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Plant endemism and natural protected areas in the peninsula of Baja California, Mexico

Hugo Riemann [a,*], Exequiel Ezcurra [b]

[a] *El Colegio de la Frontera Norte, km 18.5 Carretera escénica, Tijuana – Ensenada, San Antonio del Mar, Baja CA 22709, México*
[b] *Instituto Nacional de Ecología, Av. Periférico Sur 5000, Delegación Coyoacán 04530, México*

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Abstract

The Peninsula of Baja California, Mexico has long been recognized as a hotspot for plant richness and endemism. However, its extraordinary diversity is not adequately protected by the existing protected areas. We analyzed the distribution of the endemic vascular flora of the peninsula, and its presence or absence in protected areas. We also identified regions with greater numbers of endemic species not currently under protected status. The families Asteraceae, Cactaceae, and Fabaceae alone contain 40% of the endemic species. All the peninsular species within the Begoniaceae, Thymeliaceae, Araliaceae and Hippocastanaceae are endemic. Of the total number of endemic taxa in the region, 76.4% are present within protected areas. The endemic genera *Adenothamnus*, *Carterothamnus*, *Faxonia*, and *Ornithostaphylos* are entirely absent from protected areas. Of the 567 endemics found in protected areas 75 represent varieties or subspecies Of the 175 not found in protected areas 21 are varieties or subspecies. A gap analysis identified that the areas with the highest number of unprotected endemic species are in the Mediterranean-type ecosystems of the northwest part of the peninsula and in the deciduous dry tropical communities of the cape region at the southernmost tip of Baja California. Our findings suggest that it is necessary to create several protected areas along the peninsula for the successful conservation of rare and endemic taxa These new areas should encompass a latitudinal gradient of biogeographical units (including Mediterranean communities and montane habitats of the Sierras) along the peninsula.

1. Introduction

1.1. Endemism in Baja California

One of the most important criteria used in the identification of high-priority areas for conservation is endemism, (i.e., species of local, ecoregional, or national distribution Olson and Dinerstein, 1998; Mittermeier et al., 1998; Stattersfield et al., 1998; WWF and IUCN, 1994–1997). However, in some areas a high number of endemics may not correspond to high species richness (Prendergast et al., 1993). In Mexico, this low association between diversity and number of endemic species is noticeable in several groups, especially in vertebrates (Ceballos et al., 1998; Flores Villela, 1993; Escalante et al., 1993). Mexico as a whole has a clear dissociation between plant species richness and endemism. For example, the species rich tropical forest in the south-east has a low proportion of endemic species, whereas there are a high proportion of endemic plants in the temperate and arid northern ecoregions.

Thus, in the drylands and temperate ecosystems of northern Mexico endemism should be a primary reason to designate protected areas. A case in point is the Baja California peninsula and associated islands. Here, Wiggins (1980) described 2934 plant species, approximately 20% of which are endemic to the peninsula. The high number of endemic plant species in this region

* Corresponding author.
E-mail address: riemann@colef.mx (H. Riemann).

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is possibly the result of two processes that favor biological speciation: (1) the landscape heterogeneity and (2) isolation of the Baja California peninsula. According to Peinado et al. (1994), the numerous boundaries and ecotones between zones of limited and insufficient rainfall influenced the process of adaptive radiation that gave rise to the Pleistocene neoendemics in this region. Alternatively, the Tertiary paleoendemics owe their presence to the long-term climatic stability of regions near the Pacific Ocean (Peinado et al., 1994). Another possibility is that surviving species have gone extinct in other regions.

The purpose of this paper is to provide direction for future policies of conservation and sustainable use. We analyzed how well represented are the endemic vascular plants of Baja California in its protected areas. We identified regions with high endemism that are currently unprotected.

1.2. Protected areas in Baja California

The Baja California peninsula and neighboring islands have been the subject of 14 decrees of protected areas. Several correspond to vague pronouncements declaring large forest reserves that were originally created for reasons other than biodiversity conservation that are not enforced in practice and that have poorly defined boundaries. Therefore, 65,725 km^2 are currently under some effective protection regime, including six biosphere reserves, two national parks, one flora and fauna protection area and two marine national parks. Of the total protected area, 85.3% correspond to terrestrial environments, representing 39.5% of the total land area of the region (Table 1 and Fig. 1).

1.2.1. The study area

The study region encompasses the Baja California peninsula, Guadalupe Island in the Pacific, and the islands of the Sea of Cortés that fall under the administration of the political states of Baja California and Baja California Sur (Fig. 1). The peninsula is approximately 1300 km long and 45–250 km wide. The study area represents a region of approximately 143,000 km^2, spanning almost 10 degrees of latitude from 22°53′N in the Cape Region to 32°46′N in the Mexico–US border.

The peninsula of Baja California was formed during the Tertiary (some 5–10 million years ago), when this narrow sliver of land was detached from the mainland by tectonic forces, creating the Sea of Cortés. A series of mountain ranges (sierras) run north-south along the peninsula (Fig. 1). This steep mountain backbone separates the ecosystems sloping into the Sea of Cortés from those running into the Pacific and creates a complex physiographic gradient with a large diversity of environments and landscapes so contrasting as the Mediterranean ecosystems and the sonoran desert in less than 100 km in a west-east direction.

