Fachhochschule Köln
Cologne University of Applied Sciences

UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

FACULTADES DE CIENCIAS QUÍMICAS, INGENIERÍA Y MEDICINA

PROGRAMAS MULTIDISCIPLINARIOS DE POSGRADO EN CIENCIAS AMBIENTALES

AND

COLOGNE UNIVERSITY OF APPLIED SCIENCES

INSTITUTE FOR TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

"RESTORATION PRIORITIES FOR MEXICAN ISLANDS"

THESIS TO OBTAIN THE DEGREE OF

MAESTRÍA EN CIENCIAS AMBIENTALES

DEGREE AWARDED BY

UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

AND

MASTER OF SCIENCE

"TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

FOCUS AREA "ENVIRONMENTAL AND RESOURCES MANAGEMENT"

DEGREE AWARDED BY COLOGNE UNIVERSITY OF APPLIED SCIENCES

PRESENTS:

MARIAM LATOFSKI ROBLES

CO-DIRECTOR OF THESIS PMPCA

DR. HUMBERTO REYES HERNÁNDEZ

CO-DIRECTOR OF THESIS ITT:

DR. SABINE SCHLÜTER

ASSESSOR:

DR. ALFONSO AGUIRRE MUÑOZ

SAN LUIS POTOSÍ, MÉXICO JULY, 2012

PROYECTO REALIZADO EN:

GRUPO DE ECOLOGÍA Y CONSERVACIÓN DE ISLAS, A.C.

ENSENADA, BAJA CALIFORNIA, MÉXICO.

CON EL APOYO DE:

DEUTSCHER AKADEMISCHER AUSTAUSCH DIENST (DAAD)

CONSEJO NACIONAL DE CIENCIA Y TECNOLOGÍA (CONACYT)

LA MAESTRÍA EN CIENCIAS AMBIENTALES RECIBE APOYO A TRAVÉS DEL PROGRAMA NACIONAL DE POSGRADOS (PNPC - CONACYT)

Erklärung / *Declaración*

Name / *Nombre*: Mariam Latofski Robles

Matri.-Nr. / *N° de matricula*: 11081433 **(CUAS).,** 191557 **(UASLP)**

Ich versichere wahrheitsgemäß, dass ich die vorliegende Masterarbeit selbstständig verfasst und keine anderen als die von mir angegebenen Quellen und Hilfsmittel benutzt habe. Alle Stellen, die wörtlich oder sinngemäß aus veröffentlichten und nicht veröffentlichten Schriften entnommen sind, sind als solche kenntlich gemacht.

Aseguro que yo redacté la presente tesis de maestría independientemente y no use referencias ni medios auxiliares a parte de los indicados. Todas las partes, que están referidas a escritos o a textos publicados o no publicados son reconocidas como tales.

Die Arbeit ist in gleicher oder ähnlicher Form noch nicht als Prüfungsarbeit eingereicht worden.

Hasta la fecha, un trabajo como éste o similar no ha sido entregado como trabajo de tesis.

San Luis Potosí, den /*el* 01.07.2012

Unterschrift / *Firma*: ____________

Ich erkläre mich mit einer späteren Veröffentlichung meiner Masterarbeit sowohl auszugsweise, als auch Gesamtwerk in der Institutsreihe oder zu Darstellungszwecken im Rahmen der Öffentlichkeitsarbeit des Institutes einverstanden.

Estoy de acuerdo con una publicación posterior de mi tesis de maestría en forma completa o parcial por las instituciones con la intención de exponerlos en el contexto del trabajo investigación de las mismas.

Unterschrift / *Firma*: _____________

Dedicatoria

A Fernando, mi esposo porque siempre he contado con tu apoyo, ayuda, comprensión, consejos, distracciones, ánimo, amor y muchas cosas más que han hecho posible que haya logrado una de mis metas de vida. Gracias por ser mi compañero de viaje en toda esta gran experiencia y haberla hecho tan divertida, y sobre todo por nuestra próxima gran aventura de ser padres a este bebe que ya viene en camino. A ti, mi adorado bebe que viviste conmigo la última etapa también te dedico este logro y esfuerzo.

A mis papas, Pepe y Piki porque también siempre he contado con su apoyo incondicional y me han enseñado que uno puede lograr todas las metas que se propone en la vida, especialmente cuando te gusta lo que haces. Son un ejemplo a seguir para mí y espero hacerlos orgullosos.

A mi hermosa familia Karen y Gabriel, Belela y Belelo, Omi y Opa, Ana María, Walter e Hilda, Waltrin e Hilda, Karol y Verde, Alex, Cano y Monica, Fernando, Tere y Alejandro, pero especialmente a la nueva generación de Latofskis, Hellen, Wal, Gabrielito, Ania y los dos bebitos que no tardan en llegar; porque me han enseñado que lo mejor y más importante que tenemos en la vida es la familia.

Por último, pero no por eso menos importantes, a todos mis compañeros y amigos de la generación 2010 de la maestría, porque estos dos años que estuvimos juntos han sido geniales y ha sido en gran parte gracias a ustedes y la amistad que queda entre nosotros es de los mejores frutos que he obtenido de esta experiencia. ¡Gracias por todo!

Agradecimientos

Al Dr. Humberto Reyes Hernández por todos sus consejos, ayuda y disponibilidad a lo largo de estos dos años, para hacer de éste un mejor trabajo y que yo aprendiera mucho más y sacara provecho de esta experiencia.

A la Dra. Sabine Schlüter por su apoyo, recomendaciones y por facilitarme el programa ArcGis 10 que fue indispensable para la realización de este trabajo. Vielen Dank für alles.

Al Dr. Alfonso Aguirre Muñoz por su ayuda, consejos y confianza, no sólo al apoyarme en mi realización académica si no también en el ámbito profesional. Gracias por todas las oportunidades brindadas.

A mis compañeros y amigos del Grupo de Ecología y Conservación de Islas, primero por toda su ayuda en la búsqueda y generación de información, por responderme todas mis dudas, por darle más orientación al trabajo, etc. pero más importante porque siempre aprendo algo nuevo de ustedes y porque hacen del trabajo algo divertido. ¡Muchas gracias!

A Emilia y Juan Salvador por hacernos sentir a Fer y a mí en familia mientras vivimos aquí en San Luis Potosí y también por abrirme las puertas de su casa en esta última etapa de la maestría, muchísimas gracias.

Table of Contents

Table of Figures

"Prioridades de Restauración en Islas Mexicanas".

Resumen:

La planeación sistemática de la conservación es fundamental para hacer más eficiente la inversión en la protección de biodiversidad, especialmente cuando los fondos son limitados. Esto es particularmente importante en áreas como las islas del mundo, lugares frágiles y amenazados, pequeños en superficie pero muy valiosos en riqueza de especies y endemismos. En el caso de las islas mexicanas se requiere prevenir extinciones y proteger la mayor cantidad de especies con menor inversión a través de la priorización de sitios basada en atributos deseables. México tiene aproximadamente 1,600 formaciones insulares, que conforman sólo 0.2% de la superficie del país. De éstas, tan sólo 149 islas albergan 7% de todas las especies de vertebrados y plantas mexicanas, así como 18% de las aves y mamíferos considerados amenazados por la Unión Internacional para la Conservación de la Naturaleza. En México 55 poblaciones de 10 especies han sido erradicadas en 34 islas y continúan pendientes un número similar de erradicaciones, en islas más complejas. La priorización es reconocida como la herramienta esencial para lograr un objetivo estratégico: restaurar todas las islas mexicanas. Se aplicó un método de análisis de decisión multi-criterio por medio de Sistemas de Información Geográfica, que involucra información espacial, preferencias de conservación, y la combinación de datos y preferencias basadas en reglas de decisión impuestas por especialistas en restauración. Se incluyeron 29 islas mexicanas con presencia de mamíferos invasores. Los atributos que se consideraron son: endemismo, especies amenazadas, sitios de importancia para las aves, riesgos de reintroducción, posibilidad de erradicación y costo económico de la misma. Se agruparon las islas en 4 categorías de prioridad: 1) Socorro, Cozumel, Maria Cleofas, Maria Magdalena, Espíritu Santo; 2) Maria Madre, Guadalupe, Clarión, San Jose; 3) Angel de la Guarda, Carmen, Cedros, Cerralvo, San Marcos, Santa Catalina, San Esteban, Cayo Centro, Saliaca, Coronado, San Benito Oeste, Santa Margarita; 4) Alcatraz, Natividad, San Diego, Magdalena, El Rancho, Mujeres, Mejia, Granito. Este trabajo servirá de guía para futuros planes de restauración y desarrollo sustentable, proveyendo información a agencias gubernamentales, conservacionistas y fundaciones donadoras para decidir en cuales islas y cuando se deben programar los esfuerzos de conservación.

"Wiederherstellung Prioritäten den Mexikanischen Inseln"

Zusammenfassung:

Eine akkurat wissenschaftlich fundierte Planung ist unerlässlich, für die Maximierung von Investitionen im Naturschutz, vor allem wenn das Budget limitiert ist. Dies ist besonders wichtig in gefährdeten und schutzbedürftigen Gebieten, wie zum Beispiel für Inseln weltweit, die eine kleine Landfläche aber sehr hohe Artenvielfalt und endemische Arten vorweisen. Im Fall der mexikanischen Inseln wird versucht durch das Priorisieren der Standorte mit gewünschten Eigenschaften das Aussterben zu verhindern. Zu Mexiko zählen 1600 Inseln, was nur 0,2% der Gesamtfläche des Landes sind. Nur 149 Inseln bedueten ein Habitat für 7% aller mexikanischen Wirbeltiere und Pflanzenarten, sowie 18% der gefährdeten Vögel und Säugetiere. Die Ausrottung invasiver Säugetiere auf diesen Inseln erwies sich als eine sehr effizientes Werkzeug zur Wiederherstellung. Funfundfünfzig Ausrottungen von 10 Arten wurden auf 34 mexikanischen Inseln bisher erfolgreich durchgeführt. Eine ähnliche Anzahl von Ausrottungen steht auf komplexeren und größeren Inseln an. Priorisieren ist als wesentliches Instrument anerkannt, um ein strategisches Ziel zu erreichen: alle mexikanischen Inseln von invasiven Wirbeltieren zu befreien. Dazu wurde eine auf GIS basierte Multi-kriterium Enstcheidung-Analyse entwickelt, um invasiven Säugetierarten auf 29 Inseln zu analysieren. Dazugehörige wichtige Attribute sind: Endemismus, bedrohten Arten, wichtige Brutgebiete von Seevögeln, Artenvielfalt, Wahrscheinlichkeit die Wiedereinführung von invasiven Arten, die Durchführbarkeit die Ausrottung und wirtschaftlichen Kosten. Die Inseln wurden in 4 Kategorien anhand der Priorität gruppiert: 1) Socorro, Cozumel, Maria Cleofas, Maria Magdalena, Espiritu Santo, 2) Maria Madre, Guadalupe, Clarion, San José, 3) Angel de la Guarda, Carmen, Cedros , Cerralvo, San Marcos, Santa Catalina, San Esteban, Cayo Centro, Saliaca, Coronado, San Benito Oeste, Santa Margarita, 4) Alcatraz, Natividad, San Diego, Magdalena, El Rancho, Mujeres, Mejia, Granito. Diese Untersuchung dient als Richtlinie für eine zukünftige Wiederherstellung und für nachhaltige Entwicklungspläne und stellt Informationen für Naturschutzorganisationen, Behörden und Sponsoren dar, die entscheiden, für welche Inseln und wann die Wiederherstellung initiiert wird.

"Restoration Priorities for the Mexican Islands".

Abstract:

An accurate science-based planning is essential to maximize the investments return in conservation efforts to protect biodiversity, especially when funds are limited. This is particularly important in threatened and fragile areas, such as the islands worldwide, which have small land surface area but very high species richness and endemisms. In the case of the Mexican islands, through the prioritization of sites with desired attributes, we seek to prevent extinctions and protect more species with less investment. Mexico, being a megadiverse country, has approximately 1600 islands and islets (only 0.2 % of the country's surface). Just 149 island host 7% of all Mexican vertebrate and plant species, as well as 18% of threatened birds and mammals. Furthermore, the eradication of invasive vertebrates on islands has proved to be a very efficient restoration tool. Fifty-five eradications of 10 species have been successfully conducted on 34 Mexican islands. A similar number of eradications, on more complex and larger islands are pending. Prioritization is recognized as an essential tool to achieve a strategic goal: to have all the Mexican islands free of invasive vertebrates. A GIS-based multi-criteria decision analysis was developed, involving conservation preferences and decision rules imposed by island restoration practitioners. Twenty-nine Mexican islands with documented presence of invasive mammal species were included in the analysis. Important attributes taken into account are: endemism, threatened species, important seabird nesting areas, species richness, reintroduction probability, feasibility of the eradication and economic cost. Islands were grouped into 4 categories of priority based on these criteria: 1) Socorro, Cozumel, Maria Cleofas, Maria Magdalena, Espiritu Santo; 2) Maria Madre, Guadalupe, Clarion, San José; 3) Angel de la Guarda, Carmen, Cedros, Cerralvo, San Marcos, Santa Catalina, San Esteban, Cayo Centro, Saliaca, Coronado, San Benito Oeste, Santa Margarita; 4) Alcatraz, Natividad, San Diego, Magdalena, El Rancho, Mujeres, Mejia, Granito. This endeavor will serve as guide for future restoration and sustainable development plans, providing information for conservation practitioners, government agencies and donors to decide on which islands and when to program the restoration efforts.

Prioritizing In Conservation Planning

One of the biggest problems in conservation biology today is the struggle to diminish the current species extinction rate, and its worsening as time passes by (Myers *et al.,* 2000); meanwhile all of the ecosystem services essential for human well-being depend on biodiversity; moreover the number of species threatened far outweighs available conservation resources. Thus there have been many international declarations to promote sustainable development, conservation and restoration; such as the United Nations "Millenium Development Goals", from which target 7 aimed to reduce biodiversity loss, achieving by 2010, a significant reduction in the rate of loss –which was sadly not achieved- (UN, 2012); or the more recent Convention on Biological Diversity "Strategic Plan for Biodiversity 2011-2020" from which strategic goal B aims to reduce the direct pressures on biodiversity and promote sustainable use and strategic goal C targets to improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity (CBD, 2012).

Therefore the question now is how to protect the most endangered species per dollar invested, and the answer usually is the setting of priorities (Myers *et al.,* 2000). That is why the prioritization of places for conservation and management on the basis of biodiversity value has become an emerging goal of conservation biology (Margules & Sarkar, 2007). Analysis for priorities can be done based in many different criteria, such as species richness, rate of endemism, populations or taxonomically unusual species; however in order for these priority-setting approaches to have better results it is recommended to also use socioeconomic objectives (Carwardine, 2008). Moreover, since a large portion of resources for conservation come from intergovernmental organization and major private foundations, priority settings need to be conducted at global as well as regional and local levels (Balmford *et al*., 2003).

Since invasive alien species are recognized as a major threat to biodiversity worldwide, Butchart (2011) notes the importance of global efforts to set priorities for controlling or eradicating alien vertebrates and mentions the need to build datasets for each priority site, control pathways for reintroductions, consider synergies with climate change and finally turn these prioritization exercises into on ground action. Furthermore there is a need to develop prioritization models that integrate insular species risk of extinction and the costs of eradicating that invasive vertebrate (Croll & Tershy, 2011). The fact that the global scale of the invasions on islands outweighs resources destined for conservation makes prioritization ever more crucial (McCreless *et al*., 2011).

In Mexico priority setting analysis have already been made for many areas and taxa. One example is that made by the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (National Commission for the Knowledge and Use of Biodiversity) CONABIO in 2007, for marine biodiversity, where they examine the role of island ecosystems and its importance for marine species and finally identify 105 priority sites.

On June 2009 in Ensenada, Baja California, 130 researchers from different universities, NGO´s and governmental agencies met, for the “Encuentro Nacional para la Conservación y el Desarrollo Sustentable de las Islas de Mexico” (National Conference for the Conservation and Sustainable Development of the Mexican islands), to discuss the current situation and needs in island conservation. The conference´s outcomes include the recommendation of strategic lines, conservation actions and public policies (Aguirre-Muñoz *et al*., 2010).

Justification

Mexico is one of 17 megadiverse countries which safeguard approximately two thirds of the planets wildlife diversity, it occupies only 1.4% of the worlds land surface, yet it is home to 10% of all known species, with a high degree of endemism. It is first in number of reptile species (717), second in mammals (449), fourth in amphibians (285) and plants (26,000), and sixth in butterflies (52). It also has the highest diversity of pine and cacti species in the world.

An accurate science-based planning is essential to maximize the investment’s return in conservation efforts to protect biodiversity, especially when funds are limited. Therefore research is needed to provide relevant information on areas of conservation priority, so that an economic investment is warranted to have a real impact. Mexico’s islands are of great importance due to their high biodiversity and endemism rate, where restoration projects have already proven to be successful. It is necessary to provide information for conservation practitioners, government agencies and donors to decide on which islands and when to program the next conservation efforts. This endeavor will serve as a guide so that future restoration projects are done where they are needed the most and so it is more feasible for them to obtain funding.

Main Goal

To define priorities of restoration via eradication of alien invasive mammal species for the Mexican islands, through the use of multi-criteria and spatial analysis methods in order to guide future restoration efforts.

Specific Objectives:

- Characterize the invaded islands by their environmental, demographic and economic conditions.
- Analyze and prioritize these islands according to environmental and economic attributes through spatial and multi-criteria tests.
- Create a guide plan for future restoration projects in Mexican islands.

