Aligning conservation goals: are patterns of species richness and endemism concordant at regional scales?

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Abstract

Aligning conservation goals: are patterns of species richness and endemism concordant at regional scales?— Biodiversity conservation strategies commonly target areas of high species richness and/or high endemism. However, the correlation between richness and endemism at scales relevant to conservation is unclear; these two common goals of conservation plans may therefore be in conflict. Here the spatial concordance between richness and endemism is tested using five taxa in North America: butterflies, birds, mammals, amphibians, and reptiles. This concordance is also tested using overall indices of richness and endemism (incorporating all five taxa). For all taxa except birds, richness and endemism were significantly correlated, with amphibians, reptiles, and the overall indices showing the highest correlations (r_s = 0.527–0.676). However, "priority sets" of ecoregions (i.e., the top 10% of ecoregions) based on richness generally overlapped poorly with those based on endemism (< 50% overlap for all but reptiles). These results offer only limited support for the idea that richness and endemism are correlated at broad scales and indicate that land managers will need to balance these dual, and often conflicting, goals of biodiversity conservation.

Key words: Conservation goals, Species richness, Endemism, Regional scales.

Resumen

Ajuste de los objetivos de conservación ¿Son concordantes a escala regional los patrones de riqueza de especies y de endemismos?— Las estrategias de conservación de la biodiversidad se centran habitualmente en áreas con una gran riqueza de especies y/o un alto nivel de endemicidad. Sin embargo, la correlación entre riqueza y endemismo a escala relevante para la conservación es poco clara; por consiguiente, estos dos objetivos comunes de los planes de conservación pueden entrar en conflicto. En este trabajo se estudia la concordancia espacial entre riqueza y endemismo en Norteamérica utilizando cinco taxones: mariposas, aves, mamíferos, anfibios y reptiles. Esta concordancia se estudia también empleando índices globales de riqueza y endemismo (incorporando los cinco taxones). Para todos los taxones, excepto para las aves, riqueza y endemismo aparecen correlacionados significativamente, mostrando para los anfibios y reptiles una alta correlación de todos los índices (r_s = 0.527–0.676). Sin embargo, las "actuaciones prioritarias" de las ecoregiones (por ejemplo, el 10% de ecoregiones de vanguardia) basadas en la riqueza de especies normalmente se solapan poco con las basadas en endemismos (< 50% de solapamiento para todos los taxones excepto para los reptiles). Estos resultados apoyan limitadamente la idea de que riqueza y endemismo están correlacionados a gran escala e indica que los gestores del territorio deberán tener en cuenta estos objetivos duales, y a menudo en conflicto entre sí, de conservación de la biodiversidad.

Palabras clave: Objetivos de conservación, Riqueza de especies, Endemismo, Escala regional.

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Introduction

It is well recognized by conservation biologists that there are limited resources available to address intensifying anthropogenic threats to biodiversity (EHRLICH & WILSON, 1991; MYERS et al., 2000). Geographic priorities must therefore be established, so that these resources and effort can be allocated to areas with high biodiversity value, such as high species richness and/or endemism (CEBALLOS et al., 1998; OLSON & DINERSTEIN, 1998). While in theory this is a sound strategy, its implementation has encountered two major difficulties. First, a lack of high–quality species distribution data, especially at broad scales, has made it difficult to identify priority areas with confidence (WILLIAMS & GASTON, 1994). Second, there is frequently a difference of opinion among conservationists over which aspects of biodiversity are most important in setting priorities. Some authors have emphasized species richness, while others argue that areas of high endemism should be targeted most (PRENDERGAST et al., 1993; KERR, 1997; CEBALLOS et al., 1998).

A popular response to this first problem has been to propose indicator taxa: well–studied groups of organisms whose richness patterns can be used as surrogates for other taxa or for overall species richness. Many recent studies have either proposed indicator taxa (e.g., PEARSON & CASSOLA, 1992), assumed them to indicate overall richness and based conservation plans on them (e.g., SCOTT et al., 1993), or tested their utility directly (e.g., DAILY & EHRLICH, 1996; CARROLL & PEARSON, 1998; RICKETTS et al., 1999a; RICKETTS et al., in press). To date, tests of indicator taxa for species richness have produced mixed results, suggesting the utility of this conservation tool depends on context, taxon, and scale (WEAVER, 1995).

