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ORIGINAL PAPER

Conservation planning in a subdivided world

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Abstract The identification of priority areas for conservation tends to take place over two fundamentally different spatial extents. First, there are analyses conducted at global or large biogeographic extents. Second, there are those conducted within geopolitical units. In this paper we show, using data for North American mammals, that spatial extent can have a profound effect both on the number and locations of the priority areas identified to attain a particular conservation goal. For example, applying the same selection target to obtaining just a single representation of each species, the numbers of areas required increased by approximately an order of magnitude between treating North America as a single unit and treating the provinces separately. Although this scenario is undoubtedly extremely simplistic, such large differences are maintained with greater occurrence targets. Balancing the benefits and disadvantages of conservation planning at different spatial extents is not straightforward. However, a multi-scale approach that exploits the respective benefits and downplays the disadvantages when focussing on smaller or larger extents would seem valuable.

Keywords Complementarity · Conservation planning · Geopolitical units · Mammals · North America · Spatial extents

Introduction

The identification of priority areas for conservation is widely recognised as an important step in highlighting those regions and sites where conflicts with other forms of land use

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may be most acute, in planning networks of reserves and other forms of protected areas, and in targeting scarce conservation funding (Pressey et al. 1993; Margules and Pressey 2000). Such activities have increasingly tended to take place across two fundamentally different spatial extents: global and local.

Analyses conducted at global or large biogeographic extents, principally, have variously sought to identify areas with high concentrations of species (total richness, endemic or threatened species), areas with high levels of habitat loss, areas representing the most outstanding examples of different habitat types, or areas with some pre-defined combination of these features (e.g. Bryant et al. 1997; Mittermeier et al. 1998; Olson and Dinerstein 1998; Stattersfield et al. 1998; Myers et al. 2000; Olson et al. 2001; Roberts et al. 2002). Other studies over such extents have also sought to identify sets of areas that are complementary in terms of one or more features of their biological composition (e.g. Brooks et al. 2001; Andelman and Willig 2003; Mittermeier et al. 2003). The spatial grain at which these analyses have been conducted (the size of a typical area unit that may or may not be identified as a priority for conservation action) is extremely variable. In many cases, this is acknowledged to be much larger than that at which conservation action could realistically be conducted (i.e. 1, 1/2, 1/4 degree grid cells), with the expectation that more refined analyses would have to be performed to identify the priory sites within these areas (e.g. Fjeldsa and Rahbek 1998; Mittermeier et al. 2003). In other cases, the grain is much smaller (usually where there is no single fixed unit size in the analysis), and units may themselves be appropriate targets for conservation action (especially recognising, for example, that for some groups of organisms, such as vertebrate megafauna, protected areas need to be large in order to maintain viable populations and other ecological processes; e.g. Berger 2003).

The second, and much larger, group of analyses identifying priority areas for conservation are those conducted within geopolitical units, such as nations, states, provinces, and counties (e.g. Dobson et al. 1997; Erasmus et al. 1999; Abbitt et al. 2000; Cavieres et al. 2002; Jackson et al. 2004; Reyers 2004). These are the units within which many of the macroeconomic and administrative decisions relevant to conservation are in practice made (Hunter and Hutchinson 1994; Erasmus et al. 1999). Increasingly, such analyses have employed complementarity-based methods, acknowledging that resources available for conservation are often extremely limited, and therefore that it is important to understand how biodiversity can be represented in a set of areas with the greatest efficiency (Pressey and Nicholls 1989a), and hence at the least cost (other considerations will, of course, almost invariably modify how priorities are actually realised on the ground). The spatial grain of analyses conducted within geopolitical units is commonly much closer to that at which conservation action could realistically be conducted, although perceptions on this matter vary somewhat. Whilst for much of the world, high quality distributional data at a grain size of, say, 10 × 10 km units would be regarded as an invaluable basis for conservation planning, in much of western Europe it is commonly treated as being far too coarse to be of much assistance in this process; the intensity of human land use, the occurrence of extensive areas of natural/semi-natural vegetation, and the areal requirements of extant species, all shape regional views on these issues.