The peninsula is covered with 20 different types of climates (in Köppen's classification), that go from very arid to temperate (García, 1988). Most of Baja California has mean annual temperatures above 18 °C and mean annual rainfall lower than 200 mm. The highest rainfall (500–700 mm) occurs in the high parts of the Sierras of San Pedro Mártir and La Laguna, in both latitudinal extremes of the peninsula. The most adverse climatic conditions occur along the coasts of the Upper Sea of Cortés, in the north-east, where the highest summer temperatures and lowest annual rainfall occur.

The peninsular territory is occupied by a diversity of plant communities from winter-rain Mediterranean

Table 1
Terrestrial protected areas in the peninsula of Baja California and neighboring islands, and number of endemic vascular plants in them

Natural protected area	Category	Area (ha)	Genera	Species	Subspecies	Communities
Guadalupe Island	AR	25,000.0	1	34	4	Pacific coastal scrub
Sierra de San Pedro Mártir	NP	63,000.0	1	33	9	Chaparral and pine-oak forest
Constitución de 1857	NP	5,009.5	0	7	2	Pine forest
Sea of Cortés Islands, including Isla Rasa.	AR	150,061.0	5	143	41	Sonoran and Gulf island scrub
Valle de los Cirios	FFPA	2,521,776.0	9	164	52	Desert scrub
El Vizcaíno (BA)	BR	2,546,790.0	6	168	34	Desert scrub, coastal dunes, halophilic scrub, mangroves
El Vizcaíno (CA)			2	53	11	
Alto Golfo de California y Delta del Colorado[a]	BR	179,266.0	0	6	2	Sand dunes, halophilic scrub
Alto Golfo de California y delta del Colorado (CA)			0	0	0	
Sierra de La Laguna (BA)	BR	112,437.0	2	109	17	Pine-oak forest, tropical dry forest, palm oases, columnar cacti and desert scrub
Sierra de La Laguna (CA)			3	90	14	

Categories: BR, Biosphere Reserve (*Reservas de la Biosfera*); NP, National Park (*Parque Nacional*); FFPA, Flora and Fauna Protection Area (*Área de Protección de Flora y Fauna*); AR, Area currently under re-categorization (*Área en Recategorización*).
Sources: SEMARNAP, 1996, DOF June/07/2000.
[a] This area represents only the terrestrial and peninsular section of the reserve. (BA) buffer area, (CA) core area.