Even if suitable indicator taxa can be found, however, the second problem remains. Priorities set on the basis of species richness may not successfully conserve areas of high endemism, which are clearly important to biodiversity conservation at any scale. Data on endemism are typically less available than on species richness, and patterns of endemism are thus less well understood (BIBBY, 1992; KERR, 1997). Therefore, biologists still have a relatively poor understanding of whether patterns of species richness and endemism are concordant, and thus whether

these two common goals of conservation plans are in conflict or alignment.

This second problem is addressed here, using a large North American dataset to examine the concordance of richness and endemism patterns in five animal taxa (butterflies, birds, mammals, reptiles, and amphibians). Two specific questions are asked. First, are levels of species richness and endemism correlated across the United States and Canada? this correlation is tested for each taxon individually as well as for indices of overall richness and endemism that incorporate all five taxa. Second, to what extent do areas selected for conservation priority on the basis of richness overlap with areas selected on the basis of endemism? Answers to these questions will help determine whether the two primary goals of biodiversity conservation plans will tend to reinforce or compete with each other for limited resources.
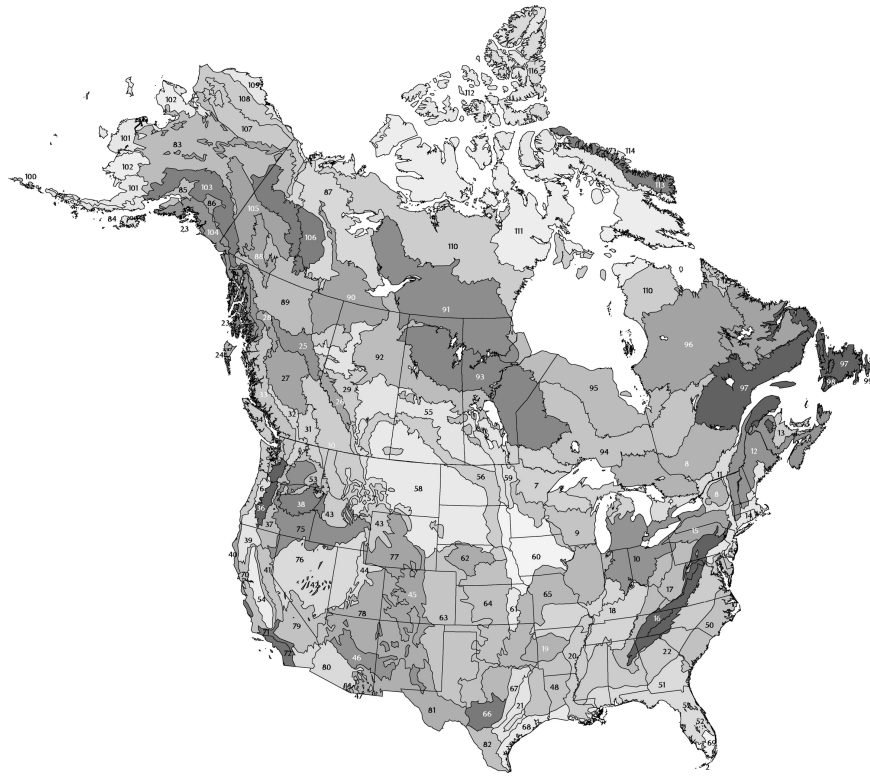
Methods

Species data

The species distribution data are based on the 110 ecoregions of the continental United States and Canada (fig. 1). These ecoregions were first developed by Ricketts et al (RICKETTS et al., 1999b), and are based largely on three established ecoregion mapping projects (ESWG 1995; GALLANT et al., 1995; OMERNIK, 1995). Ecoregions are relatively coarse biogeographic divisions of a landscape that delineate areas with broadly similar environmental conditions and natural communities. They are nested within eight major biomes in North America (fig. 1). Because of the complexity with which environmental and ecological factors vary across a landscape, ecoregion boundaries are necessarily approximate and represent areas of transition rather than sharp divisions.