Unlike global or large biogeographic extent analyses identifying priority areas for conservation, those at the scale of geopolitical units tend to encompass only a fraction (perhaps small) of the geographic ranges of most of the species of concern (Rodrigues and Gaston 2002). This is particularly so in geopolitically complex regions such as, for example, much of Central America, Europe and West Africa. In short, the relative rarity of a species within the study extent considered may not reflect its global rarity or its wider conservation relevance (Bonn et al. 2002). Given that species rarity is known to have a profound effect on the results of complementarity-based area selection methods (Pressey and Nicholls 1989b; Lombard 1995; Willis et al. 1996; Pressey 1999), significant conflict between the sets of priority areas identified over larger geographical areas and those identified at the extent of geopolitical units is likely, even if analyses at both extents were conducted at the same spatial grain size (Erasmus et al. 1999). If within a geopolitical unit 'apparent' rarities (such as species that are marginally within their geographic ranges) are treated similarly in analyses as are 'true' rarities (such as narrow endemics), then the former may strongly influence the outcomes. This may be particularly problematic, given the value often placed by local people on species that are rare in the region where they live, irrespective of their wider conservation significance (Hunter and Hutchinson 1994).

Previous studies of the potential effects of variation in spatial extent on which priority areas for conservation are identified have been conducted at sub-national or national scales (Pressey and Nicholls 1989b; Erasmus et al. 1999). In this paper, for the first time, we investigate these effects across an entire biogeographic region, using data on the distribution of mammals in North America. The general aim of this study is to highlight the implications of decisions as regards the spatial extent over which conservation-planning exercises are carried out at a spatial scale not previously considered. First, we explore variation in the number of priority areas selected that result from treating the region (the subcontinent, from Alaska to Mexico) as one unit compared with treating the geopolitical units separately: Canada, USA, and Mexico, and their 94 constituent states. Second, we examine the variation in the location of the areas selected and in their spatial distribution when using different species-level targets for identifying priority area networks. Third, we assess the influence of very restricted range species on the results of site selection algorithms. Finally, we discuss the implications of these results for conservation priority setting and protected area planning.

Methods

Data

Analyses were based on an established data set on the distribution of 833 mammal species across North America (Arita and Rodríguez-Tapia 2004), defined as the mainland extending from Alaska and Canada to Panama. Range maps were drawn for all species, using those of Hall (1981) as a starting point, but updating the information with new taxonomic and distributional data published up to the end of 2002 (Reid 1997; Wilson and Ruff 1999; Ceballos et al. 2002). The presence or absence of each species was then determined for each half-degree resolution grid cell. A species was considered present within a given grid cell if at least 50% of its range map overlapped with that specific grid cell. For the purpose of this study, the analyses were restricted to land mammals, with introduced and insular species excluded. We omitted coastal cells with less than 25% land area to avoid confounding the influence of area with other effects. A total of 608 mammal species were thus analysed within a grid consisting of 12,770 cells.

The effects of the spatial extent over which priority areas for conservation are identified on the sets of priority areas that result were explored using three different spatial extents. The largest was that of North America, defined here as Canada, the USA and Mexico. The intermediate extent was that of each of the three countries separately. The smallest spatial extent considered was that of the provinces (also called 'states' herein) of Canada, and the states of the USA and Mexico. Grid cells on the borders of these geopolitical units were attributed to that unit which contained more than 50% of the total cell area.

As with any such data set, there are a number of issues that would have to be taken into account for real-world conservation planning exercises. While we recognise various limitations (see Rodrigues et al. 2003 for a discussion), we have used the mammal data set as an exemplar only, assuming that the data correspond to the reality of species distributions in North America. The results should not, therefore, be interpreted as any attempt to propose a new priority area network for North America or any part thereof.

Analyses

The site-selection approach used in this paper is a modified minimum set covering problem (Pressey et al. 1997). Originally developed for operations research, this mathematical selection method aims to represent all natural features (e.g. species or habitats) a given number of times in the smallest possible area, fewest numbers of sites, or with the lowest overall cost (Rodrigues et al. 2000). Typically, analyses of this type have concentrated on the identification of the minimum set of sites required to represent all species at least once. However, for the present analyses, complementary networks were obtained using presence/absence data, with representation targets of 1, 10, 20, and 50 grid cell occurrences of each species (where possible). Throughout, optimal solutions were obtained using CPLEX linear programming software (ILOG 2001). Given the numbers of species and sites included in each of the site-selection algorithms, multiple optimal solutions were inevitable (Arthur et al. 1997). This does not influence the final results as, by definition, the numbers of sites required remains consistent across all optimal solutions for a given problem. It does, however, influence the precise spatial distribution of the areas selected. Consequently, 25 optimal solutions were obtained for each representation target. In all cases, successive optimal solutions (where possible) were found by adding a new constraint to the site selection algorithm to exclude the preceding optimal solution (Rodrigues et al. 2000).

