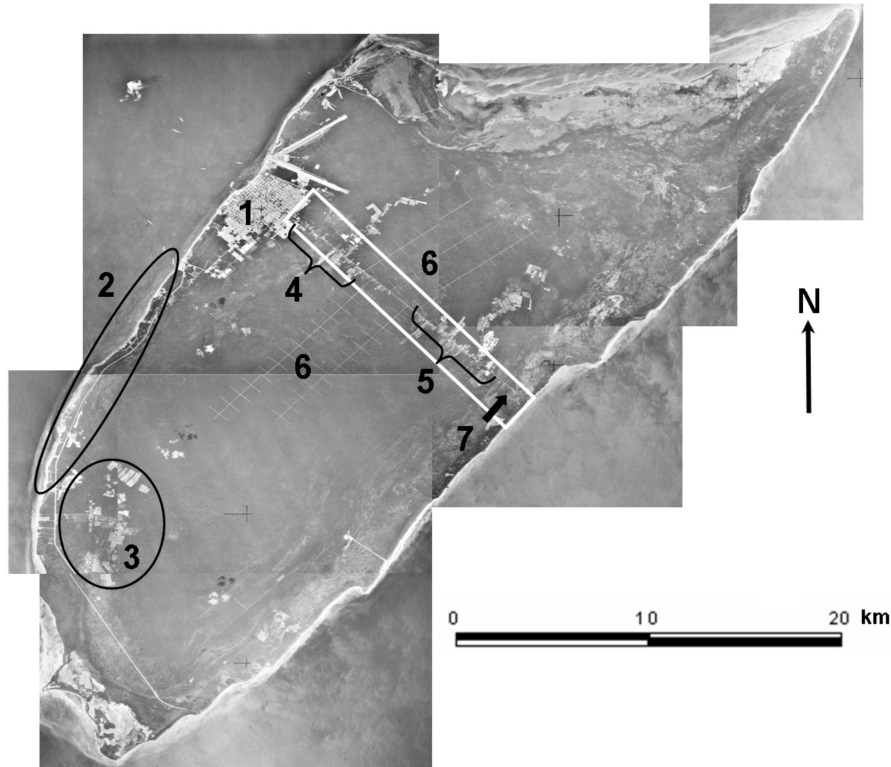


Figure 2. Aerial photography (1:70000) mosaic of Cozumel Island. (1) San Miguel's urban area; (2) hotel zone and main road; (3) El Cedral; (4) vegetation corridor affected by growth of urban area; (5) vegetation corridor affected by agricultural expansion; (6) CAPA's water capture area and road system (closed to the public); (7) vegetation corridor along the eastern coast of the island. Note how the matrix is largely constituted by native vegetation. The white rectangle highlights the road that bisects the island. Areas 2 and 3 have localized vegetation loss that is not causing major fragmentation. Areas 4 and 5 are in initial stages of a major fragmentation process. Area 6 acts as a corridor between regions to the northeast and southwest of the road. The graphic scale is approximate. The photo was obtained on 9 February 2000.

(*Dasypus novemcinctus*). It is likely, however, that some carnivores are opportunistically hunted or captured as pets.

We detected (2000–2001) three pet coatis and one captive raccoon, which according to their holders came from Cozumel. A makeshift zoo located behind a residence approximately 5 km west of the entrance of San Gervasio contained an adult female coati and an adult male raccoon. The family holding these animals claimed they captured both (on separate occasions) within 4–5 km of their home while hunting. They had been in possession of both the coati and raccoon since approximately 1996; the female coati was captured as a juvenile. Despite several years of searching for a male coati to breed with it, the family said that they had been unable to find any other coatis. The family agreed that coatis seemed to be more abundant approximately 20 years ago, but that currently all but a handful of coatis

on the island had disappeared. The second pet coati was the juvenile female living at Punta Sur Park and the third pet coati was a juvenile female kept in a restaurant at Punta Morena, along the eastern coast of the island.

