Ten years after feral goat eradication: the active restoration of plant communities on Guadalupe Island, Mexico

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Abstract As the first step towards the ecological restoration of its islands, Mexico has completed 60 eradications of invasive mammals thanks to a strong partnership between *Grupo de Ecología y Conservación de Islas, A.C.* (GECI), the federal government, local fishing communities, academia, and private donors. The removal of invasive mammals has led to the dramatic recovery of the islands' ecosystems. On Guadalupe Island, after completing the goat eradication in 2007, the native vegetation started to recover. Plants considered extinct or extirpated have been rediscovered, and plant species new to the island have been recorded. However, in order to achieve the island's full recovery, the active restoration of degraded soils and vegetation are needed. To date, GECI, in collaboration with the National Forestry Commission (CONAFOR) and the National Commission for Natural Protected Areas (CONANP), is implementing a 700 ha project to accelerate the restoration of the native vegetation communities. The project involves reforestation, erosion control, and fire prevention actions on different plant communities: forests and sage scrub. An on-site nursery has been established, seedlings—mostly from endemic trees—are being grown, and on-site reforestation planting has started. Up to June 2018, we have planted almost 40,000 trees, and will produce 160,000 seedlings during this year. Mechanical methods to control and prevent erosion have been used as we have installed more than 2,400 m of contour barriers, 57 m^3 of dams, and rehabilitated firebreaks. The actions will continue: the long-term goal being the comprehensive restoration of the vegetation communities devastated by feral goats. The Guadalupe Island experience will be useful to inform the restoration of other Mexican islands.

Keywords: erosion control, Guadalupe cypress, Guadalupe pine, reforestation, vegetation recovery

INTRODUCTION

Islands support a disproportionate amount of biodiversity in relation to their area (Myers, et al., 2000), but also are vulnerable ecosystems, highly susceptible to any alteration to their fragile equilibria (Holdgate, 1967; Simberloff, 1995; Whittaker & Fernández-Palacios, 2007). The trophic webs of oceanic islands have been described as "very simplified, with little ecological or taxonomical redundancy" (Courchamp, et al., 2003). This is one of the reasons why invasive alien species are considered one of the biggest threats to insular ecosystems and the main cause of insular biodiversity loss, as well as the alteration of ecosystem functions (Reaser, et al., 2007; Veitch, et al., 2011). Native insular species normally lack evolutionary defences, having traits that evolved in the absence of regular immigrants, and in consequence they fail to adapt to new threats posed by invasive species (Brook, et al., 2008; Berglund, et al., 2009). In contrast, invasive species have attributes that facilitate their establishment in novel environments due to their broad ecological niche (generalists) and high degree of behavioural flexibility. Consequently, they normally thrive when introduced to new environments (Mack, et al., 2000; Courchamp, et al., 2003; Sol, 2007). Among invasive mammals, feral goats (*Capra hircus*) are one of the most destructive species. Their effects include overgrazing, soil compaction, and tree and shrub damage through browsing (Coblentz, 1978; Parkes, et al., 1996; Campbell & Donlan, 2005; Chynoweth, et al., 2013).

Guadalupe Island is a priority site in terms of biodiversity conservation. It is a Biosphere Reserve, as well as an Important Bird Area (IBA; Vidal, et al., 2009) and an Alliance for Zero Extinction site (AZE, 2010). In addition, it is categorised as a Marine Priority Conservation Area by the Commission for Environmental Cooperation of North America (Morgan, et al., 2005), and it is included in the Southern Californian Pacific Marine Ecoregion (Wilkinson, et al., 2009). Unfortunately, invasive mammals – including feral goats – were introduced in the 19th century with devastating consequences for the island's flora and fauna. Goats depleted entire vegetation communities. Moran (1996) stated that "…it is most important before plants are lost, to remove all goats from the island, reversing the process of degradation and encouraging in every way the renewal of the natural vegetation. Even at best, some rare plants may die out unless propagated and replanted...". Other authors agreed, claiming that conservation actions for the island must begin by removing the feral goats and be followed with a plan of active restoration (León de la Luz, et al., 2003, Aguirre-Muñoz, et al., 2005). Also, for the Mexican Government there was an understanding that urgent restoration actions were needed. As a result, in terms of ecological restoration, much has been done during the past decade to tackle the threats posed to Guadalupe's biodiversity, particularly those from introduced species (Aguirre-Muñoz, et al., 2011; Luna-Mendoza, et al., 2007). Therefore, a long-term restoration and conservation programme has been developed for the island, aimed at removing invasive mammals to protect Guadalupe's native flora and fauna – especially seabirds – and preventing more extinctions. The successful eradication of goats, in a collaboration between GECI, federal government agencies and private donors, was the beginning of the island's recovery. The next phase is to do active restoration, mostly through reforestation of several vegetation communities.

