

# How well do the existing and proposed reserve networks represent vertebrate species in Chile?

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## ABSTRACT

Increasingly, biogeographical knowledge and analysis are playing a fundamental role in assessing the representativeness of biodiversity in protected areas, and in identifying critical areas for conservation. With almost 20% of the country assigned to protected areas, Chile is well above the conservation target (i.e. 10–12%) proposed by many international conservation organizations. Moreover, the Chilean government has recently proposed new conservation priority sites to improve the current protected area network. Here, we used all 653 terrestrial vertebrate species present in continental Chile to assess the performance of the existing and proposed reserve networks. Using geographical information systems, we overlaid maps of species distribution, current protected areas, and proposed conservation priority sites to assess how well each species is represented within these networks. Additionally, we performed a systematic reserve selection procedure to identify alternative conservation areas for expanding the current reserve system. Our results show that over 13% of the species are not covered by any existing protected area, and that 73% of Chilean vertebrate species can be considered partial gaps, with only a small fraction of their geographical ranges currently under protection. The coverage is also deficient for endemic (species confined to Chile) and threatened species. While the proposed priority sites do increase coverage, we found that there are still several gaps and these are not the most efficient choices. Both the gap analysis and the reserve selection analysis identified important areas to be added to the existing reserve system, mostly in northern and central Chile. This study underscores the need for a systematic conservation planning approach to redefine the conservation priority sites in order to maximize the representation of species, particularly endemic and threatened species.

## Keywords

Chile, conservation biogeography, gap analysis, priority sites, reserve network, vertebrates.

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## INTRODUCTION

The most effective way of shielding biodiversity from anthropogenic factors is through the protection of natural ecosystems in protected areas. Protected areas have proved to be a valuable tool in preventing habitat conversion and ensuing biodiversity loss (Bruner *et al.*, 2001; Sanchez-Azofeifa *et al.*, 2003). However, most existing systems of protected areas were not chosen to meet specific biodiversity objectives. Historically, protected areas have been selected for particular purposes (i.e. scenery, protection of headwaters, presence of flagship species, etc.), on land with low potential for economic and political conflict, or high potential for tourism and recreation, which usually do not adequately represent overall biodiversity (Pressey *et al.*, 1993; Pressey, 1994;

Rodrigues *et al.*, 1999; Margules & Pressey, 2000). Indeed, many regional analyses have proved that existing reserve networks are not adequate at protecting biodiversity (Pressey *et al.*, 1996; Williams *et al.*, 1996; Araújo, 1999; Rodrigues *et al.*, 1999; Wessels *et al.*, 2000; Eeley *et al.*, 2001; Fjeldså *et al.*, 2004; O’Dea *et al.*, 2006).

In order to reduce the rate of biodiversity loss, many conservation organizations and international commissions (i.e. IUCN, Convention on Biological Diversity) have called for the near-term protection of at least 10–12% of the total land area of each nation or ecological region (IUCN, 1993; CBD, 2004). However, these conservation targets seem to be related more with political expediency than with scientifically sound reserve design, and larger percentages of land may be needed in different areas to

protect most species (Soulé & Sanjayan, 1998; Groves, 2003; Svancara *et al.*, 2005). Furthermore, as recent analyses show (Rodrigues *et al.*, 2004a,b), the spatial location of the apportioned target percentage is of critical importance, as many species are presently not covered at the global scale. With over 18% of land assigned to protected areas and natural reserves (Pauchard & Villarroel, 2002), Chile is well above the conservation target proposed by international organizations. Furthermore, in an effort to establish a nationwide conservation strategy, the Chilean government, through the National Environmental Agency (Comisión Nacional de Medio Ambiente, CONAMA), has recently generated a list of potential conservation sites for terrestrial and marine conservation (CONAMA, 2003), which will be progressively added to the existing network of protected areas. The selection of these sites was based on the expert opinion of Chilean scientists, and the consultation of public and private organizations. The main goal is to protect 10% of each representative habitat in the country by the year 2015 (CONAMA, 2005).

Increasingly, biogeographical knowledge and analysis are playing a fundamental role in conservation (e.g. Whittaker *et al.*, 2005) by helping to assess the representativeness of biodiversity in protected areas, and identifying critical areas for conservation. Since building on the existing network of protected areas is the most practical approach to improve species representation (Pressey, 1994), the first step is to assess the degree to which biodiversity elements are represented in the existing protected area system, commonly known as gap analysis (Jennings, 2000). The next step is to select additional conservation areas using reserve selection tools to meet pre-established conservation targets (Margules & Pressey, 2000; Groves, 2003). Consequently, in this study we carried out a gap analysis for Chilean vertebrate species, by overlaying maps of the distribution of species over the map of the protected area system, and identified conservation areas that may complement the existing network. Specifically, our aims are: (1) to assess the performance of the existing protected area network in covering vertebrate species, (2) to evaluate how this coverage will likely increase if the selected priority sites are included, and (3) to identify alternative conservation areas for expanding the current protected area network.