RICKETTS et al. (1999b) compiled presence/absence data for butterflies, birds, mammals, reptiles, and amphibians on these ecoregions. The same dataset was used after performing further checks for quality and accuracy. From presence/absence data, the number of species (hereafter "richness") and the number of endemic species (hereafter "endemism") were calculated of each taxon in every ecoregion. Following

Fig. 1. A. Map of the 110 terrestrial ecoregions of the United States and Canada; B. Map showing the eight biomes represented by these ecoregions.

Fig. 1. A. Mapa de las 110 ecorregiones terrestres de Estados Unidos y Canadá; B. Mapa que muestra ocho biomas representados por estas ecorregiones.

A

B

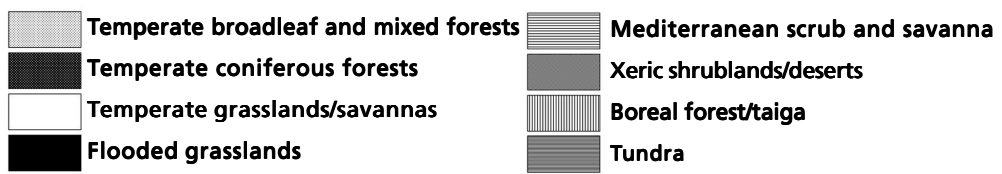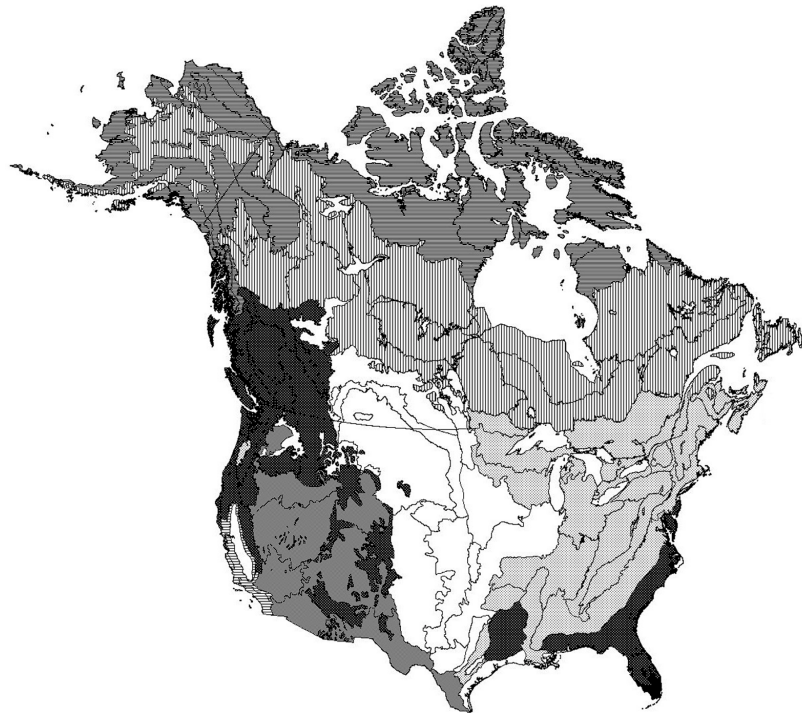|	
Temperate broadleaf and mixed forests	Mediterranean scrub and savanna
Temperate coniferous forests	Xeric shrublands/deserts
Temperate grasslands/savannas	Boreal forest/taiga
Flooded grasslands	Tundra

Table 1. Spearman rank correlations between richness and endemism for the five animal taxa considered. Results given for all 110 ecoregions, and for each biome separately: * Significance level at p < 0.05 (missing entries indicate that in the corresponding taxon, no endemic species are found in any ecoregion of the corresponding biome); All. Includes six ecoregions from minor biomes that are not included in any of the biome analyses.