SITE DESCRIPTION

Guadalupe Island is a 242 km^2 remote oceanic island located in the Pacific Ocean, 260 km off the Baja California peninsula, Mexico (29° N, 118° 20'W). It represents Mexico's last frontier on its western and northern margins; a unique territory in many ways, particularly in terms of biodiversity, a "naturalists' paradise" in the words of Dr Edward Palmer after his 1875 visit to Guadalupe (Huey, 1925).

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Guadalupe is a 5.8 km high seamount that emerges from a depth of 4.5 km, with a maximum elevation of 1.3 km above sea level (Delgado-Argote, et al., 1993). It comprises a main island, three islets and several offshore rocks. Guadalupe was discovered in 1602 by Spanish explorer Juan Sebastían Vizcaíno (León Portilla, 1989). Yet, it remained pristine and uninhabited until the beginning of the 19th century when Russian, English and American fur hunters visited the island in search of fur seals, sea otters and elephant seals (Hanna, 1925; Huey, 1925).

Guadalupe is a protected area decreed as a Biosphere Reserve by the Mexican government in 2005. The Reserve is managed by the National Commission of Natural Protected Areas (CONANP), and is safeguarded by the Ministry of the Navy, which has been watching over this important territory since the early 1900s. Besides the Navy base on the southern tip of the island, there are two more settlements: a settlement of the *Abuloneros y Langosteros* fishing cooperative on the west coast, and a biological field station of the Mexican NGO *Grupo de Ecología y Conservación de Islas, A.C.* (GECI, for its Spanish acronym) at about 1,200 m above sea level on the north-west portion of the island. Also, CONANP personnel are present permanently on site. A total of 100 people inhabit Guadalupe (CONANP, 2013). The only economic activity on the island is commercial fishing, carried out solely by the fishing cooperative to sustainably harvest valuable marine resources such as abalone (*Haliotis* spp.) and lobster (*Panulirus interruptus*) (Searcy-Bernal, et al., 2010; Méndez-Sánchez, 2012).

Climate

Guadalupe has a Mediterranean climate, characterised by hot, dry summers and cool, wet winters (Camps & Ramos, 2012; Granda, et al., 2014). Temperature is relatively stable throughout the year, with a mean of 17.2 ± 2 ºC. Relative humidity oscillates between 69 ± 8% to 82 ± 5% without a well-defined seasonal pattern (Castro, et al., 2005) and average annual cumulative precipitation is 193 ± 119 mm (CONAGUA-SARH Delgadillo in Moran, 1996; SARH-Colegio de Postgraduados, 2010). However, given the islands' complex topography, some microclimates are also recognised. The south end of Guadalupe is drier compared to the rest of the island, and the humidity increases northwards with elevation, mostly due to the fog influence. There are some records of ice and snow in winter, restricted to the cypress forest at the higher elevations (Moran, 1996; N. Silva-Estudillo, pers. comm.). It is also likely that rainfall is relatively more abundant at higher elevations (Moran, 1996). Guadalupe Island's local climate can also be influenced by regional climatic conditions. Occasional tropical storms from the south bring heavy rainfall to the island between summer and autumn (August to October) (Moran, 1996). In addition, the normal precipitation pattern can be disrupted by irregular El Niño or La Niña events, associated with supra- and subnormal precipitation, respectively, between December and March (winter and spring) (Minnich, et al., 2009). This oceanic island is heavily influenced by the California Current, which generates a peculiar pattern of wind, fog, and rainfall (León de la Luz, et al., 2003; Garcillán, et al., 2012). Winds prevail from the north-west, while the island's climate is influenced by a near-permanent fog system which allows the presence of forests on the island despite the low precipitation.

Flora

In a classification of Mexican Biogeographic Provinces, Guadalupe Island is considered as a separate province (i.e. Guadalupe Island province) within the Baja California Province, which is part of the Nearctic Region (Morrone, et al., 2002). This classification is based on distributional patterns of plants, invertebrates and birds (Morrone, et al., 1999). Floristically, it is very similar to the Channel Islands, USA (Raven, 1965). Originally, the island was home to a rich flora that included several insular and Guadalupe endemics. In total, 225 vascular plant species have been recorded on the island, 7% insular endemic (shared with other islands of the region) and 12% endemic to Guadalupe (Junak, et al., 2005; Rebman, et al., 2005; GECI, unpublished data). In addition, 36 non-vascular plants have been recorded for the site (Crum & Miller, 1956; Crum, 1972 in Moran, 1996) as well as 104 lichen species (Weber, 1994 in Moran, 1996).