## METHODS

### Data

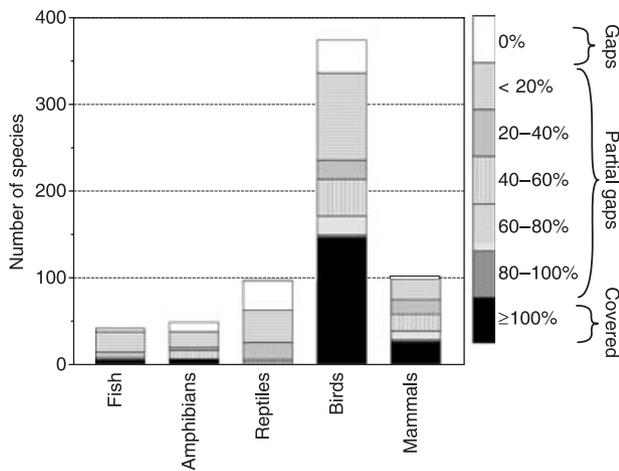
We compiled data on the distribution of all vertebrate species in Chile from primary and secondary literature (i.e. field guides, taxonomic accounts, atlases, species accounts). This information was used to digitize geographical range maps, depicting the extent of occurrence of each species as polygon layers in a geographical information system (GIS). To improve the accuracy of the digital range maps, we used several additional thematic layers (i.e. water courses, main localities, topographical maps, vegetation maps). Subsequently, all range maps were revised by Chilean scientists with expertise in each taxonomic group (i.e. mammals, birds, reptiles, amphibians, and fish). In total, we

mapped 653 terrestrial and freshwater vertebrate species (42 fish, 49 amphibians, 97 reptiles, 363 birds, and 102 mammals; data are available from the corresponding author upon request).

We digitized all existing protected areas and nature reserves ( $n = 89$ ) belonging to the National System of Protected Areas (Sistema Nacional de Areas Protegidas, SNASPE). We also included in this analysis private protected areas ( $n = 1$ ), pilot demonstration units ( $n = 4$ ) and those areas that presently have legal protection, either under Chilean law or due to international agreements signed by Chile. These include: nature sanctuaries ( $n = 24$ ), Ramsar sites ( $n = 2$ ), and reserves created by international non-government organizations ( $n = 4$ ). A total of 124 protected areas (hereafter referred to as 'protected areas') were considered at the time when this study was performed. The average size of protected areas is 122,250 ha, varying from a minimum of 0.6 ha to a maximum size of 3,711,509 ha, and a median of 10,100 ha. The protected area system represents 19.9% of the country's continental area. Additionally, we obtained from CONAMA a GIS layer with all proposed conservation priority sites to be implemented within the next 10 years to improve the coverage of the current national reserve network system. In total, 67 sites (hereafter referred to as 'priority sites') were considered as of highest priority in the layer from CONAMA (as of June 2006) and were the ones used in these analyses. These priority sites represent almost 9% of the country's continental area.

### Gap analysis

To identify covered and gap species, we overlaid the distribution maps of each vertebrate species over the map of all protected areas. All analyses followed the methodology employed by Rodrigues *et al.* (2004b) for the global gap analysis. As in their study, a species was considered covered if a predetermined percentage of its geographical range was included in one or more protected areas. This percentage is referred to as the conservation target for each species, and was calculated following Rodrigues *et al.* (2004a). Briefly, for species with geographical ranges of  $\leq 1000 \text{ km}^2$ , it was required that their entire range was covered, whereas for species with ranges of  $\geq 250,000 \text{ km}^2$ , only 10% of their geographical range was required to be included in protected areas. Conservation targets for species with intermediate geographical ranges were determined by interpolating between these two extremes using log transformation (see Rodrigues *et al.*, 2004a). The use of conservation targets for each species allows the identification of partial gaps: species for which only a fraction of their conservation target is covered by one or more protected areas. Thus, we identified gap species, partial gap species, and those that have calculated conservation targets covered by the existing network of protected areas. This analysis was carried out for all species, endemic species ( $n = 146$ ), and threatened species ( $n = 46$ ; classified as vulnerable, endangered, and critically endangered by the World Conservation Union; IUCN 2006) within each taxonomic group (i.e. fish, amphibians, reptiles, birds, and mammals). Also following Rodrigues *et al.* (2004a), only protected areas  $> 100$  ha were included in the analysis.



**Figure 1** Number of covered, gap, and partial gap vertebrate species. Percentages indicate the degree of fulfilment of the calculated conservation target. One hundred per cent indicates that a species is completely covered.

To evaluate how the priority sites proposed by CONAMA would improve the coverage of species of the existing reserve system, we performed the same analysis as described above, but this time we included all proposed priority sites regardless of their size, as only two sites are < 100 ha (95.77 ha, and 70.22 ha), and are not much smaller than the proposed threshold.

### Reserve selection analysis

We divided the country into 9190 non-overlapping hexagons of 100 km<sup>2</sup> (approximately the median size of all existing protected areas in Chile), representing the spatial units of analysis (hereafter referred to as planning units). Using GIS, we superimposed the grid of planning units with the ranges of all vertebrate species to measure the area occupied by each species. We used MARXAN version 1.8.10 (Ball & Possingham, 2000), an optimization algorithm, to systematically select conservation areas that represent target amounts of all species, first, while forcing solutions to include existing reserves, and second, while forcing solutions to include both existing reserves and proposed priority sites. In both cases, the goal was to represent target amounts of all species over a minimal additional area. For each conservation scenario we ran the optimization algorithm 100 times. To assess the conservation value of each planning unit, we used a measure of irreplaceability determined by the number of times a particular planning unit was selected. For instance, a planning unit that was selected 100 times was considered completely irreplaceable.

## RESULTS

### Gap analysis

#### Existing reserve system

We identified 87 species that were not covered by any protected area. According to their representation targets, the number of

fully covered species is 176 (26.9% of the total). Therefore, 390 species are considered partial gaps (i.e. they partially achieve their conservation target; Fig. 1). Overall, a large fraction (c. 45%) of Chilean vertebrates have less than 20% of their conservation target protected (Figs 1 and 2a). Relative to the total number of species in each taxonomic class, and the percentage of the conservation target covered, reptiles, amphibians, and fish are the groups with lower degree of protection (Fig. 1, and Fig. 2b–f). With respect to endemic species, 42 are considered gaps under this scenario. Most endemic gap species are reptiles, amphibians, and fish (Fig. 3). Of the total 136 endemic species, only nine are fully covered and the remaining 85 are partial gaps. The majority of partial gap species have less than 20% of their conservation target included in protected areas (Fig. 3, and Fig. 4a). Of the 46 threatened species, four are gaps, 33 are partial gaps, and only nine species have their conservation targets fully covered. Among partial gap species, the majority have less than 20% of their conservation targets covered (Fig. 4b).

