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On the urgency of conservation on Guadalupe Island, Mexico: is it a lost paradise?

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Abstract. Guadalupe is an oceanic island located in the Pacific Ocean off Mexico's northwest coast. Its flora is composed of many plant species with more northern affinities and disjunctions from the California Floristic Province. Almost 16% of the native plant species are endemic, including two monospecific genera. However, the activities of feral goats released in the early 19th century have devastated most of the island. At present, at least 26 native plant species have disappeared from Guadalupe and many more seem to be on the threshold. To add to the problem, 61 exotic plant species have been documented on the island, many of which are aggressive weeds. In this paper, we propose eight types of environmental conditions for the island where different species assemblages of the pristine flora probably existed before their demise. It is of obvious urgency that the island needs a recovery plan and the first step should include the eradication of the feral goats. Only after this process can subsequent conservation measures be applied to ensure any restoration of this natural heritage. The recovery plan will need to address both spontaneous and human-induced plant repopulation processes from the main island's three southern islets, which have never been impacted by goats. Also, it may be necessary to reintroduce non-endemic, native plant taxa from the nearest Californian islands and the Mexican coast in order to reestablish some of the island's original diversity of plant species and communities. However, it should be noted that the forested communities do not have great hopes of recovering in the short term, since the ground water and soil conditions have been significantly altered. Furthermore, the eradication of an estimated 4000 goats still living on the island (year 2000) depends upon the vacillating motivation and will of Mexican authorities.

Nomenclature
Moran R.V. 1996. The flora of Guadalupe Island, Mexico. Memoirs of the California Academy of Science 19: 190.

Introduction

Guadalupe is an oceanic island located approximately 260 km off of the Pacific coast along the Baja California peninsula in northwestern Mexico. The island's geographic position is at 29°03′ N and 118°17′ W. Guadalupe Island is about 36 km long on its north–south axis and 12 km wide on the east–west axis, with an approximate surface area of 250 km^2. The island is the peak of a seamount, which

may have originated from several eruptive episodes, with the oldest exposed rocks being dated around 7 million years old (Moran 1996). There are three islets off of the southern end of the main island: *Islote Negro* (30 m in elevation), *El Toro* (210 m), and *El Zapato* (190 m). Each islet has approximately 1 km^2 of surface area.

The climate of the island is maritime and heavily influenced by the cold California Current, with its characteristic features of wind, fog, and winter rainfall. A meteorological station on the southern end of Guadalupe (the driest part of the island) indicates almost 120 mm of rainfall annually and a mean monthly temperature of 17–19 °C that is relatively stable throughout the year.

Floristically, the island is considered by Moran (1996) as an 'outlier' of the California Floristic Province. Due to the island's isolation, much of the flora and fauna are unique. Hubbs and Rechnitzer (1958) indicated that the island has a high degree of endemism in its littoral marine life (e.g., seaweeds, mollusks, fishes), and Hubbs and Jehl (1976) suggested the same for its terrestrial biota, especially in vascular plants and insects that represent the most diverse groups. The plant diversity of the island has been periodically recorded by collections and field observations since the middle of the 19th century. A floristic analysis is a good method to investigate and monitor vegetation trends and to evaluate environmental degradation of an island. At present, the island's vegetation is composed mainly of weedy species; the pristine flora and natural plant communities have practically vanished.

In the early part of the 19th century, either whalers or seal hunters introduced goats (apparently Asian races), presumably as a fresh meat supply for later visits. These goats expanded their population numbers dramatically in a rather explosive manner. Moran (1996) cites an informal report, which estimated approximately 100 000 individual goats by the year 1870. This number can probably be considered the peak value for the goat population in relation to the carrying capacity of the island with respect to food resources: the terrestrial plants. Fragmentary notes by early botanists (Greene 1885) show a disastrous decline in the vegetation during the last quarter of the 19th century, not only in the scarcity of individual plants and decreasing diversity of species, but also in the elimination of entire plant communities. To compound the problem, during this time there was an increase in the traffic of goods for fishermen and visitations by explorers from other places which brought the second major insular menace: the weeds.

In this paper, we present a current assessment of the vascular flora of Guadalupe Island and its communities based upon bibliographic references (Moran 1996) and a six-day expedition made in June of 2000 under the auspices of the San Diego Natural History Museum. We interpret the status of the Guadalupe flora and discuss the possibilities and options available to save the island's native plant species from extinction. Also, we present a schematic map of the plant communities that once covered the island. We argue that conservation actions for the island must begin by harvesting, or eliminating, the feral goats and be followed with a plan to reintroduce seeds of some species from the nearest islets and probably even the continental coast.