The Importance of Islands

Besides harboring an impressive amount of biodiversity, and featuring most of the Earth's major ecological regions, islands provide many different ecosystem services, such as refuge, and areas for nesting, feeding and breeding for a wide array of migratory species (Cushman, 1995); they offer defense against natural disasters, support nutrient cycling, soil and sand formation, as well as contributing to the regulation of climate and diseases; the water that surrounds them are rich in biological productivity supplying great economic and social worth (Aguirre, 2011a); they are recognized as natural laboratories of evolution where biota with unusual characteristics such as flightlessness, gigantism or dwarfism occur; plus they have aesthetic, spiritual, educational and recreational values (Mulongoy *et al*., 2006).
Islands comprise only 3% of the world's land surface (Aguirre *et al.,* 2008) however when paired with their vast exclusive economic zones the coverage increases to 16.6%, one sixth of the planet's surface (Mulongoy *et al*., 2006). Nonetheless when compared to mainland, islands are habitat to around one fifth of the earth's plant, reptiles and bird species, they are also known for their disproportionately high percentage of endemisms, for both plants and vertebrates, approximately 5 to 7 times higher than continents (Figure 1)(Kier *et al*., 2008), this due to the fact that they are centers of range-restricted species (Whittaker & Fernandez, 2007).

Furthermore islands are very fragile ecosystems whose fine equilibrium processes can be easily disturbed, where anthropogenic impacts are more pronounced due to their vulnerabilities, isolation, small geographic ranges and lack of co-evolution of island species with more competitive ones. Moreover economic and social pressures have diminished the former resilience of island communities to natural disasters. Historically 83% of all recorded bird and mammals extinctions have occurred on islands, and 44% of today's species characterized as threatened in the Red List of Threatened Species of the IUCN are also insular (Aguirre *et al*., 2008). It is due to their fragility and vulnerability that islands and their species are the ideal messengers of change, providing us with indicators of global impacts of threats at an early stage, such as climate change (Mulongoy *et al*., 2006).

The greatest threats to insular biodiversity worldwide are invasive species and habitat loss. It has been estimated that invasive vertebrates occur on 40% of all islands and only 1% of these have had one or more invasive vertebrates successfully eradicated (Croll & Tershy, 2011).

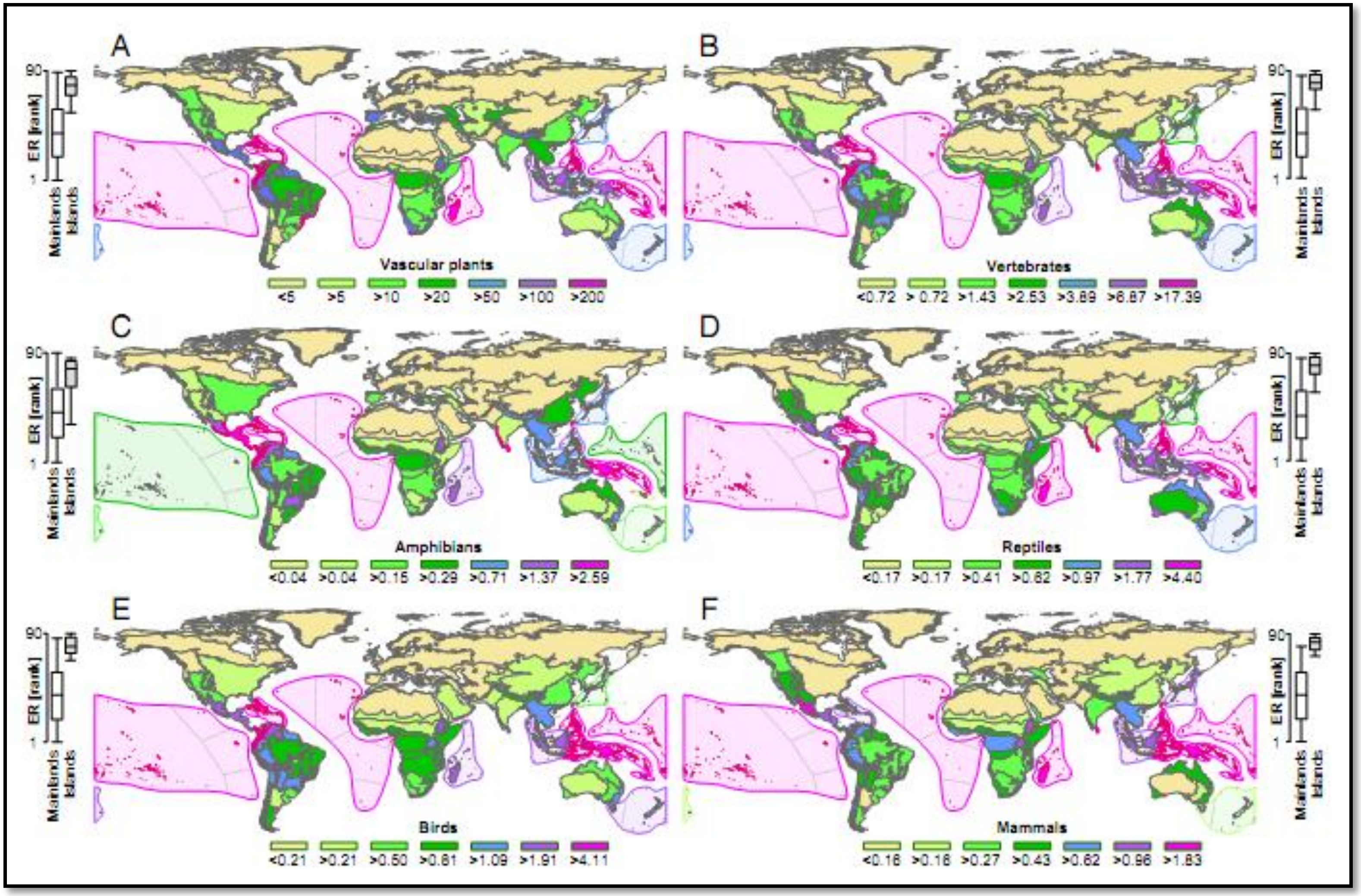


Figure 1 Global patterns of endemism richness (ER; range equivalents per 10,000 km^2) for A= vascular plants, B= terrestrial vertebrates, C= amphibians, D= reptiles, E= birds, and F= mammals, across 90 biogeographic regions. Map legends were classified using quartiles, i.e. each color class contains a comparable number of regions. Box and whiskers plots illustrate rank-based differences in endemism richness between mainland (n=75; white boxes) and island regions (n= 14; gray boxes). Boxes mark second and third quartiles; whiskers mark the range of the data. Source: Kier *et al.,* 2008.

The Theory of Island Biogeography

The fields of ecology, biogeography and conservation biology were greatly influenced in 1967 by the creation of the "Theory of Island Biogeography" by Robert H. MacArthur and Edward O. Wilson, which deals mainly with insularization, creation of biotic communities and species extinction.
In their work islands are the units to comprehend, which due to their diversity and variations in features such as size, shape and biotic communities, provide great advantages as "natural laboratories" to understand such fundamental ecological processes as dispersal, invasion, competition, adaptation and extinction.

- The Species-Area Relation: the number of species on a given island is usually approximately positively related to the area of the island, thus the larger the area the higher the species richness (Figure 2). This due to the fact that as islands become larger, their topography becomes more complex and this heterogeneity of habitats supports species that are ecologically semi-independent of each other.

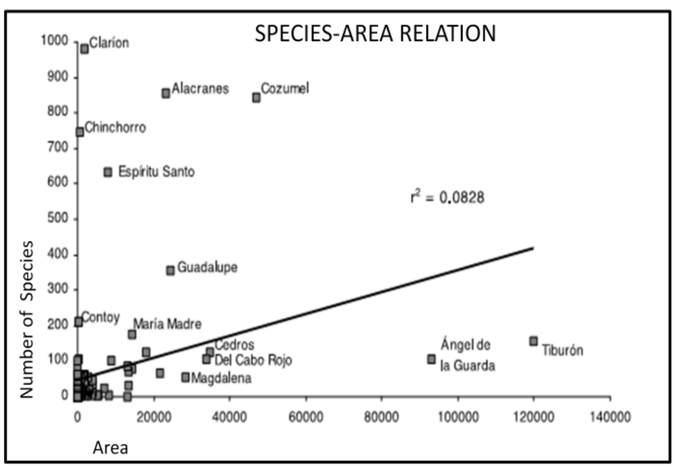


Figure 2 Species-Area chart for the Mexican Islands. Source: CONABIO-CONANP-PRONATURA-TNC, 2007.

- The Species Equilibrium: this equilibrium is reached in a taxon when the immigration and extinction rates (species/unit time) equal each other. Both rates vary with the number of species present and are greatly affected by the distance effect; that is the distance from the island to a source of possible colonizing species (immigrants) which could be mainland or other islands (Figure 3). The colonization of an island is a dynamic process, with a turnover in species and its variance is a function of the degree of saturation of the islands present. This is exemplified in the colonization curve that integrates the difference between the time curves of the immigration and extinction rates; it relates the rate of establishment of species to the number of species already present.

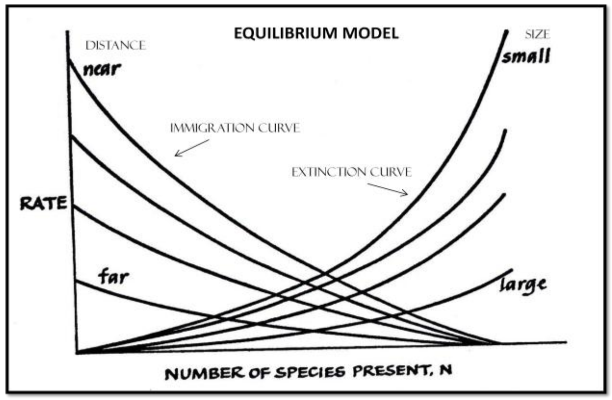


Figure 3 The equilibrium model of biotas of several islands of varying distances from the principal source area and of varying size. Source: MacArthur & Wilson, 2001.

- The Strategy of Colonization: through mathematical analysis the probability that a given species will establish a successful colony can be predicted in a density-dependent population growth, when the longevity of the population is known.

- Invasibility and the Variable Niche: there is a limit to the number of species persisting on a given island, so that a "closed" community cannot be invaded by a given species because their niche is already occupied by other species, however when the specie is a superior competitor it may successfully invade even if its niche is full, reflecting the species behavioral or morphological plasticity. Invasive species may respond to biotic changes in its new environment by contracting – meeting more competitors - or expanding – meeting fewer - its niche.

- Stepping Stones and Biotic Exchange: stepping stones islands can significantly enhance biotic exchange and dispersal, providing they are able to support populations of the species, this has a great effect in the distribution of species in archipelagos (Figure 4).

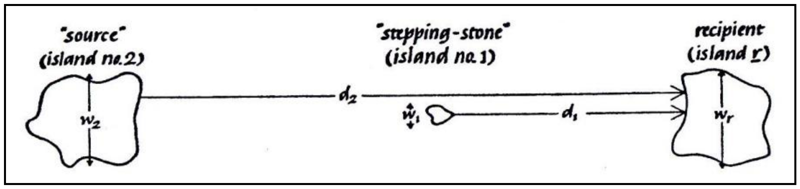
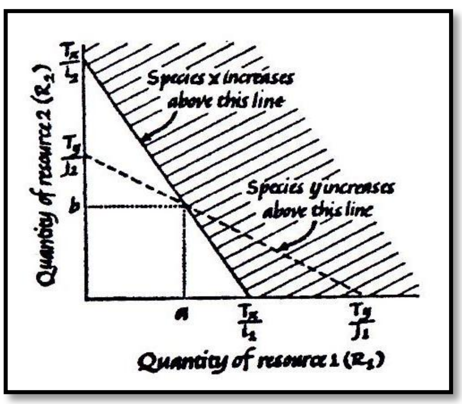
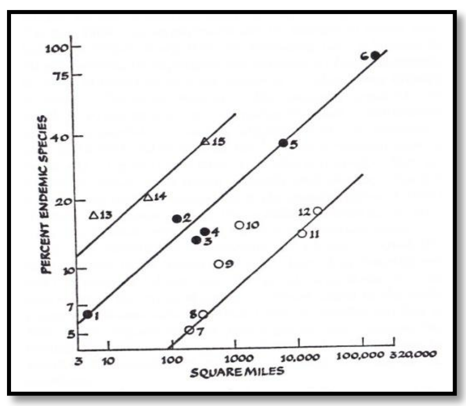


Figure 4 The stepping-stone model diagram. Source: MacArthur & Wilson, 2001.

- Evolutionary Changes Following Colonization: the intrinsic rate of population increase is amplified in the earliest stages of colonization, when population growth is unrestricted. But once they have attained their maximum population size, the carrying capacity will once again reduce the population increase rate (Figure 5). Afterwards the population begins a long-range adaptation to the peculiarities of the local environment. Evolution on islands can eventually lead to the formation of new endemic species as a result of adaptive radiation, but for this to happen islands must be relatively large and stable (Figure 6).





Right Figure 5 Diagram of competition between two species for two resources. Source: MacArthur & Wilson, 2001

Left Figure 6 Percentage of resident endemic bird species as a function of island area, in 3 kinds of islands. Dark circles: solitary, well isolated islands; Open circles: single islands near mainlands or large archipelagos; Triangles: islands in the Gulf of Guinea. Source: MacArthur & Wilson, 2001.

The Mexican Islands

Mexico boasts a total of 1,600 insular elements –islands, islets, rocks, cays and reefs- adding up to 5,127 km^2 yet they comprise only 0.2% of the country's land surface providing Mexico with a vast exclusive economic zone (EEZ) of 3,149,920 km^2 (INEGI, 2009) (Figure 7); the 13th largest EEZ in the world, thanks to its remote oceanic islands (*i.e*. Guadalupe, Socorro and Clarion) and an area 1.6 times bigger than the country's landmass of 1,959,248 km^2 (CANTIM, 2011). Islands are a strategic resource for the country in terms of sovereignty, natural resources and biodiversity; meanwhile 50% of the country's documented extinctions have occurred on islands and they're home to 18% of all currently threatened birds and mammals (Aguirre Muñoz *et al.,* 2008).

Mexican islands are also very high in species richness, only 149 islands host 7% of all Mexican vertebrate and plant species, this would mean that when compared to mainland, islands hold approximately 26 times more species richness per km^2. There are 2,066 terrestrial and 2,545 marine species recorded, of which 131 species and 40 subspecies are strictly endemic to 31 islands, while 170 species and 51 subspecies are endemic to an area of several islands (CONABIO, 2007). A great number of seabirds and pinnipeds make use of the Mexican Islands as nesting and resting sites, thus their conservation is critical. Of particular importance is the northwest region, that is the Pacific Ocean off the Baja California Peninsula, Gulf of California and the distant Revillagigedo Archipelago, which islands have more endemic plants and vertebrates than the famous Galapagos Islands of Ecuador, when compared Mexico has 25% more endemic species per km^2 (Aguirre Muñoz *et al.,* 2011b).

Islands also support the livelihood of 0.6% of Mexico's population (INEGI, 2005). Especially through the fisheries since the waters surrounding islands are very rich in biological productivity which offers great economic and social worth to the people; they have been historically harvested for highly regarded species in worldwide markets, such as abalone, lobster and tuna, some of which have been severely over-exploited in the coastal mainland. Some of these artisanal fisheries have even received certification from the Marine Stewardship Council (MSC), giving them a competitive advantage in the market and assuring buyers of the sustainability of the product; these are recognized as examples of community-based governance and sustainable activities that could be made (Aguirre *et al*., 2011a).

Figure 7 Map of the Mexican Islands and its exclusive economic zone. Geographic Data from INEGI.

There are 195 strictly endemic species, meaning they only occur on one island, distributed in 34 islands for which Guadalupe and Tiburon Islands hold the highest record; meanwhile there are 170 shared endemics, living in a group of islands, associated to 62 islands for which Espiritu Santo and Clarion Islands are the richest. Of all these endemic species approximately 10% are recognized as vulnerable, whether on the Official Mexican Norm NOM-059-SEMARNAT-2001, the Red List from the International Union for the Conservation of Nature (IUCN), or the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); the islands with most species listed under some category of protection are Espiritu Santo, Cozumel, Tiburon, Clarion and Guadalupe Islands (CONABIO, 2007).

The importance of the Mexican islands to biodiversity conservation is demonstrated by the fact that a high percentage are part of the national network of biosphere reserves and protected areas, Mexico's main conservation strategy -which covers 12% of the country- (Koleff & Urquiza-Hass, 2011); some of them are also included in different international decrees such as Alliance for Zero Extinction (AZE), UNESCO's Man and Biosphere Program, and Bird Life International's Important Bird Areas (IBA), among others. Currently there are 32 protected areas that include islands, comprising 5.20 km^2 of surface

(Aguirre *et al.,* 2010) (Figure 8); but still not all of them have a management plan. There is also an ongoing project to declare a protected area that would include many of the islands of the Pacific off the coast of the Baja California Peninsula (Aguirre Muñoz *et al*., 2005).

