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Identification of priority areas for conservation in an arid zone: application of parsimony analysis of endemicity in the vascular flora of the Antofagasta region, northern Chile

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Abstract. Endemic taxa are those restricted to a specific area, and could be defined as the exclusive biodiversity of a region. An area of endemism contains taxa found nowhere else and could be catalogued as irreplaceable and of high priority for conservation. Kerr (1997, Conservation Biology 11: 1094–2000) proposed the parsimony analysis of endemicity (PAE) as a tool to detect areas of endemism. PAE, a method of historical biogeography, is analogous to cladistic methods used in phylogenetics analysis, and unites areas (taxa in cladistics) based on their shared species (characters in cladistics) according to the most parsimonious solution. In this paper we determined with PAE, prioritary areas for conservation on the basis of concentrations of endemic species in the arid region of Antofagasta, northern Chile, and compared the results with their representation in the current Chilean National Parks and Reserves System. We found two areas suggested as priorities, one located in the north Andean zone of the region, and another at the coast. The area with the higher biodiversity and concentration of endemics was that located at the coast. However, coastal ecosystems are currently under-represented in the Chilean National Parks and Reserves System. The establishment of a new protected area in the coastal zone of the region of Antofagasta is currently under consideration, coinciding with the area suggested with PAE as priority. This new area would not only allow conserving species with evident problems of conservation, but also preserving an area where higher levels of endemism exist.

Introduction

Traditionally, biodiversity has been measured as the number of species of a certain region, so that all species are seen as equal to each other in value (Jeffries 1997). However, other measures of biodiversity, particularly those concerning the difference between entities rather than simply their numbers, have been remarkably sparse (e.g. the number of evolutionary lineages in a flora, richness of taxa above species level, and the number of endemic species; Williams et al. 1991; Humpries et al. 1995). From the species richness perspective, forested habitat has received special attention, concentrating many conservation efforts. For instance, in South America, conservation programs and protected areas have been usually focused on natural forest, ranging from the tropical to the subantarctic zone (Lauer and Erlenbach 1987; IUCN 1994). In contrast, arid zones have received considerably less attention because, from a quantitative point of view, they contain a lower biodiversity. However, arid zones could be very interesting from a 'qualitative' perspective, because their biota has adapted through extensive temporal and spatial differentiations to the harsh and highly dynamic environment, enabling the development of higher amounts of endemism (Messerli et al. 1997). Because funding for conservation action is limited, strategies for the choice of areas richest in biodiversity, both quantitative and qualitative, are needed (Olson and Dinerstein 1998).

Pressey et al. (1994) introduced the notion of irreplaceability of areas. If an area contains only common and widespread species, found in many other areas under consideration, then the area has a low irreplaceability value. In contrast, if the area has attributes found nowhere else it will have an irreplaceability value of 100%. Irreplaceable areas, if threatened, should represent high priorities for conservation actions (Vane-Wright 1996).

Endemic taxa are those restricted to a specific area, and could be defined as the exclusive biodiversity of a region (Cowling et al. 1995; Linder 1995; Kerr 1997). An area of endemism is an area of non-random distributional congruence among different endemic taxa (Platnick 1991; Harold and Mooi 1994), and it is identified by the congruent distributional boundaries of two or more species, where congruence does not demand complete agreement of those limits at all possible scales of mapping (Morrone 1994; Posadas and Miranda-Esquivel 1999). Thus, an area of endemism could be considered as irreplaceable and of high priority for conservation (*sensu* Vane-Wright 1996).

Morrone (1994) proposed the parsimony analysis of endemicity (PAE) as a tool to detect areas of endemism. PAE is analogous to cladistic methods in phylogenetic analyses, and unites areas (cf. taxa in cladistics) based on their shared species (cf. character states in cladistics) according to the most parsimonious solution. The PAE cladogram represents a group of nested areas that share taxa, where terminal dichotomies of the cladogram represent areas with exclusive species of those areas or endemisms (Morrone and Crisci 1995; Cardoso de Silva and Oren 1996). Additionally, these minor areas may contain many of the species present in the major area in which they are included; thus they can be used to suggest areas for priority efforts in conservation (Posadas 1996; Posadas and Miranda-Esquivel 1999). However, the main difficulty in the use of such an approach is the requirement of a complete knowledge of the exact distribution of each species in a region; this information is usually lacking, especially in developing countries.