The degree of spatial congruence between minimal sets at the different regional extents was evaluated using Jaccard's similarity coefficient (van Jaarsveld et al. 1998), which ranges from 0% (no selected cells in common) to 100% (all selected cells shared). The index is expressed as $C_j = i/(a + b + i) \times 100$, where i is the number of grid cells selected at both of two regional extents, a is the number of additional cells selected at the smaller regional extent but not the larger, and b is the number of additional cells selected at the larger regional extent but not the smaller. The significance of minimal set spatial congruence was determined by comparing the observed *Jaccard* with randomly generated values, following Warman et al. (2004). We generated *Jaccard* values for 100 pairs of randomly selected sets of sites (maintaining the same number of sites in each pair). Finally, the degree of spatial congruence was considered statistically significant of the observed *Jaccard* values fell within the top 5% of the randomly generated values.

Results

Numbers of areas selected

Considering North America as a single unit, all of the 608 mammal species can be represented, at least once (the minimum set), within 55 grid cells. Treating the three countries separately, this minimum set required 11 (0.15% total area) grid cells for Canada, 32 (0.69% total area) for the USA, and 39 (5.53% total area) for Mexico, giving a total requirement of 82 grid cells, 27 more cells than those required when country boundaries

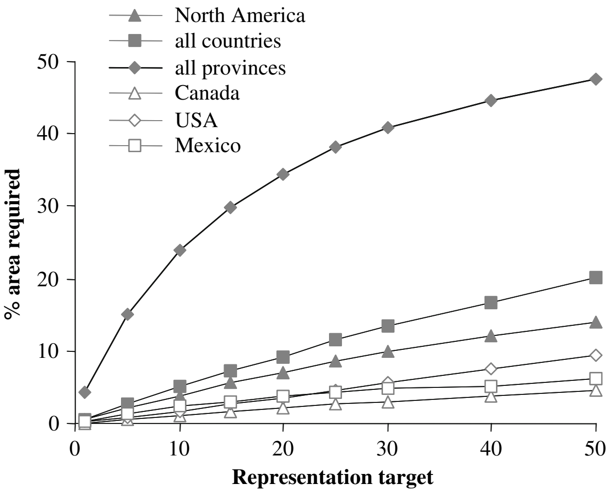

Fig. 1 Cumulative percentage of total area required to satisfy each representation target as a function of an increasing species representation target

were ignored (Fig. 1). Yet more markedly, treating the states in the three countries separately, the minimum set comprised 560 (0.95%) cells in total. This is nearly a ten-fold increase in the number of grid-cells required compared with treating North America as a single unit.

Almost invariably, this same pattern of lowered efficiency was maintained for greater representation targets, up to the maximum tested of 50 representations of each species (where this was possible; Fig. 1). The disparity generally increased for larger numbers of representations, although whilst for individual geopolitical units the number of cells required increased approximately linearly with the number of representations, summing these requirements across geopolitical units tended to result in a more asymptotic increase because of the large numbers of cells needed to attain even quite modest numbers of representations (Fig. 2).

Locations of areas selected

As is illustrated in Fig. 3, when North America is treated as a single unit, the distribution of the cells required to obtain a given number of representations of each mammal species is highly fragmented, with some southerly clustering reflecting the latitudinal gradients in numbers of species and of endemic species. Treating the three countries and the states separately reveals a tendency for sites selected to meet a given representation target to be particularly clustered along geopolitical boundaries, with the effect being marked when selection is conducted within states for relatively low numbers of representations.