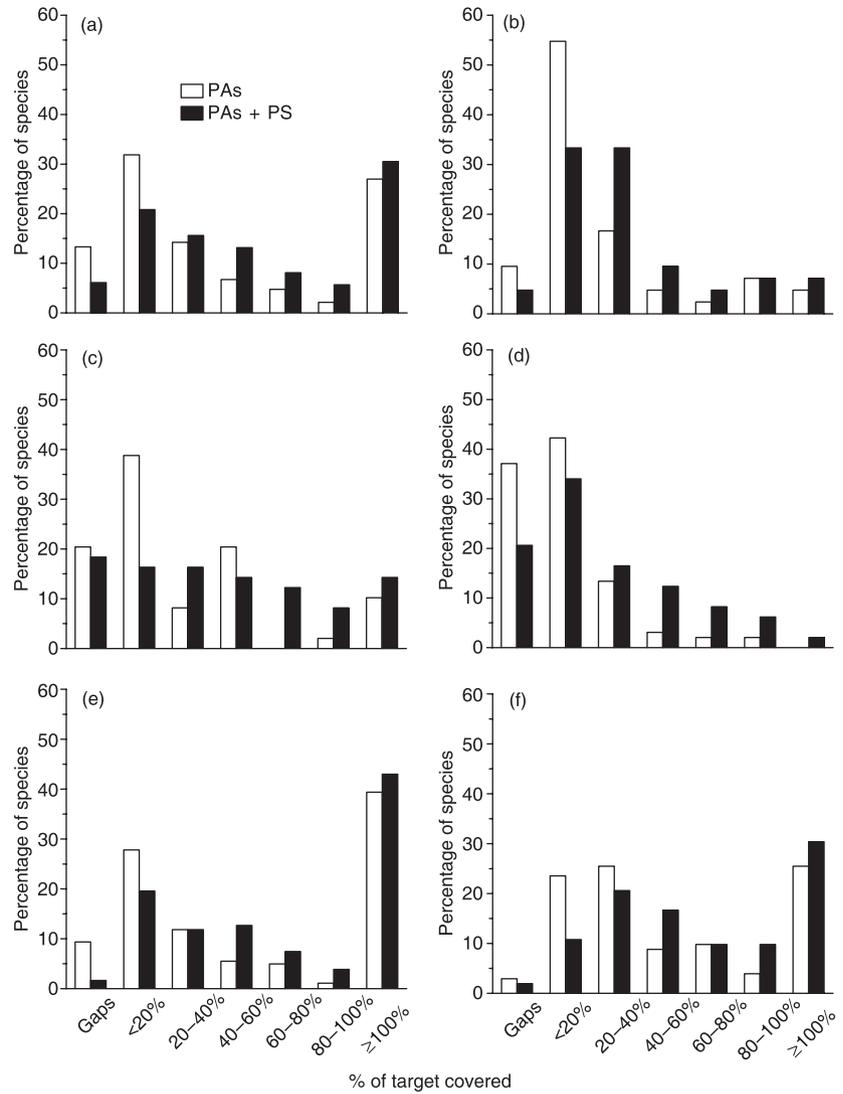
#### Proposed conservation priority sites

The 67 proposed conservation priority sites overlapped with 546 species, including 48 species identified as gap species. When we add the priority sites to the existing reserve network, the number of gap species is reduced by 55%; that is, 39 species still remain as gap species. Reptiles and amphibians are the groups with higher percentage of gap species (Fig. 2c,d).

The number of partial gap species under the current reserve network that changed their category (according to the percentage of their conservation target covered) was higher for the categories with lower percentage of the conservation target protected. Indeed, the number of species that became fully covered ( $\geq 100\%$  of the conservation target covered) was very low for most groups (Fig. 2a–f). Although birds and mammals had higher numbers of species fully covered, these were still relatively low considering the total number of partial gap species in each group (Fig. 2e,f). The number of endemic gap species is reduced by 11% (Fig. 4a), whereas the reduction of threatened gap species is only 2% (Fig. 4b). For both endemic and threatened species, the majority of the species are partial gaps, and only one or none (in the case of endemic species) become fully covered when the priority sites are added to the current reserve network (Fig. 4a,b).

### Reserve selection analysis

In total, 51.6% of the country's continental area, including the existing reserve system, was needed to meet the conservation target for all vertebrate species (Fig. 5). When the conservation priority sites were also included in the analysis, the percentage of the country's continental area to achieve the proposed conservation targets was 54.1% (Fig. 5). In general, more area was required to achieve the conservation targets of reptiles, birds, mammals, and endemic species, whereas targets for fish, amphibians, and threatened species could be represented in less area (Fig. 5). On average, adding the proposed priority sites to the existing reserve



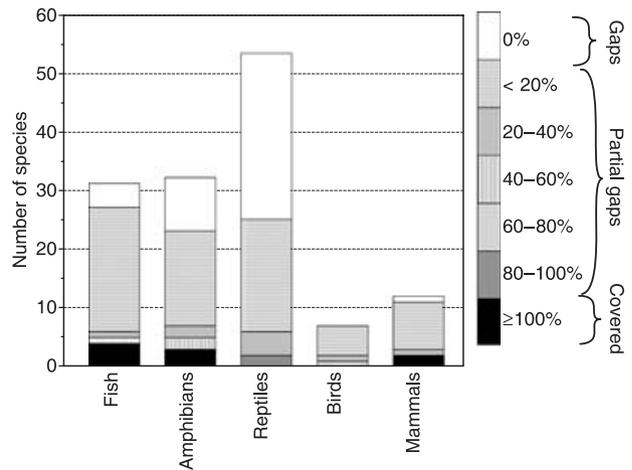
**Figure 2** Percentage of the total number of species in each taxonomic group (a, all vertebrates; b, fish; c, amphibians; d, reptiles; e, birds; f, mammals) belonging to each category of conservation target in the current reserve network (PAs; open bars), and in the proposed conservation priority sites (PAs + PS; solid bars).

network increased the percentage of area required by about 3.9%, highlighting the inefficiency of the proposed priority sites.

