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Where to conserve? Plant biodiversity and endemism in mediterranean Mexico

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Abstract Six regions of northwestern (NW) Baja California (Sierra de Juárez, Sierra de San Pedro Mártir, Punta Banda, Colonet, San Quintín and Valle Tranquilo) were compared for their floristic diversity. Checklists for each region were analyzed by their total, native, and endemic floras to give measures of floristic similarity and overlap, and to identify the strongest gradients affecting species distributions. Each region was floristically distinct, with significant variation in the distribution of state endemic taxa. The six regions are readily differentiated by their geographical position in a Principal Components Analysis. The strongest gradients were (a) the W–E gradient from the coast to the mountains and (b) the latitudinal gradient from N to S. These six adjacent regions are found within a local and global biodiversity hotspot that is subject to intense conservation challenges. Conservation of many areas is essential to adequately preserve the diversity of locally endemic taxa with restricted ranges, yet the coast lacks any protected areas at the state and federal level. Private reserves such as Reserva Natural San Quintín may be critical to the conservation of regionally endemic taxa.

Keywords Baja California · Flora · Federally protected taxa · Floristic variation · Municipio de Ensenada

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Introduction

Along the Pacific coast of North America a mediterranean climate prevails, resulting in a phytogeographic region known as the California Floristic Province (CFP) that stretches from southern Oregon to northern Baja California. The mediterranean climate is characterized by hot dry summers and cool wet winters. The California Floristic Province (CFP) has been designated as a global biodiversity hotspot, an area of high endemism that has been heavily impacted by human activity (Myers et al. 2000). The CFP, today home to 2612 endemic vascular plants, originally occupied 324,000 square kilometers (Burge et al. 2016; Myers et al. 2000). Today only 80,000 square kilometers—less than 25%, remain naturally vegetated (Myers et al. 2000). Our study is focused in mediterranean Mexico—the area between parallels 30 and 33 along the Pacific slope of Baja California, Mexico (Fig. 1). The Baja California portion of the CFP is home to around 1800 native vascular plant species, with almost half being rare, threatened, or locally endemic in the region. The state of Baja California is documented to have 2663 plant taxa, including 294 strict

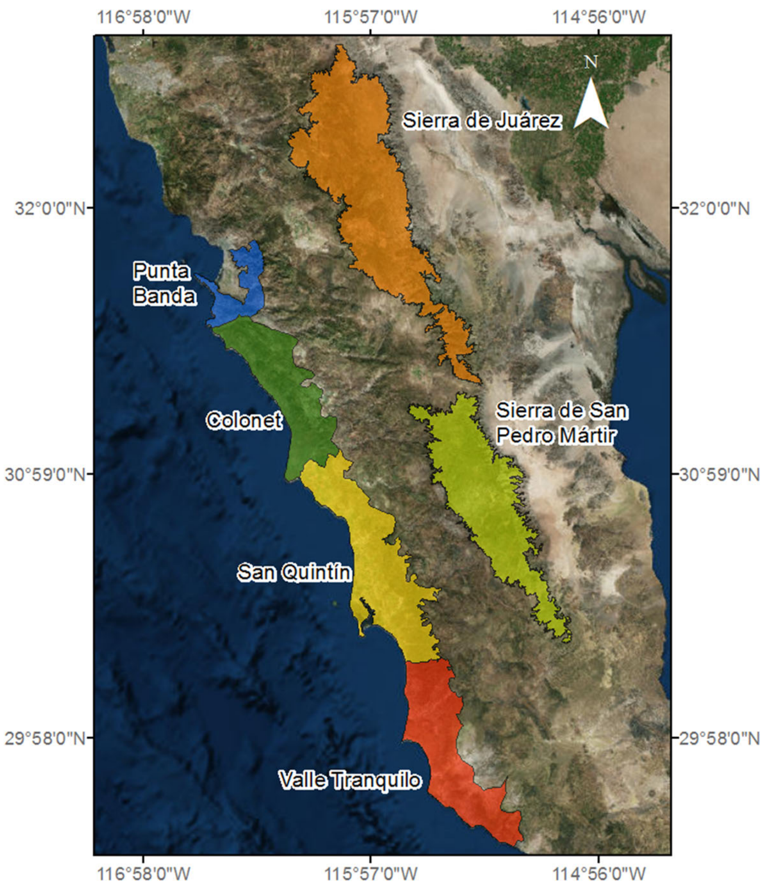

Fig. 1 The six regions; from north to south: Sierra de Júarez, Punta Banda, Colonet, Sierra de San Pedro Mártir, San Quintín, and Valle Tranquilo

endemics (Rebman et al. 2016). O'Brien et al. (in press) evaluated all plant taxa within the CFP of Baja California, scoring them for rarity and endemism, and documenting 173 plant taxa entirely endemic to the CFP region (ca. 10% of the native flora) and an additional 67 near-endemic taxa. These 239 taxa represent more than 11% of total endemism for the entire CFP in an area that is less than 5% of the size of the total province.