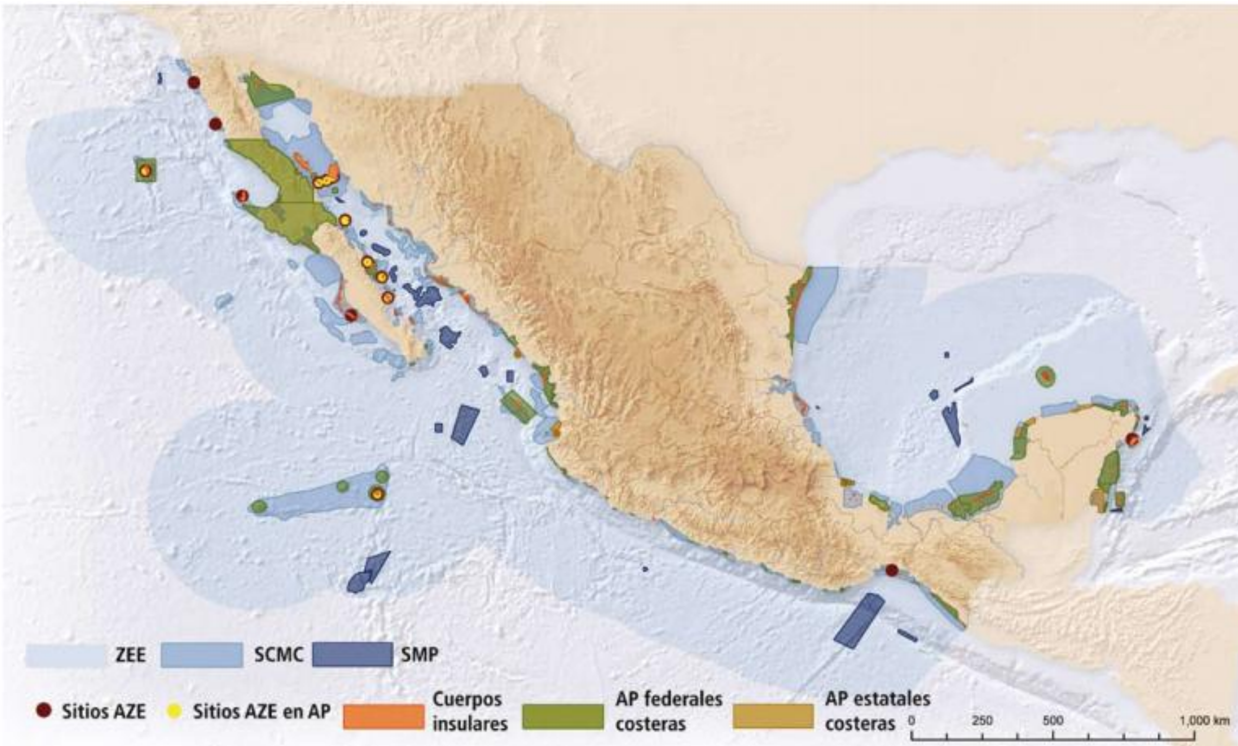


Figure 8 Map of islands under some category of protection or international decree. AZE: alliance zero extinction, AP: protected areas. ZEE= exclusive economic zone, SCMC= coastal priority areas, SMP= oceanic priority areas, Cuerpos insulares= island bodies, AP federales costeras= coastal federal protected areas, AP estatales costeras= coastal state protected areas. Source: CONABIO, 2007.

Invasive Species

The loss of biodiversity globally is one of the biggest problems we face today; the main causes of this problem have already been identified as: habitat loss, invasive alien species and climate change. In the particular case of islands the major driver of population declines and extinctions is that of introduced invasive species, that is the accidental or intentional introduction of animals and plants into an area outside their natural distribution, which are able to establish themselves and grow in population numbers as they cause severe damage to the habitat and native species (Ehrlich, 1989) (Figure 9). Even though most introductions of species into new habitats are failures, -approximately 10% of introductions succeed and approximately 10% of these will be significantly ecologically disruptive- a small proportion of successful introductions translates into a very large number of cases, which concern virtually all major islands (Williamson, 1996 in Courchamp *et al*., 2003).

As humans have colonized far places in the world, they have generally not traveled alone. Humans have served as dispersal agents of invasive species as consequence of migration, globalization and trade (Clout & Russell, 2008). Introduced species can have an impact on many ecological properties such as the dominant species in a community and an ecosystem's physical features, nutrient cycling and plant productivity (Vitousek, 1990) disrupting evolutionary processes, and causing radical changes in abundances, including extinctions (Cronk & Fuller, 1995, Rhymer & Simberloff, 1996 in Mack *et al*., 2000).

The introduction of invasive alien mammals to oceanic islands has been an unmitigated disaster as far as the native birds are concerned; but their losses have been ours too, because now there is no possibility to study the unique bird assemblages that evolved on these islands over millennia of isolation (Blackburn, 2008). Islands are especially susceptible to the harmful impacts of introduced species because their native species have evolved in these peculiar isolated conditions and thus have not developed defense mechanisms against predators and competitors (Mulongoy *et al*., 2006).

The specific vulnerability of an island to an invasion could be considered from three main perspectives: 1) risk of the introduction, establishment and spread of the introduced specie: these are the stages of a biological invasion (Mack *et al.,* 2000) and depend on ecological and socioeconomic factors, such as, climate, resource availability, lack of native predators or competitors, among others; 2) intrinsic resilience of the ecosystem: determined by ecological factors which allow native species to resist introduced ones, *i.e.* niche differentiation, refuge existence, diversity; 3) extrinsic resilience of the ecosystem: dictated by external forces, as are natural disasters, and anthropogenic impacts that influence the integrity of the island in diverse ways (Reaser *et al*., 2007).

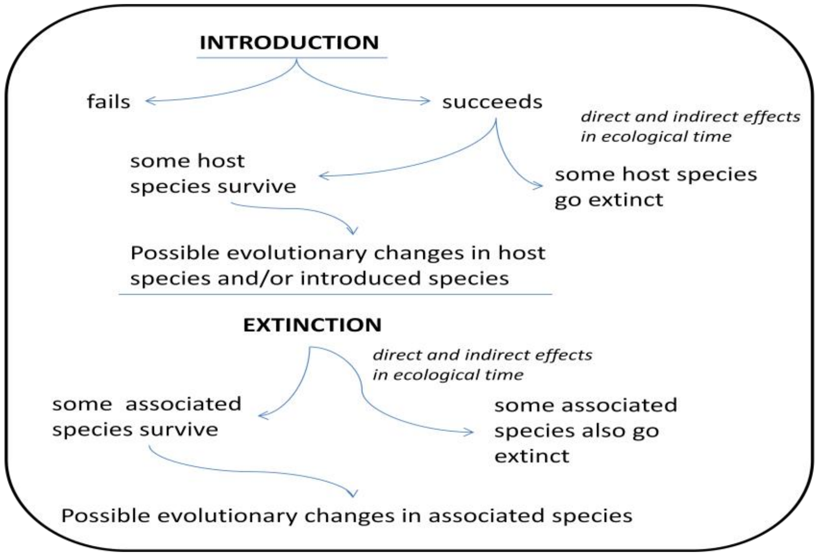


Figure 9 Diagram of events caused by introduction and extinctions. Source: Diamond, J. & T. Case, 1986.

There are several hypothesis that have tried to explain the vulnerability to invasions or the success of some invasive species, such as the "vacant niche hypothesis" which suggests that island communities with relatively small species richness cannot provide resistance to nonindigenous species; another hypothesis is the "escape from biotic constraints" which dictates that immigrants arrive to new areas where its performance cannot be undermined by biotic limits, instead of the idea that it possesses extraordinary characteristics; moreover there is the "disturbance before or upon immigration" stating that areas with sudden radical human induced disturbances in the environment, such as fire, floods or agricultural practices, are more prone to invasions (Mack *et al.,* 2000).

Introductions have many direct and indirect effects disturbing different aspects; some of them have a strong influence in the ability of ecosystems to provide their essential services. According to Mack and collaborators (2000) the impacts on biodiversity and ecological processes of species introductions are:
Of the numerous population-level effects, the most important must be the predation and grazing by invaders which has proven devastating. There are many examples and research on this problematic, such as the well known case of the predatory Nile perch (*Lates nilotica)*, introduced into Africa's Lake Victoria, which has already gravely threatened more than 200 of the 300 species of native cichlid fishes; now in the particular case of islands impacts can be easily made evident, *i.e.* feral cats and rats have repeatedly extirpated breeding populations of seabirds, decimated native rodent, reptile and avian populations in several islands worldwide (Nogales *et al*., 2004, Towns *et al*., 2006); the brown tree snake

introduced to Guam has virtually eliminated all forest birds; goats introduced to St. Helena island in 1513 drove more than 50 endemic plant species to extinction. Furthermore non-native species also compete with natives for resources and space, and they usually prove to be more efficient; such is the case of the native biota of the Galapagos Islands, threatened by goats and donkeys, not only because of grazing but due to the fact that they trample the breeding sites of tortoises and land iguanas. Moreover native species could be severely impacted by disease-causing organisms; for example, in the Hawaiian Islands the mosquito (*Culex quinquefasciatus)* which carries the avian malaria parasite was introduced, and while native birds are highly susceptible to the disease other bird invaders are resistant to it, causing the exclusion of the native birds.

On a community and ecosystem-level effect the biggest threat is the disruption of entire ecosystems and the landscape itself, which is often the case when invasive plants replace natives. For example, the Australian paperbark tree (*Melaleuca quinquenervia)*, introduced to South Florida, replaced cypress, sawgrass and other native species, while excluding all other vegetation. Adding to the problematic, it provides poor habitat for many native animals, uses huge amounts of water and intensifies the fire regime. According to Mack (1996) if left unchecked, the current pace and extent of invasions will influence other agents of global change, especially the alteration of greenhouse gases in the atmosphere.

Furthermore invasive species also impact diverse socioenomic aspects, such as those documented by Reaser and colleagues (2007):

- Fisheries: in the islands of Hawaii the oyster aquaculture industry was put out of business due to the accidental introduction of the mud blister worm (*Polydora websteri)*, which drills the shell of the mollusks creating a type of blister on them.
- Agriculture: the intentional introduction of the Indian mongoose *(Hespestus javanicus)* in Japan as a measure for biological control of the native snake (*Trimeresurus flavoviridis)* had profound detrimental effects on agriculture and poultry industry, as well as biodiversity.
- Ornamentals: the invasive cut throat coral (*Carijoa riise)i*, started outcompeting the susceptible native black coral (*Antipatharia* spp.) in Hawaii, causing problems for the black coral aquarium and souvenir trade industry.
- Infrastructure: the ground termite (*Coptotermes formosanus)* unintentionally introduced in Hawaii from South China is the most economically damaging pest recorded in the country.

- Tourism: Fregate Island was a critical refuge for two birds, six reptiles, three invertebrates and a mollusk endemic to the Seychelles which attracted many ecotourists to the island, when Norway rats (*Rattus norvegicus)* where introduced the industry became so concerned about economic losses they began an eradication program.
- Human health: various species of invasive snails, widely introduced in islands of the Asia-Pacific region, are known intermediate hosts of the rat lungworm (*Angiostrongylus cantonensis)* which causes a fatal disease (meningoencephalitis) in humans.
- Animal health: the Australian brushtail possum (*Trichosurus vulpecula)* introduced to New Zealand is an economic threat due to the transmission of bovine tuberculosis to cattle and deer, thus millions of dollars are spent every year to control the possum population.
- Governance: in Grenada the government may have lost a national election because it was deemed to slow in responding to the problem caused by the hibiscus mealy bug (*Maconellicoccus hirsutus)* which originates major direct losses to agriculture.

There has been no other time in history in which the rate of biological invasion has been higher and its consequences greater (Reaser *et al.,* 2007). A small number of mammal species has been recognized as responsible for most of the damage to invaded insular ecosystems: rats, cats, goats, rabbits, pigs and a few others (Courchamp *et al.,* 2003). It has been estimated that invasive vertebrates occur on 40% of all islands in the world and only 1% of these islands have had one or more invasive vertebrates eradicated (Croll & Tershy, 2011).

Restoration through Eradications of Invasive Species

Development of Eradications Worldwide

After documenting the detrimental effects of invasive alien species on native ones the response from conservation practitioners was to control these invasive populations, to minimize the pressure they placed upon fragile native populations. Invasive alien species population control implies limiting the abundance of the target population, thus it requires a constant effort over a long period of time, which can prove costly; on the other hand eradication campaigns aim to totally eliminate the target population, down to the last potentially reproducing individual, and so the effort lasts for a definite time period and is therefore less of a disturbance for native species and more cost-effective (Aguirre Muñoz & Mendoza Alfaro, 2009).

The early first successful rodent eradications were unintentional byproducts of rodent control efforts done in Rouzic Island in France and other islands in New Zealand (Towns & Broome, 2003). New Zealand was the first country to develop systematic techniques for eradicating rodents from islands, by conducting research on the bait station approach and other techniques that became successful intentional eradications on small islands (Moors, 1985 in Howald, 2007). Since then, these techniques have been improving and new technologies are being produced, so that nowadays invasive alien species can be successfully eradicated from larger and biologically complex islands. Eradication has become a powerful tool to prevent extinctions and restore ecosystems (Donlan *et al.,* 2003).

There are several methods to conduct and eradication campaign, it depends on the target specie –rodents, cats or ungulates-, island topography, habitat, economics and vulnerability of non-target species. Every method has advantages and disadvantages and the best strategy is almost always to combine several methods.

In the case of rodents, there are 3 techniques: 1) Bait stations, is the oldest technique used, where stations containing rodenticide (first generation anticoagulant) are distributed on a grid which size depends on the home range of the rodent targeted; these stations are monitored and kept filled with rodenticide bait for 1-2 years (Thomas & Taylor, 2002). The biggest disadvantage of this technique is that it is labor-intensive and therefore expensive at large scales, and it is impossible on islands with a complex topology; 2) Hand broadcasting, the distribution of bait so that every rodent has bait available in their home range, which proved more cost-effective, and later led to the development of; 3) Aerial broadcasting with helicopters, used in larger islands since the early 1990s (Howald *et al*., 2007). The latter technique has become the most common method used in rodent eradication campaigns (Towns & Broome, 2003), since rodenticide can be broadcasted on larger islands with steep cliffs. Other advantages of the aerial broadcasting technique are that they are single or double bait-applications events, usually 10-14 days apart, while bait station campaigns last up to 2 years, broadcasting shortens the length of the campaign and thus the period of risk to non-target species (Howald *et al*., 2007).

The most common method used for the control of cats and other medium-sized carnivores has historically been trapping, live door traps are routinely used. The traps will need to cover a substantial are and develop attractive baits. However, traps may be of limited use if the area to control is too large, with limited accessibility, if the population is too large, or if the animals are trap shy. For the eradication of cats on large islands with big populations this method would almost certainly not succeed, and a combination of methods is necessary (Courchamp *et al.,* 2003).

For the eradication of ungulates – mostly goats but also donkeys and horses- the most common method is hunting, whether ground or aerial, although live removal, poisoning, trapping, biocontrol and habitat alteration via fire have also been used. The hunting method also utilizes trained dogs and judas goats; judas goats are goats fitted with radiotelemetry collars, which help find animals at low densities given the gregarious nature of goats (Campbell & Donlan, 2005).

Whichever method is applied, its long-term success is critically dependent on solid support from several different areas, including financial support, staff commitment, and public support, among others (Courchamp *et al*., 2003).

During eradication campaigns there is also a risk for non-target species, which depends on the species present on the island, their behavior, toxicological properties, composition, and delivery method of bait; their susceptibility to the toxin and palatability to the bait, and the probability of exposure to the toxin either directly or indirectly in the trophic chain (Howald *et al*., 2007). Although there have been documented cases of impacts on non-target species by primary and secondary poisoning, these species have recovered quickly to pre-eradication population levels or higher (Howald *et al.,* 2005). Furthermore, there are mitigation techniques for non-target vertebrates, which include live capturing and temporary enclosures, which have been managed successfully for raptors, landbirds, reptiles and rodents.

Eradication Campaigns in Mexico

The sources of accidental introductions of invasive species –particularly house mice and black rats- to Mexican islands began in the 20th century with the harvesting of marine mammals and guano mining and later shifted to commercial and sport fishing. Furthermore a wide range of mammals have also been intentionally introduced to islands, such as dogs taken as pets to Guadalupe and Cedros islands, and goats introduced as supplies of fresh meat to Guadalupe, San Benito Oeste, Cedros, San José, Espíritu Santo and Cerralvo islands (Mellink, 2002), among other such cases, which however did not produce the expected benefits. It is important to mention that islands are also affected by other introduced species, such as reptiles – such as chuckwallas in Alcatraz Island and snakes in Cozumel Island-, and flora found in a great number of Mexican islands (Aguirre Muñoz *et al.,* 2011); however the focus of this particular study is on invasive mammals only.

Nonetheless it wasn´t until the 80´s that the harmful effects of invasive species were studied (Velarde & Anderson, 1994) and the situation of its islands recognized as critical. Invasive alien species have pushed 16 Mexican vertebrate species to extinction (Table 1); such is the case of the extinction of the endemic subspecies of deer mouse (*Peromyscus guardia mejiae)* from Mejia Island due to predation by cats. Another example is the case of the Socorro Dove (*Zenaida graysoni*) which has been declared extinct in the wild in its native Socorro Island, due to predation by cats and habitat change by goats, but is currently being kept and reproduced in a zoo in Germany (Aguirre Muñoz *et al*., 2011b). Furthermore many other populations have been removed and diminished by the presence of alien invasives, such as the black-vented shearwater (*Puffinus opisthomelas*) colony on Natividad Island, where only 25 cats killed more than 1,000 birds every month, before they were eradicated in the year 2000 (Keitt *et al*., 2002).

In 1994 and 1995 the first eradication projects were implemented, that of cats in Asuncion (68 ha) and black rat and cats in San Roque (37 ha) islands off the Baja California Peninsula and rats and mice on Rasa Island (68 ha), in the Gulf of California (Aguirre Muñoz *et al*., 2011b); all of them very important seabird nesting colonies.

Since 1995 up until 2012, fifty-five invasive mammal populations of 10 species have been eradicated from 34 Mexican islands (Table 2). These efforts have restored over 50,500 hectares, protected approximately 134 species of endemic plants, 117 species of endemic vertebrates and 220 populations of seabirds (Aguirre Muñoz *et al,.* 2011b). New technologies and eradication techniques have made a big difference in the size of the islands where these efforts are successfully accomplished, as is shown in the figure 10.