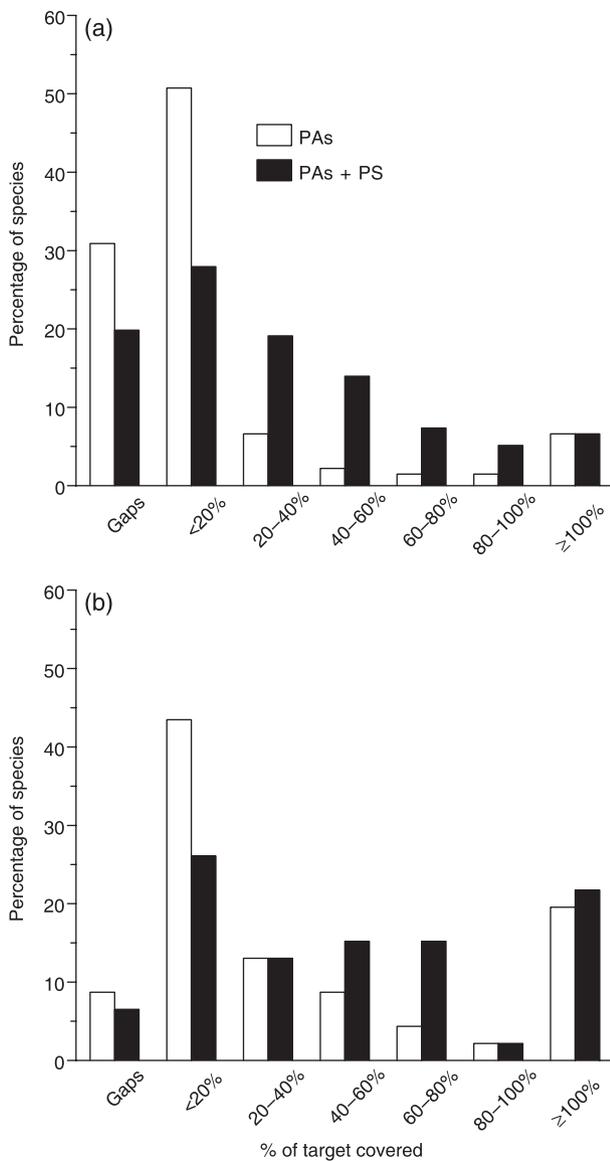
The geographical distribution of the planning units that would need to be added to the current reserve network to achieve the proposed conservation targets were mostly located in northern and central Chile (Figs 6a, 7a, and 8a). The same occurred when the proposed priority sites were also included in the analysis (Figs 6c, 7c, and 8c). The frequency distribution of the planning units selected (of the 100 solutions) followed a similar pattern in both scenarios, with many irreplaceable areas in northern and central Chile, and only a few in the southern portion of the country (Figs 6b,d, 7b,d, and 8b,d).

**DISCUSSION**

Unsurprisingly, the current system of protected areas in Chile is not adequate to represent terrestrial vertebrate diversity. Numerous regional studies have shown that protected area networks are not optimally located to conserve biodiversity (Pressey, 1994; Castro Parga *et al.*, 1996; Williams *et al.*, 1996;



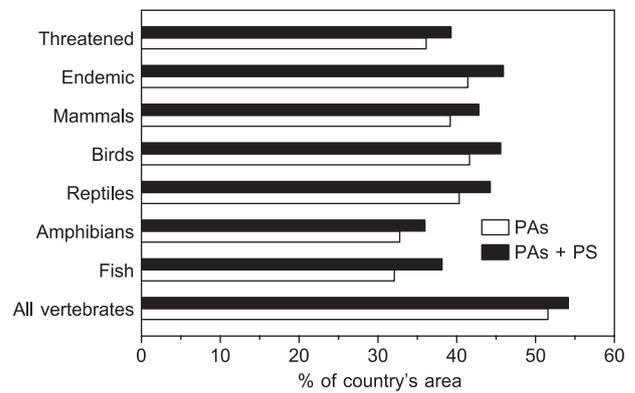
**Figure 3** Number of covered, gap, and partial gap endemic vertebrate species. Percentages indicate the degree of fulfilment of the calculated conservation target. One hundred per cent indicates that a species is completely covered.



**Figure 4** Percentage of the total number of endemic (a) and threatened (b) species belonging to each category of conservation target in the current reserve network (PAs; open bars), and in the proposed conservation priority sites (PAs + PS; solid bars).

Scott *et al.*, 2001; De Klerk *et al.*, 2004). Indeed, we show here that more than 13% of the total vertebrate species are not covered by any protected area. Moreover, endemic species are proportionally less well represented, and several of these are also threatened.