*Tabla 1. Correlaciones del rango de Spearman entre riqueza y endemismo para los cinco taxones considerados. Los resultados se indican para cada una de las 110 ecorregiones y para cada bioma por separado: * Nivel de significancia para p < 0,05 (los datos que faltan indica que en el correspondiente taxón no se han encontrado especies endémicas en ninguna ecorregión del bioma que le corresponde); All. Incluye seis ecorregiones de biomas pequeños que no están incluidas en ninguno de los biomas analizados.*

Biome	Butterflies	Birds	Mammals	Amphibians	Reptiles	Overall indices	n
All	0.304*	0.011	0.298*	0.527*	0.676*	0.588*	110
Temperate broadleaf	–0.153	0.153	–0.112	0.795*	0.430	0.635*	17
Temperate coniferous	0.471*	–	0.186	0.632*	0.526*	0.479*	30
Temperate grasslands	–	0.407	–0.098	0.704*	0.796*	0.504*	16
Xeric shrublands	0.327	0.412	0.218	–0.127	0.788*	0.753*	8
Boreal forest / Taiga	–	0.584*	0.333	–	–	0.442	17
Tundra	–	0.398	–0.212	–	–	0.047	16

RICKETTS et al. (1999b), a species to be endemic in an ecoregion was counted if it either (i) was found in no other ecoregion, including Mexico and other continents or (ii) occupied a range totaling less than 50,000 km^2 (BIBBY, 1992). Thus species with exceptionally small ranges that crossed an ecoregion boundary were considered endemics in both ecoregions.

To examine more general patterns of biodiversity, overall indices of richness and endemism that incorporate information from all five taxa were also calculated. The richness index was defined as

$$\frac{1}{5} \sum_{i}^{5} R_i / T_i$$

where R_i is the richness of taxon i in the ecoregion, and T_i is total number of species of taxon in the database (SISK et al., 1994; RICKETTS et al., 1999a). This index normalizes the richness of each taxon by the number of North American species in that taxon and then averages those fractions across all five taxa. It therefore weights taxa evenly, preventing speciose groups from dominating measures of overall richness.

The endemism index is defined as

$$\frac{1}{5} \sum_{i}^{5} E_i / R_i$$

where E_i is the number of endemic species of taxon i in the ecoregion, and R_i is as above. This index computes, for each taxon, the fraction of species in an ecoregion that is endemic there, and then averages these fractions across all five taxa. Again, the index thus normalizes counts of endemics by the taxon's richness in each ecoregion.

Analyses

Correlation between richness and endemism measures were tested using Spearman rank correlations, because data were seldom normally distributed (ZAR, 1999). Since ecoregions vary widely in area (fig. 1, RICKETTS et al., 1999b) and both richness and endemism are typically expected to increase with area (ROSENZWEIG, 1995), any correlations found may be driven by these area effects. To examine this possibility, the Spearman rank correlation between the richness and endemism measures and ecoregion area was computed. Finally, to examine whether the degree of concordance between richness and endemism differs among biomes, the richness/endemism correlations were tested for each biome independently (fig. 1, table 1).

