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Incorporating socioeconomic factors into the analysis of biodiversity hotspots

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Abstract

Hotspot analysis is the identification and ranking of countries or other geographic regions on the basis of biodiversity. Hotspots have exceptional biodiversity per unit land area. This paper introduces a new method of hotspot analysis that ranks hotspots on the basis of biodiversity and anthropogenic threats to biodiversity. These threats are represented by socioeconomic factors such as human population size, rural population density, population growth rate, and governmental debt. Residuals from multiple regression models were used to rank the 17 megadiversity countries. In general, ranks based on threats to biodiversity were different from those based on biodiversity alone.

Keywords: Biodiversity; Hotspot analysis; Human population; Megadiversity countries

Hotspot analysis involves either the identification or ranking of political and ecological regions on the basis of their biodiversity. A biodiversity hotspot is a region that has an extraordinary amount of diversity. Perhaps the first hotspot analysis was that conducted by Myers (1988, 1990) when he described the immense endemic plant diversity found in several regions of the world. Since then, hotspot analysis has become more quantitative and comprehensive. Currently, the identification and ranking of hotspots is based on the amount of biodiversity per unit land area (Veech, 2000; Curio, 2002) and may also include an assessment of the threats to biodiversity, the potential for successful conservation, and the cost of implementing specific con-

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servation strategies (Reyers, Van Jaarsveld, McGeoch, & James, 1998; Balmford, Gaston, Rodrigues, & James, 2000a; Dobson, Rodríguez, & Roberts, 2001; Sierra, Campos, & Chamberlin, 2002). This paper focuses on describing a method by which various threats to biodiversity can be included in the ranking of hotspots.

Analysing the threats to biodiversity hotspots is of great importance. Those hotspots that are the most threatened should receive the most immediate and largest share of financial resources for their preservation. Such preservation could include the continued protection and maintenance of national parks and nature reserves as well as the purchase of additional lands that increase the overall amount of biodiversity preserved. However, narrative description of the threats to each hotspot is not sufficient for a rigorous assessment of which hotspots are the most threatened and in need of financial support. Instead, hotspot analysis should always be quantitative, standardized and objective.

A method is presented here that meets these criteria. It involves identifying and ranking hotspots by regressing species richness of each hotspot against factors that may threaten biodiversity. More precisely, the standardized residuals from the multiple regression model determine the ranks of the hotspots. The rationale for this approach is that those hotspots represented by large positive residuals have 'better-than-average' species diversity for their particular size (area) or degree of threat.

This new form of hotspot analysis was developed and tested using the 17 megadiversity countries (Fig. 1). Together these contain more than 8000 endemic amphibian, reptile, mammal, and bird species, as well as more than 150 000 endemic species of plants (Mittermeier, Gil, & Mittermeier, 1997). A regression analysis plotted the species richness of each country against four variables representing potential threats to biodiversity in the megadiversity countries: current size of the human population, population growth rate, rural population density, and amount of government debt. These socioeconomic factors presumably represent processes or human activities that directly affect biodiversity or indirectly affect it by reducing natural habitat (Meffe, Ehrlich, & Ehrenfeld, 1993; Reid, 1994; Tisdell, 1994; Kerr & Currie, 1995; Maurer, 1996; Cincotta, Wisnewski, & Engelman, 2000; Rodríguez, 2000). To allow comparison, the threats were first converted to a per-species metric as explained below and then entered into multiple regression models. In this analysis, large positive residuals represented megadiversity countries whose biodiversity faces a 'greater-than-average' threat from the variable under consideration. The two main goals of this study were to present multiple regression as a method of hotspot analysis and test whether socioeconomic variables are useful in the analysis of hotspots.

Methods

Compilation of data

Data on the total number and number of endemic non-fish vertebrate species and vascular plant species in each megadiversity country (Fig. 1) were obtained from Mittermeier et al. (1997). Socioeconomic data for each country were obtained from