A strong rainfall gradient is clearly observed as one moves southward along the Pacific coast of the northern peninsula of Baja California (Caso et al. 2007; Minnich et al. 2000; Hastings and Turner 1965; Shreve 1936). Vanderplank and Ezcurra (2015) documented a reduction of 1 mm/mile in rainfall as one moves south from Ensenada to San Quintín. Mean monthly temperatures vary little across this gradient (Tijuana: 13 °C [55 °F], in winter and 23 °C [73 °F] in summer, and El Rosario: 14 °C [57 °F], in winter and 24 °C [75 °F] in summer; Vanderplank 2013) making water availability the main driver of vegetation change with latitude. The second strong gradient seen in this region is the W–E gradient as one moves eastwards from the coast into the mountains. This gradient runs from a foggy, low elevation shore, to the sometimes snow-covered inland mountains in less than 100 km.

Within northwestern Baja California there are two primary areas of high plant endemism: the mountain ranges, and the coastal plain between Ensenada and El Rosario (Riemann and Ezcurra 2007; Garcillán et al. 2010). The Sierra de Juárez and the 3000-m high Sierra de San Pedro Mártir form the spine of the peninsular ranges and intercept the predominant northwesterly winds, creating mediterranean-type climate with winter rains from the coast to the crest of the sierra, and an arid rainshadow to the east with Sonoran Desert scrub. In the coastal plain the influence of the relatively cold California Current results in a persistent stable marine layer and fogs that dominate coastal climate most of the year (Vanderplank 2011). Unique habitats have been identified within this region—namely the Maritime Succulent Scrub, noted for its high numbers of rosette-forming taxa that harvest moisture from the heavy coastal fogs (Martorell and Ezcurra 2002; Minnich and Franco-Vizcaíno 1998; Rundel et al. 1972). There are also small areas of Maritime Chaparral that favor evergreen sclerophyllous species e.g., *Arctostaphylos australis* and *Salvia brandegeei*, adapted to longer intervals between fire cycles and increased moisture from fog than inland areas (Minnich et al. 2014).

Although peaks in species richness in Baja California are often found in the ecotones between different ecoregions (Garcillán et al. 2010; Riemann and Ezcurra 2007), peaks in local endemism seem to be largely associated with specific, often isolated, sites such as islands, mountain ranges, and isolated coastal habitats such as bays or peninsulas, suggesting that a past history of evolution in isolation might be playing a critical role. Consistent with patterns seen in coastal northwest Baja California, Sorrie and Weakley (2001) show that topography per se may be a minor consideration in endemism; for example, the coastal plain of Florida has <250 m relief yet the state is second in endemism only to California.

The literature on the flora of California far exceeds that available for Baja California, and gives some insight into the origins of the present endemism and diversity in the CFP of Baja California (Lancaster and Kay 2013; Thorne and Viers 2009; Vandergast et al. 2008; Richerson and Lum 2008; Viers et al. 2006; Stebbins and Major 1965). For example, Kraft et al. (2010) found that endemics of the western edge of California deserts were evolutionarily young species, with most endemism found in habitats that have undergone post-Pleistocene isolation as North American deserts expanded northwards after the Last Glacial Maximum, and in montane sky-islands with relictual Pleistocene climates.

The need for this study

Northwestern Baja California is subject to considerable and constant development pressure. The proximity to the international border, the fertile soils, mediterranean climate, and infrastructure offered by large cities like Tijuana and Ensenada, make the region a prime target for agricultural expansion, coastal development, tourism, and large-scale factory expansions. The conservation community has struggled to prioritize target areas in the face of so many rare and unevenly distributed species, and so many threats.

The goal of this paper is to objectively compare the floristic diversity of six regions from NW Baja California: two in the mountains (the Sierra de Juárez and the Sierra de San Pedro Mártir); and four along the coast (Punta Banda, Colonet, San Quintín and Valle Tranquilo), and to develop priority criteria for future conservation efforts.

In this study we ask the following questions:

- How floristically different are each of these adjacent regions of NW Baja California, and what is the unique conservation value of each region?
- How strong is the influence of the N–S rainfall gradient compared to the W–E topographic gradient on community composition and species turnover?
- What are the primary considerations to maximize conservation of the native and endemic flora of NW Baja California?

Methods

Six regions within NW Baja California were selected based on the availability of quality information on the flora, and their position within the regional hotspots of local endemism (mountains and coast). When a published floristic checklist was available (for four of the six regions) this in part dictated the geographical extent of the polygons selected (see Table 1 for the size and elevation range of each area).

Study regions

Mountainous sites

Sierra de Juárez This large area of medium elevation includes the National Park "Parque Nacional Consitución de 1857", which was decreed in 1962. The park is a small protected area (5009 hectares), centered around Laguna Hanson and the higher elevation regions of the mountain range. Although it is an area of considerable visitation and tourist traffic, it has not received intensive botanical focus (although there have been two student theses on the park; Valenzuela Vázquez 1990; Ramírez Espinoza 2010) and there is no published

Table 1 Maximum and minimum elevations (m), and total size (h), for each of the six regions

	Punta Banda	Colonet	San Quintín	Valle Tranquilo	San Pedro Mártir	Sierra de Juárez
Elevation max m	1100	795	705	660	3080	1980
Elevation min m	0	0	0	0	1160	1170
Area (hectares)	44,560	134,310	194,650	163,380	224,400	352,500

plant checklist, which is particularly surprising because the range is home to several narrow endemics.