Several original vegetation communities have been described, based on historic records (Moran, 1996;León de la Luz, et al., 2005; Oberbauer, 2005). The communities include forests, woodlands, chaparral (shrubs), native grassland and communities dominated by low shrubs. Some of the representative species of these vegetation communities are the endemic Guadalupe cypress (*Cupressus guadalupensis*), Monterey pine (*Pinus radiata* var. *binata*) and Guadalupe palm (*Brahea edulis*). Several native species such as the juniper (*Juniperus californica* - now restricted to <10 individuals), and the shrubs island redberry (*Rhamnus pirifolia*), and laurel sumac (*Malosma laurina*) were also characteristic of some communities, along with endemic succulents such as cistanthe (*Cistanthe guadalupensis*) and liveforever (*Dudleya guadalupensis*), the endemic Guadalupe senecio (*Senecio pameri*); and three endemic species of shrubby tarweeds (*Deinandra* spp.). Some insular endemics were also representative of these environments, such as the island hazardia (*Hazardia cana*; only present on San Clemente Island, USA and Guadalupe) and the insular oak (*Quercus tomentella*; only present on five of the Channel Islands, USA and Guadalupe).

INTRODUCTION OF INVASIVE MAMMALS

Guadalupe Island remained pristine and uninhabited until the beginning of the 19th century when fur hunters arrived (Hanna, 1925; Huey, 1925). It is likely that house mice (*Mus musculus*) and feral cats (*Felis catus*) were introduced following these first human settlements (Hanna, 1925; Huey, 1925; Moran, 1996). Both species were introduced around 1880, rapidly establishing feral populations (Moran, 1996). In addition, whalers, in order to have a source of fresh meat during their voyages, introduced goats (Moran, 1996). Together, goats and cats have been responsible for the extinction and extirpation of many native and endemic species (e.g. Jehl Jr & Everett, 1985; León de la Luz, et al., 2003), and the impacts of house mice remain to be evaluated. In addition, feral dogs (*Canis familiaris*) also established a population on the island (Moran, 1996). Other mammals, such as cows *(Bos taurus*), were also introduced but never established feral populations (Aguirre-Muñoz, et al., 2011; J. Rico-Cerda pers. comm.).

Effects of feral goats on native flora

After goats were introduced, only one of the original vegetation communities, comprising low shrubs present on islets where goats or mice never were introduced, remained pristine. The other plant communities either disappeared, became restricted to a very patchy distribution, or were represented only by isolated individual plants. At least 26 plant taxa became extinct or were extirpated due to feral goats (Moran, 1996; León de la Luz, et al., 2003; Oberbauer, 2005; GECI, unpublished data). Not only were entire vegetation communities depleted, and many endemic species lost, but also many non-native species have been introduced. Since 1875, at least 69 plant species have been introduced to the island, mostly European grasses and forbs (Junak, et al., 2005; Rebman, et al., 2005; GECI, unpublished data). The heavy modification of the

ecosystem caused by the feral goats, in combination with the arrival of invasive plants, resulted in a vast extension of bare ground and vegetation dominated by European grasses (grassland community), such as slender wild oat (*Avena barbata*) and red brome (*Bromus rubens*).

CURRENT RESTORATION AND CONSERVATION ACTIONS

Ecosystem resilience – passive restoration

On Guadalupe Island, after completing the goat eradication in 2007, native vegetation started to naturally recover. Plants considered extinct or extirpated have been rediscovered and there have been new plant records for the island, including at least one undescribed species. A survey conducted in 2001 on the endemic variety of the Monterey pine—there are five endemic varieties: three in the USA and two in Mexico, all the original seed source for plantations around the world—estimated that there were only 220 adult pines left (Rogers, et al., 2006). Since the goats were eradicated, the number of new seedlings has increased to several thousands (Fig. 1). Not only have the trees have recovered, but shrubs are also returning with full strength, competing well with invasive grasses. *Ceanothus arboreus*, a shrub able to reach 6 or 7 m and a new record for the island (Junak, et al., 2005), is now very common around the cypress and pine-oak forests. Also, the maritime desert scrub in the area most impacted by the goats' presence has changed from almost 0% native vegetation coverage (areas dominated by European grasses) to 52% (Ceceña-Sánchez, 2014).

Active restoration of plant communities

In a review of passive vs active restoration effects on forest recovery, Meli, et al. (2017) suggest observing the system for a few years after intervention to inform better decisions regarding active restoration actions. In the case of Guadalupe Island, feral goat eradication was completed in 2007. The active restoration project started in 2015. Over a period of almost 10 years we documented and measured the recovery of species. Not all recovered at the same speed. Some trees, shrubs, and forbs are recovering at a fast pace. However, there are many species that still remain very fragile, given their low numbers (*Juniperus californica* < 10 known individuals; insular oak, *Quercus tomentella* < 50 adult trees; *Cistanthe guadalupensis*, almost absent from the main island and surviving only on islets), and there are others whose distribution has decreased historically from forests to small isolated patches (e.g. *Cupressus guadalupensis*).