To determine the overlap between richness–based and endemism–based priority sets of ecoregions, the ecoregions in the top decile were identified (i.e., 90th percentile and above) for each measure. The percent overlap of these sets for each taxon, and for the overall indices were then calculated (PRENDERGAST et al., 1993). The top decile of 110 ecoregions typically contains
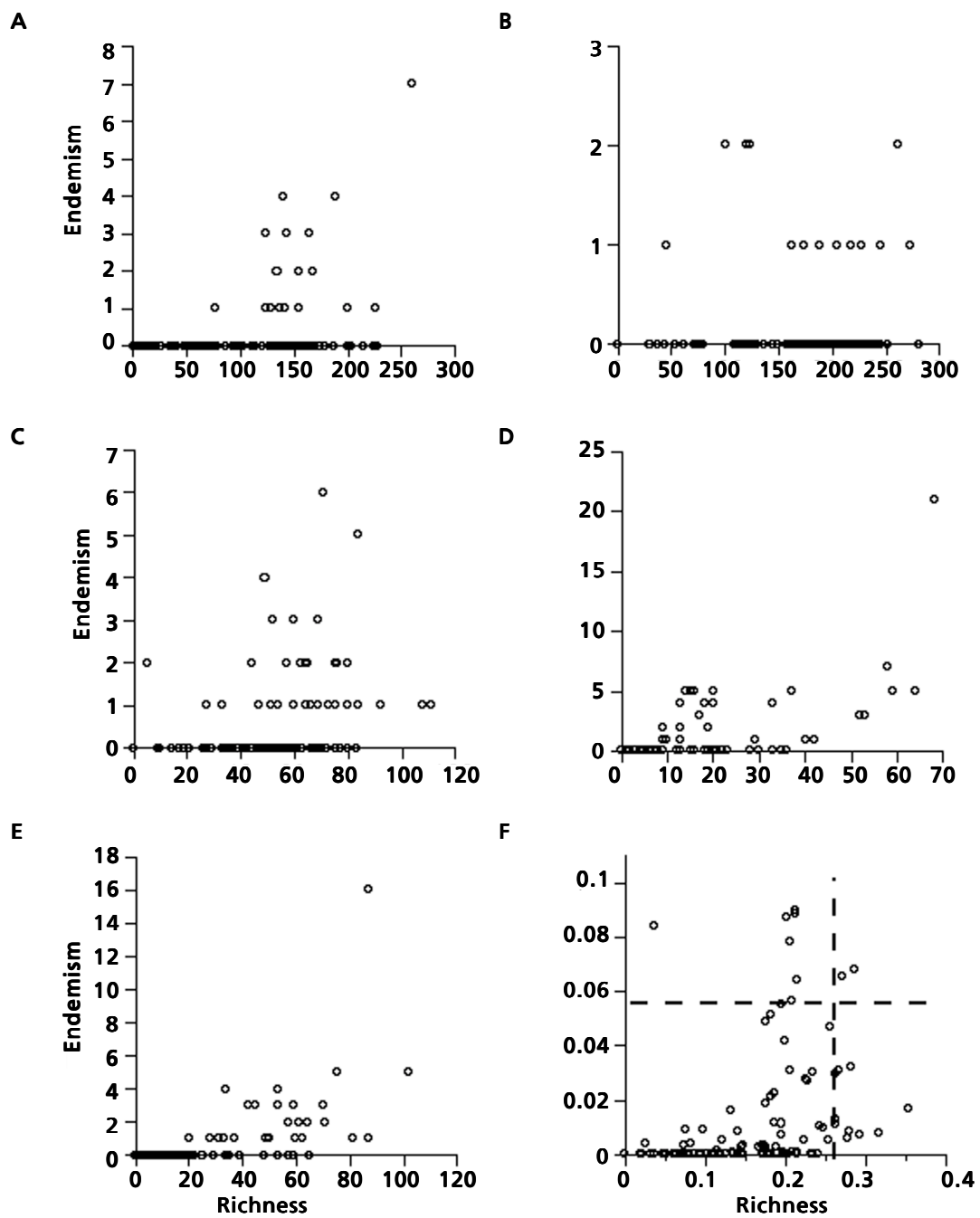
Fig. 2. Relationship between richness and endemism across all 110 ecoregions. Each circle represents an ecoregion: A. Butterflies; B. Birds; C. Mammals; D. Amphibians; E. Reptiles; F. Overall richness and endemism indices. Dashed lines in panel f delineate the top decile on each axis; note only two ecoregions lying above both lines (i.e., in the upper right quadrant). These are the only two ecoregions that are members of both richness-based and endemism–based priority sets, and they are coded in green in figure 3F.