Table 1. The Guadalupe archipelago's known flora (215 total plant taxa) categorized with respect to origin.

Category	Extant	Extinct or vanished
Endemics	35	4
Semi-endemics[a]	22	5
Introduced[b]	61	16
Non-endemic natives[c]	97	17

[a] Shared with other islands (US and Mexico); [b] Exotics, mostly weeds (most with European origin); [c] Shared with mainland communities in North America.

The pristine flora and communities

Based on the floristic summary of Moran (1996), who visited the Guadalupe archipelago 20 times between 1948 and 1988, and the authors' contributions from a recent visit in June 2000, a compiled flora is presented in Table 1.

There have been 215 different plants documented on the Guadalupe archipelago (Appendix 1). Of these, 22 taxa are considered semi-endemic (insular endemics), since they are shared with other relatively close islands in California (Channel Islands) and Mexico (Cedros), but 35 taxa are strictly endemic to Guadalupe and its adjacent islets. At least four of these strict endemics are now apparently extinct. Moreover, 61 species are considered to have been introduced since the middle of the 19th century (many of them are invasive weeds). With respect to the entire native flora, 26 taxa may now be extinct (the island's endemics) or have vanished from Guadalupe (the non-endemic natives), including one endemic, monospecific genus.

By looking at the current status of the slopes on the island, which are mostly covered either by bare and eroded soils, rocks, or by weeds, it is hard to envision the earlier pristine vegetation and cover of trees and shrubs (pre-goat introduction). Figure 1 is our interpretation of the possible expanse of eight topographical regions where presumed plant communities or groupings of different dominant plants would have occurred. The proposed distributions of ecological regions were constructed by analyzing current plant distributions on the island and factoring in topographical and environmental conditions. It should be noted that it was necessary to assume that the now disturbed surfaces of the island previously offered suitable conditions for these occurrences. A topographical map (see Moran 1996) and air surveys using a helicopter were fundamental in clarifying our early distributional concepts.

The following is our interpretation of the island's plant communities and their floristic compositions based upon the extant, native plants still found in some areas, various historical references, and aerial surveys of the whole island.

The northern part of the island with nearly vertical cliffs and steep ridges (up to 1300 m in elevation) was probably the most diverse in plant species and communities. However, it has been the area where impacts to vegetation have been severe. Currently, only about 130 old individuals of Guadalupe Island pine (*Pinus radiata* var. *binata*) are remnant evidence of a pine forest that could have covered most of the foggy northern highlands. This number of pines is in a decline from