In order to achieve the island's full recovery, the active restoration of vegetation and eroded and degraded soils was the next conservation step. The negative effects of overgrazing and soil compaction are exacerbated on a volcanic island where soil (even some of the most productive soil (Ugolini & Dahlgren, 2002)) is limited and very susceptible to loss due to erosion. A study focused on the cypress forest on Guadalupe Island concluded than the erosion rates were exceptionally high, with a minimum recorded loss of 44 ton/ha/year and the maximum 142 ton/ha/year (Ramos Franco, 2007). Although it was estimated only for the cypress forest, the erosion problem is evident across the whole island, especially at higher elevations. To date, GECI in collaboration with the National Forestry Commission (CONAFOR) and CONANP, and other partners, such as the Mexican Navy (SEMAR) and the local fishermen's cooperative *Abuloneros y Langosteros*, is implementing a 700 ha project to accelerate the recovery of native vegetation communities.

The project involves reforestation, erosion control, and fire prevention actions for different plant communities. Reforestation is being implemented over 583 ha: 33 ha of palm forest; 120 ha of pine-oak forest; 261 ha of cypress forest, 60 ha of juniper woodland and 109 ha of maritime desert scrub. Erosion control actions (17 ha) are focused only on the cypress forest, in an area with slopes of 27%, loss of around 75% of the superficial soil layer, and deep gullies (Ramos Franco 2007), which is considered as extreme degradation (CONAFOR, 2004). On the other hand, due to a fire which occurred in 2008 in the cypress forest, the quantity of accumulated fuel was alarming, around 110 t/ha on average, with a maximum of 1,000 t/ha in certain areas (Luna-Mendoza et al. 2016). For this reason, fire management actions were focused here. The goal is to carry out fuel reduction (through manual removal of surface fuels and increasing the height to live crown) in 100 ha and to restore 10 km of firebreaks.

An on-site nursery was built as part of the project (Fig. 2). The nursery (480 m^2) is surrounded by a mouse-proof, galvanised steel fence of 50 m × 30 m, as mice are responsible for the loss of huge amounts of seed and seedlings at early stages. Around 15 species of native and endemic species are being produced: Guadalupe pine, Guadalupe cypress, Guadalupe palm, insular oak, island hazardia, Guadalupe lupin (*Lupinus niveus*), Guadalupe phacelia (*Phacelia phyllomanica*), island malva (*Malva occidentalis*), Guadalupe rock daisy (*Perityle incana*), among others. Species produced were chosen based on their rarity on the island (e.g. *Leptosyne gigantea* and *Cistanthe guadalupensis*); endangerment (e.g. juniper); propagation material available; potential as nurse plant (e.g. *Sphaeralcea* spp.); importance as food or shelter for native invertebrates and landbirds (e.g. *Senecio palmeri*) and effectiveness at retaining soil (e.g. *Calystegia macrostegia* ssp. *macrostegia*). Their allocation was based on historic information of former vegetation communities as well as observations of where there has been natural recruitment.

Fig. 1 Recovery of Guadalupe pine (*Pinus radiata* var. *binata*) from 220 individuals (adult trees) to several thousands in ten years. Photo credits: GECI Archive/J.A. Soriano.

Fig. 2 Plant nursery on Guadalupe Island with the capacity to produce over 60,000 plants per year. Photo credits: GECI Archive/J.A. Soriano.

For example, goat removal allowed the recovery of the island *Ceanothus* from seed surviving in the seed bank. Now the species grows close to the cypress and pine-oak forests, but individuals are sparse. However, for this species, as seed is not capable of long distance dispersal by itself (Minnich, 1982), it can take a long time to recover its original coverage. Another species, the Guadalupe lupin, is spreading at a fast pace, but being a legume with big seed depends on rainfall to disperse seed downslope. On Guadalupe the dispersal pathways are limited, as seed-eating birds are few and native terrestrial mammals are absent. In the case of the endemic cistanthe, although the species is very common on the islets, on the main island only three individuals have been recorded in the last 10 years. This is one of the lost species of the maritime desert scrub, and a goal of this project is to reintroduce it to this vegetation community.