Recently, a complete botanical exploration of the summer–winter rainfall transitional arid zone of northern Chile (Region de Antofagasta) was carried out, permitting us to complete a database with the distribution of each plant species found within this arid region. Our goal here is to determine with PAE, priority areas for conservation on the basis of concentrations of endemic species in the region of Antofagasta, and compare the results with the current Chilean National Parks and Reserves System in the region.

Methods

Area of study

The region of Antofagasta is located in the north of Chile within the arid zone of western South America. This region extends from 21°20′ S to 25°40′ S covering a distance of 500 km from north to south and a total area of 126 121 km^2. Three physiographic units determine the geomorphological landscape. The first is the Cordillera de la Costa, a line of faulted cliffs which rise abruptly (up to 2000 m elevation) from a narrow coastal plain a few kilometers wide (Figure 1A). The second unit is the intermediate depression, a relatively flat area of ca. 200 km wide located between the Cordillera de la Costa and the Cordillera de Los Andes (Figure 1A). This unit includes part of the Atacama desert, one of the driest deserts worldwide, which extends from Peru (15° S) to north-central Chile (27° S). The third unit is the Cordillera de Los Andes, characterized by the presence of an extensive plain at 4000 m elevation (the Altiplano or Puna) which extends along the Andes from 10° to 27° south latitude. In this unit the highest summits are many volcanoes that exceed 6000 m elevation (Llullaillaco, Socompa, Licancabur). Six major vegetational zones can be recognized within the region (Figure 1B). Along the coast there are two coastal-desert formations: the coastal desert of Tocopilla, characterized by a scarce vegetation restricted to the summits of some cliffs, and the coastal desert of Tal-Tal, a richer vegetation dominated by columnar and globous cacti and low shrubs. In the intermediate depression, because of the presence of the Atacama desert, many areas are completely devoid of plants, except for some oases or along river courses where low shrubs such as *Atriplex* spp. can grow. In the Andes there is a pre-Puna belt (2700–3100 m elevation) characterized by sparse cover of small thorny shrubs, a Puna belt (3100–3800 m) presenting the highest plant abundance, and an Andean belt (3850–4200) characterized by tussock grasses and cushion plants (Villagrán et al. 1981).

Database

The region was divided into 65 quadrats of 0.5° longitude by 0.5° latitude each, as suggested by Morrone (1994). A list of the plant species of each quadrat was obtained from the check list of the vascular flora of the region (862 species, without including varieties – Marticorena et al. 1998). In some cases several quadrats were pooled because the information available did not allow the general resolution level (cf. Posadas 1996). These larger quadrats do not affect the analyses because PAE does not require all the quadrats to have the same extension and shape (Posadas 1996; Posadas and Miranda-Esquivel 1999). Additionally, two quadrats located in the driest zone of the desert were excluded because they showed no species. Thus, the final number of quadrats considered was 42.

Parsimony analysis of endemicity (PAE)

The basic PAE data set was a matrix in which the absence of a species in a quadrat