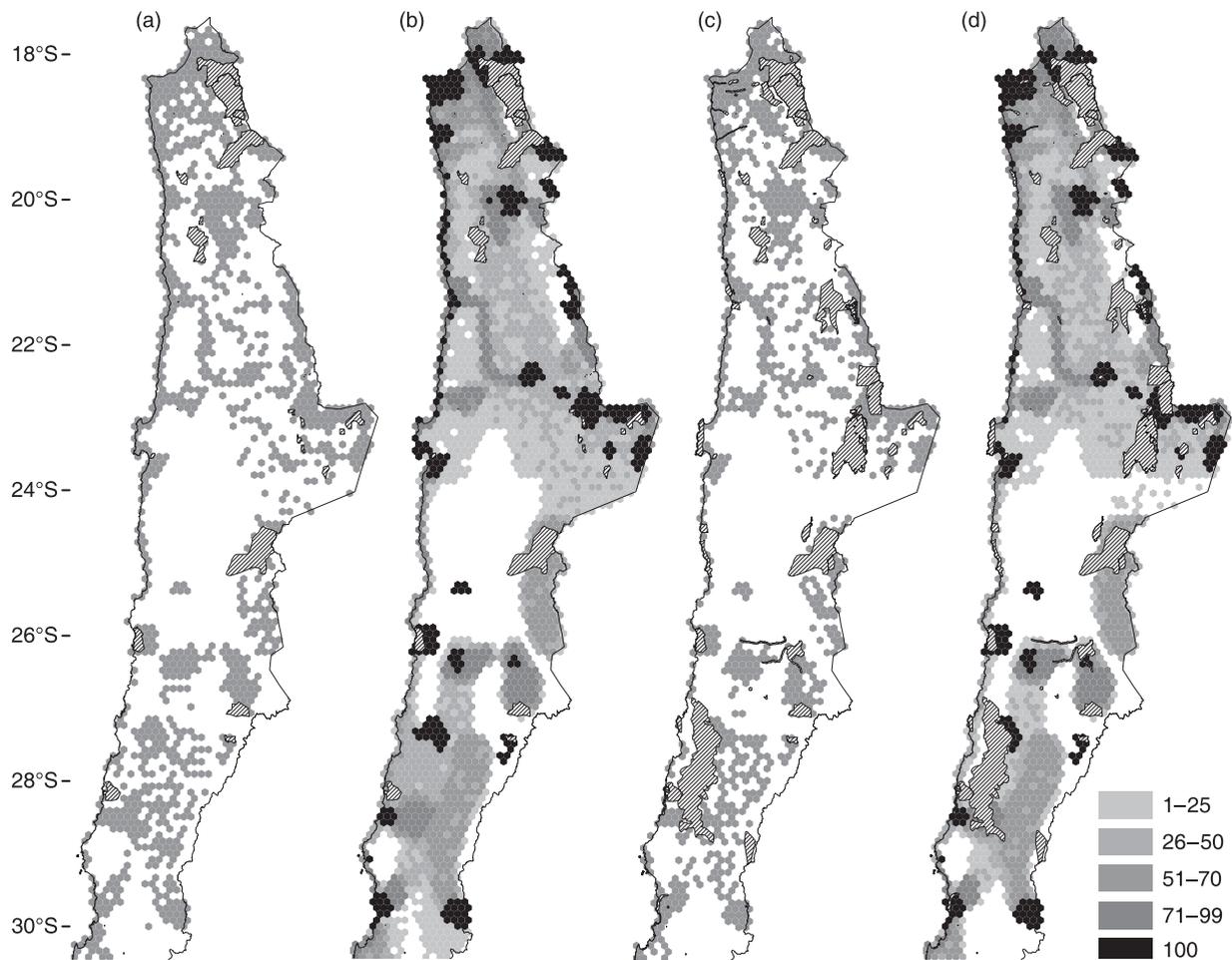
A recent assessment of the global coverage of protected areas indicates that 11.5% of the land surface is currently protected (Chape *et al.*, 2003). However, there are concerns regarding how this proportion is distributed across the globe and how well it covers biodiversity. In fact, a recent study of the number of vertebrate species worldwide (mammals, threatened birds, and amphibians) likely to be covered in the global network of protected areas (Rodrigues *et al.*, 2004a,b) found that a large fraction of them can be considered gap species (i.e. not currently



**Figure 5** Percentage of the total country area required to achieve the conservation targets when the current reserve network (PAs; open bars), and the current reserve network and proposed priority sites (PAs + PS; solid bars) are included in the analysis.

covered in any protected area). A similar situation is exemplified by our study in Chile. The network of protected areas used in this study (which includes national sanctuaries, Ramsar sites and private protected areas) covers, approximately, 20% of the country, but its spatial distribution is far from optimal in the sense of providing adequate coverage of species, especially endemic and threatened species. This is in part due to latitudinal and altitudinal biases in the distribution of protected areas in Chile, which are mostly concentrated in southern latitudes and in the lowlands (Fig. 9a). Under this scenario, it is not surprising to find as many gap and partial gap species as we have found. Although, there are insufficient data to test the representation of other taxa such as plants, a group with more than 5000 species in continental Chile, of which *c.* 43% are endemics (Marticorena, 1990), we expect that similar results might be found. Moreover, because of the restricted range distribution of many plant species, probably the proportion of gap and partial gap species is likely to be higher.

The number of gap species decreases from north to south (Fig. 9a). In northernmost Chile, in the Tarapacá Region (18° S to 22° S), gap species are mainly concentrated in the coastal area where most of the large cities occur and human population density is higher. Between 22° S and 37° S, the number of gap species remains relatively constant and is concentrated along the central valley, an area heavily impacted by human activities associated with urban and agricultural expansion, exotic species, forestry and human-induced fires (Lara *et al.*, 1996; Armesto *et al.*, 1998; Toro & Gessel, 1999; Arroyo *et al.*, 2000, 2004; Montenegro *et al.*, 2004; Azócar *et al.*, 2006; Echeverría *et al.*, 2006; Pauchard *et al.*, 2006). This area encompasses Mediterranean-type ecosystems (31° S to 36°30' S, *sensu* Di Castri, 1973), which are well known for harbouring a large proportion of earth biodiversity (Cowling *et al.*, 1996; Rundel *et al.*, 1998). In continental Chile, the area between 25° S to 47° S, and a narrow coastal strip between 19° to 25° S, are part of the Chilean Winter Rainfall-Valdivian Forest Hotspot (Arroyo *et al.*, 1999, 2004; Myers *et al.*, 2000), characterized by a large number of endemic



**Figure 6** Geographical distribution of planning units selected for both the existing protected area scenario (a and b) and the existing protected area plus proposed conservation priority sites scenario (c and d) for northern Chile. The best solution is shown for each scenario (a and c), and the frequency of selection (b and d). Cross hatched polygons show the existing protected areas (a and b) and the proposed priority sites (c and d).