Sierra de San Pedro Mártir (SSPM) This large high-elevation area encompasses the highest peak on the Baja California peninsula (Picacho del Diablo) and includes 650 square kilometers with many different vegetation types. The mountains include one of Mexico's oldest National Parks —*Parque Nacional Sierra San Pedro Mártir*—which is home to many important timber species and was decreed in 1974. The upper extremes are snow-covered in winter and early spring and the presence of a good road has resulted in a relatively high botanical collecting effort for this mountain range. The vascular plant checklist for this region (Thorne et al. 2010) included only the area above 2000 m in elevation, for a total of 487 taxa.

Coastal sites

Punta Banda This region includes the peninsula just south of Ensenada, which is unique in being part of the only transverse mountain range on the peninsula of Baja California. The low W–E range falls alongside the Agua Blanca fault line and results in elevations that are much higher than along the remainder of the coastal plain. Punta Banda is well-loved and well visited (home to the famous blow-hole known as *La Bufadora*) and as a result the flora is relatively well-known. In 1979, Mulroy et al. published a plant checklist for the Punta Banda peninsula that included 258 taxa, and various collectors have passed through the area, but access to the high crest remains challenging and it is possible that more species would be added to this list if a thorough reconnaissance of the higher elevations were possible. This area is currently popular with tourists, and as a result areas of hiking trails and beach access are fairly well conserved, but the area is without any formal protection. The only exception to this is the wetlands, which are protected by Federal Government (ZOFEMAT) concessions that are assigned to conservation (*Áreas Destinadas Voluntariamente Para la Conservación*) and international Ramsar Convention sites.

Colonet The Colonet Mesa is a flat area that is home to remarkable microhabitat diversity, including distinctive rock outcrops and the largest vernal pools in Mexico, some of which are more than a kilometer in length. This region includes the area documented by Harper et al. (2010) who found 435 vascular plant taxa. The region includes two major drainages and some degraded marsh habitat, but little dune habitat. Threats to the Colonet region from a proposed megaport in 2009 have made conservation efforts in this region challenging. The non-profit organization *Jardin Botanico San Quintín* recently purchased a small area of the mesa (22 hectares, 55 acres) which includes the second-largest pool (the Medina complex) and has significant conservation value despite its small size.

San Quintín The San Quintín region includes a small volcanic complex with 10 cones, and unique volcanic substrates that are home to a handful of narrow endemics. This region includes the area documented by Vanderplank (2011) in her vascular plant checklist of the coastal region that documented 435 plant taxa. San Quintín is perhaps the best-collected of the six regions, with the most historical and recent specimens accessible in regional herbaria. The major dune system (El Socorro Dunes) is subject to illegal sand mining (Rodríguez Revelo et al. 2014), and salt-water intrusion threatens many habitats in the region (Vanderplank et al. 2014). The non-profit, land trust organization Terra Peninsular, A.C., acquired significant areas of the San Quintín bay (1133 hectares) in 2012 and 2015. This land includes large stretches of dune habitat and some of the smaller volcanic cones. The salt marshes of San Quintín bay are particularly renowned for their extensive and pristine condition, and currently protected by ZOFEMAT concessions and the international Ramsar Convention.

Valle Tranquilo Valle Tranquilo lies at the very southern extreme of the California Floristic Province. It is an area dominated by sandstone marine terraces with clay mesas and three main tributaries. The area encompassed in this analysis includes a region currently under study by Jim Riley and colleagues. Their preliminary checklist from 2015 identified 293 vascular plant taxa and was included in our analysis. Terra Peninsular owns 3845 hectares (9500 acres) in this region and has an additional approximately 4047 hectares (10,000 acres) under contract for future purchase.

Mountainous sites fall into the Montane Temperate Forest and the Chaparral ecoregions of Baja California, while the coastal sites fall into the Coastal Sage Scrub and Succulent Maritime Scrub ecoregions of Baja California (González-Abraham et al. 2010). The mountainous sites have been previously classified within the Supramediterranean bioclimatic belt, and the coastal sites within the Thermomediterranean and Inframediterranean bioclimatic belts (Peinado et al. 1995).

Published checklists were combined with a wealth of herbarium specimen data gathered from the Baja California Botanical Consortium (which includes records from the seven regional herbaria: SD, BCMEX, RSA-POM, UCR, HCIB, SDSU, and SBBG). The specimen records and their geographical coordinates were verified, and additional taxa were combined with any published checklists available. Sierra de Juárez has no published floristic checklist, therefore this list is purely based on herbarium specimens in the online repository at www.Bajaflora.org. The Valle Tranquilo checklist is a work in progress, anticipated for publication in 2017. All the published lists and herbarium specimens included in this analysis have had their taxonomy corrected to reflect the latest revisions in nomenclature and phylogeny. As such, synonyms have been removed and our final lists should render in accurate detail the current state of our knowledge of the region. Taxonomy mostly follows Rebman et al.'s (2016) Annotated Checklist of the Vascular Plants of the Baja California region. The resultant table (see appendix 1 in Supplementary Material) shows which plant taxa were found in each region of NW Baja California.