Island	Common name	Species	Year of last record	Year of last field research	Invasive species implicated and eradication status
Birds					
Guadalupe	Guadalupe storm-petrel	*Oceanodroma macrodactyla*	1912	2000	Cat (SP) Goat (ER)
	Northern flicker	*Colaptes auratus rufipileus*	1906	2003	
	Bewick's wren	*Thryomanes bewickii brevicauda*	1892	2003	
	Ruby-crowned kinglet	*Regulus calendula obscurus*	1953	2003	
	Spotted Towhee	*Pipilo maculatus consobrinus*	1897	2003	
Socorro	Socorro dove *	*Zenaida graysoni*	1972	1981	Cat (SP) Sheep (ER)
	Elf owl	*Micrathene whitneyi graysoni*	1932	1981	
Todos Santos	Rufous-crowned sparrow	*Aimophila ruficeps sanctorum*	1927	2005	Cats (ER)
Mammals					
Monserrat	Bailey's pocket mouse	*Chaetodipus baileyi fornicatus*	1975	2003	Cats (ER)
Todos Santos	Anthony's woodrat	*Neotoma anthonyi*	1950's	2005	Cats (ER)
Coronados	Bunker's woodrat	*Neotoma bunkeri*	1980's	1997	Cats (ER)
San Martin	San Martin island woodrat	*Neotoma martinensis*	1925	2006	Cats (ER)
Maria Madre	Nelson's rice rat	*Oryzomys nelsoni*	1898	2002	Cats (SP) Ship rats (SP)
Granito	Angel de la Guarda deer mouse	*Peromyscus guardia harbisoni*	1973	1999	Ship rats (SP)
Mejia	Angel de la Guarda deer mouse	*Peromyscus guardia mejiae*	1973	1999	Cats (ER)
San Roque	Deer mouse	*Peromyscus maniculatus cineritius*	1960's	2009	Cats (ER) Ship rats (ER)

Table 1 Extinctions of vertebrate species due to invasive species on Mexican Islands. SP= still present, ER= eradicated. *Socorro dove extinct in the wild, still being kept in zoos. Source: Aguirre Muñoz *et al.,* 2010.

Next Page. Table 2 Restored islands in Mexico. Source: Grupo de Ecología y Conservación de Islas, A.C., 2012.

	Island	Area (ha)	Species removed	Eradication Date	Methods	last field search
Pacific Ocean	Asuncion	41	Cat	1995	Trap	2009
	Clarion	1,958	Sheep, pig	2002	Hunt	2003
	Coronado Norte	37	Cat	1995-1996	Trap	2009
	Coronado Sur	126	Cat, goat, donkey	2003	Trap, hunt	2009
	Guadalupe	24,171	Rabbit, donkey Horse Goat Dog Goat, sheep	2002 2004 2003-2006 2007 1997	Live removal Live removal Live removal, trap, hunt, telemetry Live removal, trap, hunt Live removal	2010
	Natividad	736	Cat Dog	1998-2000 2001	Trap, hunt, live removal Live removal	2006
	San Benito Este	146	Rabbit	1999	Trap and hunt	2009
	San Benito Medio	45	Rabbit	1998	Trap and hunt	2009
	San Benito Oeste	364	Rabbit, goat Donkey	1998 2005	Trap and hunt Live removal	2009
	San Jeronimo	48	Cat	1999	Trap and hunt	2006
	San Martin	265	Cat	1999	Trap and hunt	2006
	San Roque	35	Cat Ship rat	1995 1995	Trap Bait stations	2009
	Socorro	13,033	Sheep	2010	Hunt and telemetry	2010
	Todos Santos Norte	34	Cat, rabbit Donkey	1999-2000 2004	Trap and hunt Live removal	2009
	Todos Santos Sur	89	Cat Rabbit	1997-1998 1999-2004 1997	Trap and hunt Trap and hunt	2009
Gulf of California	Coronados	715	Cat	1998-1999	Trap	2008
	Danzante	412	Cat	2000	Trap	2008
	Estanque	82	Cat	1999	Trap and hunt	2003
	Farallon de San Ignacio	17	Ship rat	2007	Aerial broadcast	2009
	Isabel	80	Cat Ship rat	1995-1998 2009	Trap, hunt & bait stns Aerial broadcast	2009
	Mejia	245	Cat	1999-2001	Trap and hunt	2008
	Montserrat	1,886	Cat	2000-01/03	Trap and hunt	2008
	Partida Sur	1,533	Cat	2000	Live removal	2007
	Rasa	57	Ship rat, house mouse	1995-1996	Bait stations	2009
	San Jorge Este	9	Ship rat	2000-2002	Bait stations	2004
	San Jorge Medio	41	Ship rat	2000-2002	Bait stations	2004
	San Jorge Oeste	7	Ship rat	2000-2002	Bait stations	2004
	San Francisquito	374	Cat Goat	2000 1999	Trap and hunt Hunt	2005
	San Pedro Mártir	267	Ship rat	2007	Aerial broadcast	2009
	Santa Catalina	3,890	Cat	2002-2004	Trap and hunt	2008
Caribbean	Perez	11	Ship rat	2011	Hand broadcast	2011
	Muertos	15.6	House mouse	2011	Hand broadcast	2011
	Pajaros	2.3	House mouse	2011	Hand broadcast	2011
	Cayo Norte Mayor	28.8	Ship rat	2012	Aerial broadcast	2012
	Cayo Norte Menor	14.6	Ship rat	2012	Aerial broadcast	2012
	Total: 35	50,815	54			

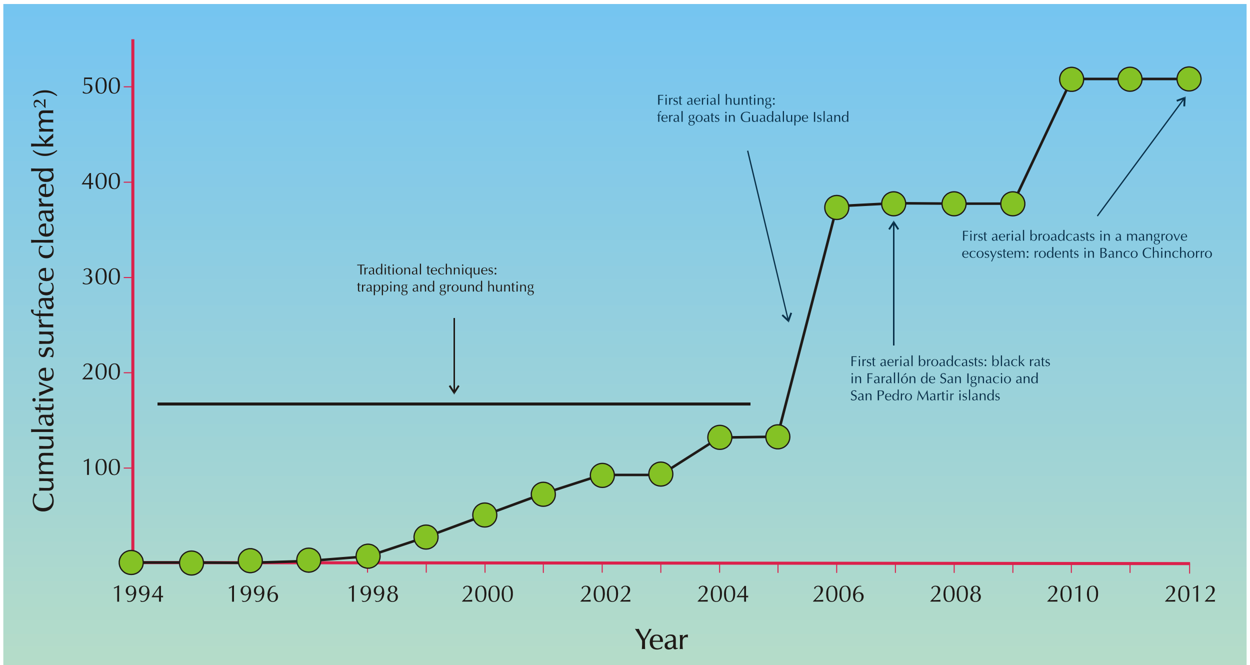


Figure 10 Restored insular surface in Mexico over the years. Source: Grupo de Ecología y Conservación de Islas, A.C., 2012.

Even though there have been great advances in liberating the Mexican islands from the pressure of invasive species there are still many more in need of eradication campaigns, as a first step in the restoration process. Figure 11 shows the Mexican islands where successful eradications have been accomplished and those in need of these conservation efforts.

In many cases, the elimination of the alien invasive species is followed by a rapid and often spectacular recovery of the impacted native populations (Courchamp *et al.,* 2003). In the case of the Mexican islands there are many examples of the benefits that the islands where invasive species have been eradicated experience, such as those documented over the years by the Grupo de Ecología y Conservación de Islas, A.C. (Island Conservation and Ecology Group) named Conservación de Islas from now on (Samaniego-Herrera *et al*., 2011) (table 3).

Figure 11 Map of completed and pending eradications of invasive mammals in Mexican islands. Source: Grupo de Ecología y Conservación de Islas, A.C. 2012.

Island	Species	Changes recorded after rodent eradication
Farallon de San Ignacio	*Phaethon aethereus* Tropicbird	60% increase in number of nests after two years without rats. Percentages of egg-hatching success and development of juveniles also increased.
	Phyllodactylus homolepidurus Sonoran leaf-toed gecko	Changed from extremely rare to low abundance after two years without rats.
Isabel	*Ctenosaura pectinata* Spiny-tailed iguana	Population abundance increased.
	Onychoprion fuscatus Sooty tern	Nesting again after few years of extirpation.
Rasa	*Larus heermanni* Heerman's gull	Breeding success increased five times.
	Thalasseus elegans Elegant tern	Population (55,000 individuals in 1995) has increased to 200,000.
San Pedro Martir	*Lampropeltis getula nigrita* Mexican black kingsnake	"Reappeared" on the island after two years without rats.
	Synthliboramphus craveri Xantus's murrelet	Nesting again after decades of extirpation.
San Roque	*Phalacrocorax penicillatus* Brandt's cormorant	Nesting again after years of extirpation. Also several new records of seabirds in recent years.
	Ptychoramphus aleuticus Cassin's auklet	Nesting again after years of extirpation.

Table 3 Examples of benefits from eradication campaigns. Source: Samaniego Herrera *et al*., 2011.

In other cases however, eradications are not sufficient for the ecosystem to revert to its former state, and complementary actions are required, such as species re-introduction (Courchamp *et al.,* 2003). Eradications are not the only restoration tool currently under use on Mexican islands. Since 2008 Conservación de Islas has implemented social attraction projects for birds on Asunción and San Roque islands where rats and cats had caused the extirpation of breeding colonies of: Cassin's Auklet (*Ptychoramphus aleuticus*), Xantus's Murrelet (*Synthliboramphus hypoleucus*), Hermann's Gull (*Larus heermanni*), Elegant Tern (*Thalasseus elegans*) and the Brown Pelican (*Pelecanus occidentalis*). Two of these species (Elegant Tern and Hermann's Gull) have already been recorded interacting with the social attraction systems on the island, which represents the first step in the colonization process (Aguirre-Muñoz *et al*., 2008b).

Through all of these restoration actions Mexico contributes in a great way to the Aichi Biodiversity Targets set by the Convention on Biological Diversity (CBD). Specifically to the following (Grupo de Ecologia y Conservacion de Islas, 2012):

- Target 1: people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably.
- Target 4: users have implemented plans for sustainable production and have kept the impacts of use of natural resources well within safe ecological limits.
- Target 5: loss, degradation and fragmentation of natural habitats (e.g. islands) are at least halved.
- Target 9: invasive alien species and pathways are identified and prioritized, and controlled or eradicated accordingly; measures to control introduction pathways are in place.
- Target 11: by 2020 at least 17% of terrestrial and inland water and 10% of coastal and marine areas are conserved and integrated into the wider landscapes and seascapes.
- Target 12: extinction of threatened species is prevented and their conservation status improved.
- Target 14: ecosystems that provide essential services (e.g. islands) contributing to livelihood and well-being are safeguarded.
- Target 19: knowledge, the science base and technologies relating to biodiversity, and the consequences of its loss, are improved, shared, transferred and applied.
- Target 20: the mobilization of financial resources for effectively implementing the Strategic Plan of Biodiversity 2011-2020 should increase substantially from the current levels.

Economic Investment on Eradication Campaigns

Even though the economic benefits of conserving biodiversity are very well known, current conservation resources fall well short of those needed to prevent major extinctions (Balmford *et al*., 2003). The eradication of invasive alien species from islands is recognized as a powerful tool to prevent further extinctions and restore ecosystems, often with high conservation returns from a cost-benefit perspective (Howald *et al.,* 2007).

In order to prioritize invasive species eradications on islands, a system for objective estimation of the conservation gain and an internally consistent method of predicting its financial cost is required (Martins *et al.,* 2006); although the prediction of financial cost has proven very difficult due to the difference between fixed and variable costs, without considering costs, the conservation community could not make the crucial decision whether to concentrate its limited eradication resources on smaller or larger islands (Brooke *et al.,* 2007).

According to Martins and collaborators (2006) the primary determinant of the cost of an eradication is island area and its remoteness; also of consequence is whether the invasive species to be eradicated are rodents or ungulates, the former being 1.7-3.0 times more expensive for a given island area. In another study Howald *et al*. (2007) analyzed 47 eradications campaigns worldwide and concluded that the costs of invasive rodent eradications varied from US$3 per hectare to US$20,000/ha. Furthermore, Donlan & Wilcox (2007) concluded that in addition to the factors above mentioned, eradication campaigns costs can differ drastically depending on a suite of fixed and nonfixed costs, including mitigation for non-target species, techniques used, local capacity and bureaucracy.

Conservation costs are markedly lower and with higher benefit-to-cost ratios in less developed parts of the world, where, ironically current conservation spend is the lowest and unmet conservation needs are greatest (Balmford *et al.,* 2003).

In the particular case of the Mexican Islands, the average cost of invasive species eradication campaigns is US$188 per hectare, including 50,500 hectares where rodents, goats, sheep and cats, were removed. This also comprises state-of-the art techniques such as aerial hunting and aerial baiting. Through these efforts 313 seabird colonies and 85 endemic terrestrial vertebrates have been protected on the islands of western Mexico at a cost of US$17,000 per colony or US$35,000 per endemic taxon (Aguirre Muñoz &

Mendoza Alfaro, 2009). Therefore, the overall return on investment for conserving biodiversity in Mexico is among the highest in the world (Aguirre Muñoz, *pers. comm*.).

The Multi-Criteria Decision Analysis

Planning can be considered as a tool that supports decision making by assisting the decision makers (governments, resource managers, stakeholders) to use resources in such a way that current problems are reduced and specific social, economic and environmental goals are satisfied (Bronsveld *et al.,* 1994 in Laskar, 2003).

Decision analysis is defined as a set of systematic procedures for analyzing complex decision problems. It is a sequence of activities starting with the recognition of a problem and ending with a recommendation, and eventually with a final choice of alternative. Decision making must be based on numerous data concerning the problem at hand (Drobne, 2009).

According to Simon's (1977) framework for planning and decision-making there are three phases to the process: 1) Intelligence: identification of the problem, analyses the difference between the actual state and the desired state which leads to the setting of goals and objectives of the decision; 2) Design: generating, developing and analyzing possible courses of action, establishing feasible alternatives and criteria; 3) Choice: evaluating alternative options and selecting the course of action (Laskar, 2003) (Figure 12).

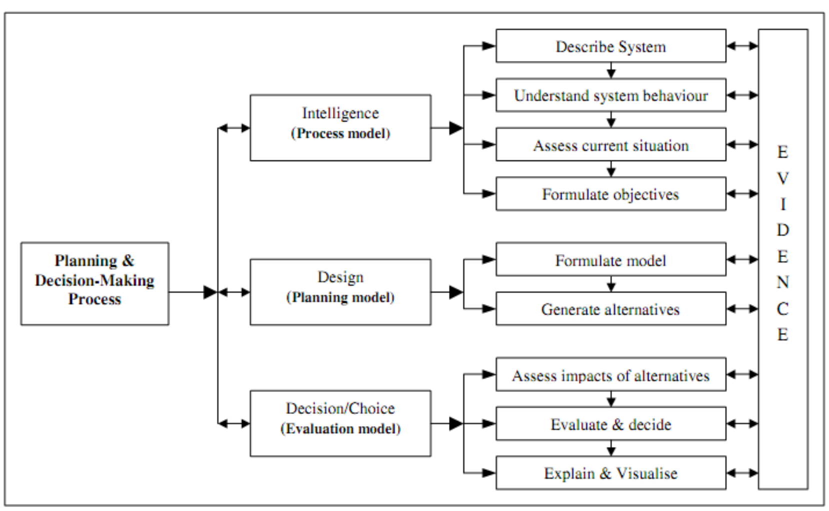


Figure 12 Planning and decision-making process framework. Source: Laskar, 2003.

Multi-criteria decision making (MCDM) techniques are considered as a promising framework for planning and decision-making process as they have the potential to take account of conflicting, multidimensional, incommensurable and uncertain effects of decisions (Ananda *et al*., 2003 in Laskar, 2003). Multi-criteria decision problems generally comprises of a set of alternatives which are evaluated on the basis of conflicting and incommensurable criteria of quantitative, qualitative or both in nature (Malczewski, 1999). Spatial decision problems, like most real-world problems of land use suitability, site selection and resource evaluation are, often require that a large number of alternatives be evaluated on the basis of multiple criteria. Spatial multi-criteria decision analysis combines and transforms geographical data (input maps) into a resultant decision (output maps) (Malczewski ,1999).