Values of spatial overlap (here reported as the average values across the 25 optimal solutions for each representation target between the grid-cells selected at the different spatial extents were extremely variable. On the one hand, the degree of overlap between the cells selected treating the states separately and those selected treating North America (continent unit) as a single unit was 1.9 % (range 1.4–2.5%). Likewise, treating the states separately and treating the countries separately, the degree of average overlap between the cells selected was 4.1% (range 3.3–4.6%). On the other hand, the degree of mean overlap

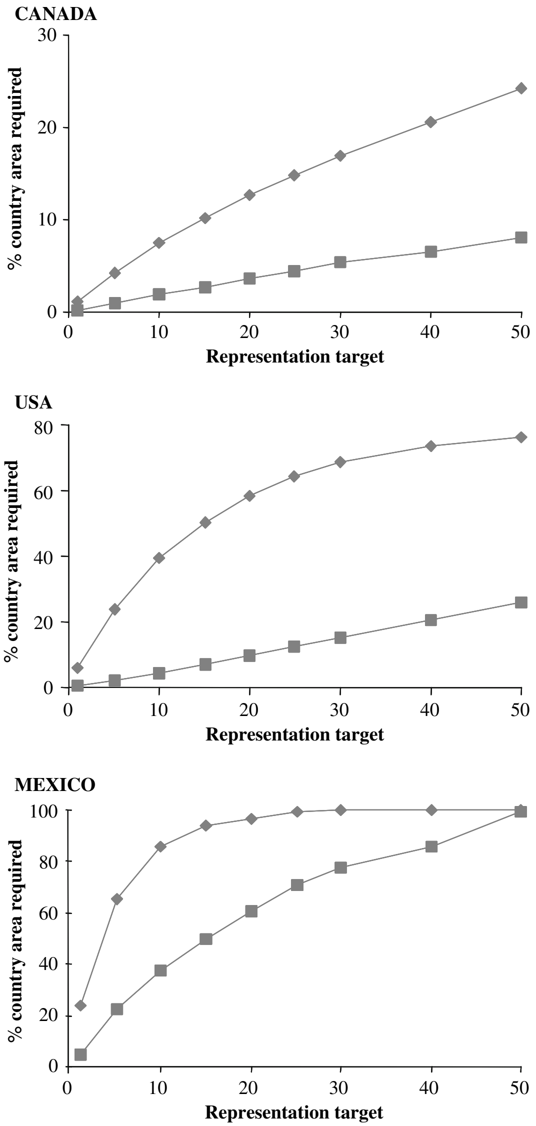

Fig. 2 Cumulative percentage of total country area required to satisfy each representation target as a function of an increasing species representation target, when states are treated separately (diamonds), and when state boundaries are ignored for each country (squares)

between the cells selected treating the countries separately and those selected treating North America as a single unit was 16.9% (range 15.4–18.3%). Finally, the observed *Jaccard's* similarity values were significantly higher than would have been expected by chance alone (0–1.2% overlap continent versus single states, 0–5.4% for continent versus countries, and 0–2.2% on states and countries).

Excluding records

To assess the influence of very restricted range species on the total number of complementary grid cells identified, we excluded from the analyses all species having only 1, 2 and 3 occurrences in each spatial unit of analysis (North America, a country or a state); this is an