Data bias and intensity of collection

San Quintín is probably the best-collected site. The SSPM and Colonet floras are both well-collected and include recent contributions, but the Punta Banda flora was written some time ago, and the Valle Tranquilo checklist is preliminary. The Sierra de Juárez flora is the most understudied, and is the only region without a formal checklist for a region within its boundaries.

Statistical analysis

With the resulting dataset we built a sites $\times$ species floristic matrix describing the presence or the absence of all the recorded species (1770 in total) among the six sites. We then created a subset of this matrix, retaining only the species known to be native to Baja California (1578 in total) and eliminating all the introduced species found in the dataset.

Finally, we created a subset of this second matrix, retaining only the species known to be endemic to the selected study sites (214 species). Each of the three matrices was subject to two analyses in order to detect how much of the between-site floristic variation could be attributable to one or both of the main regional ecological gradients: (a) the W–E complex topographical gradient (where, together with altitude, a series of other environmental variables such as temperature and relative moisture also change), and (b) the N–S precipitation gradient that runs throughout the region.

We first subjected the three matrices to a Principal Components Analysis (PCA) to identify covariation in species presence. Using the broken-stick distribution as our null model, we tested how many multivariate axes of variation were concentrating more floristic variance than could be expected by chance alone (Jackson 1993). We then tested the site-scores along the first statistically significant PCA axes against distance to the Pacific coast (a proxy for the W–E topographic gradient) and latitude (a proxy for the N–S aridity gradient).

We also subjected the three matrices to a clustering procedure using Euclidean distance between group means as the clustering criterion. The final results were expressed in the form of a dendrogram showing the similarity between sites. For all our analysis we used the R statistical package (R Core Team 2017).

Finally, we calculated for each pair of sites their floristic overlap using Sorensen's overlap index ($S = \Sigma ab/\sqrt{(\Sigma a \Sigma b)}$, where Σa is the total number of species in site a; Σb is the total number of species in site b, and Σab is the number of species common to both site a and site b. In order to estimate a statistical significance for high overlap values, we used a simple X^2 test where the expected overlap between two sites a and b under random species distribution was estimated as $e = \Sigma a \Sigma b/N$, where N is the total number of species in the dataset.

Results

The resultant data matrix included 1770 taxa, of which 1578 (89%) are native, 214 endemic and near-endemic, and 23 are on the Mexican Endangered Species List—the NOM 059 (see online appendix 1). Table 2 shows a summary of the results for each region, including total and native plant diversity, the number of state and micro-endemics, and the number of taxa Federally Protected in Mexico (NOM 059); Table 3 shows the same summary for coastal sites combined and mountainous (inland) sites combined.

PCA gradient analysis

The PCA yielded three significant axes, absorbing a larger proportion of the overall floristic variance than predicted by the Broken-Stick random distribution. We obtained similar results for the entire floristic dataset, for natives only, and for the endemic species subset. For simplicity, we will describe here the results for the native species data (Fig. 2). Axis 1, explaining 45% of the floristic variation in the dataset, separated the two mountain sites on the positive side from the four coastal sites on the negative side. Axis 2, explaining 19% of the overall floristic variation, separated the northernmost mountain site, Sierra de Juárez, from the more southern Sierra de San Pedro Mártir. Similarly, axis 3, explaining 15% of the variance, arranged the coastal sites along the N–S latitudinal/aridity gradient placing the northernmost sites (Punta Banda and Colonet) on the positive side and the

Table 2 Summary results for each region, showing total and native plant diversity and percentage, as well as the number of state and micro-endemics, and plant taxa Federally Protected in Mexico (NOM 059)

	Punta Banda	Colonet	Valle Tranquilo	Sierra San Pedro Mártir	San Quintín	Sierra de Juárez
Total plant taxa	415	719	426	907	690	796
Native plants	349	616	382	849	569	738
% native	84	86	90	94	82	93
State endemics and near-endemics	39	56	57	64	70	37
Micro-endemics (and near-endemics)	4 (+2)	4 (+2)	0	24	2 (+4)	6
NOM plants	6	10	3	15	8	8

Table 3 Summary for coastal and mountainous sites combined, showing total and native plant diversity and percentage, as well as the number of state and micro-endemics, and plant taxa Federally Protected in Mexico (NOM 059)

	Coastal sites combined	Mountainous sites combined
Total plant taxa	1074	1188
Native plants	909	1109
% native	85%	93%
State endemics (and near-endemics)	148	103
Micro-endemics (and near-endemics)	10 (+8)	30
NOM plants	13	16

southernmost sites (San Quintín and Valle Tranquilo) on the negative site. Together, the first three axes explained 79% of the overall floristic variance among sites. Tests against independent external variables confirmed the interpretation of the axes: Axis 1 was significantly correlated with distance to the coast ($r^2 = 0.99$, $P = 0.02$) and the PCA score of coastal sites in axis 3 was correlated with latitude ($r^2 = 0.87$, $P = 0.1$). The low degrees of freedom of the montane sites ($n = 2$) did not allow for significance testing, but the N–S trend here is obvious.