Geographical information systems are a set of tools for the input, storage and retrieval, manipulation, analysis and output of spatial data, due to its functionality it plays a crucial role in a comprehensive decision-making process (FAO, 1976, Goodchild, 1987, Grinshaw, 1994 in Drobne, 2009) (Figure 13).

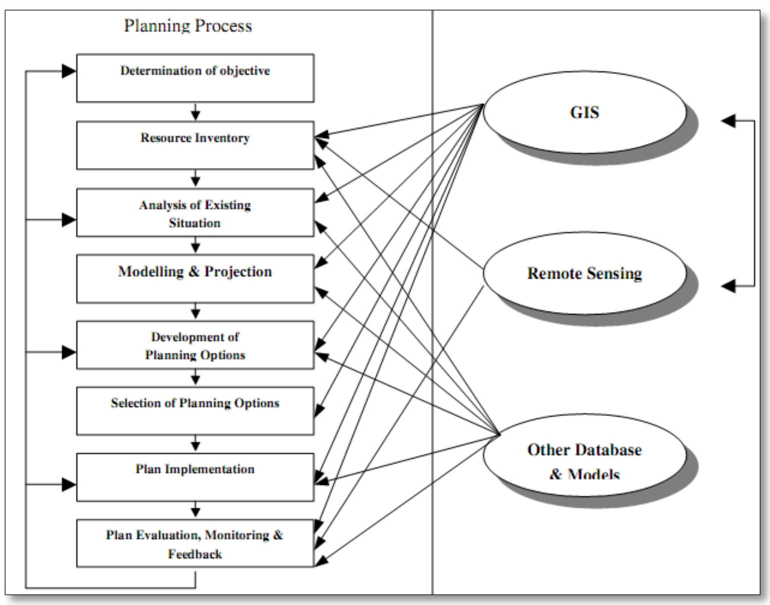


Figure 13 The planning process integrating remote sensing, geographic information systems and other database and models. Source: Laskar, 2003.

There are several methods to solve multi-criteria decision-making problems based on its decision analysis. In this particular effort the multi-attribute decision making (MADM) method will be used, and it will be achieved through the weighted linear combination (WLC) model. The WLC model is one of the most widely used GIS-based decision rules (Malczewski, 1999). In the WLC model continuous criteria are standardized to a common numeric range and then combined by means of a weighted average. The decision maker assigns the weights of relative importance directly to each attribute map layer. The method can be executed using any GIS system with overlay capabilities, and allows the evaluation criterion map layers to be combined in order to determine the composite map layer which is output (Drobne, 2009).

According to Drobne (2009) and Malczewski (2000) multi-attribute decision making methods are based on:

- Attribute: a concrete descriptive value, a measurable characteristic of an entity, including interentity relationships. They are quantifiable indicators of the extent to which associated objectives are realized. They can be represented on maps and stored in a GIS database.
- Objective: a statement about the desired state of a real-world geographical system, by assigning one or more attributes that directly or indirectly measure the level of achievement. It indicates the direction of improvement.
- Criterion: the basis for a decision, it can be measured and evaluated, it includes both objectives and attributes.
- Alternatives: represented by an individual pixel or a combination of pixels. It is feasible if it satisfies all limits and constraints.
- Weight: value assigned to an evaluation criterion indicative of its importance relative to other criteria under consideration.
- Decision rule: procedure by which criteria are selected and combined to produce a particular evaluation, and by which evaluation are compared and acted upon.

According to Malczewski (2000) the Weighted Linear Combination Procedure can be formalized by means of the multi-attribute decision making problem. If the set of decision alternatives are represented by $X = \{ x_{i*} | \, i = 1,2,\ldots,m\}$. The alternatives are represented by the set of cells or pixels in a raster GIS database. Thus, the index i indicates the location of the i-th alternative. Each alternative is described by means of its locational attribute (coordinate data) and attribute data (attribute values associated with the location). Since the attributes serve as decision variables we can designate a decision outcome (criterion value) by x_{ij}, that represents the level of the j-th attribute with respect to alternative i. Hence, an alternative i can be characterized by the vector in equation (1),

$X_{i*} = (x_{i1}, x_{i2}, \ldots, x_{in})$, for i = 1,2, …, m, and the levels of attributes across an alternative are represented by the vector in equation (2), $X_{*j} = (x_{1j}, x_{2j}, \ldots, x_{mj})$, for i = 1,2, …, n,.

The input data for equation (1) and (2) can be organized in a tabular form (evaluation matrix or geographical matrix). Accordingly, the data can be stored in a GIS as a set of map layers. The data consists of a set of n data layers and each grid-cell in the data layer contains an attribute value x_{ij}. In a particular decision situation the set of alternatives can be limited by imposing constraints on the attribute values (aspatial constraints) or on the locational attributes (spatial constraints).
Given the input data, the problem is to aggregate the map layers according to the WLC decision rule. Formally, the decision rule evaluates each alternative, a_i, by the following value function:

$$V\,(x_i) = \sum j \;\; w_j v_j(x_i) = \sum j \; w_j r_{ij}$$

Where w_j is a normalized weight, such that $\Sigma w_j = 1$, $v_j\,(x_i)$ is the value function for the j-th attribute,
$x_i = (x_{i1}, x_{x2}, \ldots, x_{in})$, and r_{ij} is the attribute transformed into the comparable scale. The weights represent the relative importance of the attributes. The most preferred alternative is selected by identifying the maximum value of $V(x_i)$ for $i = 1,2,\ldots,m$.

GIS Weighted Linear Combination Procedure (Malczewski 2000).

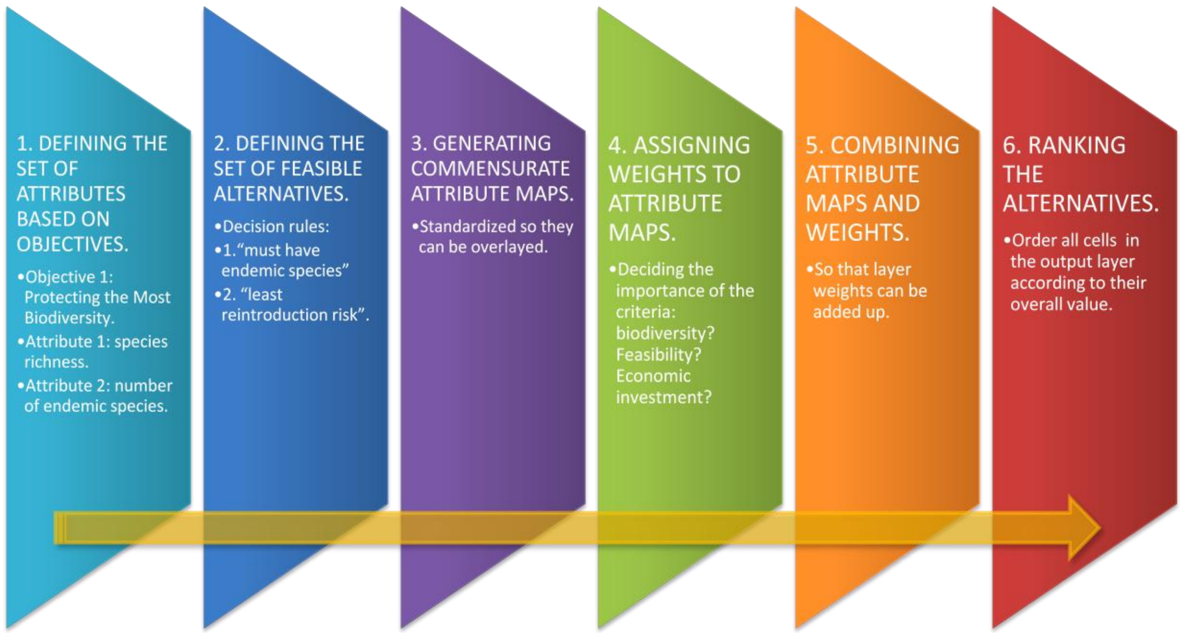


Figure 14 WLC procedure framework.

A description of the GIS-WLC procedure based on Malczewski (2000) (Figure 14):

1. <u>Defining the set of attributes.</u> These will be represented on maps. They should be comprehensive, measurable, complete, operational, nonredundant and minimal. The process of identifying the set of attributes is heavily dependent on the availability of georeferenced data.
2. <u>Defining the set of feasible alternatives</u>. By deciding the limits or constraints imposed on the decision rule. Feasible alternatives are identified either by exclusionary screening or by imposing target constraints on the set of all alternatives. It is important to decide the scale of the map appropriate to the problem at hand in order to have the most efficient alternatives.
3. <u>Generating commensurate attribute maps</u>. WLC requires that the values contained in the different attribute map layers are transformed into comparable units. It relates possible decision outcomes to a scale which reflects the decision maker's relative preferences.
4. <u>Assigning weights to attribute maps</u>. The weights assigned to attribute maps should be derived by asking the decision maker to compare a change from the least-preferred to the most-preferred value on one attribute map to a similar change in another attribute. There are several methods to achieve this; a ranking method is used.

5. Combining attribute maps and weights. There are two assumptions implicit in the WLC method: linearity (the desirability of an additional unit of an attribute is constant for any level of that attribute) and additivity (attributes under consideration are mutually preference independent of each other).
6. Ranking the alternatives. The final stage involves the ranking procedure to order all the cells on the output layer according to their overall score value. The cell assigned the rank of 1 is the best alternative.

The successful outcome of decision making and problem solving within the planning process is dependent on the input information and its subsequent manipulation and handling. For effective and efficient decision-making the prime requirement is the data on various facts. This information can be categorized in to two classes: 1) hard information –objective- derived from reported facts, quantitative estimates, census data, remote sensing data, etc.; and 2) soft information –subjective- represents the preferences, judgments, priorities of the interest groups and decision makers (Malczewski, 2003 in Laskar, 2003).

Methodology

First of all an exhaustive bibliographic research was done in order to create a database of relevant information, which will serve as attributes, for each of the 29 islands with documented presence of invasive mammals selected: size, distance from the continent, species richness, endemisms, number of species included under protection in the NOM-059-SEMARNAT-2010, invasive species present, previous restoration efforts, human population, land use, biosecurity risks (introduction or reintroduction), if it is currently a protected area, area of interest for different international agreements, approximate economic investment needed, and feasibility of the eradication. These will also be the criteria for the analysis. All the information gathered will be entered in a GIS project using the program ArcMap version 10 from ArcGis 10 developed by ESRI, with a license provided by the Institute for Tecnology and Resources Management in the Tropics and Subtropics at the Cologne University of Applied Sciences. The maps of Mexico and its islands were obtained from the Instituto Nacional de Estadística y Geografía (INEGI, National Statistics and Geography Institute).

Some flaws of multicriteria analysis have been identified (Maguire, 2011), such as: omitting important factors that are hard to measure, defining performance categories too vaguely for different users to produce consistent ratings and losing control over the weight accorded to each factor in composing the overall rating. These flaws were taken into account in order to be avoided during this work.

The Evaluation Criterion

The term evaluation criterion is a generic term that includes both the concept of objectives and attributes. These objectives are made operational by assigning to each objective under consideration one or more attributes that directly or indirectly measure the level of achievement (Malczweski, 2000). Figure 15 shows the relationship between the objectives set for this multicriteria analysis and the attribute sets used to measure them.

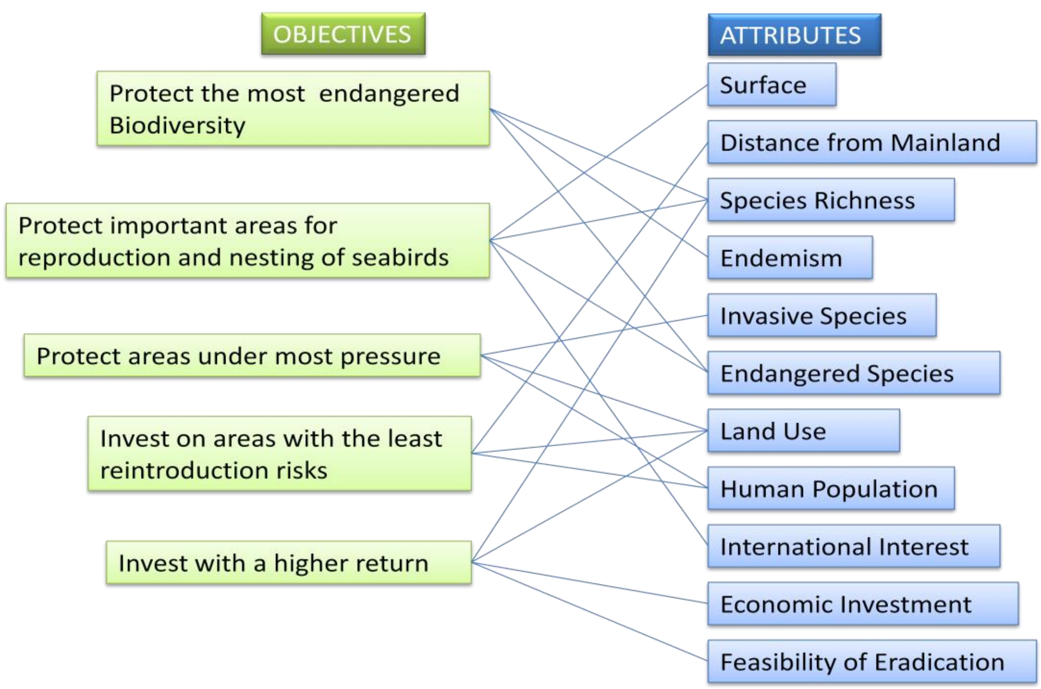


Figure 15 Relationship matrix of objectives and attributes set for the analysis.

Attribute Data Taken Into Account for the Analysis

- Surface: the size of the island, in hectares, is of importance due to the habitat it provides, probable number of species present and the importance factor it plays in eradication efforts.
- Distance from Mainland: distance in kilometers from the nearest point in mainland, important for the possibility of reintroductions and its influence in the cost of the eradication campaign.
- Species Richness: number of vertebrate, terrestrial species that use the island, not only residents but also migratory species were taken into account.
- Endemism: species and subspecies that are only found on the islands both exclusively and shared by a group of nearby islands.
- Invasive Species: terrestrial mammal species that are out of their natural distributional area and arrived to the islands accidentally or were intentionally introduced and pose a threat to native species.
- Endangered Species: species that are listed in the NOM-059-SEMARNAT-2001 under different categories of protection; also species listed on the Red List of the IUCN.
- Land Use: human use of the resources and economic activities that take place on the island and the water that surrounds it.
- Human Population: when it is the case, the number of people living on the island, also important due to pressure on the natural resources and possibility of reintroductions.
- International Interest: the islands that are part of the internationally recognized list of Birdlife International as "Important Bird Areas", this because they are considered crucial nesting areas for seabirds, as well as those that are listed in the Alliance for Zero Extinction database for mammals and seabirds.
- Economic Investment: a predicted amount of money needed to perform eradications due to the complexity of the islands topography, environmental and ecological conditions, along with the expertise provided by the NGO "Conservación de Islas"; divided in 4 categories from 1 – most expensive, moving down to 4 – least expensive.
- Feasibility of the Eradication: technical or ecological grade of difficulty of the campaign due to the type of invasive species, size of the island, distance from mainland or impact on non-target species, along with the expertise provided by the NGO "Conservación de Islas"; divided in 4 categories from 1 – least feasible, moving down to 4 - most feasible.

- Reintroduction Probability: probability of the invasive species, or others, to get back in to the island after a successful eradication campaign; due to distance from mainland or other islands, land use, human population, also based on the expertise provided by the NGO “Conservación de Islas”; divided in 4 categories, from 1 – higher reintroduction probability, moving down to 4 – lower reintroduction probability.

Decision Rules

On several meetings with the group of experts on Island conservation and restoration from the Mexican NGO Conservación de Islas, which have been responsible for most of the successful eradication campaigns in Mexican islands, the decision rules were decided and weights of importance assigned, in order for islands to be considered a priority (Table 4).

It is generally acknowledged that the risk of reintroduction of invasive species plays a major role on the decision of performing an eradication campaign, so that investments in removing invasive species must be weighed against the risk of reintroduction (Carrion *et al*., 2011), thus the potential contribution of the eradication is higher on a long-term or sustainable wildlife conservation rather than immediate financial cost-effectiveness (Harris *et al*., 2011). However this project’s biggest goal is to protect the unique and fragile insular biodiversity and thus improve human health and livelihoods, as most conservation projects are (Saunders *et al.,* 2011).

This study is an effort to develop a prioritization model that integrates insular species risk of extinction, and the cost of eradicating invasive vertebrates, such as is recognized as crucial by Croll & Tershy (2011); and furthermore integrates other aspects such as risk of depletion of important seabird nesting populations, and areas of high species richness, with the feasibility, reintroduction risk and costs of eradications.

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

Table 4 Decision rules and their importance set for the analysis.

Setting the Criterion Weights

The rank sum method is used for the setting of weights. According to Malczewski (1999) the weights are usually normalized to sum to 1. In the case of *n* criteria, a set of weights is defined as follows:

W = $(w_1, w_2,...,w_j,..., w_n)$, and $\Sigma\, w_j = 1$.

Every criterion under consideration is ranked in the order of the decision maker's preference.

In the rank sum method weights are calculated according to the following formula:

$$w_j = \frac{n - r_j + 1}{\sum(n - r_k + 1)}$$

Where w_j is the normalized weight of the *j*th criterion, *n* is the number of criteria under consideration (k=1,2,…n), and r_j is the rank position of the criterion. Each criterion is weighted $(n - r_j + 1)$ and then normalized by the sum of all weights, that is, $\sum(n - r_k + 1)$.