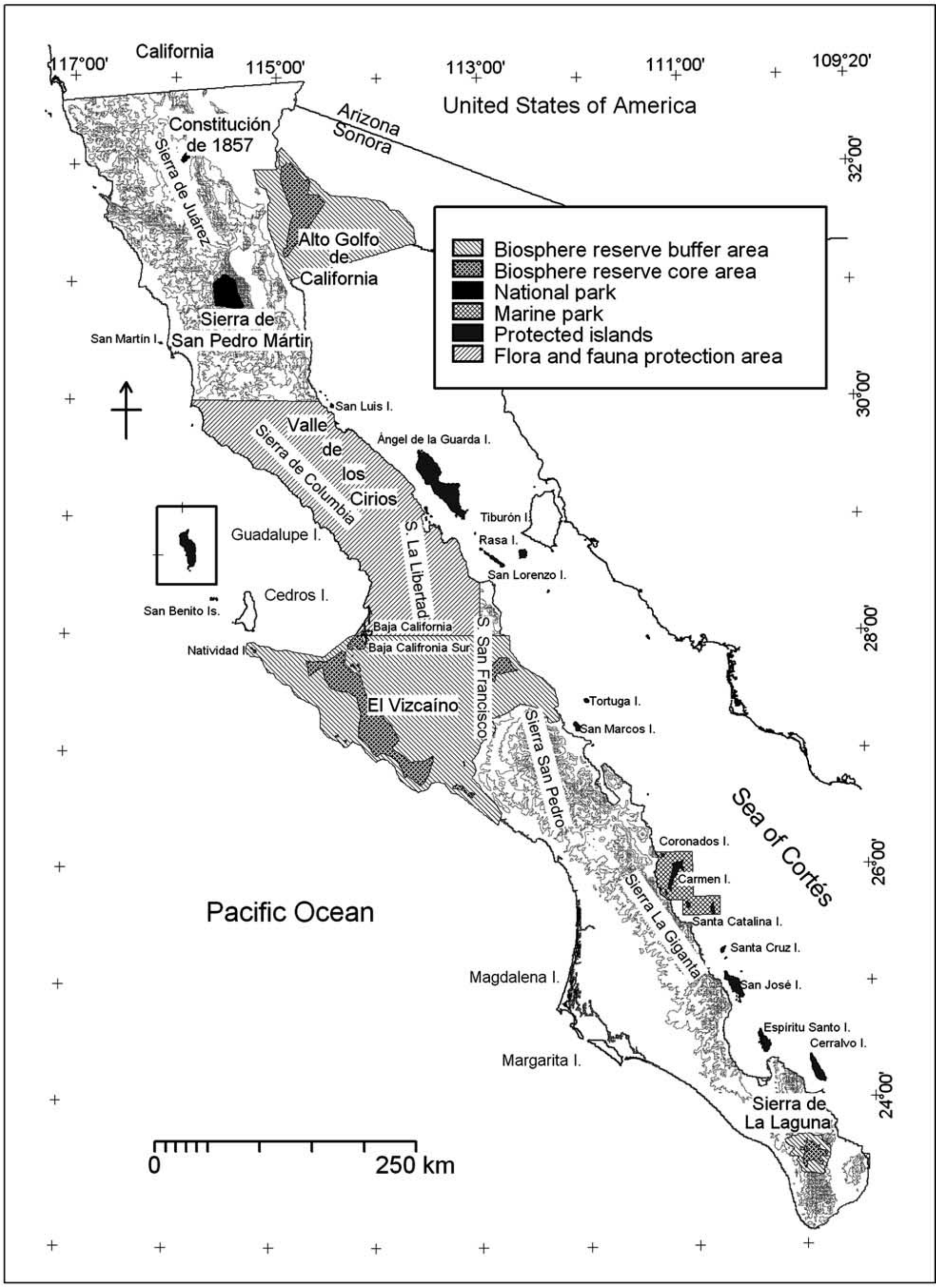

Fig. 1. Natural protected areas in Baja California and adjacent islands. Although some reserves include marine ecosystems, this study only took into consideration their land areas.

scrubs and coniferous forests in the north-west and microphyllous scrub in the north-east to tropical deciduous forests of the cape region with a heterogeneous array of sarcophyllous, sarcocaulescent, and crassicaulescent desert communities in the central deserts (Wiggins, 1980).

2. Methods

We restricted the data to the vascular endemic plants of the study region. Information was obtained from the literature and from herbaria. Because of the obvious association between the biogeographic definition of the peninsula of Baja California and the political boundaries of the two Mexican states that lie within it, we arbitrarily defined endemic species as those that had a distribution restricted to the insular and peninsular territory administered by the states of Baja California and Baja California Sur. This operational criterion may introduce some error in the case of species that occur along the northern border of the peninsula, which may be classified as non-endemic when in reality they may have a narrow biogeographic distribution. However the funding obtained for this study forced us to impose this political, as opposed to natural, boundary to our study area that otherwise would include the coast of the near Mexican Sonora state and contiguous Southern California.

We consulted the herbaria at the San Diego Natural History Museum, Rancho Santa Ana at Claremont, University of California at Berkeley, and California Academy of Sciences. A topographic map (1:250,000) geographically referenced information from the collections (taxa and locality) (INEGI, 1982). The georeferenced database, which consisted of a file of 12,287 records, corresponded to 3925 field sites. This database was transferred to a Geographical Information System (GIS) (ITC, 1998). Repeated data points of the same species for the same site were excluded.

To integrate these digital data points to our GIS we used the following method. First, we digitized the topographic cartography of the peninsula. Second, we used the database of collection sites to generate a map of collection points. Third, we digitized the boundaries of all protected areas in the published decrees. Fourth, we digitized the five major phytogeographic regions of the peninsula and neighboring islands from several sources (INEGI, 1988; Wiggins, 1980; Brown and Lowe, 1980; SPP, 1982) and our own field experience. Thus, the GIS consisted of four maps and the corresponding databases. We transformed these data layers to a raster format with 150×150 m pixels and reprojected to Lambert conformal canonic projection. The lists of protected and unprotected endemic species were obtained by performing a gap analysis. The procedure consisted of overlapping the data points, protected areas and phytogeographic regions layers. The resultant map of this overlapping permitted us to identify the gap areas or regions rich in unprotected endemics (Scott et al., 1993).

3. Results

3.1. Taxonomic distribution of endemics

The literature review and the revision of existing collections yielded 3789 species. Of these, 20% are endemic to the peninsula and adjacent islands. About three-fourths (74%) of indigenous plants have distribution outside the Baja region; the remaining 6% are introduced species.

Of the 155 indigenous plant families in the Baja California flora 83 contain endemic taxa (species or subspecies) and 23 of these have only one endemic taxon. Forty percent of the endemic taxa are concentrated in only three families: Asteraceae (143), Cactaceae (95), and Fabaceae (75). In Baja California, all species in the families Begoniaceae, Thymeliaceae, Araliaceae, and Hippocastanaceae are endemic, and families Agavaceae and Ebenaceae contain 86%, and 75% endemics.

Eighteen of the 926 indigenous genera of Baja California are endemic and, of these, 13 are monospecific. The endemic genera families (Anacardiaceae, Asteraceae, Boraginaceae, Cactaceae, Ericaceae, Liliaceae, Onagraceae, Polemoniaceae, Polygonaceae, and Scrophulariaceae) contain in total 30 species. The Poaceae, the third family in number of species (326), has only six endemics, none at the genus level.