Cluster analysis and floristic similarity

The cluster analysis reproduced the main results of the PCA gradient analysis. The first division separated the mountain sites from the coastal sites into two groups (Fig. 3). The next branching of the dendrogram separated Sierra de Juárez, the northernmost montane site, from Sierra de San Pedro Mártir, the southernmost range of our study region. Finally, the third branching separated Punta Banda and Colonet, the two northernmost coastal sites, from San Quintín and Valle Tranquilo, the two southernmost coastal sites. As with the PCA gradient analysis, the coast-to-mountain gradient first, the north-to-south gradient along the mountains second, and the N–S coastal gradient lastly, seem to be the most important factors driving floristic change in mediterranean Mexico.

Comparing the sites now only for their endemic flora using Sorensen's similarity coefficient, we got similar results (Table 4). The highest inter-site similarity was observed between the two southernmost coastal sites (Valle Tranquilo and San Quintín, $S = 0.71$,

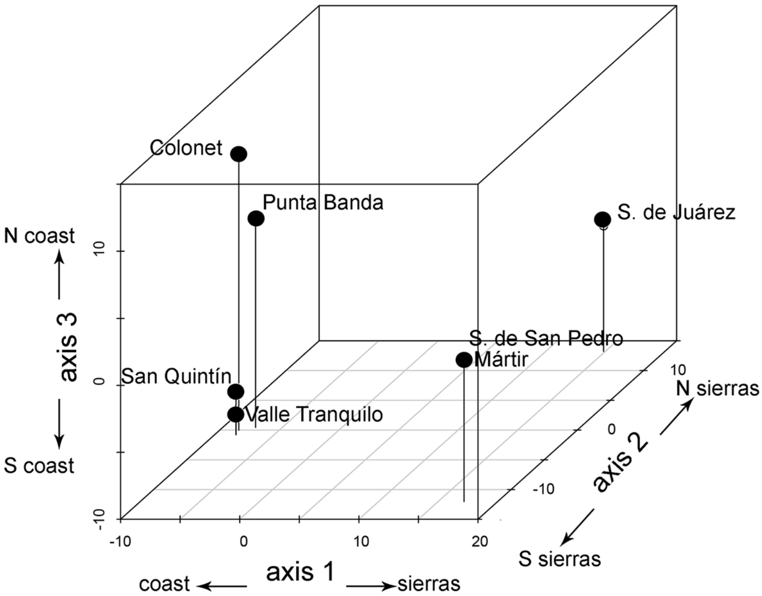

Fig. 2 Scatterplot to show the results of the principal components analysis in three-dimensional space

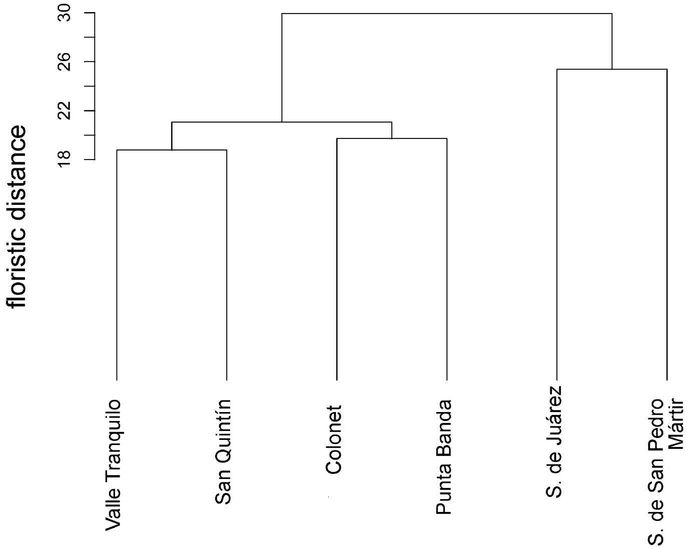

Fig. 3 Dendrogram of floristic clustering analysis

$P < 0.0001$), followed by the two northernmost coastal sites (Colonet and Punta Banda, $S = 0.63$, $P < 0.0001$), and, lastly, by the two montane sites (Sierra de San Pedro Mártir and Sierra de Juárez, $S = 0.45$, $P = 0.02$).

Table 4 Floristic overlap, measured as Sorensen's Index, for regional endemics among all six sites

	Colonet	San Quintín	Valle Tranquilo	Sierra de Juárez	San Pedro Mártir
Punta Banda	**0.63****	**0.45***	0.38	0.15	0.14
Colonet		**0.60****	**0.49***	0.14	0.18
San Quintín			**0.71****	0.26	0.28
Valle Tranquilo				0.13	0.18
Sierra de Juárez					**0.45***

Numbers in bold indicate positive overlap values significantly higher than could be expected by chance. Significance levels for a X^2 test on the observed and expected shared species are indicated by asterisks (* $P < 0.05$; ** $P < 0.01$). All values in bold show sites that share more species than could be expected by chance

Indicator species

The species with the highest loadings on each axis, as well as the overall species list, is given as an electronic appendix (Tables SI1–SI4). As expected, PCA axis 1 had, on one extreme, a total of 232 species that are listed only for the mountains of Baja California, including some emblematic plants such as the pines (*Pinus* spp.), the manzanitas (*Arctostaphylos* spp.), the flannelbush (*Fremontodendron californicum*), and the Tecate cypress (*Calocedrus decurrens*). On the other extreme of the gradient, the list includes 67 species that occur in coastal environments strictly, or almost so, including Shaw's agave (*Agave shawii*), the lemonade berry (*Rhus integrifolia*), the velvet cactus (*Bergerocactus emoryi*), two coastal gooseberries (*Ribes* spp.), the wild rose (*Rosa minutifolia*), the Santo Tomás redberry (*Rhamnus insula*), the alkali-heath (*Frankenia salina*), the sand verbena (*Abronia maritima*), and two species of wolfberries (*Lycium* spp.).