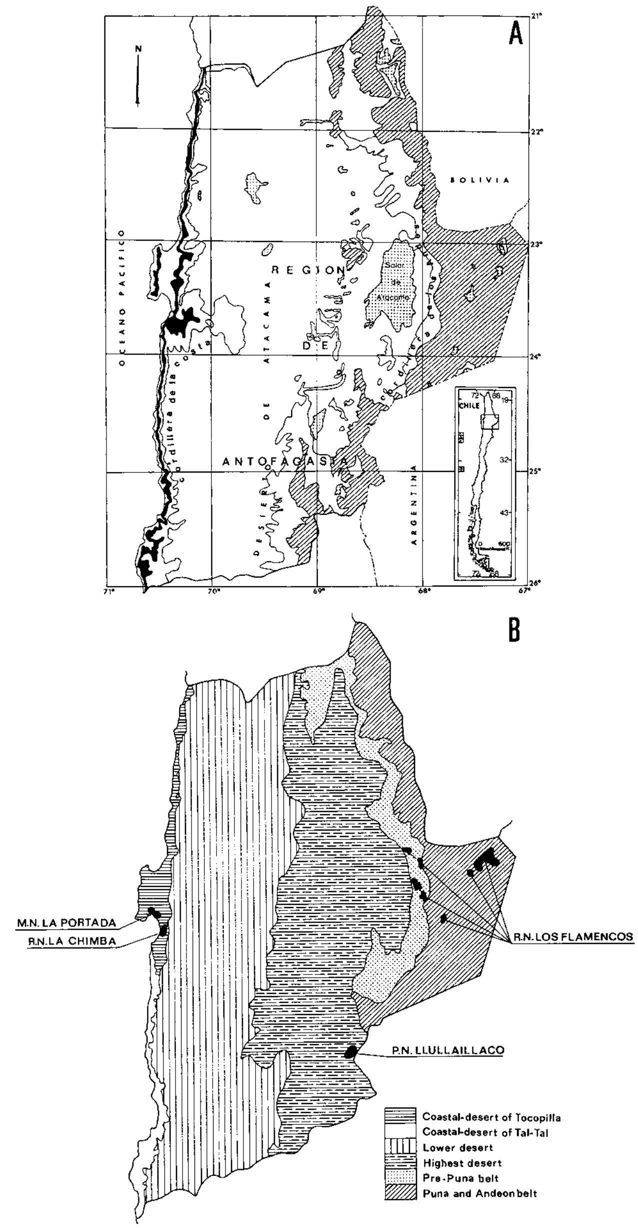

Figure 1. (A) Major geographical features of the Antofagasta region. The coastal range (Cordillera de la Costa) is shown in black, while the Andes range (Cordillera de los Andes) is shown with crossed lines. Between these two ranges there is the intermediate depression which includes the Atacama desert (Desierto de Atacama). (B) Major vegetational zonation in the Antofagasta region (modified after Gajardo 1994), and location of protected areas (RN = National Reserve; PN = National Park).

was coded as '0' and presence as '1'. A hypothetical area that has no taxa at all was included in the matrix to provide a root for the resulting cladogram. The matrix was analyzed with NONA 1.6 (Goloboff 1997). A heuristic search was performed randomizing 45 times the order of entering of the quadrats, and an additional swamping command was applied in order to find all equally parsimonious trees. The strict consensus tree was obtained and the distribution of the character states (species) on the consensus tree was performed with the program CLADOS 1.5 (Nixon 1997). 'Monophyletic' groups of quadrats, defined by at least two species, were delimited and mapped. Terminal dichotomies of a 'monophyletic' group of quadrats were mapped and their distribution was compared with the actual distribution of the National System of Protected Areas.

Results

The analysis of the data matrix produced 78 equally parsimonious trees. The strict consensus tree showed two larger areas of endemism: zones A and B (Figure 2). Zone A included minor zones (A1 and A2, Figure 2), of which zone A1 showed a nested pattern. When quadrats in each zone were mapped, one large endemism area was located in the Andes (zone A), while the other was located at the coast (zone B) (Figure 3).

The area of the Andes (zone A) was defined by the exclusive presence of three species (*Acaena magellanica*, *Gutierrezia espinosae* and *Gypnothamnium pinifolium*). Zone A1 corresponded to the pre-alpine area (Figure 3) and was defined by two species (*Astragalus arequipensis* and *Argylia glutinosa*). Zone A2 was defined by five species (*Fagonia chilensis*, *Gentianella tarapacana*, *Malesherbia deserticola*, *Senecio eriophyton* and *S. madariagae*). Inside zone A2, a terminal dichotomy was found: quadrats 11 and 16, defined by 53 species.