A total of 754 endemic taxa (species and subspecies) were found, 348 endemics are restricted to the peninsular mainland, 83 have strict insular distributions, 66 on the islands of the Pacific and 17 on the islands of the Sea of Cortés, while 323 occur in both the islands and the peninsula.

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3.2. Representation of endemism in protected areas

We obtained location data for 742 of the 754 endemic taxa. In total, 567 taxa (species and subspecies or varieties) occur in protected areas (Table 1). The core areas of two of the three federally decreed Biosphere Reserves (Vizcaíno, and Sierra de la Laguna) only contain 13.5% of the endemic flora. The core area of the Ojo de Liebre Lagoon in the Vizcaíno BR and the core area of the Alto Golfo de California BR, jointly totaling 296 km^2, lack endemic plants.

A total of 187 taxa belonging to 51 families have not been collected within the protected areas of the peninsula and neighboring islands. These unprotected taxa are widely scattered along the study region (Fig. 2). The endemic genera *Adenothamnus*, *Carterothamnus*, *Faxonia*, and *Ornithostaphylos* are all absent from protected areas. The endemic genus *Cochemiea* has two species, and the endemic genus *Harfordia* one subspecies, all absent from protected areas see web site http://200.23.245.225/alinvestigadores/invriemann/endemism/Appendix1.htm for the list of species included in this research.

Of the 567 endemics found in protected areas 75 represent varieties or subspecies. Of 175 georeferenced endemics not collected in protected areas 21 are varieties or subspecies, 85 of these endemics have local distribution (i.e., microendemics, whose distribution is smaller than 1000 km^2); 87 have restricted distributions (i.e., meso-endemics, ranging between 1000 and 10,000 km^2); and 3 have regional distributions, occupying a large part of the peninsula of Baja California (i.e., macroendemics, with distributional areas exceeding 10,000 km^2). The protected areas shelter a large proportion of

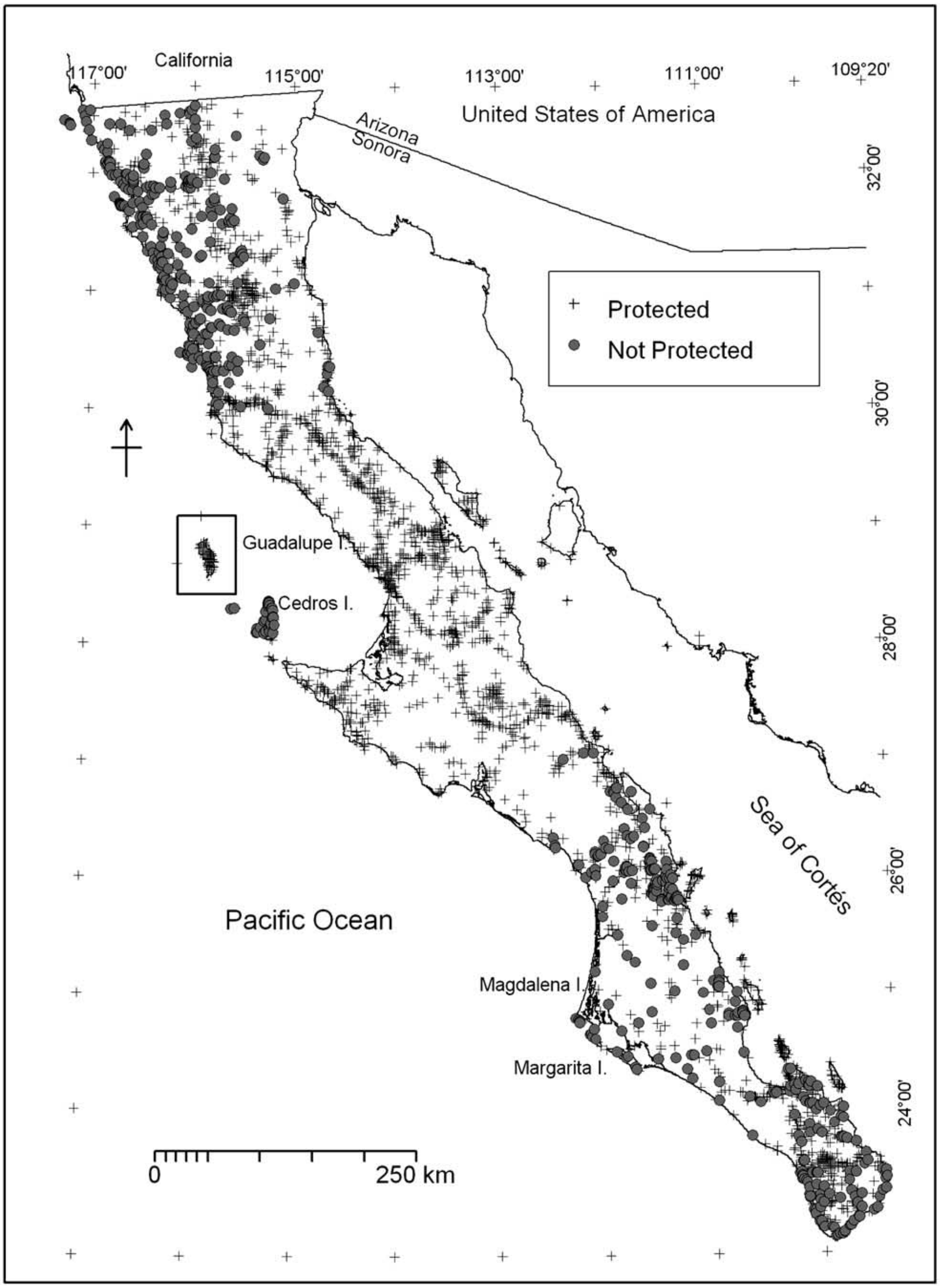

Fig. 2. Distribution of endemic taxa: Taxa not found in the interior of protected areas (closed circles), taxa with populations inside the protected areas (+).