Mexican Islands with Invasive Species

There are 39 Islands where the presence of alien invasive species has been documented (table 5).

Island	Surface (ha)	Invasive Species	Region
Coronado Sur	126	House mouse	North Pacific
Guadalupe	24,171	Cat, house mouse	
San Benito Oeste	364	Cedros Island cactus mouse	
Cedros	34,933	Dog, goat, cat, house mouse, ship rat, donkey	
Natividad	736	White-tailed antelope squirrel	
Magdalena	27,773	Dog, cat, house mouse, donkey	
Santa Margarita	21,504	Dog, goat, cat, donkey, hose, white-tailed antelope squirrel	
Granito	27	Ship rat	Gulf of California
Mejía	247	House mouse, ship rat	
Angel de la Guarda	93,068	Cat, house mouse, ship rat	
Tiburon	119,875	Dog, ship rat, bighorn sheep	
San Esteban	3,966	Ship rat	
Alcatraz	50	House mouse	
San Marcos	2,855	Goat, cat	
Carmen	14,461	Goat, cat, bighorn sheep	
San Jose	18,109	Goat, donkey, cat	
San Diego	56	Goat	
San Vicente	14	House mouse	
Melliza Este	1	Ship rat	
Pajaros	82	Ship rat	
Almagre Chico	10	Ship rat	
Santa Catalina	3,890	Northern baja California deer mouse	
Espiritu Santo	7,991	Goat, cat	
Cerralvo	13,505	Goat, cat	
Saliaca	2,000	House mouse, ship rat	
El Rancho	232	House mouse, ship rat	
Roca del Coyote	25	Dog, cat	
Maria Madre	14,388	Goat, cat, ship rat, horse, rabbit	Central Pacific
Maria Magdalena	6,977	Goat, white-tailed deer, cat, ship rat	
Maria Cleofas	1,963	Goat, cat, ship rat	
Socorro	13,033	House mouse, cat	
Clarion	1,958	Rabbit	
Mujeres	396	House mouse, ship rat	Caribbean
Cozumel	47,000	House mouse, ship rat	
Holbox	5,540	Ship rat	
Pajaros	2	House mouse	
Cayo Centro	537	Ship rat, cat	

Table 5 Mexican Islands with invasive species.

Of all these islands however only 29 could be included in this prioritization analysis. Most of them had to be left out because of lack of the basic information needed; such was the case of Melliza Este, Pájaros, Almagre chico, Roca del Coyote and San Vicente in the Gulf of California, and Holbox and Pájaros in the Gulf of Mexico. In the particular case of Tiburon Island it wasn´t considered due to two reasons, the first was doubt whether the invasive ship rat is actually there, since field biologists from Conservación de Islas have spent time there and didn´t trap any, the other because the bighorn sheep cannot be considered invasive given that its population is being managed by the native Seri people who own the island and its being used as cinegetic lands for hunting (Samaniego Herrera, *pers. comm*.).

Each of the 29 islands with invasive species was characterized by its ecological and socioeconomic traits so that these data could be fed into the database for the analysis. This information is shown in Tables 6, 7, 8, 9, and 10 dividing the islands by region (figure 16). The information for fauna includes only terrestrial vertebrate species and pinnipeds. The mammal invasive species included are still present. The meaning of abbreviations used is: SEMAR= Secretaría de Marina (Navy Secretariat), SCT= Secretaría de Comunicaciones y Transportes (Communications and Transportation Secretariat), IBA= Important Bird Area (BirdLife International), AZE= Alliance Zero Extinction.

The information was gathered from both published and grey literature, different field information databases created by Conservación de Islas, as well as the following sources:

Samaniego Herrera, A., A. Peralta García & A. Aguirre Muñoz (Eds.). 2007. Vertebrados de las Islas del Pacífico de Baja California. Guía de campo. Grupo de Ecología y Conservación de Islas, A.C. Ensenada.

GECI. 2009. Proposal for the Eradication of Introduced Mice on West San Benito Island, Mexico. 40 pp.

Aguirre-Muñoz, A., J.E. Bezaury-Creel, H. de la Cueva, I.J. March-Mifsut, E. Peters-Recagno, S. Rojas-Gonzalez de Castilla & K. Santos-del Prado Gasca (Compiladores). 2010. Islas de México: Un Recurso Estratégico. Instituto Nacional de Ecología (INE), The Nature Conservancy (TNC), Grupo de Ecología y Conservación de Islas, A.C. (GECI), Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE).

CONABIO-CONANP-TNC-PRONATURA. 2007. Análisis de Vacios y Omisiones en Conservacion de la Biodiversidad Marina de Mexico: Oceanos, Costas e Islas. Comision Nacional para el Conocimiento y Uso de la Biodiversidad, Comision Nacional de Areas Naturales Protegidas, The Nature Conservancy-Programa Mexico, Pronatura, A.C. Mexico, D.F.

Gallo-Reynoso, J.P. & M.C. García-Aguilar. 2008. Analisis Preliminar De La Presencia De Perros Ferales En La Isla De Cedros, Baja California. Revista mexicana de mastozoología. 12:130-140.

Donlan, C.J., B.R. Tershy & D.A. Croll. 2002. Islands and Introduced Herbivores: Conservation Action as Ecosystem Experimentation. Journal of Applied Ecology. 39:235-246.

Oberbauer, T.A. 2000. Vegetation and Flora of Islas los Coronados, Baja California, Mexico. 12 pp.

Junak, S.A. & R. Philbrick. 2000. Flowering Plants of Natividad Island, Baja California, Mexico. 11 pp.

Carrillo-Aispuro, E.L., J.A. Castillo-Guerrero & J.A. Navarrete. 2006. Monitoreo de los Recursos Naturales en las Islas de la Zona Norte de la Bahía de Santa María – La reforma: El Rancho, Saliaca y La Garrapata. Informe técnico inédito. OIKOS-CONANP.

Jimenez Serranía, Virginia. 2005. Borrador Programa de Conservación y Manejo Área de Protección de Flora y Fauna Isla Alcatraz. Prescott College. 66 pp.

Programa de Manejo Área de Protección de Flora y Fauna Islas del Golfo. 2000 CONANP-SEMARNAT.

Programa de Manejo Complejo Insular del Espíritu Santo. CONANP-SEMARNAT. 165 pp.

Programa de Manejo Reserva de la Biosfera Isla Guadalupe. 2009. CONANP-SEMARNAT. 162 pp.

Programa de Conservación y Manejo Reserva de la Biosfera Islas Marías. 2006. CONANP-SEMARNAT.220

Programa de Conservación y Manejo Reserva de la Biosfera Archipiélago de Revillagigedo. 2004. CONANP-SEMARNAT. 222 pp.

Programa de Manejo Reserva de la Biosfera Banco Chinchorro. 2000. CONANP-SEMARNAT. 193 pp.

Programa de Manejo Parque Marino Nacional Arrecifes de Cozumel. 1998. CONANP-SEMARNAT. 166 pp.

Programa de Manejo Parque Marino Nacional, Costa Occidental de Isla Mujeres, Punta Cancún y Punta Nizuc. 1998. CONANP-SEMARNAT. 161 pp.

Figure 16 Geographical regions division for the Mexican islands.

	Table 6 Islands in the North Pacific Region						
Off the Coast	Baja California				Baja California South		
Island	Coronado Sur	Guadalupe	San Benito Oeste	Cedros	Natividad	Magdalena	Santa Margarita
Surface	122 ha	24,171 ha	386 ha	35,674 ha	728 ha	29,099 ha	21,761 ha
Distance to mainland	13 km	260 km	145 km	100 km	9.3 km	7.7 km	3 km
Species Richness	Flora 42 Fauna 36	Flora 216 Fauna 126	Flora 51 Fauna 31	Flora 52 Fauna 88	Flora 63 Fauna 17	Flora 3 Fauna 38	Flora 4 Fauna 51
Endemisms	Flora 4 Fauna 7	Flora 34 Fauna 4	Flora 8 Fauna 5	Flora 1 Fauna 12	Flora 5 Fauna 2	Flora 1 Fauna 5	Flora 0 Fauna 6
Protected Species	Fauna 18	Fauna 13	Fauna 11	Flora 9 Fauna 35	Fauna 6	Flora 1 Fauna 12	Flora 3 Fauna 21
Invasive species	House mouse, dog	House mouse, cat	Cactus mouse	Dog, goat, cat, House mouse, ship rat, donkey	Antelope squirrel	Dog, donkey, cat, house mouse	Dog, goat, donkey, horse, cat, antelope squirrel
Extinct species	0	Fauna 6	Fauna 1	0	0	0	0
Protected Area	No	Isla Guadalupe Biosphere Reserve	no	no	El Vizcaíno Biosphere Reserve	no	no
Land use	Lighthouse, SEMAR & SCT	Houses, biological station, lighthouse, SEMAR	Lighthouse, fishing camp	Houses, salt exporter, fishing camps, SEMAR, SCT	Lighthouse, houses, aquatic farm	Lighthouse, houses, fishing camp	Lighthouse, houses , SEMAR
Human Population	8	92	70	1,339	302	350	415
International Interest	IBA	IBA AZE	IBA	IBA AZE	IBA	0	IBA AZE
Economic Investment	3	1	3	1	2	1	3
Eradication Feasibility	4	1	4	1	2	2	2
Reintroduction Probability	3	2	3	1	3	2	2

	Table 7 Islands in the Gulf of California Region						
Off coast of	Baja California				Sonora	Sinaloa	
Island	Granito	Mejia	Angel de la Guarda	San Esteban	Alcatraz	El Rancho	Saliaca
surface	26 ha	244 ha	93,604 ha	4,072 ha	47 ha	232 ha	2,000 ha
Distance to mainland	75 km	76 km	30 km	54 km	1.4 km	1 km	1 km
Species Richness	Flora 4 Fauna 8	Flora 32 Fauna 8	Flora 199 Fauna 53	Flora 123 Fauna 40	Flora 43 Fauna 67	Flora 7 Fauna 65	Flora 29 Fauna 130
Endemisms	Flora 0 Fauna 6	Flora 0 Fauna 5	Flora 7 Fauna 8	Flora 2 Fauna 5	Flora 0 Fauna 2	0	0
Protected Species	Flora 0 Fauna 4	Flora 0 Fauna 4	Flora 1 Fauna 21	Flora 0 Fauna 12	Flora 1 Fauna 13	Flora 1 Fauna 6	Flora 5 Fauna 7
Invasive species	Ship rat	House mouse, ship rat	Cat, house mouse, ship rat	Ship rat	House mouse	House mouse, ship rat	House mouse, ship rat
Extinct species	Fauna 1	Fauna 1	0	0	0	0	0
Protected Area	Islas del Golfo de California Protected Area for Flora and Fauna					No	No
Land use	0	0	0	0	0	0	0
Human Population	0	0	0	0	0	0	0
International Interest	0	0	IBA	AZE	0	IBA	IBA
Economic Investment	4	4	1	1	4	4	4
Eradication Feasibility	4	4	1	2	4	4	4
Reintroduction Probability	2	2	2	3	3	1	1

	Table 8 Islands in the Gulf of California Region						
Off coast of	Baja California South						
Island	San Marcos	Carmen	San Diego	San Jose	Espiritu Santo	Cerralvo	Santa Catalina
surface	3,007 ha	15,100 ha	100 ha	19,400 ha	11,200 ha	16,000 ha	4,300 ha
Distance to mainland	15 km	7 km	90 km	82 km	25 km	15 km	52 km
Species Richness	Flora 142 Fauna 48	Flora 163 Fauna 68	Flora 75 Fauna 13	Flora 219 Fauna 92	Flora 249 Fauna 79	Flora 143 Fauna 55	Flora 122 Fauna 46
Endemisms	Flora 4 Fauna 9	Flora 4 Fauna 6	Flora 1 Fauna 2	Flora 0 Fauna 9	Flora 2 Fauna 9	Flora 5 Fauna 7	Flora 4 Fauna 9
Protected Species	Flora 0 Fauna 23	Flora 2 Fauna 22	Flora 0 Fauna 3	Flora 3 Fauna 40	Flora 4 Fauna 56	Flora 0 Fauna 15	Flora 0 Fauna 13
Invasive species	Antelope squirrel, goat, cat	Goat, cat, ship rat, house mouse, dog	Goat	Goat, donkey, cat	Goat, cat	Goat, cat	House mouse
Extinct species	0	0	0	0	0	0	0
Protected Area	Islas del Golfo de California Protected Area for Flora and Fauna						Bahia de Loreto National Park
Land use	Mining	Houses, school, ex-salt exporter	0	Fishing camp	0	0	0
Human Population	394	0	0	46	0	0	0
International Interest	IBA	IBA	0	IBA	IBA	IBA	IBA AZE
Economic Investment	4	2	3	2	3	2	1
Eradication Feasibility	4	2	4	3	4	3	3
Reintroduction Probability	2	3	3	2	3	3	3

	Table 9 Islands in the Central Pacific Region				
Off coast of	Nayarit			Colima	
Island	Maria Cleofas	Maria Magdalena	Maria Madre	Socorro	Clarión
Surface	2, 730 ha	8,677 ha	14,787 ha	13,206 ha	1,980 ha
Distance to mainland	132 km	132 km	132 km	690 km	1,000 km
Species Richness	Flora 387 Fauna 175	Flora 387 Fauna 185	Flora 387 Fauna 188	Flora 201 Fauna 150	Flora 165 Fauna 145
Endemisms	Flora 11 Fauna 14	Flora 11 Fauna 14	Flora 11 Fauna 14	Flora 41 Fauna 12	Flora 20 Fauna 6
Protected Species	Flora 6 Fauna 32	Flora 6 Fauna 32	Flora 6 Fauna 32	Flora 2 fauna 22	Flora 1 Fauna 18
Invasive species	Goat, cat, ship rat	Goat, white-tailed deer, cat, ship rat	Goat, cat, black rat, horse, rabbit	Cat, house mouse	Rabbit
Extinct species	0	0	Fauna 1	Fauna 2	0
Protected Area	Islas Marias Biosphere Reserve			Revillagigedo Archipelago Biosphere Reserve	
Land use	0	0	Federal jail	SEMAR	SEMAR
Human Population	0	0	3,980	30	30
International Interest	IBA	IBA	IBA	IBA AZE	IBA
Economic Investment	3	2	1	1	1
Eradication Feasibility	3	2	2	2	2
Reintroduction Probability	3	3	1	3	3

	Table 10 Islands in the Caribbean Region		
Off coast of	Quintana Roo		
Island	Cayo Centro	Cozumel	Mujeres
Surface	611 ha	60,000 ha	8,673 ha
Distance to mainland	30 km	16 km	6 km
Species Richness	Flora 78 Fauna 107	Flora 68 Fauna 334	Flora 11 Fauna 53
Endemisms	Flora 2 Fauna 0	Flora 0 Fauna 26	0
Protected Species	Flora 5 Fauna 5	Flora 8 Fauna 48	Flora 4 Fauna 4
Invasive species	Cat, ship rat	House mouse, ship rat	Ship rat
Extinct species	0	0	0
Protected Area	Banco Chinchorro Biosphere Reserve	Arrecifes de Cozumel Marine National Park	Costa occidental de Isla Mujeres, Punta Cancun y Punta Nizuc Marine National Park
Land use	Lighthouse, biological research station	City	Hotels, airport, fishing camp
Human Population	50	77,326	12,642
International Interest	0	IBA AZE	0
Economic Investment	3	1	2
Eradication Feasibility	4	1	2
Reintroduction Probability	3	1	1

Results

Three different multi-criteria analyses were made in order to know the difference between three important aspects of this decision making process: the first was based only on biodiversity values, second based on strategy, and the final third including both aspects.

For the biodiversity values analysis, the data from endemism, species richness, species included in the NOM-059-SEMARNAT-2001 of threatened species and whether the island is recognized as Important Bird Area and Site of the Alliance Zero Extinction, was considered in the following way (table 11).

Criterion	Straight Rank	Weight	Normalized Weight
Endemism	1	4	0.4
IBA & AZE	2	3	0.3
NOM059	3	2	0.2
Species Richness	4	1	0.1
Total: 4		10	1.00

Table 11 Rank Sum method for Biodiversity Value Analysis.

The software ArcGis 10 includes the model builder, which allows showing graphically the steps and processes followed in the analysis run. For the biodiversity value analysis the model builder was as shown on figure 17.

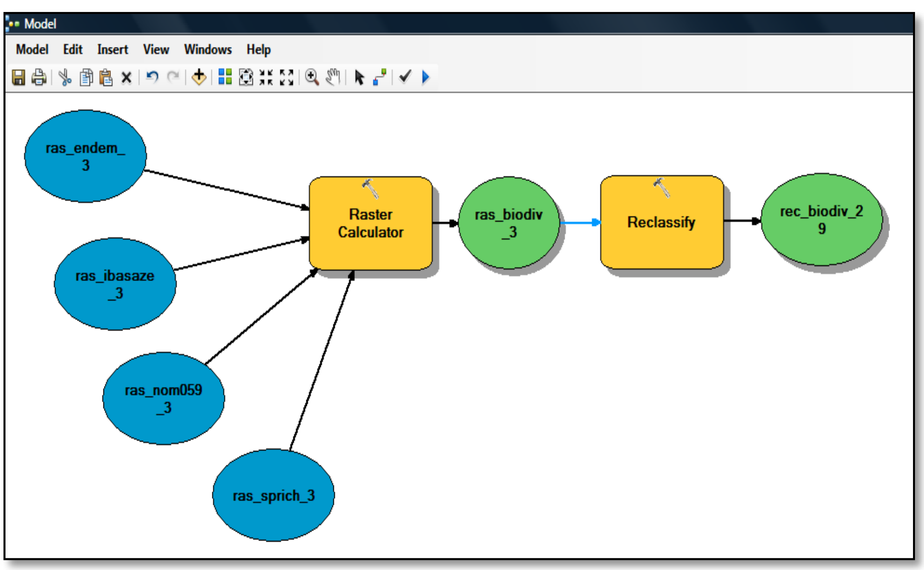


Figure 17 ArcGis model builder for the biodiversity value analysis.