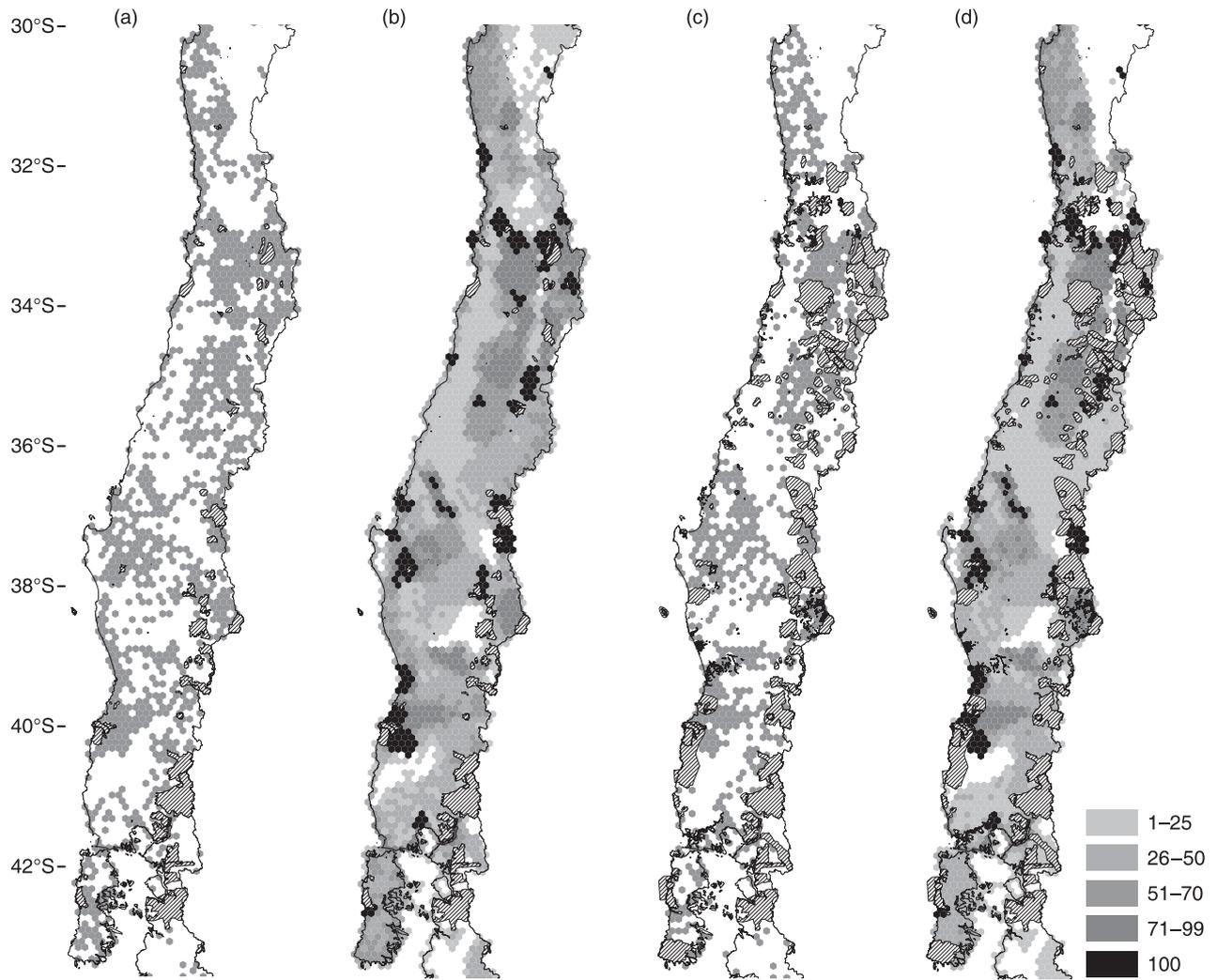
animal and plant species. The lack of an adequate protection of species and the large number of partial gap species in this area require urgent action, particularly considering the low percentage of protected areas herein located (Armesto *et al.*, 1998; Cofré & Marquet, 1999; Fig. 9a), the current rates of human encroachment (Azócar *et al.*, 2006; Echeverría *et al.*, 2006; Pauchard *et al.*, 2006), and its vulnerability to future land use changes (Wilson *et al.*, 2005).

The geographical distribution of protected areas, gap species, and partial gap species described above (Fig. 9a–c) correlates well with the pattern of planning units selected to achieve the proposed conservation targets (Figs 6–8a–d). The high number of gap and partial gap species in northern and central Chile is a consequence of the large number of vertebrate species found there and the low percentage of areas under protection in those regions; factors that in combination accrue for the high conservation value of these areas. Indeed, most of the irreplaceable sites identified in the reserve selection analysis are located in these areas. Remarkably, many of the irreplaceable sites identified in our analysis are adjacent or in close proximity to existing protected areas, which has important implications for expanding

the current reserve system. Also, it is worth highlighting that the conservation priority sites identified by the Chilean government do not match very well with the planning units identified as irreplaceable in the first scenario where the existing reserve system is included in the analysis. Indeed, only 10% of the planning units corresponding to the 67 proposed conservation priority sites are irreplaceable.