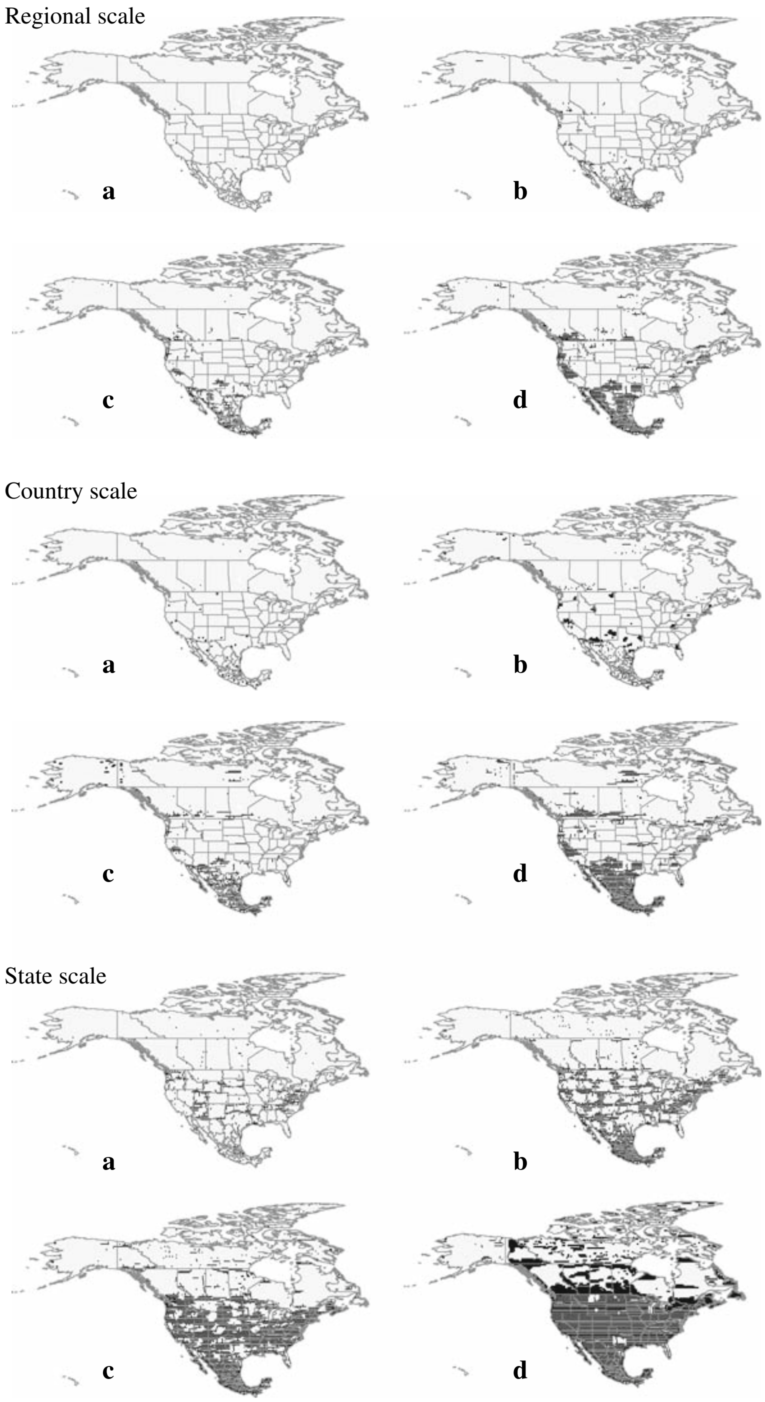

Fig. 3 Maps showing exemplar spatial distributions of sets of complementary cells using different species representation targets at three spatial extents. All mammal species are represented (where possible) at least: (**a**) once, (**b**) 10 times, (**c**) 20 times and (**d**) 50 times

arbitrary cut-off, but the conclusions are not sensitive to the precise boundary chosen. Unsurprisingly, the total number of cells selected was always lower than the corresponding numbers using all of the mammal species. Seventy cells were required to represent all species with more than three occurrences by at least one representation on the country-scale, as opposed to the 82 cells required to cover all the species. At the provincial extent, 357 cells were selected, close to 40% less than when all species were considered in the analysis. However, excluding the rarest species (≤three occurrences) in the whole region made no difference to the numbers of cells selected.

Discussion

The results reported here demonstrate that the geographic extent of the region considered has a profound effect on the numbers and locations of the priority areas that are identified. Whilst this is not unexpected, and fits with earlier studies conducted over markedly narrower extents (Pressey and Nicholls 1989b; Erasmus et al. 1999; Rodrigues and Gaston 2002), the magnitude of the difference is stark. For example, applying the same selection rule to obtaining just a single occurrence representation of each species, the numbers of areas required increased by approximately an order of magnitude between treating North America as a single unit and treating the states separately. Although this scenario is undoubtedly extremely simplistic, such large differences are maintained with greater occurrence targets and are likely to remain for more complex models that seek disproportionate representation of rare species (Rodrigues et al. 2000), and take additional considerations into account.