Similarly, PCA axis 2 separated the two sierras on the basis of 12 species only present in the northern Sierra de Juárez, such as the chaparral candle (*Hesperoyucca whipplei*), and 24 more dryland-prone indicator species only present in the southern Sierra de San Pedro Mártir, such as the brittlebush (*Encelia farinosa* var. *phenicodonta*), the cochal cactus (*Myrtillocactus cochal*), Orcutt's dalea (*Dalea bicolor* var. *orcuttiana*), and the chalk-lettuce (*Dudleya pulverulenta*).

Lastly, PCA axis 3 separated the two southernmost coastal sites from the two more northern ones on the basis of 62 species present in the northern coastal sites and 125 in the south, including the Pomona milkvetch (*Astragalus pomonensis*), the coastal scrub oak (*Quercus dumosa*), the Mexican flannelbush (*Fremontodendron mexicanum*), two California lilacs (*Ceanothus spinosus* and *Ceanothus tomentosus*), the redberry (*Rhamnus pirifolia*), the mountain mahogany (*Cercocarpus betuloides*), and the blackberry (*Rubus ursinus*; all species with affinities to coastal California) in the north, and *Justicia californica*, the blue fan palm (*Brahea armata*), the cholla (*Cylindropuntia alcahes*), the senita cactus (*Lophocereus schottii*), the mesquite (*Prosopis glandulosa* var. *torreyana*), the ocotillo (*Fouquieria splendens*), and the desert wolfberry (*Lycium andersonii* var. *deserticola*; all species with geographic affinities to the drier and southern Baja California succulent scrub) in the south.

Discussion

The analysis clearly distinguishes strong differences between each region and its neighbors. There is a significant difference in the flora of the mountainous and coastal regions, but also a significant difference in their protection and management. The mountainous regions both include national parks that are managed and protected by the Federal government (CONANP); yet the coast has no formal government protection, but localized conservation involvement from the non-profit community. It is unsurprising that the conservation community is concerned with the coastal area because it contains highly restricted and unique species that are greatly impacted by the human footprint. The total native plant diversity for the coastal regions comprises 1007 taxa, and for the mountains 1108 taxa.

The coast has much higher invasion of non-native species, and is also much more threatened by development, agriculture and tourism (González-Abraham et al. 2015; Vanderplank et al. 2014). The coastal floras are low elevation (up to 660 m in Valle Tranquilo and to 1000 m elevation at Punta Banda) whereas the Sierra de San Pedro Mártir spans more than 2000 m of elevation change. The Sierra de Juárez area is by far the largest of our selected regions at 352 thousand hectares, with coastal floras ranging in size from just 45,000 hectares at Punta Banda to a maximum of 195,000 hectares at San Quintín. These differences in size and elevation have a profound effect on plant distributions and species richness and it is remarkable that the relatively flat coastal flora is so diverse.

Environmental gradients and biodiversity

The W–E gradient, summarized by the first axis of the Principal Component Analysis, concentrates the highest variation in floristic composition within the region and highlights the dramatic floristic difference between mountains and coast. The N-S gradient dominates both the second and third axes of the analyses indicating a difference in the latitudinal effect on the coastal and inland floras. The second axis clearly separates the inland sites from one-another when all native plants are analyzed, but when just the endemics are analyzed, the coastal gradient is dominant. This suggests that the coast has been more significant in the evolution of locally endemic taxa, supporting the idea that coastal fogs maintain paleotaxa and promote speciation along the coast (Vanderplank 2013). Axis 2 for the endemic plants identifies clusters between the Punta Banda and Colonet floras and the San Quintín and Valle Tranquilo floras.

Floristic variation and conservation value

The floristic similarity analysis (Sorensen's Index) for endemics clearly repeats the main trends in the general dataset. The two northernmost coastal sites (Punta Banda and Colonet) have a 63% similarity, while the two southernmost sites (San Quintín and Valle Tranquilo) have a 71% similarity value. The two intermediate sites (Colonet and San Quintín) also are significantly more similar than could be expected by chance ($S = 0.60$), a fact that highlights the latitudinal continuum of coastal sites. In contrast, and despite the proximity of some coastal sites to the nearest mountain (e.g., Punta Banda to Sierra Juárez), the overlap between the floras of mountains and coastal sites was in all cases non significant. In fact, the mountains never shared more than 28% of their endemic flora with that any of the coastal regions. In contrast, the coastal sites have a mean similarity value of

0.54. Although much of the variation throughout the coastal plain is attributable to increasing aridity towards the south, some of it is also likely due to differences in local geology and evolutionary history—Punta Banda is a rocky peninsula, Colonet a clay mesa, San Quintín a volcanic field, and Valle Tranquilo is composed of coastal terraces.