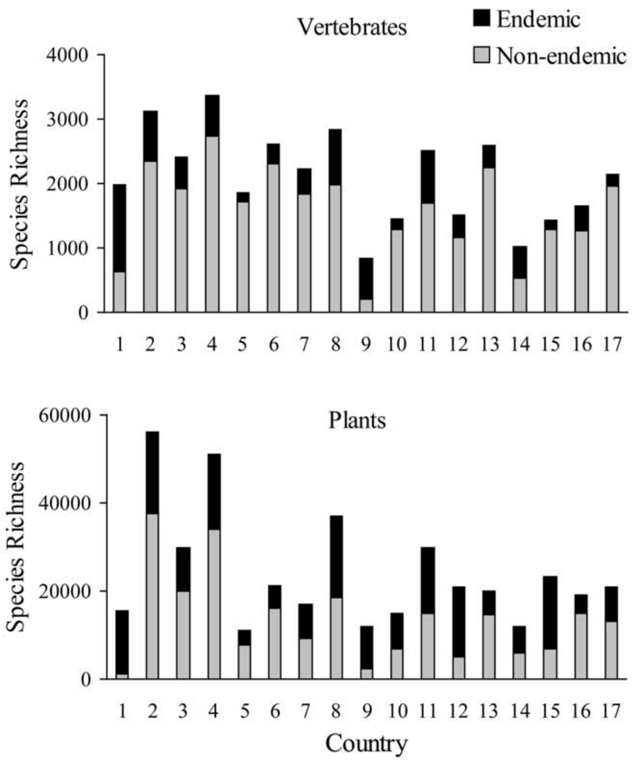

Fig. 1. Species richness of endemic and non-endemic vertebrates and plants in the megadiversity countries identified by Mittermeier et al. (1997). Countries are coded as follows: 1 − Australia, 2 − Brazil, 3 − China, 4 − Colombia, 5 − Democratic Republic of the Congo, 6 − Ecuador, 7 − India, 8 − Indonesia, 9 − Madagascar, 10 − Malaysia, 11 − Mexico, 12 − Papua New Guinea, 13 − Peru, 14 − Philippines, 15 − South Africa, 16 − United States of America, and 17 − Venezuela.

their 'Data Profiles' on the World Bank website (http://www.worldbank.org/data/), specifically population size, population growth rate, rural population density, and debt (detailed definitions of each variable can be found on the World Bank website). For some variables, data existed for multiple years. In those cases, only the most recent year (typically 1999) was used. The one exception is rural population density; for all countries this was available for 1995 only. Geographic size (i.e. land surface area) of each country was also obtained from the data profiles.

Defining threat on a per-species basis: the species load

Prior to conducting the hotspot analysis, the four socioeconomic variables were standardized to the number of species within a hotspot; these standardized variables are referred to as 'species loads'. For instance, the species load for population size is simply the population size divided by the number of species within a country (e.g. the species load for endemic vertebrates in Mexico is 0.12×10^6 people per endemic

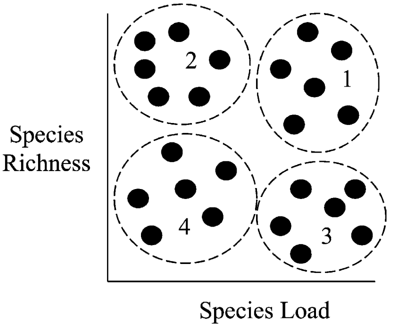

Fig. 2. The effect of species load in identifying or ranking threatened hotspots. Each dot in the figure represents a country or other region (e.g. a megadiversity country) under analysis. Countries within cluster 1 are ranked higher than those in either 2, 3, or 4, because they have the greatest species load and the greatest species richness. Countries within clusters 2 and 3 are ranked higher than those within 4 because they have either greater species richness for a given amount of species load (2 compared to 4) or a greater load for a given richness (3 compared to 4). The order of ranking between clusters 2 and 3 can only be resolved if species richness is deemed to be more critical than species load, or vice versa.

species). There are several reasons for treating threats to biodiversity in this way. First, species load variables assess the threat to biodiversity relative to the amount of biodiversity in the country. A country with high biodiversity and tremendous threat per species should be ranked higher than a country with the same level of biodiversity but less threat per species, or a country with less biodiversity but the same amount of threat per species (Fig. 2). Secondly, the species load for any threat (i.e. socioeconomic variable) will generally decline with increasing species richness, such that positive residuals from a regression equation will always represent the higher ranked hotspots (Fig. 3). Thirdly, species load is relative to the group or type of species under consideration. In other words, the species load for endemic species will always be greater than that for all species. Likewise, species load for plants may be different from that for vertebrates. This is an attractive property of the species