Up to June 2018, 90,000 plants have been produced in the nursery. The final goal is to produce 160,000 plants, mostly trees and shrubs. We have planted almost 40,000 plants, most of them trees. To date we have nearly completed reforestation of the pine-oak and cypress areas (Fig. 3). Some challenges have arisen: logistics linked to working on an island; lack of plant propagation information for some species (especially endemics); limited amount of seed (insular-endemic or Guadalupe-endemic species and very few individuals left); diseases; and limited amount of water (relying mostly on the fog). In the last rainy season there was virtually no rainfall and fog has been very intermittent and scarce. We are therefore using resources such as the commercial hydrophilic polymer based on polyacrylamide, called Lluvia sólida®. We add 1.5 to 2 l of this hydrated polymer to each plant. So far, results are encouraging, as survivorship of planted individuals is above 85%. Regarding soil restoration, mechanical methods to control and prevent erosion, such as check dams and contour barriers, have been implemented. More than 1,500 m of contour barriers of rocks and logs have been built as well as 66 m^3 of rock and log check dams. So far, 27 hectares have been cleared of fuel and 1,500 m^3 of material has been removed.

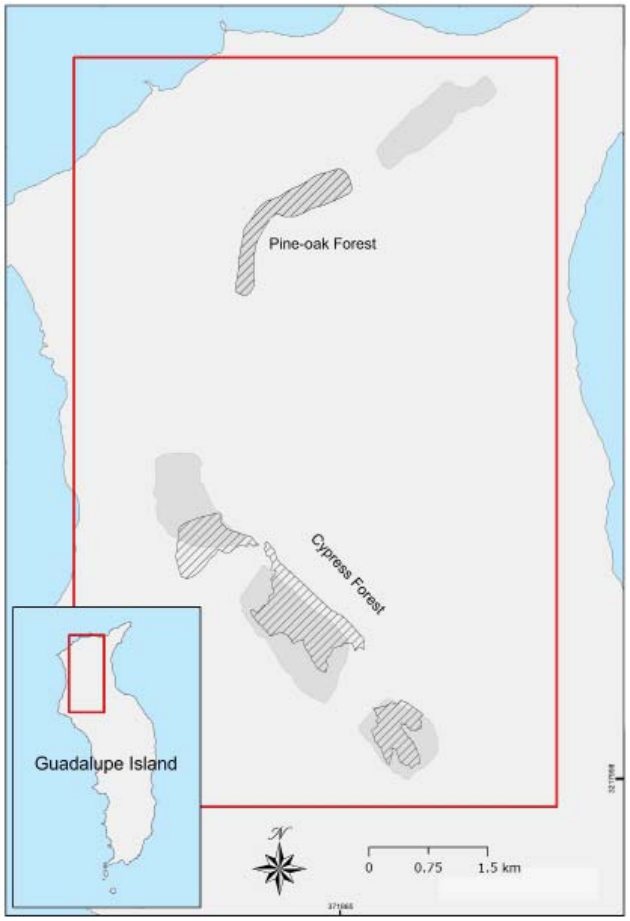

Fig. 3 Reforested areas on Guadalupe Island. The polygon in the north relates to pine-oak forest and the three polygons in the south are in the cypress forest area. Shaded (grey) areas are the original areas proposed in the project and striped areas are the ones completed (up to June 2018).

WHAT'S NEXT?

There still much to be done on Guadalupe Island. A period of 130 years of feral goats on the island caused severe ecosystem degradation. However, with collaborative projects, such as the one described here, we are heading in the right direction to restore the island's ecosystem services and biodiversity. Future projects, conducted in collaboration with CONANP, are to continue with fuel reduction actions in the cypress and pine-oak forests, to collect seed of endemic species to be stored at national seed banks and to estimate carbon sequestration in forest ecosystems. As a country, Mexico is now fully committed to the recovery of its islands, going a step further than eradication actions. On Socorro Island (Revillagigedo Archipelago; Pacific Ocean), feral sheep were removed a few years ago. This island is very similar to Guadalupe and faces the same challenges: soil degradation and a need to do some active restoration of the forest, not only for the vegetation itself but to restore the habitat for many endemic land birds which were close to extinction. In some cases we cannot wait for the islands to recover naturally, especially where other threats are still present (other invasive mammals). Currently other islands in Mexico, such as Espíritu Santo Island (Gulf of California), and María Cleofas Island (Las Marías Archipelago, Pacific Ocean), are being cleared of herbivores, and hopefully more active restoration actions could be established on these sites in the near future.

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REFERENCES

Aguirre-Muñoz, A., Samaniego-Herrera, A., García-Gutiérrez, C., Luna-Mendoza, L., Rodríguez-Malagón, M. and Casillas-Figueroa, F. (2005). 'El Control y la Erradicación de Fauna Introducida Como Instrumento de Restauración Ambiental: Historia, Retos y Avances en México'. In: O. Sánchez, E. Peters Recagno, R. Márquez-Huitzil, E. Vega, G. Portales, M. Valdés and D. Azuara (eds.) *Temas sobre Restauración Ecológica,* pp. 215–229. México, D.F.: Instituto Nacional de Ecología.