First the analysis was run so that we could obtain a prioritization order for each of the 29 islands based on its biodiversity value (Figure 18). The results show that the Islas Marias Archipelago are of the utmost importance for biodiversity conservation, followed by Cozumel, Socorro and Guadalupe, while the small Mejia and Granito islands of the Gulf of California are of poorer on biodiversity.

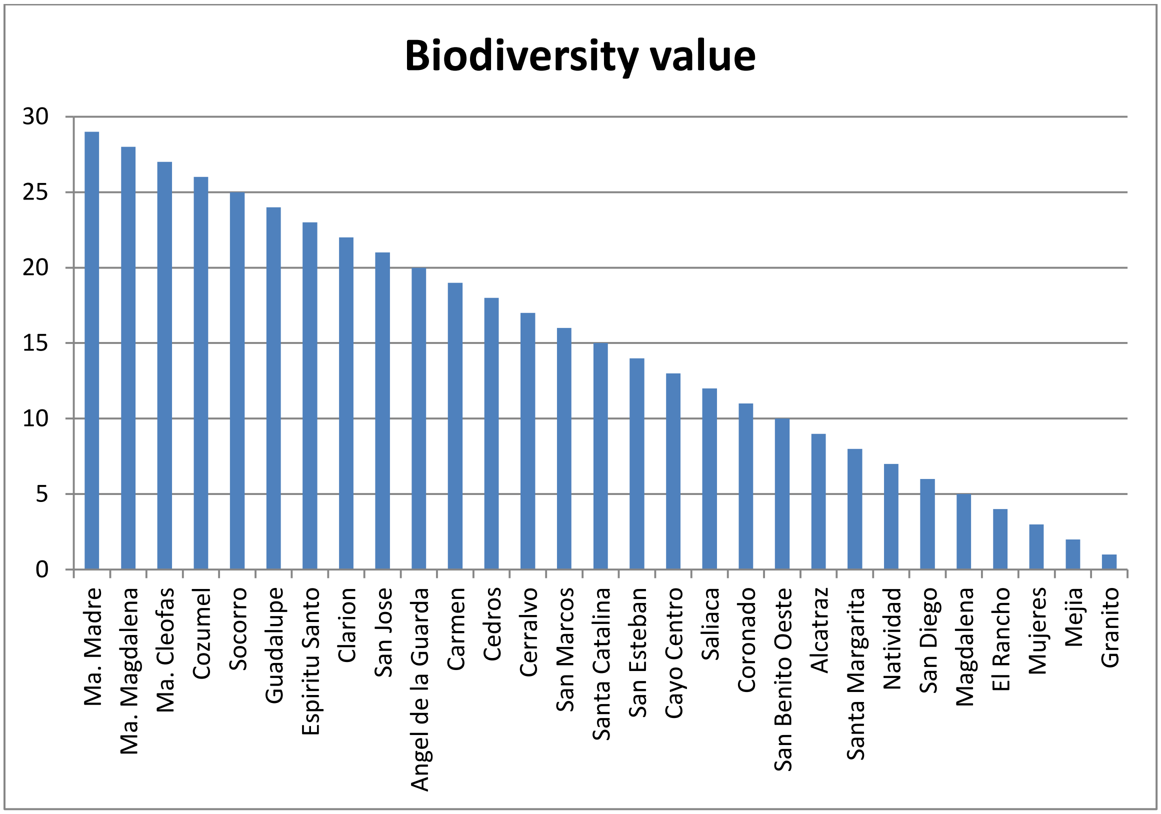


Figure 18 Histogram of biodiversity value for the Mexican Islands with invasive species.

A second analysis was run with the difference that the islands were divided in 4 categories by an equal interval classification, for each attribute –species richness, endemism, etc- to thus obtain packages of prioritization (table 12).

Island	Biodiversity
Socorro	1
Cozumel	
Ma. Cleofas	
Ma. Magdalena	
Ma. Madre	2
Guadalupe	
Clarion	
Espiritu Santo	
San Jose	
Angel de la Guarda	
Carmen	3
Cedros	
San Marcos	
Santa Catalina	
Santa Margarita	
Cerralvo	
San Esteban	
Cayo Centro	
Saliaca	
Coronado	
San Benito Oeste	
Alcatraz	4
Natividad	
San Diego	
Magdalena	
El Rancho	
Mujeres	
Mejia	
Granito	

Table 12 Prioritization for Biodiversity Value.

For the strategy analysis three criteria were considered: probability of reintroduction of an invasive species to the island, feasibility of the eradication campaign, and economic cost of the eradication itself. There were 4 set of categories for each criteria, and experts from Conservación de Islas, where asked to rank the islands based on their knowledge and experience, giving the category 1 to the most possibility of reintroduction/ most difficult eradication campaign/ most expensive cost for eradication efforts, and downgrading to category 4 to the least possibility of reintroduction/ easiest eradication campaign / least costly eradication efforts.

These criteria were also given weight through the rank sum method (table 13).

Criterion	Straight Rank	Weight	Normalized Weight
Probability of reintroductions	1	3	0.5
Feasibility of the eradication	2	2	0.3
Economic cost of the eradication	3	1	0.2
Total	3	6	1.00

Table 13 Weight assigned to the criteria for the strategy analysis.

The process run for the strategy analysis is shown on the model builder figure 19.

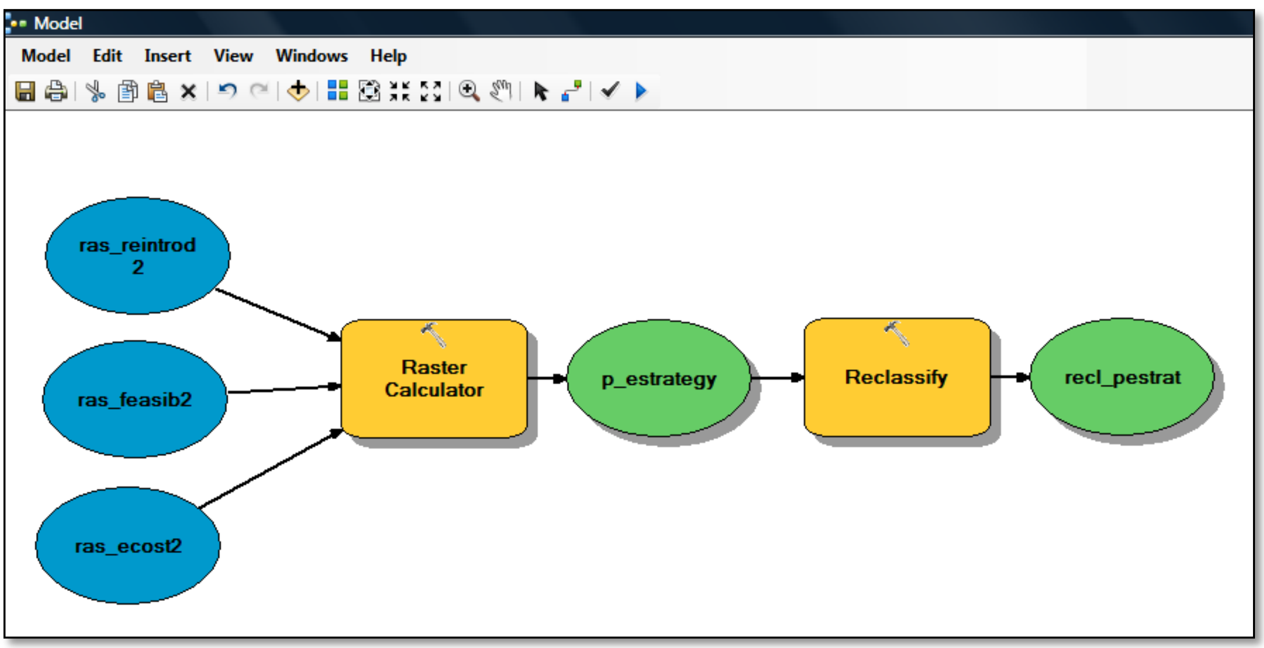


Figure 19 ArcGis model builder for the strategy analysis.

Therefore the result for the strategy analysis was also packages of prioritization categories (table 14).

Island	Strategy
Ma. Cleofas	1
Espiritu Santo	
San Marcos	
Cayo Centro	
Coronado	
San Benito Oeste	
Alcatraz	
San Diego	
Mejia	
Granito	
Socorro	2
Ma. Magdalena	
Clarion	
San Jose	
Carmen	
Cerralvo	
Santa Catalina	
San Esteban	
Saliaca	
Natividad	
El Rancho	3
Santa Margarita	
Magdalena	4
Cozumel	
Ma. Madre	
Guadalupe	
Angel de la Guarda	
Cedros	
Mujeres	

Table 14 Prioritization categories for the strategy analysis.

For the final and complete prioritization analysis combining both the biodiversity and strategy criteria, the weights were assigned in the following way (table 15).

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

Table 15 Rank sum method for the final prioritization analysis.

The process run for the final prioritization analysis is shown on model builder figure 20.

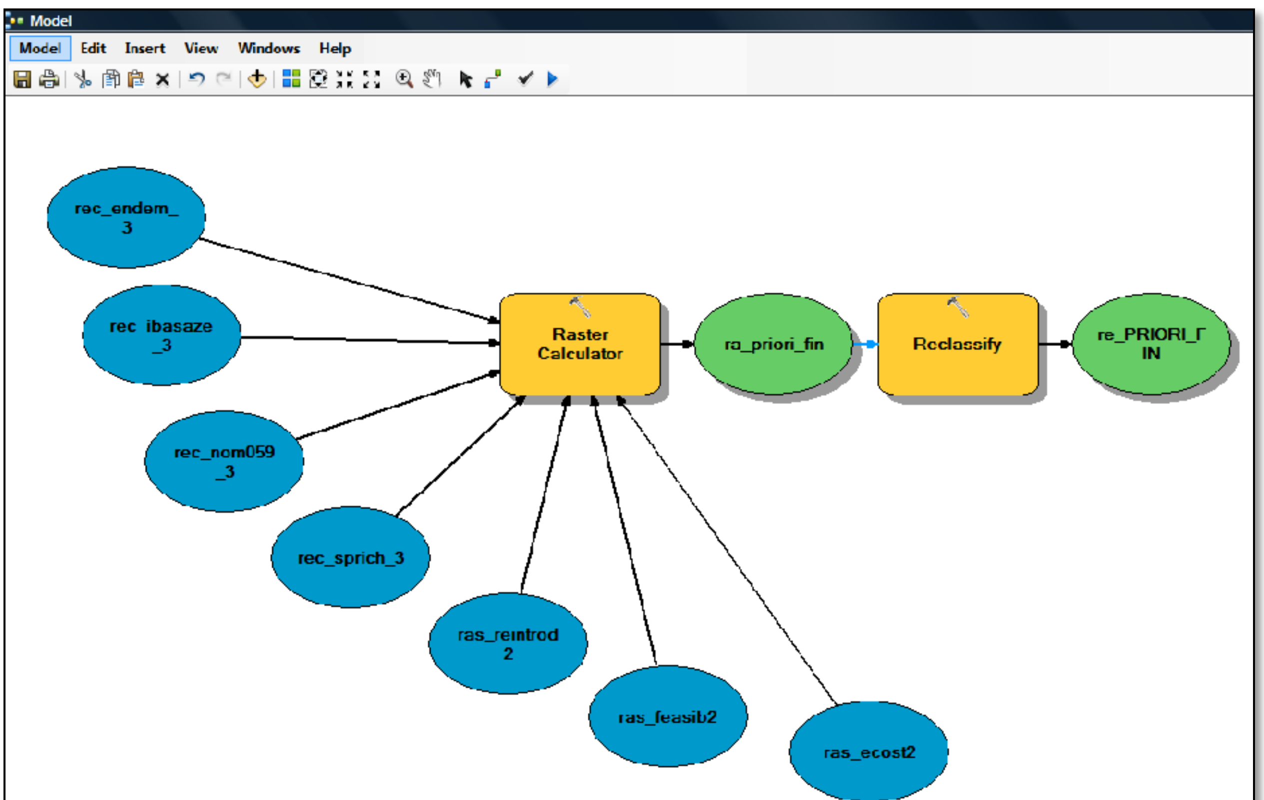


Figure 20 ArcGis model builder for the final priority analysis.

The results are a combination of all the attributes of importance and derive from the decision rules set beforehand. In table 16 the results for each analysis are shown so that they can be compared.

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

Table 16 Comparison of priorities for each analysis made.

Figure 21 Final map of restoration priorities for the Mexican Islands.

Figure 22 Restoration priorities for the northwest region.

Figure 23 Restoration priorities for the tropical and central pacific region.

Figure 24 Restoration priorities for the Caribbean region.

Discussion

This multi-criteria prioritization effort achieved grouping the islands in to 4 categories depending on the characteristics of the islands. It is also very interesting to see the differences between the islands set as priorities based only for biodiversity values or strategy with those in the final group merging both aspects. Noticeable is that, as was designed by the setting of weights in the analysis, the biodiversity values prevailed over strategy.

The first priority group, Socorro, Cozumel, Maria Cleofas, Maria Magdalena (from the Islas Marias Archipelago) and Espiritu Santo islands, is comprised by some of the islands with the highest endemism value and highest species richness documented. All of these islands were also recognized as priorities in the “Conference for Conservation and Sustainable Development of the Mexican Islands” in 2009, which included all of the Mexican islands –not just those with invasive species present- divided by regions, and acknowledging the threat of invasive species as their greatest conservation concern, in the case of these islands (Aguirre Muñoz *et al.,* 2010). The island that stands out the most from this group is Cozumel, given its low score on the strategy analysis; so even though it is definitely one of the most important islands in Mexico and restoration measures should be implemented, eradications projects would be extremely difficult given the size of its human population and urban development, difficulty in preventing reintroductions, size of the island, many non-target species that could be affected and sheer cost of the project. Meanwhile Maria Cleofas and Espiritu Santo are first in the strategy analysis, meaning their eradication projects are the most feasible from the group, with Socorro and Maria Magdalena in second place.

The second priority group, Maria Madre (from the Islas Marias Archipelago), Guadalupe, Clarion and San Jose, is also formed by islands with high endemism value but a little lower species richness, which is logical given the further distances from mainland –Guadalupe and Clarion Islands- as the theory of island biogeography predicts. All of these islands were also recognized as priorities in the above mentioned conference, San José Island as a part of the Bahía de Loreto Archipelago. From this group the islands Maria Madre and Guadalupe are also part of the last strategy category; in the case of Maria Madre this is due to the fact that a federal prison is located there, its highly populated, and there are several endemic mammals for which mitigation efforts would be complex; while for Guadalupe island the main reasons are the size of the island and its remoteness, making the eradication very expensive.

The third priority group is the largest of all, comprising Angel de la Guarda, Carmen, Cedros, Cerralvo, San Marcos, Santa Catalina, San Esteban, Cayo Centro (from Banco Chinchorro), Saliaca, Coronado, San Benito Oeste and Santa Margarita islands. While most of the islands from this category were also recognized as priorities in the previous conference, some of them were not; such was the case of Coronado, Santa Margarita, Saliaca and Cayo Centro. Furthermore most of the islands in this group are categorized as most feasible eradications in the strategy analysis; leaving out only Angel de la Guarda and Cedros Island, both due mostly to their enormous sizes and presence of native mammals.

The fourth and last group, conformed by Alcatraz, Natividad, San Diego, Magdalena, El Rancho, Mujeres, Mejia and Granito, is also the group with the least worth in the biodiversity value analysis, but some of the highest scores in the strategy analysis; except for Mujeres Island which is in the last strategy category mostly due to the numerous tourism activities and high probability of reintroduction of invasive species. Of these islands only Mejia, Granito and San Diego were recognized as priorities in the island conservation conference, but only because they are part of the area known as Region de las Grandes Islas (Big Islands Region) and Loreto Archipelago, respectively.

The Tropical Pacific region is where the islands hold the highest priority category, as can be seen in the map (figure 23). There the islands hold some of the highest species richness and endemisms, which is in accordance with their tropical zone. Also some of the documented extinctions due to invasive species have occurred there, the Nelson's rice rat in Maria Madre and the Elf owl and Socorro dove in Socorro Island. The Northwest Mexico region (figure 22) including the Gulf of California is where most islands are, however, they are probably lower in species richness given their climatic conditions and more desertic vegetation; however they are high on endemism rate and very important areas for the breeding and nesting of seabirds and pinnipeds. The South Mexico region (figure 24) is also high on species richness, given their tropical location, but lower on endemisms probably given their proximity to land and small sizes –except for Cozumel island-.

Nation-wide prioritizations are recognized as more cost-effective than planning for regions separately (Arponen, 2011). In fact there are several countries that have undertaken the task of prioritizing their island restoration needs, such as New Zealand, Australia and the United States, among others. Each country has taken different approaches to their analyses, for example the United States based it only on biological considerations and left out costs (U.S. F&WS, 2009). It is believed that after priorities have been set, the benefits and strategies for implementing those eradication priorities in a sequence designed explicitly to seek minimized program costs should be evaluated, in order to achieve the biodiversity, economic and social goals previously set. These sequences refer to supporting eradications for whole archipelagos or clusters of islands, and thus achieve efficiencies in planning and implementation that could result in a higher return on investment (Saunders *et al*., 2011). For the Mexican Islands this would mean focusing first perhaps on the Islas Marias Archipelago, where 3 islands have been grouped in the first and second priority category, the same for the remote Revillagigedo Archipelago.