Five of the six regions are home to their own locally endemic taxa, with the highest peak in micro-endemism being at the Sierra San Pedro Mártir. Valle Tranquilo, although it has no endemic taxa of its own, is home to a particularly high number of regional endemics (57), more than Colonet, Punta Banda and Sierra Juárez. The highest level of regional endemism is however seen in San Quintín, with 70 endemic taxa. This is higher than even the Sierra San Pedro Mártir which is known to have 24 taxa endemic to the mountain range.

Conservation priorities for mediterranean endemics

The mountainous regions have the highest diversity of native plants, and encompass a wider variety of habitats. They also have a higher percentage of native plants and include much wider variation in altitude and habitat. However, the patterns for endemic plant distribution are striking. There are more state endemics in the coastal regions than in the montane regions, and more state endemics occur in the smallest region, Punta Banda, than in the largest region, Sierra de Juárez. The distribution of endemic plant species is heavily skewed towards the coast despite the topographical uniformity. Vanderplank (2011) found no correlation between the local and global abundance of taxa in San Quintín (i.e., a plant that was globally rare was equally likely to be rare, frequent or abundant locally). This places most endemics in the 'locally abundant but restricted geographically' or 'constantly sparse and geographically restricted' categories (Rabinowitz 1981). This finding appears to hold true across the coastal plains of the region since rare and endemic plants are distributed without obvious geographic boundaries. Because of their extreme geographic rarity, microendemics (i.e., species that only occur within one region) are of especial importance in conservation efforts. Overall, San Quintín had the highest number of regional endemics of all six areas and should be a focal point for species conservation. The *Reserva Natural San Quintín* may therefore be critical to protection of regional diversity and should be expanded. Colonet and Punta Banda have almost no formal protection and should be a focal region for future protection.

The distribution of Mexican Federally-Listed (NOM 059) Species is particularly high in the mountain parks as many of the nation's timber-production trees (pines) are protected. Despite this, numbers of protected species are surprisingly high at Colonet (10) and San Quintín (9), given that the SSPM has the highest occurrence of protected plants with 14 species.

Conclusions

The mediterranean area of NW Baja California has and extremely rich flora of endemics and also a very high floristic turnover. This region of Mexico is particularly significant nationally, being the only location in the country with mediterranean climate, harboring more than 1000 plants of the California Floristic Province (CFP). The rarest of these are distributed throughout northwestern Baja California, a small but extremely important subset of the CFP.

Conservation in NW Baja California is a complicated task, as it involves dramatic gradients going from rapidly developing coasts to rugged, often highly inaccessible, mountain ranges, but our results speak to the value of many small reserves throughout the biologically complex and rich coastal environments where no large, governmentally managed, reserves have been established. Despite a plethora of attempts at designating natural protected areas and developing regional ordinances in the state of Baja California, protected areas remain limited, and the coastal plain has no formal protection from the state. The stepping-stone model of ecological parks throughout each municipality which was formerly proposed has not come to fruition, and although there are still plans for a riparian protected area near Ensenada there is not a single state protected area at the time of writing. While two large national parks protect the mountain ranges in Baja California, the reserves of Terra Peninsular and Jardín Botánico San Quintín are the only ones to protect the coasts and play a critical role in the conservation of regional rare and endemic taxa in the coastal region.

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References

Burge D, Thorne JH, Harrison SP, O'Brien BC, Shevock JR, Alverson ER, Hardison LK, Delgadillo J, Junak S, Oberbauer T, Rebman JP, Riemann H, Vanderplank SE, Barry T (2016) Plant diversity and endemism in the California Floristic Province. Madroño 63(2):3–206

Caso M, González-Abraham C, Ezcurra E (2007) Divergent ecological effects of oceanographic anomalies on terrestrial ecosystems of the Mexican Pacific coast. PNAS 104:10530–10535

Garcillán PP, Gonzalez-Abraham CE, Ezcurra E (2010) The cartographers of life: two centuries of mapping the natural history of Baja California. J Southwest 52(1):1–40

González-Abraham CE, Garcillán PP, Ezcurra E (2010) Ecorregiones de la península de Baja California: una síntesis. Boletín de la Sociedad Botánica de México 87:69–82

González-Abraham C, Ezcurra E, Garcillán PP, Ortega-Rubio A, Kolb M, Creel JEB (2015) The human footprint in Mexico: physical geography and historical legacies. PLoS ONE 10(3):e0121203

Harper A, Vanderplank S, Dodero M, Mata S, Ochoa J (2010) Plants of the Colonet region, Baja California, Mexico, and a vegetation map of Colonet Mesa. Aliso 29:25–42

Hastings JR, Turner RM (1965) Seasonal precipitation regimes in Baja California, Mexico. Geogr Ann 47(4):204–223

Jackson DA (1993) Stopping rules in principal components analysis: a comparison of heuristical and statistical approaches. Ecology 74:2204–2214

Kraft NPR, Baldwin B, Ackerly DD (2010) Range size, taxon age and hotspots of neoendemism in the California flora. Divers Distrib 16:403–413