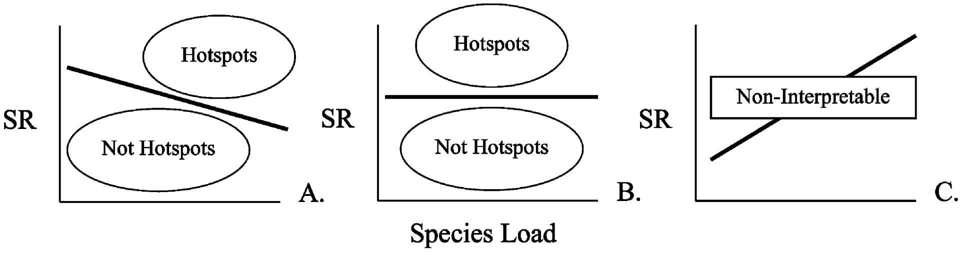

Fig. 3. The identification or ranking of hotspots based on standardized residuals from a regression equation. If the regression line has a negative slope (A) or zero slope (B) then hotspots (or highly ranked hotspots) are those that lie above the line (i.e. positive residuals). If the regression line has a positive slope (C), then hotspots cannot be inferred from either positive or negative residuals. Note that a line with a positive slope divides clusters 1 and 4 from Fig. 2, producing positive and negative residuals within both clusters.

load because it reinforces our intuition that the threat faced by the biodiversity composed of endemic species should be greater than that faced by the biodiversity composed of all species. That is, the threat to the biodiversity of a smaller or more distinctive group of species should be considered greater than the threat to a larger less unique group. Fourthly, using the term 'species load' and measuring threat on a per-species basis emphasizes that the targets of the threats are species and their continued existence.

Using multiple regression for hotspot analysis

Using data from all 17 megadiversity countries, a multiple regression was performed of species richness against the inverse of the area of each country and the species load for population size (L_{pop}), population growth rate (L_{pgr}), rural population density (L_{rpd}), and debt (L_{deb}). The inverse of area was used so that the relationship between area and species richness would be negative, as were the relationships between the species load variables and species richness. The five independent variables were log-transformed before conducting the regression so as to minimize the heteroscedasticity of the data. This reduces the leverage that some outlying observations would have on fitting the regression line (Neter, Wasserman, & Kutner, 1989). Some of the independent variables were correlated. However, because the purpose of each multiple regression was only to obtain and rank the residuals and not to test for significant relationships, correlations among independent variables could be disregarded. That is, the residuals obtained from a regression analysis measure the deviations of the actual observations from those predicted by the regression line, regardless of the extent of correlation among the independent variables. For each regression, each megadiversity country was ranked according to the value of its standardized residual (Veech, 2000). Megadiversity countries with the greatest positive residuals were identified.

Sixteen different regressions were performed in which the response variable was either endemic vertebrate, total vertebrate, endemic plant, or total plant species richness. The following four regression models were used on each response variable: full model (all five independent variables), L_{deb} excluded, L_{pgr} excluded, and an area-only model. The L_{deb}-excluded model was used to examine the rankings of hotspots that result when an analysis is based only on population data and area. When L_{deb} was included, Australia and the United States were excluded from the analysis, given that estimates of debt for those countries were not available. The L_{pgr}-excluded model was chosen post-hoc because L_{pgr} had the greatest regression coefficient in the full model; this allowed for an assessment of the influence of L_{pgr} on the full model. The area-only model was used because it provided a ranking of hotspots that did not include an assessment of threat. This ranking was then compared to the ranking obtained from the full model as a way of validating the use of threat variables. That is, if the area-only model and the full model both give the same ranking, then there is no need to incorporate threat variables into hotspot analysis. Spearman rank correlation coefficients were used to compare the rankings obtained from separate regressions (Reyers & James, 1999; Veech, 2000).

Results

The area-only model revealed that species richness of endemic vertebrates decreased slightly with an increase in the inverse of log(area) (slope = −0.21), whereas richness of endemic plants decreased very little with the inverse of log (area) (slope = −0.06) (Fig. 4). The total richness of vertebrates and plants decreased only slightly with the inverse of log (area); the slopes of the regression lines for both groups was −0.13 (Fig. 4). The least-squares lines were negative for the univariate regressions of each species load variable against endemic species richness (Fig. 5) and against total species richness (not shown).

All eight of the multiple regressions that included population growth rate generally fit the data very well; all adjusted R^2 values were greater than 0.75 and most were greater than 0.85. The four regressions that excluded population growth rate (L_{pgr}) did not fit the data as well (Table 1). As evidenced by the coefficients for each variable, L_{pgr}, had the greatest influence in the multiple regression equations (Table 1).