Aguirre-Muñoz, A., Samaniego-Herrera, A., Luna-Mendoza, L., Ortiz-Alcaraz, A., Rodríguez-Malagón, M., Méndez-Sánchez, F., Félix-Lizárraga, M., Hernández-Montoya, J.C., González-Gómez, R., Torres-García, F., Barredo-Barberena, J.M. and Latofski-Robles, M. (2011). 'Island restoration in Mexico: ecological outcomes after systematic eradications of invasive mammals'. In: C.R. Veitch, M.N. Clout and D.R. Towns (eds.) *Island invasives: eradication and management,* pp. 250–258. Occassional Paper SSC no. 42. Gland, Switzerland: IUCN and Auckland, New Zealand: CBB.

AZE. (2010). *2010 AZE Update*. Alliance for Zero Extinction. <www.zeroextinction.org>. Accessed 18 June 2017.

Berglund, H., Järemo, J. and Bengtsson, G. (2009). 'Endemism predicts intrinsic vulnerability to nonindigenous species on islands'. *The American Naturalist* 174**:** 94–101.

Brook, B.W., Sodhi, N.S. and Bradshaw, C.J.A. (2008). 'Synergies among extinction drivers under global change'. *Trends in Ecology and Evolution* 23**:** 453–460.

Campbell, K. and Donlan, C.J. (2005). 'Feral goat eradications on islands'. *Conservation Biology* 19**:** 1362–1374.

Camps, J. and Ramos, M. (2012). 'Grape harvest and yield responses to inter-annual changes in temperature and precipitation in an area of north-east Spain with a Mediterranean climate'. *International Journal of Biometeorology* 56**:** 853–864.

Castro, R., Mascarenhas, A., Sánchez-Barba, A., Durazo, R. and Gíl-Silva, E. (2005). 'Condiciones Meteorológicas en el sur de Isla Guadalupe'. In: E. Peters and K. Santos Del Prado (eds.) *Restauración y Conservación de la Isla Guadalupe,* pp. 27–37. México, D.F.: Instituto Nacional de Ecología.

Ceceña-Sánchez, M.L. (2014). 'Estudio Fitosociológico de las Comunidades Vegetales de los Matorrales de Isla Guadalupe, México'. MSc thesis. Ensenada: Universidad Autónoma de Baja California.

Chynoweth, M.W., Litton, C.M., Lepczyk, C.A., Hess, S.C. and Cordell, S. (2013). 'Biology and impacts of Pacific Island invasive species. 9. *Capra hircus*, the feral goat (Mammalia: Bovidae)'. *Pacific Science* 67: 141–156.

Coblentz, B.E. (1978). 'The effects of feral goats (*Capra hircus*) on island ecosystems'. *Biological Conservation* 13: 279–285.

CONAFOR. (2004). *Protección, Restauración y Conservación de Suelos Forestales. Manual de Obras Prácticas*. Jalisco, México: Comisión Nacional Forestal, Secretaría del Medio Ambiente y Recursos Naturales.

Courchamp, F., Chapuis, J.-L. and Pascal, M. (2003). 'Mammal invaders on islands: Impact, control and control impact'. *Biological Reviews* 78**:** 347–383.

Crum, H. and Miller, H.A. (1956). 'Bryophytes from Guadalupe Island, Baja California'. *The Southwestern Naturalist* 1**:** 116–120.

Delgado-Argote, L.A., García-Abdeslem, J. and Mendoza-Borunda, R. (1993). 'Correlación Geológica entre la Batimetría y los Rasgos Estructurales del Oriente de la Isla Guadalupe, México'. In: L.A. Delgado-Argote and A. Martín-Barajas (eds.) *Contribuciones a la Tectónica de México,* pp. 1–11. México: Monografía No. 1 de la Unión Geofísica Mexicana.

Garcillán, P.P., Vega, E. and Martorell, C. (2012). 'The *Brahea edulis* palm forest in Guadalupe Island: A North American fog oasis?' *Revista Chilena de Historia Natural* 85**:** 137–145.

Granda, E., Rossatto, D., Camarero, J.J., Voltas, J. and Valladares, F. (2014). 'Growth and carbon isotopes of Mediterranean trees reveal contrasting responses to increased carbon dioxide and drought'. *Oecologia* 174**:** 307–317.

Hanna, G.D. (1925). 'Expedition to Guadalupe Island, Mexico, in 1922'. *Proceedings of the California Academy of Sciences, Fourth Series* XIV**:** 217–275.