the meso and macroendemics. Inside and outside the protected areas (Fig. 3. and web site) microendemics at any level (genera, species, or subspecies) are equally represented.

There are five major phytogeographic regions in Baja California (Fig. 4). The Lower Colorado Desert scrub showed the lowest number of endemics to the region, while endemism was very high in the San Lucan xeric scrub (Table 2). These tropical ecosystems also showed the highest percentage of regionally endemic species that have not been recorded within protected areas. Based on our gap analysis, we found six gap-areas that harbor the highest number of unprotected taxa (Fig. 5).

3.2.1. Coastal mediterranean

The Californian bioregion is defined as the portion of Baja California between parallels 30°00′ and 32°15′ (i.e., Mediterranean scrub) of Mexico. This area has high number of species of restricted or of local distribution (Villaseñor and Elias, 1995). This narrow band of coastal sage and succulent-rosette scrubs, chaparrals, and temperate forest has 134 recorded endemics with 35 not

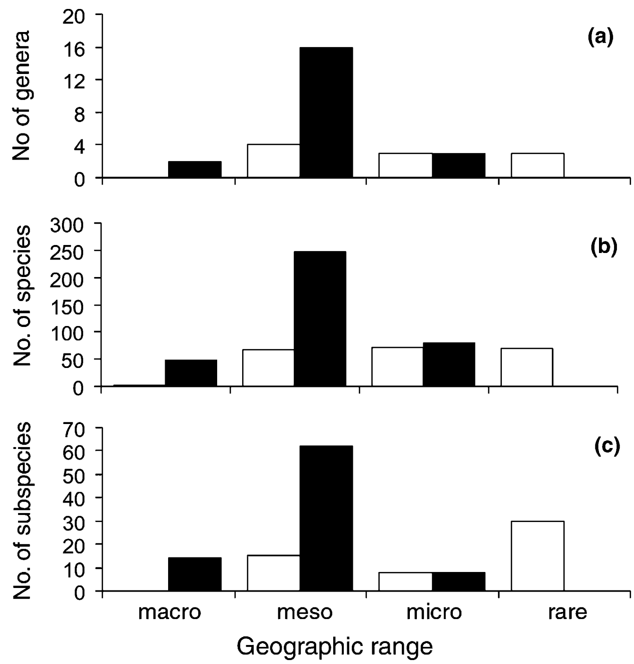

Fig. 3. Distribution of endemic taxa in Baja California classified according to their geographic range (see definitions in main text): (a) endemic genera, (b) endemic species, and (c) endemic subspecies. Black bars indicate taxa collected inside one or more protected areas, and white bars indicate taxa not collected inside a protected area. The "rare" column indicates taxa that have been collected without a georeferenced location.

found in protected areas (Fig. 5). Species such as *Sanicula deserticola*, *Hazardia ferrisiae*, *H. orcutti*, *Hemizonia perennis*, *Ferocactus fordii fordii*, *Mammillaria brandegei*, *M. louisae*, *Astragalus anemophilus*, *A. sanctorum*, *Leucaena brandegeei*, *Chorizante inequalis*, *C. jonesiana*, and *Galvezia juncea pubescens* are all restricted to this zone. Given the high intensity of land-use, this is the most threatened region of Baja California, agriculture, tourism, industry, and urban development increase, aim to a great risk of germplasm loss in the short term.

We developed a scenario of a hypothetical protected area in the Mediterranean lowlands of Baja California (including chiefly chaparral and coastal scrubs), stretching from the coast up to an altitude of 600 m and occupying 11,992 km^2. This reserve, if created, could potentially protect up to 176 taxa in addition to the 13 already mentioned, including the monospecific genus *Adenothamnus* and a more effective protection to the genus *Bergerocatus* that has most of its populations without protection.

3.2.2. Montane mediterranean

In the heights of the Sierra de Juárez and San Pedro Mártir were two national parks are located we found another region with a high number of endemic taxa. These parks, however, are small and their high perimeter-to-area ratio makes them highly vulnerable to adjacent agricultural activities. This is especially true in the case of Constitución de 1857 National Park (Sierra de Juárez), which has an area <50 km^2. Additionally, many high-elevation temperate endemics do not occur within the boundaries of these two parks. With this in mind, we proposed another protected area in the Mediterranean uplands consisting primarily of temperate forests and chaparral, stretching from 800 to 3100 m elevation and occupying 12,836 km^2. This proposed reserve would protect at least 19 more endemic taxa including the endemic genus *Ornithostaphylos*, currently outside protected areas. Other researchers have previously highlighted the possibility of creating a reserve in the mountains of northern Baja California, potentially extending its influence across the US border into Southern California (Franco-Vizcaíno and Sosa-Ramírez, 1991).