Hurricanes

Hurricanes may also be an important factor affecting Cozumel carnivores. Although the Cozumel biota may have a long evolutionary history of co-existence with hurricanes, a severe hurricane coupled with increasing anthropogenic disturbance and small population size could have catastrophic consequences for the carnivores of Cozumel. Anecdotal information from local inhabitants indicates that the decline of some wildlife populations (or the increase of introduced species, such as the boia) was exacerbated after Hurricane Gilbert.

Potential threats

Potential threats to carnivores, and wildlife in general, on Cozumel come from pressure to use more freshwater for tourism infrastructure (e.g., hotels, golf courses) and urban services for an expanding population. On Cozumel there are no rivers or other bodies of superficial freshwater except for *cenotes* (sinkholes) and seasonal ponds. These water bodies are crucial for the survival of many wildlife species, particularly during the dry season (Martínez-Morales 1999; Martínez-Morales and Cuarón, unpublished data). All water for human consumption and urban services on Cozumel comes from underground sources, to which the water level of *cenotes* is intimately linked. Although there are technical ways to exploit underground freshwater at greater levels or to obtain freshwater from the sea, this would be extremely costly or may have negative effects on wildlife.

Concurrent with continued population growth on the island and an increase in tourism, there would be an expected rise in land-cover conversion and an increased demand for natural resources.

Current conservation actions

The Cozumel coati, pygmy raccoon, and kinkajou are included in the official Mexican list of threatened species (SEMARNAT, Secretaría de Medio Ambiente y Recursos Naturales 2002), but real conservation actions on Cozumel are extremely limited. Refugio Estatal de Flora y Fauna Laguna de Colombia (Punta Sur Park; ca. 1000 ha) protects portions of the native habitats of Cozumel, and Parque Marino Nacional Arrecifes de Cozumel, which protects Cozumel's impressive coral reefs, also includes a small amount of coastline.

Some *de facto* protection exists in other areas on Cozumel. As part of the protection of water catchment areas, significant portions (ca. 6500 ha) of tropical forest are being protected by Comisión de Agua Potable y Alcantarillado (CAPA), the agency governing the management and supply of freshwater for human use.

Additionally, San Gervasio Archaeological Site (ca. 300 ha) contains carnivore habitat. While Cozumel Island has been considered a priority region for conservation by the Mexican government (Arriaga Cabrera et al. 1998) and an 'Important Bird Area' (Arizmendi and Marquez-Valdelamar 2000), these designations provide no legal protection. Habitat protection for Cozumel carnivores remains inadequate and further conservation is needed.

Management recommendations

Based on the information available, we suggest that the Cozumel coati and the pygmy raccoon should be recategorized and considered as Critically Endangered species according to the IUCN classification system (IUCN 2001). The Cozumel population of the gray fox should also be considered Critically Endangered. Based on the IUCN system (IUCN 2001), these taxa would be CR A4bce B1abc C2b (see Appendix). The origin of the kinkajou on Cozumel should be determined, and it should be clarified if there is an established population.

Addressing the pressures described in this paper will require a concerted effort at several scales and from different perspectives. We propose immediately implementing the following management recommendations to promote the conservation of Cozumel's native carnivores:

1. The importation of wildlife from the continent onto Cozumel, particularly of congeners of native Cozumel species, should be prevented. Because most animals are likely to enter the island through the docks, law enforcement should be concentrated there. Federal, state and municipal authorities should work jointly in this endeavour. Permanent checkpoints at the docks by the Procuraduría Federal de Protección al Ambiente (PROFEPA), with the support of the police and/or military, would be a valuable contribution. Non-native animals already on the island should be removed or at least sterilized and placed under continuous veterinary supervision. Under no circumstances should non-native animals be released onto the island.
2. The feral populations of dogs and cats should be controlled and, if possible, eradicated to avoid predation on native wildlife. A domestic carnivore vaccination program should be undertaken to mitigate the potential of disease spill-over. Local people should be aware of the dangers of releasing unwanted domestic animals and of having loose domestic animals in rural areas. Current small-scale efforts towards this goal made by the private sector should be expanded and reinforced with the support of the local government.
3. Native vegetation connectivity along the transversal road and other key sites on the island should be maintained and restored to avoid habitat fragmentation and provide corridors for wildlife (Figure 2). This can be achieved by establishing protected areas in critical sites, by land acquisition, or through negotiations with land-owners. The budding system of protected areas on the island should be expanded to more fully incorporate *both* the island's biological and cultural heritage. Special attention should be given to the protection of *cenotes* as key