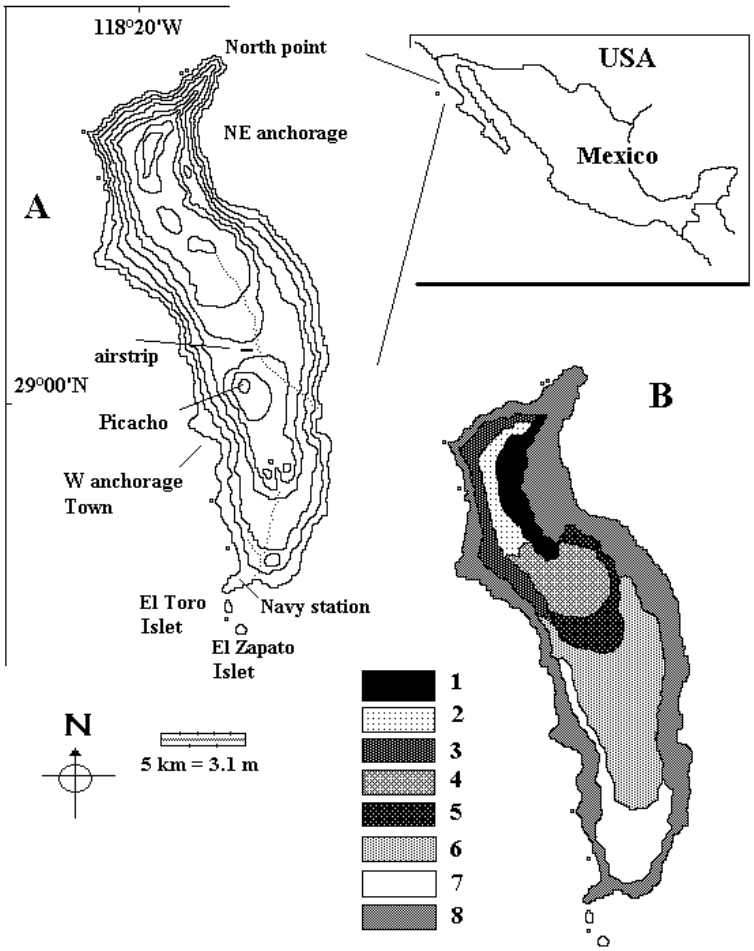

Figure 1. Guadalupe Island's geographical position in northwestern Mexico. (A) Topography of the island (isolines in 200 m increments) and main reference locations. (B) Reconstruction of the main vegetation types according to the authors: 1. pine and oak–pine forest (>1000 m); 2. oak and oak–palm forest (900–1000 m); 3. palm forest (400–900 m, NW side); 4. cypress forest (800–1000 m); 5. herbland (600–800 m); 6. marine desert-like scrubland (400–600 m); 7. succulent herbland (200–400 m); 8. rocky cliff slopes and coastal belt.

more than 360 trees registered 34 years ago (Libby et al. 1968). Beneath individual pines and in some small groves, a thin layer of litter provides suitable conditions for pine germination and development. In fact, a few seedlings were observed, although they are short-lived due to the effects of goat browse. In most areas, this layer of litter and the associated soils have been completely eroded away between individual trees and small groves. Therefore, the large, older trees seem to act as nurse-plants to

the young pine seedlings. Condensation of water droplets on the needles of the older trees during the frequent fogs facilitates regular watering for any seedlings that grow beneath the larger trees. Absence of these older trees may have an adverse effect on the success of any repopulation efforts for pines.

The island oak (*Quercus tomentella*) has similarly suffered a major decline on Guadalupe. Historical accounts from earlier botanists make reference to hundreds of oak trees. However, on our visit we registered only 20 individuals. This number is down from approximately 100 trees reported 50 years ago (Moran 1996). None of the oaks appear to be reproducing and all seem vulnerable to mortality within a relatively short time due to soil erosion and damage to their trunks from goat grazing.

A community of the endemic palms (*Brahea edulis*) extends from the pine forest at 700–800 m down to 150 m. In the higher parts of this zone, the palms used to grow with oaks and pines, but the oaks and pines have since retreated from most of this area. At present, there are still hundreds of old palms on the island, but recruitment for new generations seems absent since no younger palm trees were seen, again probably due to their consumption by feral goats.

An extensive plateau in the northern sector of the island is still occupied by the endemic Guadalupe Island cypress (*Cupressus guadalupensis* var. *guadalupensis*). In the past, an almost monotypic community of this species was much more extensive and probably occupied some of the flatter areas to the south of the plateau. Early records indicate that the trees extended several hundred feet lower in elevation below the east side of the plateau. At present, limited groves of a few thousand individual trees grow in two stands near the highest point on the island. In a manner similar to the other tree species of the island, no tree seedlings escape the goats during their first year. Many of the older trees demonstrated severe damage of their bark and trunks as a result of goat browse. Apparently due to soil erosion and possibly a lowering water table from the decrease in fog-condensing trees, adult mortality seems rapid and extensive in this community, as can be seen by the large number of recently fallen trees. Our current estimation of the cypress population is over 4000 individuals, but they seem to have an annual mortality rate of 3–4% (E. Ezcurra, personal communication). The California juniper, *Juniperus californica*, currently seems to be extinct on the island. Early records indicate that it grew in relatively extensive groves in the central portion of the island, but a mass die-off occurred in the early part of the last century (Moran 1996).

In the central part of the island, there is another plateau that gradually descends from 800 m southward to 600 m. At present, this sector is occupied by a herbland composed mainly of exotic weeds such as *Centaurea melitensis*, *Hordeum murinum*, *Polypogon monspeliensis*, *Avena* spp., *Bromus* spp., *Mesembryanthemum* spp., *Sisymbrium orientale*, and *Chenopodium murale*, among others. During our terrestrial survey, we identified several native species in this community such as *Perityle emoryi*, *Calystegia macrostegia*, *Sphaeralcea palmeri*, *Cryptantha* spp., *Filago* spp., *Amblyopappus pusillus*, *Lasthenia californica*, *Gilia nevinii*, and *Harpagonella palmeri*, which were either locally abundant or uncommon and sparsely distribut-

ed. A prairie-type community may have originally occupied this habitat with native species of grasses interspersed with springs and pools. The arroyos in this region might have contained various shrubby species and other plants associated with more mesic soils such as *Cammisonia*, *Ribes*, *Ceanothus*, *Crossosoma*, and *Malosma*. The arroyos were definitely fed from the uplands of the island and augmented by fog drip in upland forests. When the majority of the cypress and juniper communities collapsed, this also reduced the supply of water in this region. The endemic, monotypic genus *Hesperalea palmeri* (Oleaceae) was found in this area of the island. It was reported to have a tree habit up to 8 m in height; however, it is now extinct (Moran 1996).