Fig. 2. Relación entre riqueza y endemicidad en las 110 ecorregiones. Cada círculo representa una ecorregión: A. Mariposas; B. Aves; C. Mamíferos; D. Anfibios; E. Reptiles; F. Índices globales de riqueza y endemicidad. Las líneas discontinuas en la figura F delimitan el decilo superior de cada eje; obsérvese que únicamente dos ecorregiones se encuentran por encima de ambas líneas (por ejemplo en el cuadrante superior derecho). Éstas son las dos únicas ecorregiones que optan a la vez por las actuaciones prioritarias basadas en la riqueza y en el endemismo, están indicadas en negro en la figura 3F.

11 ecoregions. In some cases, however, ties between the 11th–ranked ecoregion and those ranked below it forced inclusion of more than 11 in the priority set. Overlap between richness and endemism in these cases was calculated by dividing the number of shared ecoregions by the number of ecoregions in the smaller of the two priority sets (PRENDERGAST et al., 1993).

Results

Across all North American ecoregions, species richness and endemism were in general positively correlated (table 1, top row). For all taxa except birds, richness and endemism were significantly correlated, with amphibians, reptiles, and the overall indices showing the highest correlations. There is a large amount of scatter in bivariate plots for all taxa, however (fig. 2), indicating a low degree of predictive power in these relationships.

Richness and endemism for most taxa were not significantly correlated with ecoregion area (table 2). The only three significant relationships found (i.e., involving endemism in butterflies,

Table 2. Spearman rank correlations between ecoregion area and measures of richness and endemism for the five taxa and for the overall indices: * Significance level p < 0.05 (n = 110).

*Tabla 2. Correlaciones de rango de Spearman entre área de ecorregión y medidas de la riqueza y endemicidad para los cinco taxones y para la totalidad de índices: * Nivel de significación p < 0,05 (n = 110).*

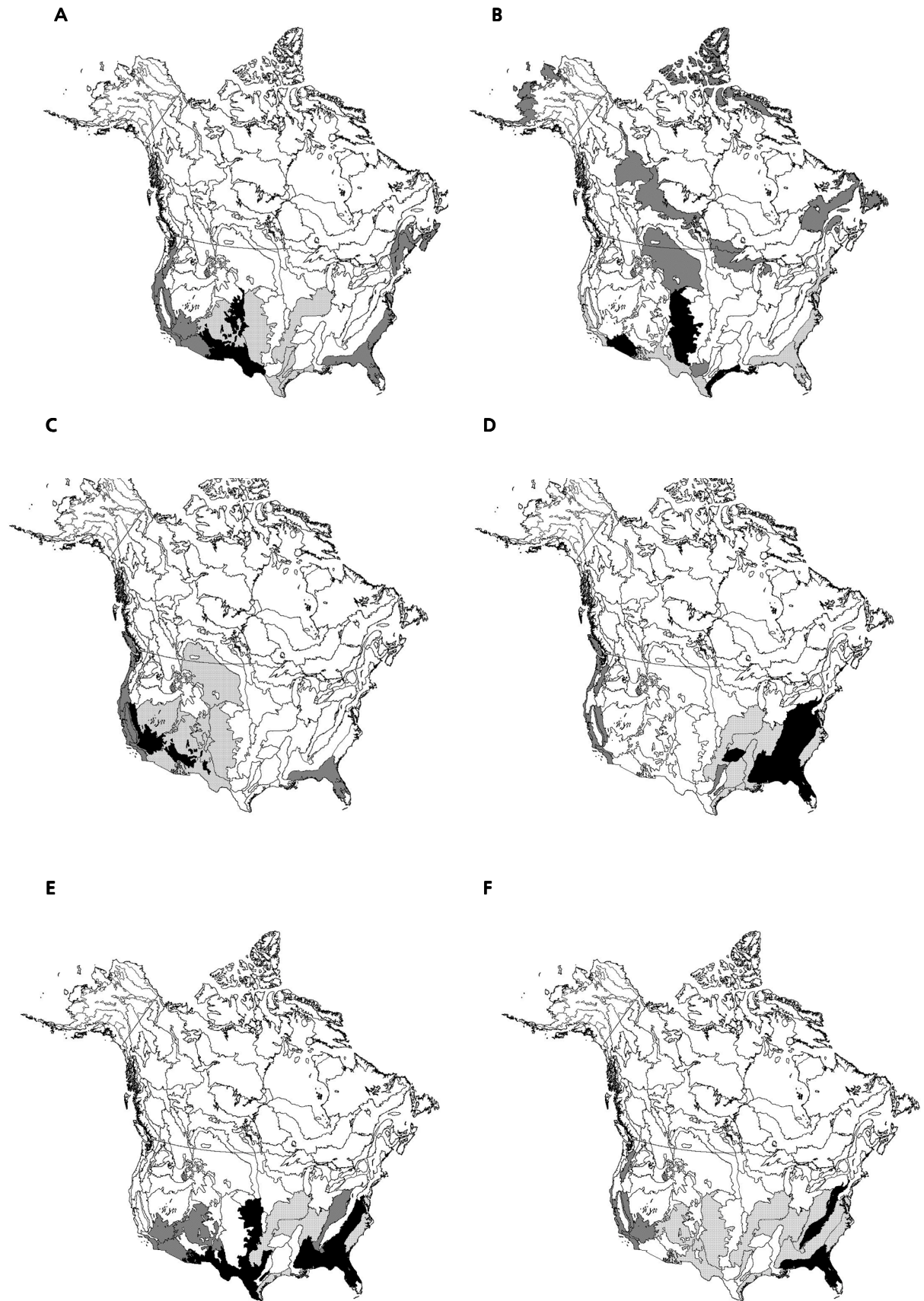| Taxon	Richness	Endemism
Butterflies	0.09	-0.21*
Birds	0.07	0.19*
Mammals	0.15	-0.26*
Amphibians	0.05	-0.08
Reptiles	-0.02	0.00
Overall indices	0.09	-0.16