sources of water for wildlife. The tropical forest in the water catchment area under the control of CAPA should be permanently protected, as it provides important environmental services, habitat for wildlife, and contributes to the maintenance of partial forest connectivity along the transversal road (Figure 2). Other areas that deserve protection are the mangrove forests in the north of the island and the wetlands, seasonally flooded areas, and coastal areas in eastern Cozumel.

4. The need for a captive breeding program for Cozumel carnivores should be evaluated, and responsible and potentially interested institutions for such a program should be identified. Such a program should have a strong representation on the island, but should not be restricted to the island, so as to avoid catastrophic events such as hurricanes or disease outbreaks simultaneously affecting the captive and wild populations. The establishment of a founding captive population, however, should wait until more detailed population and demographic studies are available.
5. Island-wide planning and explicit public policies on key issues that may determine the environmental quality of Cozumel should be implemented. These include clear policies on human population limits for Cozumel and the type of infrastructure and economic activities that can be promoted on the island. Crucial is the approval of (a) a land-use plan (*Ordenamiento territorial*) that promotes the conservation of Cozumel's unique biological diversity and mitigates the negative impacts on it, and (b) policies to maintain the quality and superficial level of freshwater on the island for wildlife and human use.
6. Public awareness campaigns to promote the conservation of Cozumel native wildlife, particularly endemic taxa, and their habitats should be conducted and reinforced. These programs should cross age and social classes, and also target the many national and foreign visitors of the island.
7. Management activities should be based on sound scientific information. Little to nothing is known about the ecology and evolutionary history of Cozumel's carnivores. This information is crucial in order to determine conservation priorities and periodically assess the effectiveness of carnivore management activities on the island.

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Appendix

Criteria used to categorize the Cozumel coati, the pygmy raccoon, and the Cozumel population of the gray fox, as Critically Endangered (CR) according to the IUCN classification system (IUCN 2001).

A taxon is CR when the best available evidence indicates that it meets any of the following criteria (A–E; only A–C shown here), and it is therefore considered to be facing an extremely high risk of extinction in the wild.

(A) Reduction in population size based on [. . .] the following:

1. [. . .]

4. An observed, estimated, inferred, projected or suspected population size reduction of 80% over any 10 years or three generation period, whichever is longer (up to a maximum of 100 years in the future), where the time period must include both the past and the future, and where the reduction of its causes may not have ceased OR may not be understood OR may not be reversible, based on (and specifying) any of:

(a) [. . .]

(b) an index of abundance appropriate to the taxon.

(c) A decline in area of occupancy, extent of occurrence and/or quality of habitat.

(d) [. . .]

(e) the effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.

(B) Geographic range in the form of extent of occurrence OR area of occupancy OR both:

1. Extent of occurrence estimated to be less than 100 km², and estimates indicating at least two of a–c:

(a) Severely fragmented or known to exist at only a single location.

(b) Continuing decline, observed or inferred or projected, in any of the following:

(i) extent of occurrence,

(ii) area of occupancy,

(iii) area extent and/or quality of habitat,

(iv) number of locations or subpopulations,

(v) number of mature individuals.

(c) Extreme fluctuations in any of the following:

(i) extent of occurrence,

(ii) area of occupancy,

- (iii) number of locations or subpopulations,
- (iv) number of mature individuals.

- (C) Population size estimated to number fewer than 250 mature individuals and [. . .]:
1. [. . .]
 2. A continuing decline, observed, projected or inferred, in number of mature individuals AND at least one of the following:
 - (a) [. . .]
 - (b) Extreme fluctuations in number of mature individuals.