In the coastal area (zone B) a terminal dichotomy was found, formed by quadrats 33 and 37 (Figures 2 and 3), defined by the exclusive presence of 163 species. Thus, the areas formed by quadrats 11 and 16 at the coast, and quadrats 33 and 37 in the Andes could be suggested as priorities for conservation in the region of Antofagasta (Figure 3). Quadrats 11 and 16 contained a total of 259 species, with 36 species (13.9%) endemic to Chile and seven (2.7%) endemic to the region. Quadrats 33 and 37 contained 402 species, with 251 (62.4%) endemic to Chile and 80 (19.9%) endemic to the region.

Discussion

The northeastern part of the Antofagasta region, where quadrats 11 and 16 were located, belongs to the Puna zone also present in Bolivia, Peru and northeastern Argentina. It has been shown that in the Puna, because of the extremely cold and xeric environment, diversity at different taxonomical scales (e.g. species, genera, families) is very low in comparison with other high elevation habitats (Arroyo et al.

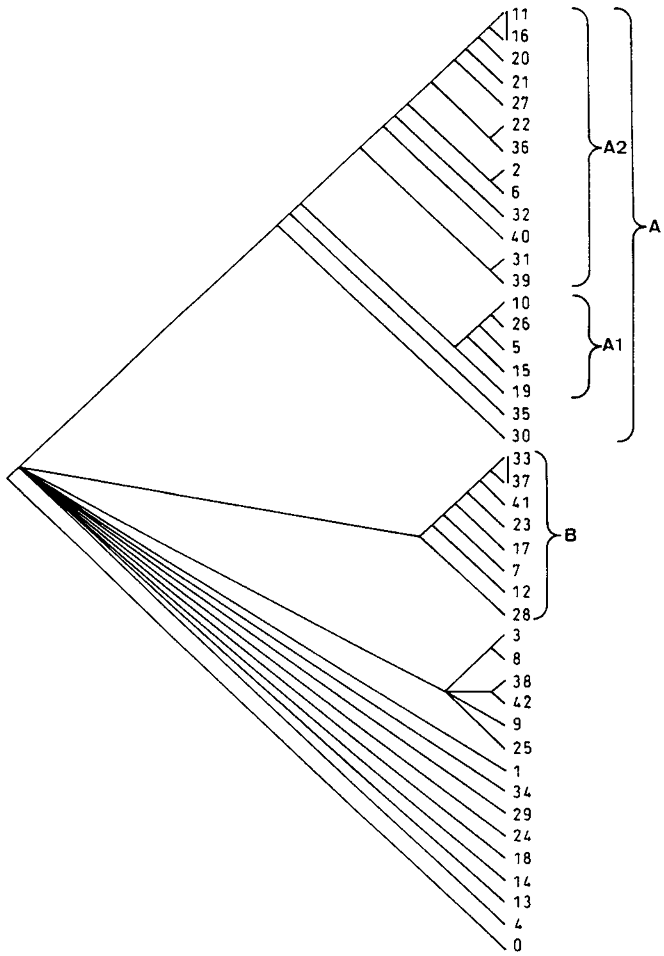

Figure 2. Strict consensus tree resulting from PAE. A and B are major monophyletic groups of quadrats. A1 and A2 are minor groups of monophyletic quadrats inside zone A. Vertical lines represent terminal dichotomies inside monophyletic groups.

1988; Squeo et al. 1998). The lower endemism shown by these quadrats (13.9%) is in agreement with data reported by Squeo et al. (1994) who showed that the Chilean Andes from 17° to 24° S contains ca. 14% of endemic species, while further south (25° to 32° S) endemism increases to 27%. The lower level of endemism registered in the northern Andes of Antofagasta seems to be related with the fact that the particular geological, geomorphological and microclimatic conditions that facilitated the formation of endemism can be found all over the Puna, which is shared with the neighboring countries, impeding the definition of higher amounts of endemism to Chile, and even less endemism at the region level (Squeo et al. 1993).