This is not to pass judgement on whether conservation planning should be conducted across broader or narrower regional extents. There are pros and cons to both approaches. Specifically, planning across broader spatial extents better reflects the overall geographic distributions of species (especially when issues of connectivity, isolation, or migration are to be explicitly addressed), places emphasis on true rarities rather than apparent ones (see Introduction), and provides an opportunity for more ‘joined up thinking’ in the planning and implementation processes of smaller scale geopolitical units. Such reasoning underpins many of the international schemes for identifying priority areas (e.g. global hotspots, wilderness regions, global 200 ecoregions, Ramsar sites). For example, Ramsar Sites for waterfowl are selected on the basis of internationally agreed criteria, some of which relate to the international context of the population (1% threshold levels; Ramsar Bureau 1999). In this way, although actual implementation of the Convention is at the national-scale, the ensuing set of protected areas is global in coverage and priorities. However, planning at broad regional extents also tends to result in disproportionate numbers of priority areas in some geopolitical units, which may under-exploit the opportunities for conservation action in other units (see Brooks et al. 2001; Andelman and Willig 2003). For example, in the results reported here the majority of priority areas identified when treating North America as a single unit lie in Mexico, at higher representation targets this trend is more evident (Fig. 3), because of the large numbers of narrowly distributed species that are found there (Arita et al. 1997). Planning at broad regional extents may also, ironically, under represent more widely distributed species in priority areas; occurrence targets may, for example, be achieved through an unrepresentative (e.g. geographically clumped) distribution of priority areas, although this may to some extent be off-set because occurrences of widespread species may also incidentally be picked up in other priority areas. This is a potential concern, given that in many regions such species are undergoing major declines (e.g. Ceballos and Ehrlich 2002; Sanderson et al. 2002).

Planning across narrower spatial extents typically better reflects the widespread devolution of real conservation decision-making to state and provincial geopolitical units, and provides a better match between the spatial resolution at which priorities are identified and that at which they are implemented. For example, across the European Union (EU), although the Birds Directive is itself pan-EU in its focus, both planning and conservation action (identification and management of Special Protection Areas [SPAs]) takes place within the individual Member States using criteria developed and applied within each State independently. The justification is that, given the wide-ranging social, economic, political and biological conditions apparent across the different Member States, a blanket approach would be infeasible and almost certainly ineffective. This approach has, however, resulted in insufficient numbers and coverage of protected areas in many Member States (BirdLife International 2004). For example, using the inclusion of BirdLife International's Important Bird Areas (IBAs) within the SPAs as a benchmark, only five Member States (Luxembourg, Denmark, The Netherlands, Belgium and Finland) have performed adequately (classified greater than 70% of the IBAs). Furthermore, the total area of SPAs classified across all Member States amounts to less than half that of the IBAs (BirdLife International 2004). In response to this largely poor implementation of the Birds Directive, the European Commission has used the IBA inventory as a basis from which to pursue action against several Member States (e.g. France, Finland and Italy).

Applying conservation planning at local extents also better captures the value often placed by local people on species that are rare in the region where they live (Hunter and Hutchinson 1994; Erasmus et al. 1999). Indeed, as Hunter and Hutchinson (1994) point out, a great motivating force for conservation action and support is the affinity people feel to things that are close to them. However, this parochial approach can also place much emphasis on apparent rarities (e.g. Bonn et al. 2002; for a discussion see Rodrigues and Gaston 2002).

Balancing the benefits and disadvantages of conservation planning at different spatial extents is not straightforward. A multi-scale approach that exploits the respective benefits and downplays the disadvantages when focussing on smaller or larger extents would seem attractive. However, in practice, given issues of data availability (appropriate quality, quantity and resolution) and the various political and economic considerations affecting the application of conservation planning exercises, a multi-scale approach is likely to be difficult to employ in most regions of the world. In practice, conservation planning will almost inevitably continue to occur preferentially within geopolitical units. In this respect, these analyses highlight some of the key issues likely to confound such an approach; principally, those concerned with species representation biases within priority areas. Various tools exist to deal with such biases using species-specific representation targets and have been applied at a range of spatial extents (e.g. Stroud et al. 1990; Jackson et al. 2004; Perez-Arteaga et al. 2005). Such approaches can be used within a systematic conservation framework to deal, for example, with apparent rarities by weighting species in terms of global, biogeographic or national-scale priorities. The analyses reported here demonstrate the importance of so doing.

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