3.2.3. Sierra de La Giganta

Farther south, the Sierra de la Giganta also has an important concentration of endemism. It possesses 259 endemics and 43 of these not present within any protected area. *Galium carterae*, *Agave gigantensis*, and *Acacia kellogiana* are among the species restricted to this region. The endemic genus *Carterothamnus* occurs in the middle and southern part of this range.

3.2.4. San Lucan region

Near the tip of the peninsula, east of the 110°20′ meridian occurs a low deciduous tropical dry forest (Rzedowski, 1978). These communities intermingle gradually with neartic elements at middle heights of the Sierra de La Laguna, where a temperate pine-oak relictual forest prevails at the highest elevations and includes local endemics such as *Pinus lagunae*. This southern portion of the peninsula shows the highest number of micro, and meso-endemics (i.e., species with local or restricted distributions). The genera *Clevelandia* and *Bessera* are restricted to this part of the peninsula. This portion of the peninsula harbors no less than 304 endemic species, 55 of which are not found within any protected area and 39 of which are restricted solely to this area.

3.2.5. Cedros island

Located 22.5 km off shore the Pacific Coast between 28°02′ and 28°22′, this island is also another important center of endemism. This small island of approximately 367 km^2 contains 77 endemic taxa. Of these, 22 are not under protection, including *Rhus integrifolia cedrosensis*, *Encelia cedrosensis*, *Senecio cedrosensis*, *Cochemiea pondii*, *Ferocactus chrysacanthus*, *Mammillaria goodrigei*, *Dudleya cedrosensis*, *D. pachyphytum*, *Lotus cedrosensis*, *L. nudatus*, *Monardella thymipholia*, *Eriogonum molle*,