The number of 402 species found in quadrats 33 and 37 is highly remarkable for a

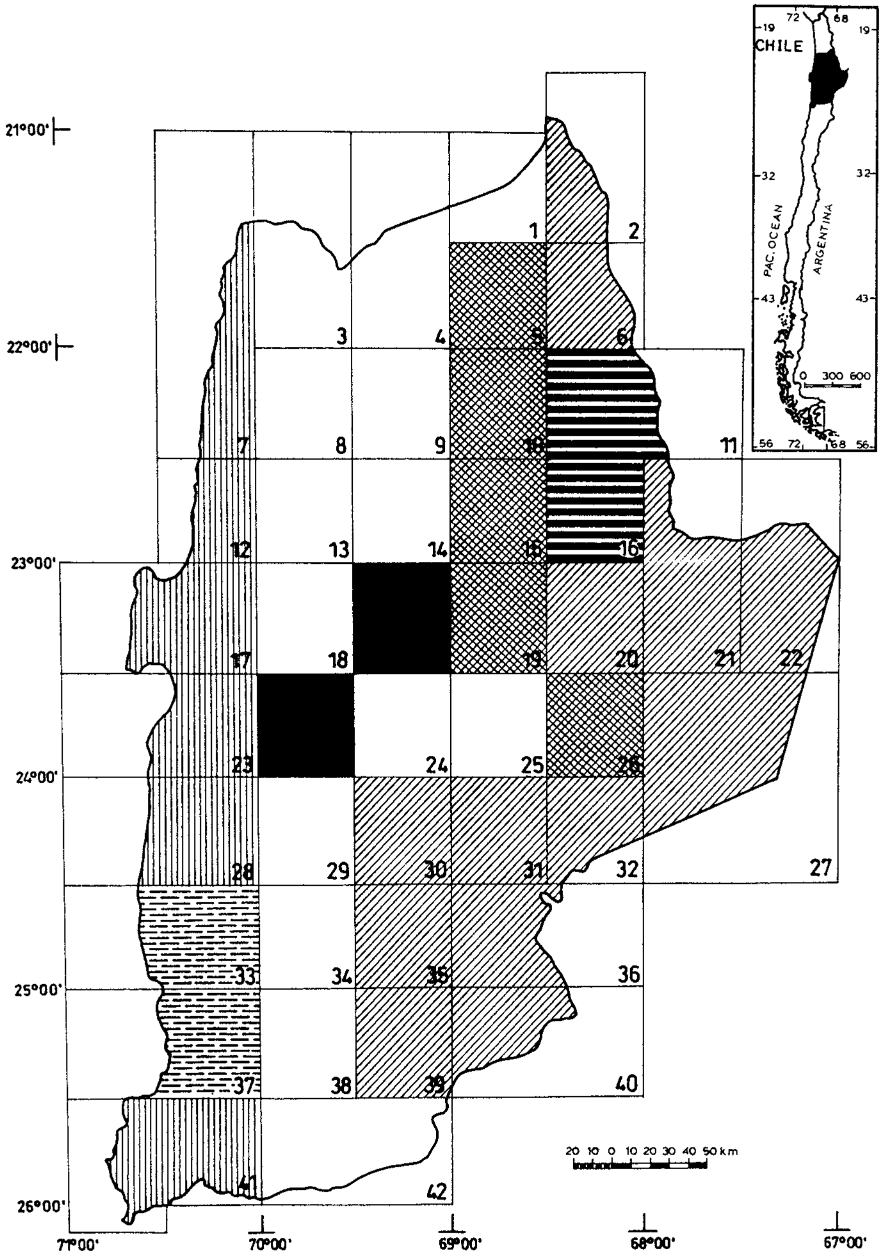

Figure 3. Map of the region showing the spatial representation of zones A1 (crossed lines), A2 (oblique lines) and B (vertical lines) from Figure 2. Horizontal dashes show the location of quadrats suggested as priorities for conservation efforts.

coastal-desert landscape, especially considering that the entire flora of the Peruvian 'lomas' formation (a coastal desert extending between 5° and 17° S latitude) comprises 557 species (Rundel et al. 1991), and that the total flora for the coastal desert of Tal-Tal (24°–26° S) is 532 species (Squeo et al. 1998). Moreover, if we consider that the area covered by both quadrats is ca. 5000 km^2, we have eight plant species per 100 km^2, higher than those found in more mesic habitats such as central Chile [two species per 100 km^2, estimated from data given by Arroyo and Cavieres (1997), one of the hotspot areas of the world (Myers et al. 2000)].