Lancaster L, Kay K (2013) Origin and diversification of the California flora: re-examining classic hypotheses with molecular phylogenies. Int J Org Evolut 67:1041–1054

Martorell C, Ezcurra E (2002) Rosette scrub occurrence and fog availability in arid mountains of Mexico. J Veg Sci 13(5):651–662

Minnich RA, Franco-Vizcaíno E (1998) Land of chamise and pines: historical descriptions of vegetation in northern Baja California. Univ Calif Publ Bot 80:1–166

Minnich RA, Franco-Vizcaíno E, Dezzani RJ (2000) The El Niño Southern Oscillation and precipitation variability in Baja California, Mexico. Atmósfera 13:1–20

Minnich RA, Franco-Vizcaíno EF, Goforth BR (2014) Distribution of chaparral and pine-oak "skyislands" in central and southern Baja California and implications of packrat midden records on climate change since the Last Glacial Maximum. In: Whencke E, Lara-Lara R, Álvarez-Borrego S, Ezcurra E (eds) Conservation science in NW Mexico. Instituto Nacional de Ecología, CICESE, UC MEXUS, Mexico

Mulroy T, Rundel P, Bowler P (1979) The vascular flora of Punta Banda, Baja California Norte, Mexico. Madroño 26:69–90

Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403:853–858

O'Brien B, Delgadillo J, Junak S, Oberbauer T, Rebman J, Riemann H, Vanderplank S (In Press) Rare, endangered, and endemic vascular plants of the California Floristic Province (CFP) portion of Northwestern Baja California, Mexico, Aliso

Peinado M, Alcaraz F, Aguirre JL, Delgadillo J, Aguado I (1995) Shrubland formations and associations in Mediterranean-desert transitional zones of northwestern Baja California. Plant Ecol 117(2):165–179

R Core Team (2017) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/

Rabinowitz D (1981) Seven forms of rarity. In: Synge H (ed) The biological aspects of rare plants conservation. Wiley, London, p 205–217

Ramírez Espinoza EL (2010) Diagnosis de las formas biológicas y de vida de la flora vascular se la Sierra de Juárez, Baja California. Facultad de Ciencias, Universidad Autónoma de Baja California. Ensenada, Baja California, México

Rebman JP, Gibson J, Rich K (2016) Annotated checklist of the vascular plants of Baja California, Mexico. San Diego Natural History Museum, San Diego, p 352

Richerson PJ, Lum K (2008) Patterns of plant species diversity in California: relation to weather and topography. Am Nat 116(4):504–536

Riemann H, Ezcurra E (2007) Endemic regions of the vascular flora of the peninsula of Baja California, Mexico. J Veg Sci 18:327–336

Rodríguez Revelo N, Rendón Márquez G, Espejel I, Jiménez Orocio O, Vázquez M, Luisa M (2014) Provenance analysis of sand from the parabolic dune complex at El Socorro, Baja California, Mexico, by means of mineralogic and ganulometric characterization. Boletín de la Sociedad Geológica Mexicana 66:355–363

Rundel PW, Bowler PA, Mulroy TW (1972) A fog-induced lichen community in Northwestern Baja California, with two new species of *Desmazieria*. Byrologist 75:501–508

Shreve F (1936) The transition from desert to chaparral in Baja California. Madroño 3:257–264

Sorrie BA, Weakley AS (2001) Coastal plain vascular plant endemics: phytogeographic patterns. Castanea 66(1–2):50–82

Stebbins GL, Major J (1965) Endemism and speciation in the California Flora. Ecol Monogr 35:1–35

Thorne JH, Viers JH (2009) Spatial patterns of endemic plants in California. Nat Areas J 29(4):344–366

Thorne RF, Moran RAV, Minnich R (2010) Vascular Plants of the High Sierra San Pedro Mártir, Baja California, México: an Annotated Checklist. Aliso 28:1–57

Valenzuela Vázquez C (1990) Estudio florístico del Parque Nacional "Constitución de 1857, Sierra Juárez, Baja California. Tesis de Licenciatura en Biología. Escuela Superior de Ciencias Biológicas, Universidad Autónoma de Baja California. Ensenada, Baja California, México

Vandergast AG, Bohonak AJ, Hathaway SA, Boys J, Fisher RN (2008) Are hotspots of evolutionary potential adequately protected in southern California? Biol Conserv 141(6):1648–1664

Vanderplank SE (2011) The flora of greater San Quintín, Baja California, Mexico. Aliso 29:65–106

Vanderplank S (2013) Endemism in an ecotone: from Chaparral to Desert in Baja California, Mexico. In: Hobhom C (ed) Endemism in vascular plants. Springer, Berlin, pp 205–218

Vanderplank SE, Ezcurra E (2015) How marine influence controls plant phenological dynamics in Mediterranean Mexico. J Plant Ecol 9(4):410–420

Vanderplank SE, Ezcurra E, Delgadillo J, Felger R, McDade L (2014) Conservation challenges in a threatened hotspot: agriculture and plant biodiversity losses in Baja California, Mexico. Biodivers Conserv 23(9):2173–2182

Viers JH, Thorne JH, Quinn JF (2006) CalJep: a spatial distribution database of CalFlora and Jepson plant species. San Franc Estuary Watershed Sci 4(1):1–18