Holdgate, M.W. (1967). 'The influence of introduced species on the ecosystems of temperate oceanic islands'. In: C.E. Conrad and W.C. Oechel (eds.). *Towards a new Relationship of Man and Nature in Temperate Lands. Part III. Changes due to Introduced Species,* pp. 152–177. Lucerne: IUCN.

Huey, L.M. (1925). 'Guadalupe Island: An object lesson in man-caused devastation'. *Science* 61**:** 405–407.

Jehl Jr., J.R. and Everett, W.T. (1985). 'History and status of the avifauna of Isla Guadalupe, Mexico'. *Transactions of the San Diego Society of Natural History* 20**:** 313–336.

Junak, S.J., Keitt, B., Tershy, B., Croll, D., Luna-Mendoza, L. and Aguirre-Muñoz, A. (2005). 'Esfuerzos Recientes de Conservación y Apuntes sobre el Estado Actual de la Flora de Isla Guadalupe'. In: E. Peters and K. Santos del Prado (eds.) *Restauración y Conservación de la Isla Guadalupe,* pp. 83–93. México, D.F.: Instituto Nacional de Ecología.

León de La Luz, J.L., Rebman, J.P. and Oberbauer, T.A. (2003). 'On the urgency of conservation on Guadalupe Island, Mexico: Is it a lost paradise?' *Biodiversity and Conservation* 12**:** 1073–1082.

León de La Luz, J.L., Rebman, J.P. and Oberbauer, T.A. (2005). 'El Estado Actual de la Flora y la Vegetación de Isla Guadalupe'. In: E. Peters and K. Santos del Prado (eds.) *Restauración y Conservación de la Isla Guadalupe,* pp. 55–65. México, D.F.: Instituto Nacional de Ecología.

León Portilla, M. (1989). *Cartografía y Crónicas de la Antigua California.* México, D.F.: Universidad Nacional Autónoma de México.

Luna-Mendoza, L., Keitt, B. and Junak, S. (2007). 'The restoration of Guadalupe Island revisited'. *Fremontia* 35**:** 14–17.

Luna-Mendoza, L., Aguirre-Muñoz, A., Méndez-Sánchez, F., Vargas-Hernández, J.J., Rodríguez-Chávez, O.G., Martínez-Rodríguez, J.M., Cosio-Muriel, D., Gómez-Reyes, J., Puebla-Hernández O. y Luvianos-Colin, S. (2016). *Restauración Integral del Ecosistema del Bosque de Ciprés de la RB Isla Guadalupe. Reporte final*. Ejercicio PROCER 2016. GECI-COLPOS-CIPACTLI. Report for the Comisión Nacional de Áreas Naturales Protegidas-Reserva de la Biosfera Isla Guadalupe.

Mack, R.N., Simberloff, D., Lonsdale, W.M., Evans, H., Clout, M.N. and Bazzaz, F.A. (2000). 'Biotic invasions: Causes, epidemiology, global consequences, and control'. *Ecological Applications* 10**:** 689–710.

Meli, P., Holl, K.D., Benayas, J.M.R., Jones, H.P., Jones, P.C., Montoya, D. and Mateos, D.M. (2017). 'A global review of past land use, climate, and active vs passive restoration effects on forest recovery'. *PLOS ONE* 12: e0171368.

Méndez-Sánchez, F.A. (2012). 'Co-management and Small-scale Fisheries in Mexico: The Case of a Fishers' Cooperative in Cedros and San Benito islands'. MSc thesis. Auckland, NZ: University of Auckland.

Minnich, R. A. (1982). 'Grazing, Fire and the Management of Vegetation of Santa Catalina Island, California'. In: C.E. Conrad and W.C. Oechel (eds.). *Proceedings of the Symposium on Dynamics and Management of Mediterranean-type Ecosystems,* pp. 444–449. Berkeley, CA: USDA, Forest Service, Pacific Southwest Forest and Range Experiment Station, General Technical Report PSW-58.

Minnich, R.A., Franco Vizcaino, E. and Dezzani, R.J. (2009). 'The El Niño/Southern Oscillation and precipitation variability in Baja California, Mexico'. *Atmósfera* 13**:** 1–20.

Moran, R. (1996). *The Flora of Guadalupe Island, Mexico,* San Francisco, USA: California Academy of Sciences.

Morgan, L., Maxwell, S., Tsao, F., Wilkinson, T.A.C. and Etnoyer, P. (2005). *Marine Priority Conservation Areas: Baja California to the Bering Sea*. Montreal, Canada: Commission for Environmental Cooperation of North America and the Marine Conservation Biology Institute.

Morrone, J.J., Organista, D.E., Zúñiga, C.A. and Bousquets, J.L. (1999). 'Preliminary classification of the Mexican biogeographic provinces: A parsimony analysis of endemicity based on plant, insect, and bird taxa'. *The Southwestern Naturalist* 44**:** 507–514.