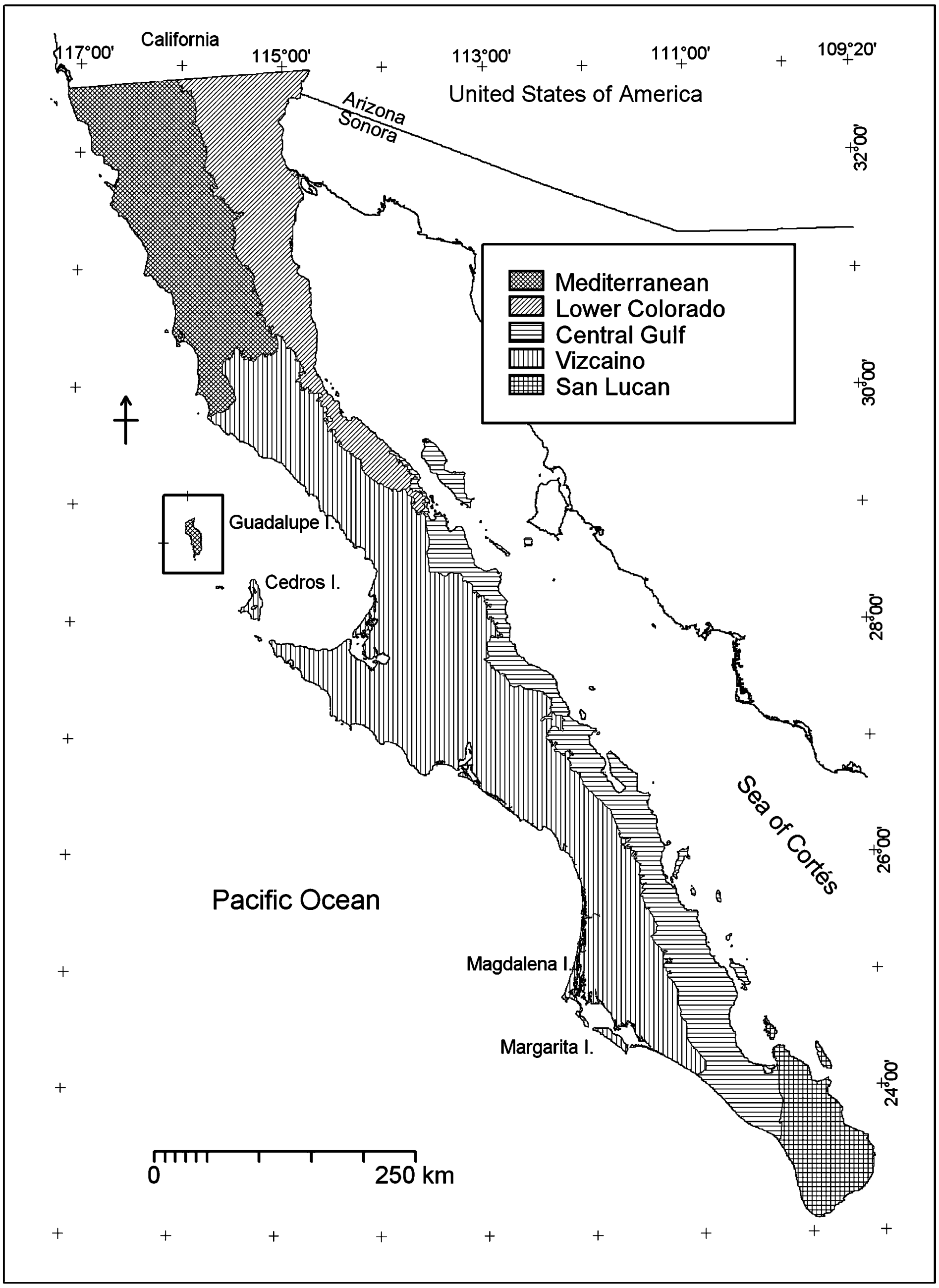

Fig. 4. Major phytogeographic regions in Baja California.

Table 2
Phytogeographic regions of Baja California and number of endemic species in them

Phytogeographic region	Number of endemic species		
	Baja Califofnia	Regional	Unprotected (%)
Mediterranean	268	93	39 (42)
Lower Colorado	116	4	3 (75)
Central Gulf	326	33	17 (52)
Vizcaíno	399	52	23 (44)
San Lucan	315	102	38 (37)

Numbers in parentheses indicate the percentage of the regional endemics that have not been found within existing protected areas.

Harfordia macroptera, *Mimulus stellatus*, and *Penstemon cedrosensis*.

3.2.6. Magdalena and Margarita islands

Located near the Pacific coast between parallels 25°16′ and 24°18′, Magdalena and Margarita islands have a geological origin that differs from the neighboring coastline by the time they detached from the continent (Durham and Allison, 1960). Possibly, because of this, the islands shelter some rare microendemisms such as *Agave margaritae*, *Asclepias masonii*, *Brickellia*

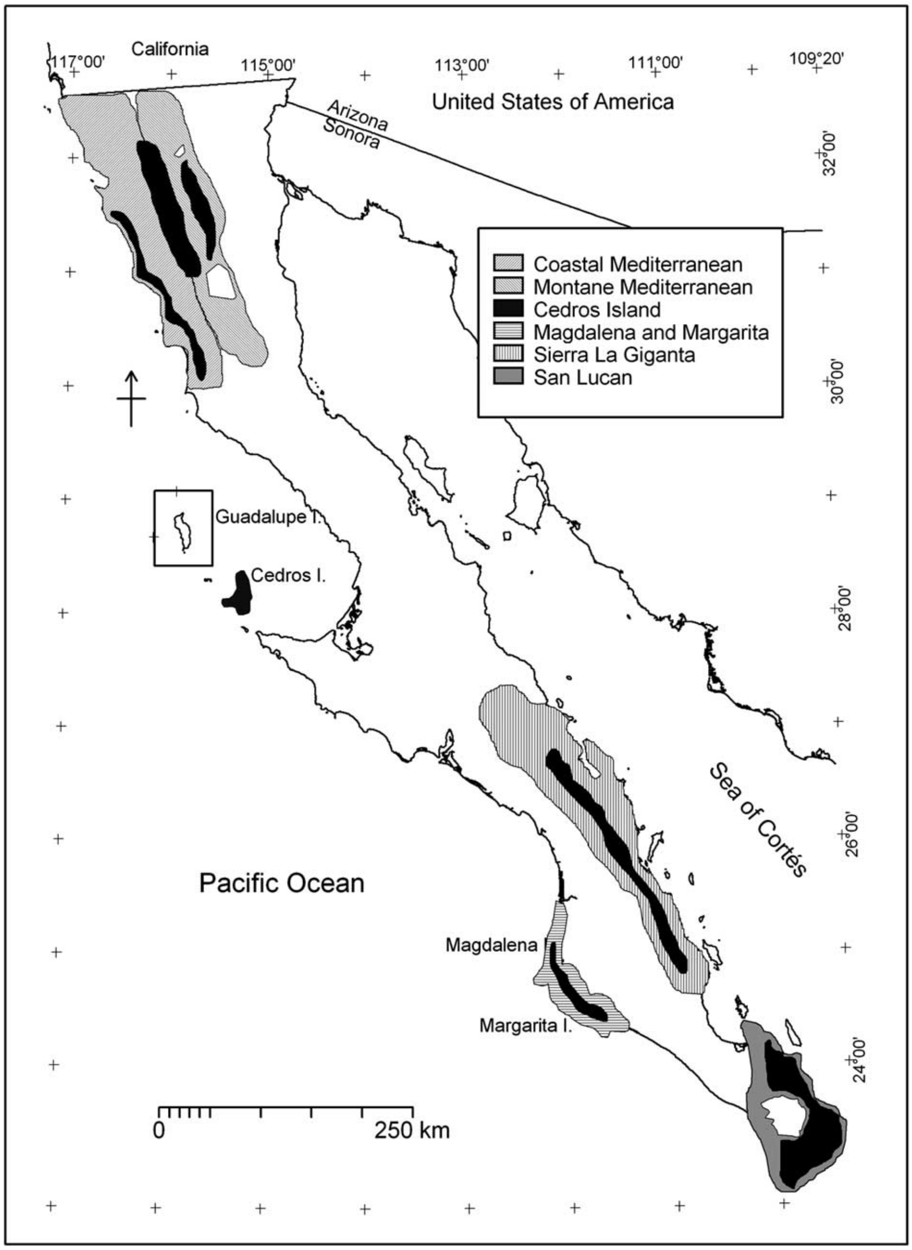

Fig. 5. Major gap areas in Baja California. Black areas represent potential future protected areas, see text.