Endemism in quadrats 33 and 37 is also remarkably high: 62% species endemic to Chile, 20% species endemic to the region and 12% endemic of these quadrats, indicating a high concentration of endemism in a very small area. Considering the area covered by the quadrats we have five endemic plant species per 100 km^2, a number comparable with the endemism found in tropical 'hotspots' such as South China, western Ecuador and the tropical Andes (Myers et al. 2000). Rundel et al. (1991) and Dillon and Hoffmann (1997) have discussed that species richness and endemism of the Chilean coastal desert is related with the presence of a coastal fog ('camanchaca') that brings moisture to an extremely arid landscape. Due to the presence of a high coastal range (ca. 1000 m elevation in the zone of quadrats 33 and 37), cool moisture-laden marine air is confined to escarpment cliff and western slopes, forming a persistent fog zone of stratus clouds between 300–800 m elevation and deep ravines (Rundel et al. 1991). Thus, vegetation is confined to isolated patches in deep ravines or escarpment slopes (Zizka 1992). Additionally, there is a group of species that are largely dependent on the sporadic rains brought by ENSO events, which are highly unpredictable (Ehleringer et al. 1998). Thus, the higher levels of endemism found in this coastal zone would be the result of a general isolation of the flora due to the restriction of the vegetation to spatially separated ravines and fog areas, and the high unpredictability of ENSO events that bring rain (Dillon and Hoffmann 1997).

Some authors have argued that regions of high endemism should receive priority in conservation (Myers 1988, 1990; Kerr 1997), whereas others do not (Prendergast et al. 1993). However, it has been shown that regions with high endemism also have high species richness, indicating that the controversy over the relative importance of endemism and species richness may not be necessary (Kerr 1997). Myers et al. (2000) claim to devote conservation effort to 'hotspots' or areas featuring exceptional concentration of endemic species and experiencing exceptional loss of habitat. Although the coastal-desert zone remained well preserved, road construction in association with mining operations, overgrazing by goats, extraction of fuelwood and commercial gathering of plants by the increasing human occupation are the major threats in this zone (Dillon and Hoffmann 1997). Thus, considering the high concentration of species endemic to Chile, endemic to the region, endemic to specific localities and the potential threats, this coastal zone should be considered as priority for conservation efforts.

Although the National Parks and Reserves (NPR) comprises 18% of the Chilean territory, this system has a low representation of desert and arid ecosystems (Benoit 1996). The NPR system in the region of Antofagasta comprises two National Parks, five National Reserves and one National Monument, representing 2.5% of the region's total area (Muñoz et al. 1996). According to Squeo et al. (1998), 672 species (69% of the total flora of the region) are included inside this NPR system. However, the larger units are located in the Andean puna zone (Llullaillaco National Park and Los Flamencos National Reserve). Coastal ecosystems, which concentrate the highest diversity at different taxonomic levels (Squeo et al. 1998) and higher endemisms at different scales (this study), are clearly underrepresented. Recently, Muñoz et al. (1996) have proposed that the surroundings of Paposo and Tal-Tal should be considered as a priority area for conservation efforts. This proposal was based on the fact that these areas have a high concentration of animal species with conservation problems, and the establishment of a new protected area in this zone is currently under consideration (Reserva Nacional Paposo project). According to our results, this protected area would not only allow to conserve animal species with evident problems of conservation, but also preserve an area where a high level of endemism in plant species exists, especially at the local level.

The use of historical biogeography approaches, such as the PAE, has allowed the determination of areas that, besides containing many of the species characteristic of larger areas, contained higher amounts of endemic species (Morrone and Crisci 1995; Posadas 1996; Posadas and Miranda-Esquivel 1999). If areas with concentrations of endemic taxa are considered as priorities for conservation efforts, then the use of these approaches provides a tool in order to supplement the selection of zones that should be classified as priorities for conservation.

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