The spatial analyses, through Geographic Information Systems, provide many advantages. This is of importance in conservation planning and strategic planning, because management should be adaptive and dynamic (Margules & Sarkar, 2007) so that the model can be perfected and can help decision makers in more precise ways. There is only one aspect of Geographic Information Systems that should be taken in consideration for its use in regards with islands, and that is the scale. Since the Mexican islands vary widely in sizes, if all of the islands wanted to be integrated in one analysis it would represent a problem, because some of them are so small that even with the finest pixel cell size resolution they cannot be represented in the same raster map. For this analysis the pixel size had to be set to 0.4 (default size is 5) so that all the islands could be represented in the raster information and their weights summed for the analysis.

For this analysis only the islands with invasive mammal species were taken into account, this due to several facts, first that mammals have caused more problems than any other vertebrate group (Ebenhard, 1988, Lever, 1994 in Courchamp, 2003), but also because their eradication is more feasible with the knowledge, methods and tools that exist today. However it should be remarked that there are islands in Mexico with the presence of invasive reptiles that can also be very harmful to native species, not to mention invasive flora which disrupts entire ecosystems and restoration efforts are crucial to conserve species and the capacity of the islands to provide their ecosystem services.

It is important to mention that there is an important gap of information for many islands, which had to be left out of this analysis, but yet another problematic is the inconsistencies in the literature for the same island, which makes the gathering of reliable information for the analysis difficult. In this study this was partly dealt with by recategorizing the basic biodiversity information (species richness, endemism, species under protection) into groups, so that if maybe the exact number of species richness wasn´t correct it would still be in the group of islands that have the same characteristics. This recategorization of information is mentioned by Maguire (2011) as something that should be avoided during prioritization analysis, but was found to be best in this particular case, knowing that perhaps in the future, when better baseline information is available it could be analyzed again more precisely.

The results of this study provide important information for both the "Estrategia Nacional sobre especies invasoras en México" (National Strategy for Invasive Species in Mexico); especially in regards to their strategic action number 5, to generate knowledge for an informed decision making, so that society can responsibly assume actions to prevent, control and eradicate invasive species (Comité Asesor Nacional sobre Especies Invasoras, 2010); and the "Estrategia Nacional para la Conservación y el Desarrollo Sustentable del Territorio Insular Mexicano" (National Strategy for the Conservation and Sustainable Development of the Mexican Insular Territory) currently under public consultation, in one of their basic principles –attention to priorities- which sets goals to eradicate all invasive species populations in the Mexican islands with a long term plan (Comité Asesor Nacional sobre el Territorio Insular Mexicano, 2011).

There is much room for improvement in this analysis, if the baseline information were available; such as integrating invertebrate species to the analysis. There are many endemic insects in the Mexican islands which also play a major role in the ecosystem, and are affected by invasive species and should be protected; however there is much need for research in the area. Also the important role of climate change could be integrated in an analysis to see which islands and species would be most impacted in the future, especially since it has been demonstrated that they have strong connections and each exacerbates the effects of the other (Pyke *et al.,* 2008) so that mitigation methods can be put in place.

Conclussions

One of the biggest threats of invasive species is the homogenization of species across the globe by the loss of biodiversity. This biodiversity provides crucial ecosystem services that are fundamental for our planets life support system. Invasive species affect not only biodiversity but humans directly in several dimensions such as health and economy and should therefore be managed accordingly.

Islands are disproportionately high in biodiversity and endemism and should thus be a priority for conservation, but furthermore they provide the most cost-effective opportunities for protecting many endangered species. Therefore their ecological restoration and conservation is critical, moreover eradications worldwide have proven to be a powerful tool in the prevention of extinctions.

The results of this analysis provides important information for conservation practitioners and environmental agencies as to where and when to channel the limited resources for restoration and be sure that their investment has the highest conservation gains. The database generated by the characterization of the islands could continue to grow and serve in further analysis. The set of priority categories could also help plan the timing of eradication campaigns in a more cost-efficient manner.

Of course every eradication project must be accompanied by an equally important reintroduction prevention system and environmental education plan adequate for each particular islands condition, and monitored for a long term after the eradication with an early detection system for invasive species. The islands designated as top priority where eradication projects may prove extremely difficult, such as Cozumel, Maria Madre and Guadalupe should be protected through other restoration methods, such as control of the population of invasive species or fencing, among others.

Through the implementation of future restoration actions Mexico will continue to contribute greatly to the Aichi Biodiversity targets set by the Convention on Biological Diversity, as well as its own long-term conservation aims set in the national strategy for invasive species and national strategy for the conservation and sustainable development of the insular territory.

The strategic management of the islands would gain greatly by the creation of indicators of success, both for the eradication, prevention, control and mitigation of invasive species, so that set targets would be easier to monitor and achievements analyzed in the long term objectives for the conservation of the Mexican islands and their natural and cultural heritage.

Cited Literature:

Aguirre-Muñoz, A., D.A. Croll, C.J. Donlan, R. W. Henry III, M.A. Hermosillo, G.R. Howald, B.S. Keitt, L. Luna-Mendoza, M. Rodríguez-Malagón, L.M. Salas-Flores, A. Samaniego-Herrera, J.A. Sánchez-Pacheco, J. Sheppard, B.R. Tershy, J. Toro-Benito, S. Wolf & B. Wood. 2008. High-Impact Conservation: Invasive Mammal Eradications from the Islands of Western Mexico. Ambio. 37(2):101-107.

Aguirre-Muñoz, A., R. Mendoza Alfaro *et al.* 2009. Especies Exóticas Invasoras: Impactos Sobre las Poblaciones de Flora y Fauna, los Procesos Ecológicos y la Economía, en Capital natural de Mexico, vol. II: Estado de conservación y tendencias de cambio. CONABIO, Mexico. Pp. 277-318.

Aguirre-Muñoz, A., J.E. Bezaury-Creel, H. de la Cueva, I.J. March-Mifsut, E. Peters-Recagno, S. Rojas-Gonzalez de Castilla & K. Santos-del Prado Gasca (Compiladores). 2010. Islas de México: Un Recurso Estratégico. Instituto Nacional de Ecología (INE), The Nature Conservancy (TNC), Grupo de Ecología y Conservación de Islas, A.C. (GECI), Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE).

Aguirre-Muñoz, A., M. Rodríguez-Malagón, A. Samaniego-Herrera, L. Luna-Mendoza, A. Ortiz-Alcaraz, F. Méndez-Sánchez, M. Félix-Lizárraga & M. Latofski-Robles. 2011a. Community and Social Actors Involvement in Conservation on Mexican Islands. In: ICCB 2011 Engaging Society in Conservation. 25th International Congress for Conservation Biology. New Zealand.

Aguirre-Muñoz, A., A. Samaniego-Herrera, L. Luna-Mendoza, A. Ortiz-Alcaraz, M. Rodriguez-Malagón, F. Méndez-Sánchez, M. Félix-Lizárraga, J.C. Hernandez-Montoya, R. Gonzalez-Gómez, F. Torres-García, J.M. Barredo-Barberena & M. Latofski-Robles. 2011b. Island Restoration in Mexico: Ecological Outcomes after Systematic Eradications of Invasive Mammals. In: Veitch, C.R., M.N. Clout & D.R. Towns (Eds). Island Invasives: Eradications and Management. IUCN. Gland, Switzerland.

Arponen, A., M. Cabeza, & M. Moilanen. 2011. Spatial Conservation Prioritization for Multiple Administrative Regions. In: ICCB 2011 Engaging Society in Conservation. 25th International Congress for Conservation Biology. New Zealand.

Balmford, A., K.J. Gaston, S. Blyth, A. James & V. Kapos. 2003. Global Variation in Terrestrial Conservation Costs, Conservation Benefits and Unmet Conservation Needs. PNAS. 100:1046-1050.

Blackburn, Tim M. 2008. Using Aliens to Explore How Our Planet Works. PNAS. 105(1):9-10.

Brooke, M. de L., G.M. Hilton & T.L.F. Martins. 2007. The Complexities of Costing Eradications: A Reply to Donlan & Wilcox. Animal Conservation. 10:157-158.

Butchart, S.H.M. 2011. Eradicating Invasives: Where Next? In: ICCB 2011 Engaging Society in Conservation. 25th International Congress for Conservation Biology. New Zealand.

Campbell, K. & C. J. Donlan. 2005. Feral Goat Eradications on Islands. Conservation Biology. 1362-1374.

Carrion, V., C.J. Donlan, K.J. Campbell, C. Lavoie, F. Cruz. 2011. Archipelago-Wide Island Restoration in the Galapagos Islands: Reducing Costs of Invasive Mammal Eradication Programs and Reinvasion Risk. PLoS ONE 6(5):1-7.

Carwardine, J., K.A. Wilson, G. Ceballos, P.R. Ehrlich, R. Naidoo, T. Iwamura, S.A. Hajkowicz & H.P. Possingham. 2008. Cost-Effective Priorities for Global Mammal Conservation. PNAS. 105(32):11446-11450.

Clout, M.N. & J. Russell. 2007. The Invasion Ecology of Mammals: A Global Perspective. Wildlife Research. 35:180-184.

Comité Asesor Nacional sobre Especies Invasoras. 2010. Estrategia Nacional Sobre Especies Invasoras en México, Prevención, Control Y Erradicación. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Comisión Nacional de Áreas Naturales Protegidas, Secretaría de medio Ambiente y Recursos Naturales. México.

Comité Asesor Nacional sobre el Territorio Insular Mexicano (CANTIM). 2011. Estrategia Nacional para la Conservación y el Desarrollo Sustentable del Territorio Insular Mexicano. Documento para Consulta Pública. Instituto Nacional de Ecología, Comisión Nacional de Áreas Naturales Protegidas, Secretaría de Medio Ambiente y Recursos Naturales, Secretaría de Gobernación, Grupo de Ecología y Conservación de Islas, A.C. México, D.F. y Ensenada, B.C. 121 pp.

CONABIO-CONANP-TNC-PRONATURA. 2007. Análisis de Vacios y Omisiones en Conservación de la Biodiversidad Marina de México: Océanos, Costas e Islas. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Comisión Nacional de Áreas Naturales Protegidas, The Nature Conservancy-Programa México, Pronatura, A.C. México, D.F.

Convention on Biological Diversity. Strategic Plan for Biodiversity 2011-2020. Available at: https://www.cbd.int/sp/targets/ Visited: 16/06/2012.

Croll, D.A. & B.R. Tershy. 2011. Invasive Vertebrates on Islands: Scope of the Problem, Data Needs, and Approaches. In: ICCB 2011 Engaging Society in Conservation. 25th International Congress for Conservation Biology. Auckland, New Zealand.

Courchamp, F., J.L. Chapuis & M. Pascal. 2003. Mammal Invaders on Islands: Impact, Control and Control Impact. Biol. Rev. 78:347-383.

Cushman, J.H. 1995. Ecosystem-Level Consequences of Species Additions and Deletions on Islands. Pp. 135-147. *In*: Vitousek P.M., L.L. Loope & H. Anderson (Eds.). Islands: Biological Diversity and Ecosystem Function. Berlin, Germany. Springer-Verlag.

Diamond, J. & T. Case. 1986. Introductions, Extinctions, Exterminations and Invasions. In: Community Ecology. Harper and Row. New York.

Donlan, C.J., B.R. Tershy, K. Campbell & F. Cruz. 2003. Research for Requiems: the Need for More Collaborative Action in Invasive Species Management and Conservation. Conservation Biology. 17:1850-1851.

Donlan, C.J. & C. Wilcox. 2007. The Complexities of Costing Eradications. Animal Conservation. 10:156-158.

Harris, D.B., S.D. Gregory, L.S. Bull & F. Courchamp. 2011. Island Prioritization for Invasive Rodent Eradications with an Emphasis on Reinvasion Risk. Biological Invasions. 13 pp.

Howald, G., K.R. Faulkner, B. Tershy, B. Keitt, H. Gellerman, E. M. Creel, M. Grinnel, S. Ortega & D.A. Croll. 2005. Eradication of Black Rat from Anacapa Island: Biological and Social Considerations. Pages 299-312. In: Gardelon & Schwemm (Eds.). Proceedings of the sixth California Island Symposium. Institute for Wildlife Studies, Arcata, California.

Howald, G., C.J. Donlan, J.P. Galvan, J.C. Russell, J. Parkes, A. Samaniego, Y. Wang, D. Veitch, P. Genovesi, M. Pascal, A. Saunders & B. Tershy. 2007. Invasive Rodent Eradication on Islands. Conservation Biology. 21(5):1258-1268.

Instituto Nacional de Estadística, Geografía e Informática (INEGI) 2005. Territorio Insular de México. Continuo Nacional, Primera Edición, Escala 1:250 000. Instituto Nacional de Estadística, Geografía e Informática. Aguascalientes, Aguascalientes, México.

Instituto Nacional de Estadística, Geografía e Informática (INEGI). 2009. Catálogo del Territorio Insular. Instituto Nacional de Estadística, Geografía e Informática. Encuentro Nacional para la Conservación y el Desarrollo Sustentable de las Islas de México. Presentación de Francisco Takaki Takaki. 23 a 26 de junio 2009. Ensenada, Baja California.

Kier, G., H. Kreft, T.M. Lee, W. Jetz, P.L. Ibisch, C. Nowicki, J. Mutke & W. Barthlott. 2009. A Global Assessment of Endemism and Species Richness across Island and Mainland Regions. PNAS 106(23):9322-9327.

Koleff, P. & T. Urquiza-Haas. 2011. Complementarity as a Strategy for Ecorregional Priorization. In: ICCB 2011 Engaging Society in Conservation. 25th International Congress for Conservation Biology. Auckland, New Zealand.

MacArthur, R.H. & E.O. Wilson. 2001.The Theory of Island Biogeography. 13th Edition. Princeton, New Jersey. Princeton University Press. 203 pg.

Mack, R.N., D. Simberloff, W.M. Lonsdale, H. Evans, M.N. Clout, & F. Bazazz. 2000. Biotic Invasions: Causes, Epidemiology, Global Consequences and Control. Ecological Applications. 10: 689-710.

Maguire, L.A. 2011. Improving Multicriteria Rating Systems for Setting Conservation Priorities. In: ICCB 2011 Engaging Society in Conservation. 25th International Congress for Conservation Biology. Auckland, New Zealand.

Margules, C.R. & S. Sarkar. 2007. Planeación Sistemática de la Conservación. Cambridge University Press.

Martins, T.L.F., M. de L. Brooke, G.M. Hilton, S. Farnsworth, J. Gould & D.J. Pain. 2006. Costing Eradications of Alien Mammals From Islands. Animal Conservation. 1-6.

McCreless, E., C. Wilcox, D. Spatz, D. Croll & B. Tershy. 2011. Development of Novel Quantitative Approaches for Prioritizing Eradications. In: ICCB 2011 Engaging Society in Conservation. 25th International Congress for Conservation Biology. Auckland, New Zealand.

Mulongoy, K.J., Webbe, J., Ferreira, M. & C. Mittermeier. 2006. The Wealth of Islands –A Global Call for Conservation. Special Issue of the CBD Technical Series, Montreal, vi+23 pages.

Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A.B. da Fonseca & J. Kent. 2000. Biodiversity Hotspots for Conservation Priorities. Nature. 403:853-858.

Pyke, C.R., R. Thomas, R.D. Porter, J. J. Hellman, J.S. Duke, D.M. Lodge & G. Chavarria. 2008. Current Practices and Future Opportunities for Policy on Climate Change and Invasive Species. Conservation Biology. 22(3):585-592.

Samaniego-Herrera, A., A. Aguirre-Muños, M. Rodriguez-Malagon, R. Gonzalez-Gomez, F. Torres-García, F. Méndez-Sánchez, M. Félix-Lizárraga & M. Latofski-Robles. 2011. Rodent Eradications on Mexican Islands: Advances and Challenges. Pages 350-355. In: Veitch, Clout & Towns (Eds.). Island Invasives: eradication and management. IUCN, Gland, Switzerland.

Saunders, A., J.P. Parkes, A. Aguirre-Muñoz, & S.A. Morrison. 2011. Increasing the Return on Investments in Island Restoration. Pages 492-495. In: Veitch, Clout & Towns (Eds.). Island Invasives: eradication and management. IUCN, Gland, Switzerland.

Thomas, B.W. & R. H. Taylor. 2002. A History of Ground-Based Rodent Eradication Techniques Developed In New Zealand, 1959-1993. Pages 301-310 in: Veitch & Clout (Eds.). Turning the tide: the eradication of invasive species. World Conservation Union, SSC Invasive Species Specialist Group, Gland, Switzerland.

Towns, D.R. & K.G. Broome. 2003. From Small Maria To Massive Campbell: Forty Years Of Rat Eradications From New Zealand Islands. New Zealand Journal of Zoology. 30:377-398.

United Nations. Millenium Development Goals. Available at: http://www.un.org/millenniumgoals/environ.shtml visited: 16/06/2012

U.S. Fish and Wildlife Service. 2009. Priorities for Restoration of islands Addressing Invasive Species. Availabe at: http://www.fws.gov/migratorybirds

Velarde, E. & D.W. Anderson. 1994. Conservation and Management of Seabird Islands in the Gulf of California: Setbacks and Successes. In: Nettleship, Burger & Gochfeld (Eds). Seabirds on islands: threats, case studies and action plans. Pp. 229-243. Birdlife International. Cambridge.

Whittaker, R.J. & J.M. Fernandez-Palacios. 2007. Island Biogeography. Oxford University Press. Oxford, UK. 2nd Edition.