The standardized residuals from the regressions were ranked, allowing a comparison of the ranking of the megadiversity countries on the basis of endemic versus total species and vertebrates versus plants. Rankings based on endemic vertebrate richness agreed very well with those based on total vertebrate richness when ranks were determined from either the full regression model or the debt-excluded model (Table 2). Rankings of endemic vertebrate and endemic plant richness also agreed for all four regression models used (Table 2). Even if agreement is assessed in terms of identifying the top five ranks, there is substantial concordance of endemic vertebrate and plant ranks (Table 2). Rankings of endemic plant richness agreed with rankings of total plant species richness, for all four models (Table 2). Lastly, rankings

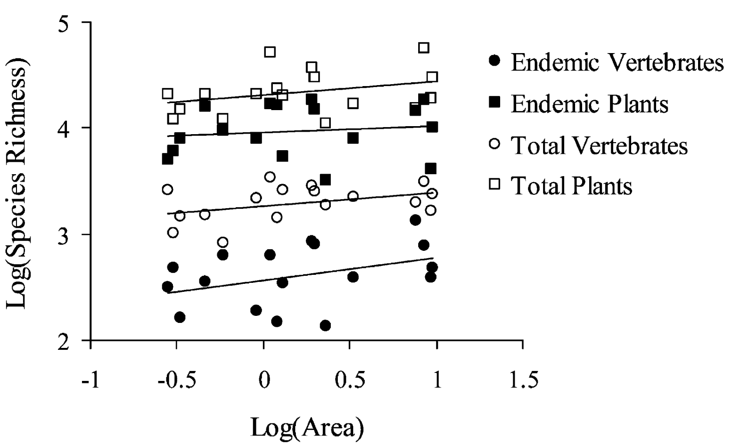

Fig. 4. The relationship between the inverse of log(area) and species richness for endemic vertebrates, endemic plants, total vertebrates, and total plants in the megadiversity countries. The lines are not intended to indicate statistical significance.

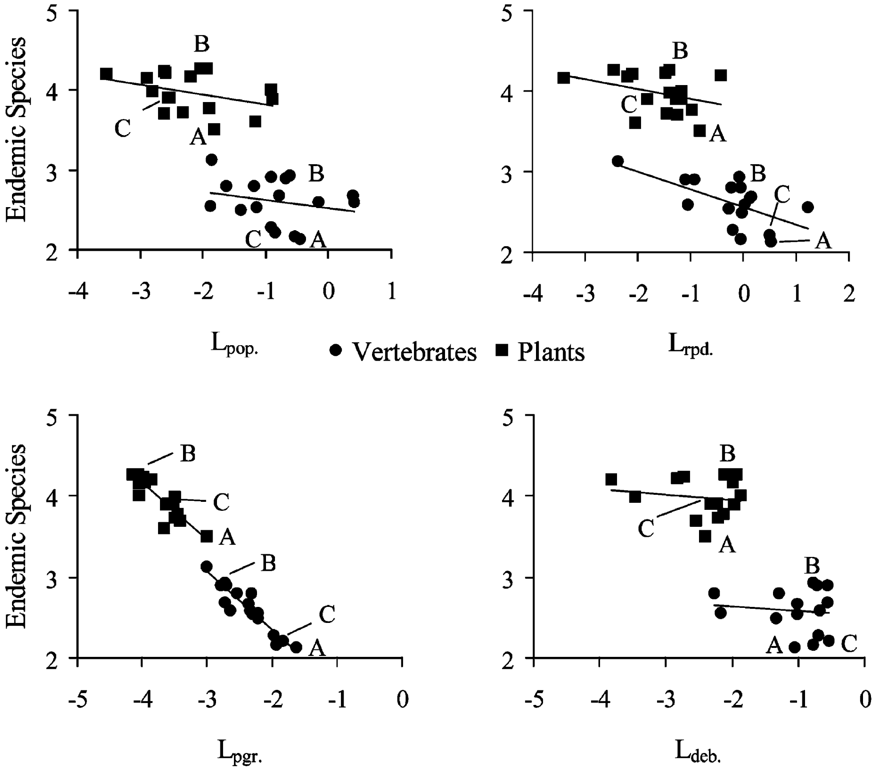

Fig. 5. The relationships between the species load variables and species richness of endemic vertebrates and plants on a log−log scale. The letters represent the following countries: a − Democratic Republic of the Congo, b − Indonesia, and c − Malaysia, which are the top three ranks from the full regression model.

of total vertebrate and plant species richness were in agreement for all regression models except the area-only model (Table 2).