Morrone, J.J., Espinosa-Organista, D. and Llorente-Bousquets, J. (2002). 'Mexican biogeographic provinces: Preliminary scheme, general characterizations, and synonymies'. *Acta Zoológica Mexicana* 85**:** 83–108.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A. and Kent, J. (2000). 'Biodiversity hotspots for conservation priorities'. *Nature* 403: 853–858.

Oberbauer, T.A. (2005). 'La Vegetación de Isla Guadalupe: Entonces y Ahora'. In: E. Peters and K. Santos del Prado (eds.). *Restauración y Conservación de la Isla Guadalupe,* pp. 39–53. México, D.F.: Instituto Nacional de Ecología.

Parkes, J., Henzell, R. and Pickles, G. (1996). *Managing Vertebrate Pests: Feral Goats*. Canberra: Australian Government Publishing Service.

Ramos Franco, C.A. (2007). 'Propuesta de Manejo de la Erosión Hídrica para la Restauración de Suelo del Bosque de Ciprés de Isla Guadalupe.' MSc thesis. Ensenada: Universidad Autónoma de Baja California.

Raven, P.H. (1965). 'The Floristics of the California Islands'. In*:* R.N. Philbrick (ed.) *1st Symposium on the Biology of the California Islands*, pp. 57–71. Santa Barbara, California: Santa Barbara Botanic Garden.

Reaser, J.K., Meyerson, L.A., Cronk, Q., De Poorter, M., Eldrege, L.G., Green, E., Kairo, M., Latasi, P., Mack, R.N., Mauremootoo, J., O'Dowd, D., Orapa, W., Sastroutomo, S., Saunders, A., Shine, C., Thrainsson, S. and Vaiutu, L. (2007). 'Ecological and socioeconomic impacts of invasive alien species in island ecosystems'. *Environmental Conservation* 34**:** 98–111.

Rebman, J.P., Oberbauer, T.A. and León de La Luz, J.L. (2005). 'La Flora de Isla Guadalupe y sus Islotes Adyacentes'. In: E. Peters and K. Santos del Prado (eds.) *Restauración y Conservación de la Isla Guadalupe,* pp. 67–81. México, D.F.: Instituto Nacional de Ecología.

Rogers, D.L., Matheson, A.C., Vargas-Hernández, J.J. and Guerra-Santos, J.J. (2006). 'Genetic conservation of insular populations of Monterey pine (*Pinus radiata* D. Don)'. *Biodiversity and Conservation* 15**:** 779–798.

SARH-Colegio de Postgraduados. (2010). *Normales Climatológicas 1951–2010*. <http://www.cm.colpos.mx/meteoro/progde/norm/norm24/listd.htm>. Accessed 28 November 2012.

Searcy-Bernal, R., Ramade-Villanueva, M.R. and Altamira, B. (2010). 'Current status of abalone fisheries and culture in Mexico'. *Journal of Shellfish Research* 29**:** 573–576.

Simberloff, D. (1995). 'Why do introduced species appear to devastate islands more than mainland areas?' *Pacific Science* 49**:** 87–97.

Sol, D. (2007). 'Do Successful Invaders Exist? Pre-Adaptations to Novel Environments in Terrestrial Vertebrates'. In: W. Nentwig (ed.) *Biological Invasions,* pp. 127–141. Berlin, Heidelberg: Springer.

Ugolini, F.C. and Dahlgren, R.A., (2002). 'Soil development in volcanic ash'. *Global Environmental Research–English Edition* 6: 69–82.

Veitch, C.R., Clout, M.N. and Towns, D.R. (eds.) (2011). '*Island invasives: eradication and management'.* Occassional Paper SSC no. 42. Gland, Switzerland: IUCN and Auckland, New Zealand: CBB.

Vidal, R.M., Berlanga, H. and del Coro Arizmendi, M. (2009). 'Important Bird Areas: Mexico'. In: C. Devenish, D.F. Díaz Fernández, R.P. Clay, I. Davidson and I. Yépez Zabala (eds.) *Important Bird Areas Americas - Priority Sites for Biodiversity Conservation.* Quito: BirdLife International (BirdLife Conservation Series No. 16).

Whittaker, R.J. and Fernández-Palacios, J.M. (2007). *Island Biogeography: Ecology, Evolution, and Conservation.* New York: Oxford University Press.

Wilkinson, T., Wiken, E., Bezaury-Creel, J., Hourigan, T., Agardy, T., Herrmann, H., Janishevski, L., Madden, C., Morgan, L. and Padilla, M. (2009). *Marine Ecoregions of North* America*.* Montreal: Commission for Environmental Cooperation.