There are at least two caveats related to the use of geographical range maps in our study. On one hand, our estimates of gap and partial gap species can be considered as conservative, as species occurrences are inferred from geographical distributions or extent of occurrence (*sensu* Gaston, 1994), which include areas of unsuitable habitats where the species may not be found. Thus, range maps are an overestimate of the species real area of occupancy and of the percentage that may be under protection, which may lead to commission errors (Rodrigues *et al.*, 2004a). On the other hand, the amount of land required to achieve the proposed conservation targets would probably be much smaller if we use the area of occupancy in our analysis.

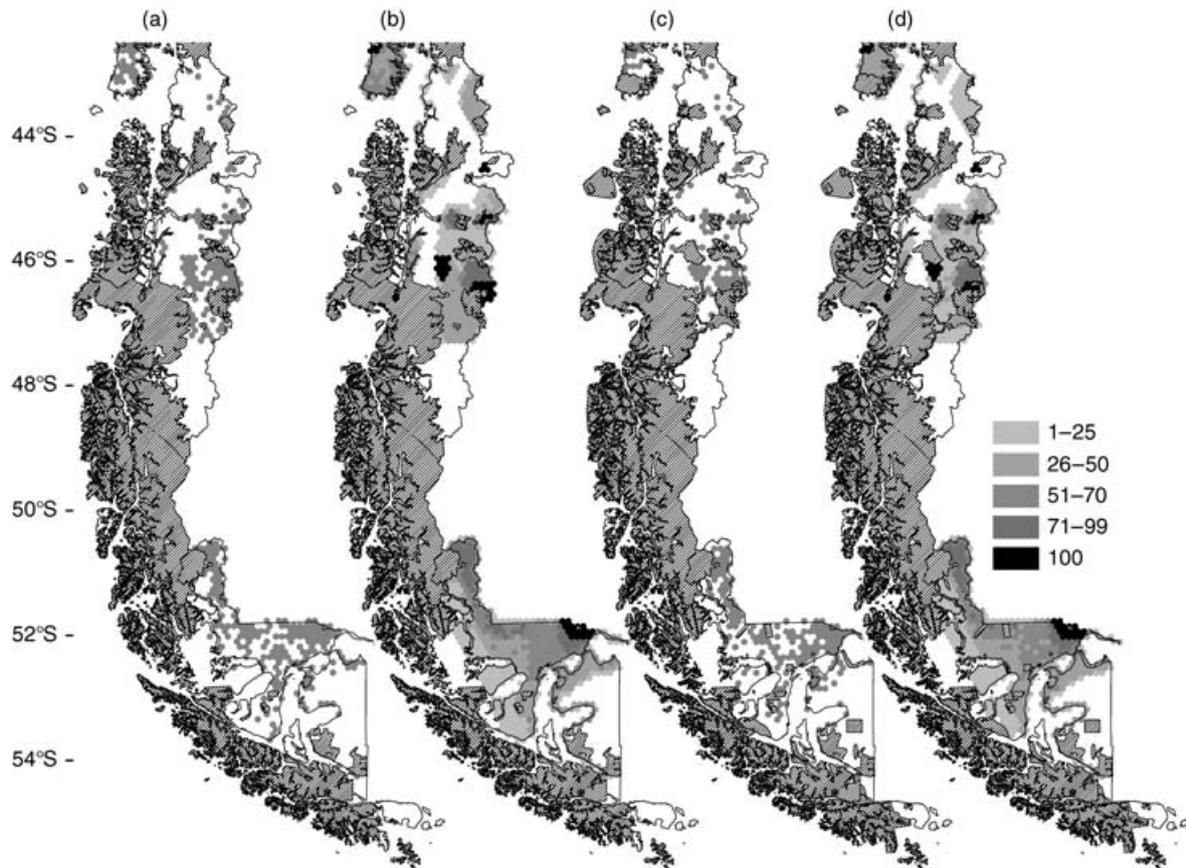
The results of the reserve selection analysis regarding the amount of land that we deem to be adequate for the long-term



**Figure 7** Geographical distribution of planning units selected for both the existing protected area scenario (a and b) and the existing protected area plus proposed conservation priority sites scenario (c and d) for central Chile. The best solution is shown for each scenario (a and c), and the frequency of selection (b and d). Cross hatched polygons show the existing protected areas (a and b) and the proposed priority sites (c and d).

protection of all vertebrate species may seem unrealistic. However, a recent review of the literature addressing the issue of conservation targets (Svancara *et al.*, 2005) showed that evidence-based approaches from conservation assessments and threshold analyses recommended average percentages of protected area of 30.6% and 41.6%, respectively. They found these conservation target values to be almost three times as high as those from policy-driven approaches, which averaged 13.3% (Svancara *et al.*, 2005). Furthermore, they warn about the risk that the implementation of minimalist, policy-driven approaches to conservation could have in the decrease of biodiversity and the increase of threatened species. The problem of establishing how much is enough is still a challenge for conservation biologists, and there is not a single, absolute answer (Tear *et al.*, 2005). However, a science-based conservation planning framework that sets clear, measurable goals and objectives, and addresses representation, resiliency, and redundancy is more defensible (Svancara *et al.*, 2005; Tear *et al.*, 2005).

Unfortunately, the prospects for biodiversity in Chile are not promising, because most land is in private hands, highly productive, and highly priced, and will likely become the basis of Chile's economic growth as the country aims to boost its food industry. In this context, it is important to provide more support and expand the existing network of protected areas and, at the same time, promote the expansion of a private protected area network. However, as shown by Rodrigues *et al.* (2004a,b) at global scales, and reinforced by this study at a country level, this expansion must go beyond policy-based targets for total land in protected areas and consider biodiversity patterns. In the Chilean case, given the current state of Chilean landscapes and the increasing threat they face, these actions might need to be complemented with conservation efforts in the 'seminatural matrix' (Brown *et al.*, 2003), or land neither intensively used for cities or agriculture nor set aside as natural reserves, as these areas are likely to harbour a large fraction of biodiversity and provide connectivity in an otherwise human-dominated landscape.