The southern portion of the island is dominated by one large mountain, *El Picacho*, but southward, there is a series of lower hills cut by small valleys, washes, and canyons. Except for the 975 m *El Picacho*, the elevation in this area is below 600 m. However, on the island's southeast and southwest shores steep coastal cliffs rise dramatically. A type of maritime, desert-like scrub probably dominated the landscape in this sector. Currently, in some small valleys and on a few ridges, the landscape still harbors some of the native vegetation like *Ambrosia camphorata*, *Atriplex barclayana*, *Lycium californicum*, and *Cylindropuntia prolifera*.

At the southern end of the island there exists another extensive mesa with surrounding hill terrain. This vegetation type is characterized by succulent, perennial herbs such as *Cistanthe guadalupensis*, *Stephanomeria guadalupensis*, *Baeriopsis guadalupensis* (an endemic, monotypic genus), plus *Coreopsis gigantea* and *Dudleya guadalupensis*. Other plant species in this community include *Hemizonia greeneana*, *H. palmeri*, and *Perityle incana*. This portion of Guadalupe undoubtedly has the greatest potential for success with respect to spontaneous and man-induced revegetation efforts, since many of the plant species that we presume to have occurred naturally here are still extant on the adjacent pristine islets, which have never been affected by goats.

On the very steep rocky cliffs and slopes that occupy a relatively high proportion of the island's surface area, there is a rather depauperate vegetation due to the lack of soil and the instability of the substrate. However, due to their inaccessible nature most of the cliffs are botanically unexplored, so it is possible that various species of the native flora still remain in these safe havens, protected against the goats and not yet discovered. The coastal belt of the island has many sheer cliffs as well and is botanically also poorly known.

Prospects for restoration

Even though a few initial plans to protect the botanical resources of the island have been developed and implemented by the Mexican government, e.g., reforestation, exclusion of areas, and harvesting of goats, none of these actions has reversed the progressive desertification and extinction processes on Guadalupe Island. Although theoretically, by Mexican law the island has been a protected area since 1928, no real actions have effectively addressed the major problems for the plants, which

center on grazing by goats and soil erosion. Nevertheless, even if all of the goats are removed from the island, the question that will remain is whether the native plant species and their fragmented populations will be able to recolonize spontaneously into their respective habitats.

It is easy to assume that many of the native species will have the ability to expand their ranges from remaining relictual populations on the island, such as in cliff safe havens, or that various species will disperse seeds northward a few hundred meters across the ocean from the southern islets. However, many of these plant species will have a daunting task to become reestablished in the island's niches, because now they will have to compete with some aggressive, exotic weeds that have been introduced in their absence. Another alternative for reintroduction to the island is to import genotypes for missing, but native plant taxa from other areas such as other islands of Baja California and California or from the mainland. But this endeavor will require more of an investment in economic and manpower resources. This last alternative is probably the most applicable to the 21 non-endemic, but native plant taxa, which are now extinct on the island.

It is convenient to say that the elephant seal *(Mirounga angustirostris)* and the Guadalupe fur seal *(Arctocephalus townsendi)*, two conservation icons for the island, were at the edge of extinction at the turn of the 20th century, but a protective law allowed the recovery of both species from tens of individuals (Berdegué 1957). However, the question of the genetic diversity or lack thereof in the current populations of thousands of animals in these two species is still a matter of discussion and debate.

Theoretical models of species recovery in many impacted communities are pessimistic, since traditional data shows that as the amount of habitat declines in a landscape, the probability of long-term survival for many species first declines slowly and then faster (Kurki et al. 2000). As a result, some species may go extinct even if there is quite a bit of natural habitat left. With regard to species survival, the main questions are: how much habitat is enough to ensure recovery for a group of native plant species; is it possible to consider thresholds regarding habitat loss; and how do these concepts vary among life forms and in different types of environments?

The recovery of biodiversity not only relates to increasing the number of species in a region, but it also includes habitats, genes, and an array of different processes across a range of spatial and population scales (patches, stands, and landscapes). How much of the biodiversity has been lost forever from the Guadalupe Archipelago due the feral goats? There is no way to answer this question yet, but we would have a better understanding of the details of this question in a few years if we addressed the primary detriment to the natural resources of the island by taking the first step: feral goat extirpation.