References

- Anderson R.P. and Handley C.O. 2002. Dwarfism in insular sloths: biogeography, selection and evolutionary rates. *Evolution* 56: 1045–1058.
- American Ornithologist Union 1998. Checklist of North American Birds. 7th edn. AOU, Washington, DC.
- Arizmendi M.C. and Marquez-Valdelamar L. (eds) 2000. Areas de importancia para la conservación de las aves en México. CIPAMEX, CONABIO, FMCN, Mexico.
- Arriaga Cabrera L., Aguilar Sierra V., Alcocer Durand J., Jiménez Rosenberg R., Muñoz López E. and Vázquez Domínguez E. (eds) 1998. Regiones hidrológicas prioritarias: Fichas técnicas y mapa. CONABIO, Mexico, DF.
- Buckland S.T., Anderson D.R., Burnham K.P. and Laake J.L. 1993. Distance Sampling. Estimating Abundance of Biological Populations. Chapman & Hall, London.
- Carrillo E., Wong G. and Cuarón A.D. 2000. Monitoring mammal populations in Costa Rican protected areas with different hunting restrictions. *Conservation Biology* 14: 1580–1591.
- Case T.J. 1978. A general explanation for insular body size trends in terrestrial vertebrates. *Ecology* 59: 1–18.
- Cuarón A.D. 1997. Land-cover changes and mammal conservation in Mesoamerica, Ph.D. Thesis, University of Cambridge, Cambridge, UK.
- Daszak P., Cunningham A.A. and Hyatt A.D. 2000. Emerging infectious diseases of wildlife. Threats to biodiversity and human health. *Science* 287: 443–449.
- Davidson W.V. 1975. The geographical setting. In: Sabloff J.A. and Rathje W.L. (eds), *Changing Pre-Colombian Commercial Systems*. Peabody Museum Monograph No. 3. Harvard University, Cambridge, Massachusetts, pp. 47–59.
- Decker D.M. 1991. Systematics of the coatis, genus *Nasua* (Mammalia: *Procyonidae*). *Proceedings of the Biological Society of Washington* 104: 370–386.
- Escamilla A., Sanvicente M., Sosa M. and Galindo-Leal C. 2000. Habitat mosaic, wildlife availability and hunting in the tropical forest of Calakmul, México. *Conservation Biology* 14: 1592–1601.
- Foster J.B. 1964. Evolution of mammals on islands. *Nature* 202: 234–235.
- Funk S.M., Fiorello C.V., Cleaveland S. and Gompper M.E. 2001. The role of disease in carnivore ecology and conservation. In: Gittleman J.L., Funk S.M., Wayne R.K. and Macdonald D. (eds), *Carnivore Conservation*. Cambridge University Press, Cambridge, UK, pp. 443–466.
- Genoways H.H. and Jones J.K. 1975. Annotated checklist of mammals from the Yucatan Peninsula, Mexico. *Occasional Papers from the Museum, Texas Tech University* 26: 1–22.
- Glatston A.R. 1994. The red panda, olingos, coatis, raccoons, and their relatives: status survey and conservation action plan for procyonids and ailurids. IUCN (World Conservation Union), Gland, Switzerland.
- Goldman E.A. 1950. Raccoons of North and Middle America. *North American Fauna* 60: 1–153.