Table 3. Percent overlap between priority sets of ecoregions based on richness and endemism.

Tabla 3. Porcentaje de solapamiento entre prioridades de ecorregiones basado en riqueza y endemicidad.

	Butterflies	Birds	Mammals	Amphibians	Reptiles	Overall indices
Richness set	11	11	11	11	11	12
Endemism set	18	13	15	13	15	11
Overlap	4 (36%)	3 (27%)	3 (27%)	5 (45%)	7 (64%)	2 (18%)

Fig. 3. Maps showing the distribution of, and overlap between, richness and endemism priority sets. Light gray ecoregions are in the top decile for richness, medium gray ecoregions are in the top decile for endemism, and black ecoregions are in the top decile for both: A. Butterflies; B. Birds; C. Mammals; D. Amphibians; E. Reptiles; F. Overall richness and endemism indices.

Fig. 3. Mapas que muestran la distribución y la coincidencia de las acciones prioritarias en riqueza y endemicidad: Gris claro, ecorregiones situadas en el decilo superior en cuanto a riqueza; Gris medio, ecorregiones situadas en el decilo superior en cuanto a endemicidad; Negro, ecorregiones situadas en el decilo superior para ambas prioridades: A. Mariposas; B. Aves; C. Mamíferos; D. Anfibios; E. Reptiles; F. Índices globales de riqueza y endemicidad.

birds, and mammals) were weak and inconsistent in their sign (table 2). Therefore, the correlation results in table 1 are unlikely to be caused by the commonly–expected effects of area on richness and endemism.

When correlations were tested within each biome independently, the results generally reflected those found using all ecoregions (table 1). Amphibians, reptiles, and the overall indices again tended to show strong correlations in all but the tundra and taiga biomes. Correlations for butterflies, birds and mammals, which showed weak or no correlation using all ecoregions, remained generally non–significant in the biome–by–biome analyses.

Overlap between richness-based and endemism–based priority sets were generally low, varying between 27% (birds and mammals) to 64% (reptiles) (table 3). In addition, priority ecoregions for richness and endemism were often found on opposite sides of the continent and often in different biomes (fig. 3).