hastata, *Ibervillea insularis*, *Cochemiea halei*, *Echinocereus barthelowanus*, *Opuntia pycnantha*, *O. santamaria*, *Sphaeralcea coulteri margaritae*, *Gongylocarpus fruticulosus fruticulosus*, *G. fruticulosus glaber*, and *Castela peninsularis*. All these species are absent from protected areas.

4. Discussion

It is interesting to note that the regions with the highest level of endemism (Mediterranean and San Lucan), both form parts of larger areas recently singled-out by Myers et al. (2000) as global biodiversity hotspots: the Californian Floristic Province and the Mesoamerican Tropical Forests. In these communities there seems to be a closer association between diversity and number of endemics as is also the case in the neighboring south-western part of the USA (Kerr, 1997). In a study preceding our work, Villaseñor and Elias (1995), who restricted their investigation to 552 species of endemic angiosperms, identified the Mediterranean region, in the north-west part of the peninsula, as the richest in plant endemisms.

The data analyzed here assumes the current existence of all the endemics recorded for the region. However, in the consulted herbaria we found that 74 endemics have not been collected during the last 32 years and some have failed to show up in the collections for almost 100 years. It is likely that even an intense collection effort may fail to encounter all the taxa included in this research. Some of the peninsular endemics, such as the genus *Faxonia*, are solely represented in the collections by the type specimen. This stresses the importance of establishing protected areas in the region as soon as possible.

A possible source of error to our research may arise from the assumption that the absence of collection records within the protected areas presupposes the absence of the taxa in their interior. Although more intensive collecting may change the results of our study, it is unlikely it could change the qualitative conclusions. The unrecorded presence of a taxon in low numbers within a protected area does not suggest the existence of a healthy population, or a level of genetic variation adequate for the persistence of the species. Given the great latitudinal span of Baja California, it is unlikely that the protected areas that currently exist could harbor a significant proportion of the genetic variation of the endemic peninsular flora, especially those species that have not been detected to date in protected sites.

Although the peninsula has been surveyed for the last 150 years, especially by US botanists, the region continues to be a territory for which a large part of the collection accessions still comes from sites near the main roads. A greater collection effort would permit the discovery of new species or new records in regions that have had little collecting in the past and would allow confirmation of the distribution and condition of the endemic taxa, especially in those ecosystems suffering the greatest pressures from development projects.

Other threats such as cattle ranching, agriculture, mining, and the introduction of exotic animal and plant species have been increasing causes of environmental disturbance in the last decade. As a result of these, there is a wide distribution of weedy exotic taxa such as salt cedar or tumble weed, and a high number (78) of introduced species of the family Poaceae.

The concentration of agriculture and cattle ranching along the wetter habitats such as creeks and vernal pools has had a strong effect on these ecosystems. This is especially important to conservation policies because these communities, usually rich in species and high in endemism, are specially susceptible to exotic species invasion as has been documented in other regions (Stohlgren et al., 1998, 1999). Even in remote sites such as Guadalupe Island, the introduction of exotic plants and animals has caused a serious modification of the native flora; there has been a failure to re-collect in recent times previously recorded endemics (Moran, 1996).

To achieve the successful conservation of rare and endemic taxa it is necessary to take into account the distribution of regions rich in endemism. These regions should be of high priority for the creation of new protected areas, especially if the core areas of new reserves are to have a high level of protection.

We recommend that this be best achieved by means of several protected areas that would allow capturing most of the diversity along the peninsula. The size and status of these areas should be the result of a compromise between the needs of development and those of conservation. These new reserves should include extensive areas of the low and upland north-west Mediterranean communities, together with the highest parts of the midlatitude sierras of La Libertad and Columbia, San Francisco, Santa Clara, and Tres Vírgenes in the middle of the peninsula. In the middle-south part of Baja California, new reserves should include the Sierra de La Giganta and the islands of Magdalena and Margarita and also, an area to the east of the 110°20′ meridian that would complement the current Sierra de La Laguna reserve, to include lowlands and coastal vegetation.

Although the current system of terrestrial protected areas in the Peninsula of Baja California is worthy of praise for the recent efforts that have been done to decree comprehensive reserves, it is still far from meeting the ideal goal of protecting a large proportion of regional endemics. This creates a challenge and an opportunity to rethink the existing system and to develop new alternatives of protected areas that would help effectively preserve the extraordinary endemism of this unique peninsula.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version at doi:10.1016/j.biocon.2004.07.008.

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