- Gompper M.E. 1996. Foraging costs and benefits of coati (*Nasua narica*) sociality and asociality. *Behavioral Ecology* 7: 254–263.
- Gompper M.E. 1997. Population ecology of the white-nosed coati (*Nasua narica*) on Barro Colorado Island, Panama. *Journal of Zoology (London)* 241: 441–455.
- Hall E.R. 1981. *The Mammals of North America*. John Wiley and Sons, New York.
- Hamblin N.L. 1984. *Animal Use by Cozumel Maya*. The University of Arizona Press, Tucson, Arizona.
- Heaney L.R. 1978. Island area and body size of insular mammals: evidence from the tri-colored squirrel (*Callosciurus prevosti*) of Southeast Asia. *Evolution* 32: 29–44.
- Hilton-Taylor C. 2000. 2000 IUCN Red List of threatened species. IUCN, Gland, Switzerland.
- Howell S. and Webb S. 1995. *A guide to the birds of Mexico and Northern Central America*. Oxford University Press, New York.
- IUCN 2001. IUCN Red List categories and criteria: Version 3.1. IUCN Species Survival Commission, Gland, Switzerland.
- Janzen D.H. 1970. Altruism by coatis in the face of predation by *Boa constrictor*. *Journal of Mammalogy* 51: 387–389.
- Jones J.K. Jr. and Lawlor T.E. 1965. Mammals from Isla Cozumel, Mexico, with description of a new species of harvest mouse. *University Kansas Publishing, Museum of Natural History* 16: 409–419.
- Lomolino M.V. 1985. Body size of mammals on islands: the island rule re-examined. *American Naturalist* 125: 310–326.
- Martínez-Meyer E., Martínez-Morales M. and Sosa-Escalante J. 1998. First record of the kinkajou, *Potos flavus* (Carnivora: Procyonidae), from Isla Cozumel, Quintana Roo, Mexico. *Southwestern Naturalist* 43: 101–102.
- Martínez-Morales M.A. 1996. *The Cozumel Curassow: abundance, habitat preference and conservation*. M.Phil. Thesis, University of Cambridge, Cambridge, UK.
- Martínez-Morales M.A. 1999. Conservation status and habitat preferences of the Cozumel Curassow. *Condor* 101: 14–20.
- Martínez-Morales M.A. and Cuarón A.D. 1999. *Boa constrictor*, an introduced predator threatening the endemic fauna on Cozumel Island, Mexico. *Biodiversity and Conservation* 8: 957–963.
- Merriam C.H. 1901. Six new mammals from Cozumel Island, Yucatan. *Proceedings of the Biological Society of Washington* 14: 99–104.
- Navarro D.L. and Suárez M. 1989. A survey of the pygmy raccoon (*Procyon pygmaeus*) of Cozumel, Mexico. *Mammalia* 3: 458–461.
- Schreber 1774. *Die Säugethiere*. 1(9): pl 42 [1774]; text: p. 187 [189] index [1774].
- Schreber 1775. *Die Säugethiere*. 2(13): pl 92 [1775]; text: 3(21): 361 [1776].
- SEMARNAT, Secretaría de Medio Ambiente y Recursos Naturales 2002. Norma Oficial Mexicana NOM-059-ECOL-2001, Protección ambiental – Especies nativas de México de flora y fauna silvestres – Categorías de riesgo y especificaciones para su inclusión, exclusión o cambio – Lista de especies en riesgo.: *Diario Oficial de la Federación (Segunda Sección; 6 de marzo)*. pp. 1–81.
- Taylor H.L. and Cooley C.R. 1995. A multivariate analysis of morphological variation among parthenogenetic Teiid lizards of the *Cnemidophorus cozumela* complex. *Herpetologica* 51: 67–76.
- Thomas L., Laake J.L., Derry J.F., Buckland S.T., Borgers D.L., Anderson D.R. et al. 1998. *Distance 3.5*. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK, available at <http://www.ruwpa.st-and.ac.uk/distance/>.
- Thomas O. 1901. New insular forms of *Nasua* and *Dasyprocta*. *Annals and Magazine of Natural History* 7: 271–273.
- Valenzuela D. 1998. Natural history of the white-nosed coati, *Nasua narica*, in a tropical dry forest of western Mexico. *Revista Mexicana de Mastozoología* 3: 26–44.
- Valenzuela D., Ceballos G. and García A. 2000. Mange epizootic in white-nosed coatis in western Mexico. *Journal of Wildlife Diseases* 36: 56–63.
- Weidie A.E. 1985. Geology of the Yucatan Platform, Part 1. In: Ward W.C., Weidie A.E. and Back W. (eds), *Geology and Hydrogeology of the Yucatan and Quaternary Geology of Northeastern Yucatan Peninsula*. New Orleans Geological Society, New Orleans, Louisiana, pp. 1–19.
- Wilson D.E. and Reeder D.M. (eds) 1993. *Mammal Species of the World: A Taxonomic and Geographic Reference*. 2nd edn. Smithsonian Institution Press, Washington, DC.