Discussion

These results offer mixed support for the idea that richness and endemism patterns are correlated at broad scales. On one hand, two taxa and the overall indices showed quite strong and consistent correlations across the 110 ecoregions and within each major temperate biome (table 1). On the other hand, three of the five taxa showed much weaker or no correlations, and the scatter in all of these relationships (and thus their unpredictability) was high for all taxa.

On the more practical level of choosing areas for conservation investment, the results are even less encouraging. Because of the scatter mentioned above, the statistical correlations found, even when strongly significant, do not translate into high overlap between priority sets based on richness and endemism (table 3, fig. 2). A good example is the relationship between the overall richness and endemism indices (fig. 2F); the statistical correlation between them is quite high (table 1), but their priority sets overlap in only 2 out of a possible 11 ecoregions (table 3). This contradiction is best understood by examining figure 2F; although the two variables are correlated overall, only two ecoregions fall in the top decile for both richness and endemism. Indeed, for all taxa except reptiles this overlap is less than 50% (table 3). Basing conservation strategies on richness, therefore, will seldom effectively conserve areas of high endemism.

Previous studies on this topic also show a mixture of results. In North America, KERR (1997) found relatively strong correlations between richness and endemism in four taxa: mammals, a bee genus, a moth subfamily, and a butterfly family. PRENDERGAST (1993), however, reported little concordance between species–rich hotspots and rare species in Great Britain, using birds, butterflies, dragonflies, liverworts, and aquatic angiosperms. Similarly, CEBALLOS et al. (1998) found "very low correspondence" among areas of high mammalian richness and endemism in Mexico.

What accounts for the differences in results among these studies? Among other factors, results may be influenced by the taxa and region considered, the scale of observation (both extent and resolution, LEVIN, 1992; PRENDERGAST et al., 1993), the definition of endemism used, and the choice of geographic units. For example, PRENDERGAST (1993) based their analyses on 10 km grid squares in Great Britain, while KERR (1997) used much larger (2.5° of latitude and longitude) grids over a much larger extent in North America (in addition to testing different taxa). Clearly the four studies (i.e., the three mentioned above and mine) differ among themselves in several of these factors, making it difficult to glean general lessons from the collective results.

Perhaps of most interest are the contrasting findings between my study and that of KERR (1997). These two studies were performed in the same region at similar scales, with one taxon in common (mammals). Nevertheless, KERR (1997) found high correlation in mammals (r = 0.807, p < 0.001), while the results presented here show quite a weak relationship (table 1). This difference may be due to differences in the definition of endemism. KERR (1997) calculates the endemism value of a given square by summing, over all species present in the square, the inverses of the number of squares occupied by each species (e.g., 1/24+1/137+1/3…). This measure, however, is not independent of richness; the more species present, the more inverses are added to the sum. In contrast, counting the simple number of true endemics in an area (i.e., species found nowhere else) is not statistically related to richness measures, and thus may better reveal the actual relationship between these two measures of conservation priority.

One caveat deserves mention here. Since a typical species range overlaps with several ecoregions (and thus ecoregions do not accrue their richnesses independently), these richness data probably contain a certain degree of spatial autocorrelation (JONGMAN et al., 1995). This problem tends to inflate the degrees of freedom used in significance testing, and therefore the probabilities reported here should be interpreted with caution. However, these results remain useful for comparing strengths of relationships among taxa, because the correlation coefficients themselves are unaffected (only the significance tests). In addition, endemism, by definition, does not suffer this same problem.

In conclusion, the results presented here and in other studies (PRENDERGAST et al., 1993; KERR, 1997; CEBALLOS et al., 1998) indicate that conservation biologists may not have the luxury of assuming that management plans based on

"hotspots" of species richness will also capture important centers of endemism. Additional studies undertaken at different scales and with different taxa may yield a better understanding of the factors that determine the degree of concordance between richness and endemism patterns. Until then, however, conservation biologists and land managers will need to continue to balance these dual, and often conflicting, goals of biodiversity conservation.

Acknowledgements

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