Conclusions

Based upon the results of feral sheep eradication on some of the California Channel

islands (Wehtje 1994), some botanists and ecologists are optimistic about the recovery of the native flora on these islands in a rather short time span. However, the first condition to promote this floristic recovery on island habitats is the removal of the feral animals in order to alleviate continuing impacts. The current problem, with respect to Guadalupe Island and goat eradication, seems to be the will of some of the Mexican agencies who have authority on the island: SEMARNAT (Environmental and Natural Resources Secretariat), the Navy, and the Interior Secretariat. Some of these agencies have even considered the goats as a positive consequence. They regard the island's goat population as a valuable resource with unique germplasm (the distinctiveness of a goat race adapted to harsh conditions), which may be exportable and usable for human populations that need food alternatives. However, this argument is not really supported by logic. The value of this new 'line' (germplasm) of goats is not comparable with the unique nature of the native and endemic plants of Guadalupe Island.

The tree species of Guadalupe, particularly the pines, oaks, and cypresses, may well be headed towards imminent extinction on this island. These species, which have historically made up the forested communities on the island, depend upon well-developed soils that are now practically absent due to erosion. To ensure the survival of these species, and some other plants from the island, a special conservation plan addressing seed storage should be developed, until suitable environmental conditions can guarantee their reestablishment.

All of the island's endemic species have an innate scientific and spiritual value. Some of the plants, like the pine and cypress species, are especially valuable to the timber industry. For example, *Pinus radiata* is a rather fast growing pine species that is an economically important plant in many southern hemisphere plantations. Other Guadalupe plants such as *Brahea edulis* and *Cistanthe guadalupensis* are valuable to horticulturists and these are practically at the edge of extinction.

Guadalupe Island with its unique flora is an international botanical treasure that urgently needs effective conservation protection.

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Appendix 1

List of the Guadalupe archipelago endemic plant taxa.

Conifers
Cupressus guadalupensis S. Wats. var. *guadalupensis*, Cupressaceae
Pinus radiata D. Don. var. *binata* (Engelm.) Lemon, Pinaceae
Angiosperms: dicots
Baeriopsis guadalupensis J.T. Howell, Asteraceae
Deinandra frutescens (A. Gray) B.G. Baldwin, Asteraceae
Deinandra greeneana (Rose) B.G. Baldwin ssp. *greeneana*, Asteraceae
Deinandra palmeri (Rose) B.G. Baldwin, Asteraceae
Perityle incana A. Gray, Asteraceae
Senecio palmeri A. Gray, Asteraceae
Stephanomeria guadalupensis Brandegee, Asteraceae
Cryptantha foliosa (Greene) Greene, Boraginaceae
Erysimum moranii Rollins, Brassicaceae
Githopsis diffusa A. Gray var. *guadalupensis* Morin, Campanulaceae
Dudleya guadalupensis Moran, Crassulaceae
Dudleya virens (Rose) *Moran* var. *extima* Moran, Crassulaceae
Marah guadalupensis (S. Watson) Greene, Cucurbitaceae
Lupinus niveus S. Wats., Fabaceae
Phacelia phyllomanica A. Gray, Hydrophyllaceae
Pogogyne tenuiflora A. Gray, Lamiaceae[a]
Satureja palmeri (A. Gray) Briq., Lamiaceae[a]
Lavatera lindsayi Moran, Malvaceae
Sphaeralcea palmeri Rose, Malvaceae
Sphaeralcea sulphurea S. Wats., Malvaceae
Hesperelaea palmeri A. Gray, Oleaceae[a]
Camissonia guadalupensis (S. Wats.) Raven var. *guadalupensis*, Onagraceae
Eschscholzia elegans Greene, Papaveraceae
Eschscholzia palmeri Rose, Papaveraceae
Eriogonum zapatoense Moran, Polygonaceae
Cistanthe guadalupensis (Dudley) Carolin in Hershkovitz, Portulacaceae
Heteromeles arbutifolia (Lind.) M. Roem var. *macrocarpa* (Munz) Munz, Rosaceae[b]
Galium angulosum A. Gray, Rubiaceae
Castilleja fruticosa Moran, Scrophulariaceae
Castilleja guadalupensis Brandegee, Scrophulariaceae[a]
Planta sp. Familia ignota[a,b]
Angiosperms: monocots
Brahea edulis H. Wendl., Arecaceae
Triteleia guadalupensis L. W. Lenz, Themidaceae

[a] Extinct; [b] presumably endemic, according to Moran (1996).

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