**Figure 8** Geographical distribution of planning units selected for both the existing protected area scenario (a and b) and the existing protected area plus proposed conservation priority sites scenario (c and d) for southern Chile. The best solution is shown for each scenario (a and c), and the frequency of selection (b and d). Cross hatched polygons show the existing protected areas (a and b) and the proposed priority sites (c and d).

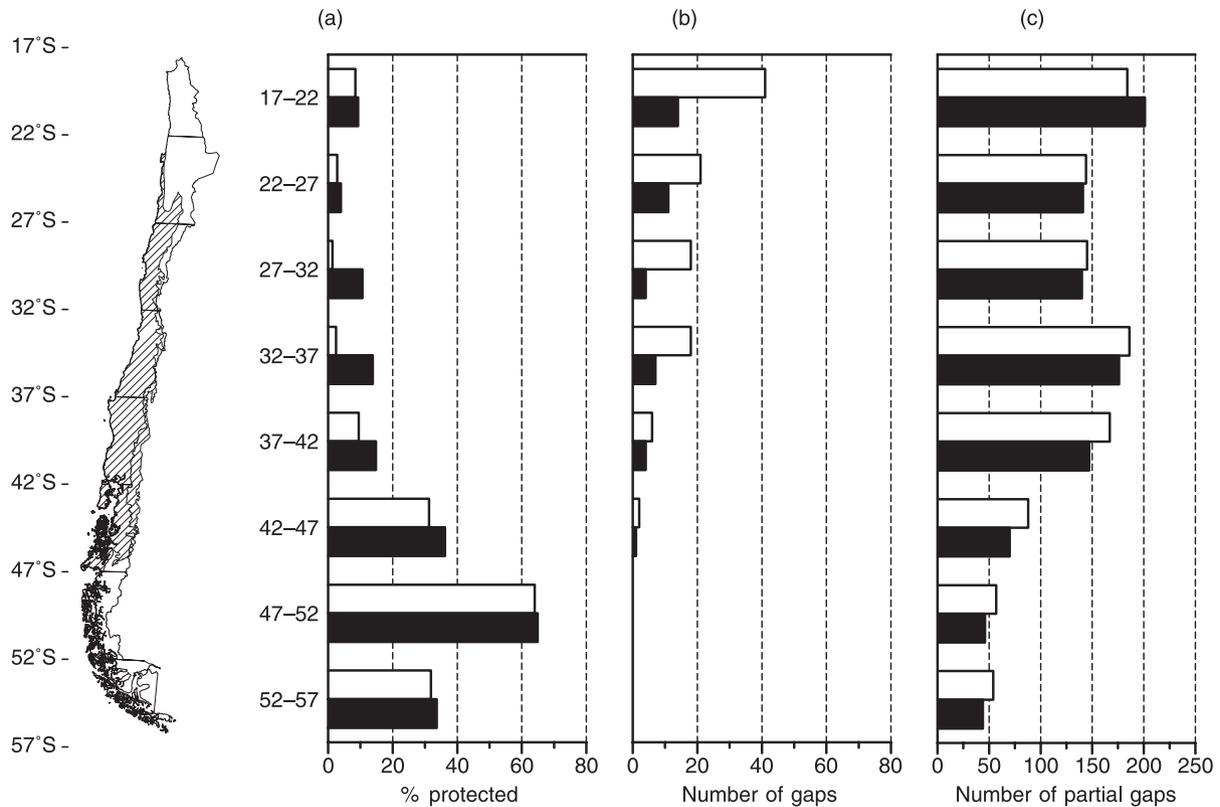
A remarkable result of this study is the disproportionately high number of reptile and amphibian species that have none or very little of their geographical ranges under protected area coverage. Many of these have very restricted distributions and are endemic to Chile. However, despite this fact, no reptile species is listed under any of the threatened categories of IUCN. We expect that several of these species will be listed during the ongoing Global Reptile Assessment by IUCN, as this is most likely a reflection of lack of studies rather than a sign of successful conservation. Similarly, Chilean amphibians should also be the target of continuous surveys and monitoring programs given the high number of endemic species (65% of the species are endemic), a large fraction of which (28.12%) are gap species. Although the proposed conservation priority sites improve the coverage of species, there are still significant gaps in the protection of many of them, particularly endemic and threatened ones.

It is not unexpected that the existing reserve network performs poorly at protecting species, as most protected areas simply have not been established with the specific objective of protecting biodiversity. However, given that the proposed priority sites have been specifically selected for conservation purposes, it would be expected that they perform better at protecting biodiversity. This raises the question of the effectiveness of establishing

countrywide conservation priority sites based on expert opinion *vis-à-vis* a systematic conservation planning approach using appropriate reserve selection algorithms. We acknowledge that this is a preliminary, coarse assessment, and that finer studies incorporating more detailed information on the species conservation needs, as well as incorporating socioeconomic factors into the planning process, are needed. We hope that our research helps redefine priority sites to yield a better network of protected areas for Chile.

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**Figure 9** Geographical distribution of existing protected areas, proposed conservation priority sites, gap, and partial gap species along Chile. Cross-hatched polygon shows the hotspot of biodiversity. (a) Open bars indicate percentage of protected area in each latitudinal band of 5°, whereas solid bars indicate percentage of protected areas and priority sites per latitudinal band. (b) Open bars indicate number of gap species per latitudinal band when only the existing reserve network is considered, and solid bars indicate number of gap species in each band when both the protected areas and the priority sites are included in the analysis (note that some species may overlap more than one band and are counted more than once). (c) Open bars show number of partial gap species per latitudinal band when only the existing reserve network is considered, whereas solid bars show the same number when the proposed conservation priority sites are added.

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