Rankings derived from the full regression model were also compared with those derived from each of the other three models. The debt-excluded model was the only one that tended to give rankings similar to those obtained from the full regression model, for endemic vertebrate richness, total vertebrate richness, endemic plant richness, and total plant richness (Table 3). The model that excluded population growth rate (i.e. L_{pgr}) and the area-only model both ranked some of the same countries in the top five as did the full model, even though the low Spearman correlation coefficients indicate a lack of overall agreement between each of those models and the full model (Table 3).

Table 1
Coefficients for the four regression models used in this study[a]

Model	Species[b]	Intercept	1/Area	L_{pop}	L_{rpd}	L_{pgr}	L_{deb}	R^2
Full	EV	0.78	0.07	0.04	−0.07	−0.73	−0.15	0.91
	TV	1.32	−0.01	−0.04	−0.04	−0.60	−0.05	0.84
	EP	1.09	0.04	−0.01	−0.05	−0.69	−0.11	0.90
	TP	1.619	−0.04	−0.07	−0.02	−0.61	−0.01	0.93
Debt-excluded	EV	0.73	0.06	−0.07	0.01	−0.77	–	0.89
	TV	1.27	0.03	−0.06	0.02	−0.65	–	0.75
	EP	1.02	0.05	−0.09	0.03	−0.76	–	0.86
	TP	1.41	0.04	−0.06	0.04	−0.70	–	0.86
Population Growth Rate-excluded	EV	2.30	−0.17	0.02	−0.29	–	−0.26	0.21
	TV	3.17	−0.28	−0.20	−0.04	–	−0.14	0.35
	EP	3.16	−0.25	−0.14	−0.16	–	−0.11	0.20
	TP	3.96	−0.37	−0.28	−0.4	–	0.16	0.41
Area-only	EV	2.57	−0.21	–	–	–	–	0.10
	TV	3.27	−0.13	–	–	–	–	0.11
	EP	3.96	−0.06	–	–	–	–	0.01
	TP	4.31	−0.13	–	–	–	–	0.05

[a] The regression coefficients correspond to the $\log_{10}$-transformed species load variables (see text for abbreviations).
[b] The abbreviations correspond to the following species groups: EV = endemic vertebrates, TV = total vertebrates, EP = endemic plants, and TP = total plants.

Discussion

Threats to biodiversity and hotspot analysis

The primary goal of this study was to test whether threats to biodiversity can be usefully incorporated into a comprehensive hotspot analysis. More specifically, it tested whether the ranking of hotspots was significantly improved by including socio-economic variables presumed to represent processes (e.g. habitat destruction) that result in the loss of biodiversity. Using the standardized residuals obtained from multiple regression models, the megadiversity countries were ranked on the basis of the threat per species (i.e. species load variables) and the number of species per unit land area; this was the full regression model. This ranking was then compared with a ranking based only on the number of species per unit land area. The ranking obtained from the full regression model differed substantially from that obtained from the area-only model, as evidenced by the low Spearman rank correlation coefficients comparing the two models (Table 3). In particular, the ranking of three countries was dramatically increased by including threats to biodiversity in the hotspot analysis. For endemic vertebrate diversity, the Democratic Republic of the Congo (DRC) went from rank 17 in the area-only model to 1 in the full model, Malaysia rose from rank 14 to 3, and India from rank 11 to 5. For endemic plant diversity, DRC increased from 17 to 1, Malaysia from 10 to 3, and India from 12 to 4. Clearly, protecting

Table 2
Spearman rank correlation coefficients (r_s) of the rankings of endemic vertebrates vs. total vertebrates, endemic plants vs. total plants, endemic vertebrates vs. endemic plants, and total vertebrates vs. total plants, as derived from each regression model.

Comparison[a]	Model	r_s[b]	Percentage Agreement on Top 5 ranks[c]
EV vs. TV	Full	0.70**	80
	Debt-excluded	0.65**	60
	Population Growth Rate-excluded	0.41	60
	Area-only	0.27	60
EP vs. TP	Full	0.86****	60
	Debt-excluded	0.87****	80
	Population Growth Rate-excluded	0.72**	60
	Area-only	1.00****	100
EV vs. EP	Full	0.97****	100
	Debt-excluded	0.83***	80
	Population Growth Rate-excluded	0.87****	80
	Area-only	0.53*	60
TV vs. TP	Full	0.74**	80
	Debt-excluded	0.88**	100
	Population Growth Rate-excluded	0.61*	80
	Area-only	0.19	60

[a] The abbreviations correspond to the following species groups: EV = endemic vertebrates, TV = total vertebrates, EP = endemic plants, and TP = total plants.
[b] Significance indicated as follows: *$P<0.05$, **$P<0.01$, ***$P<0.001$, and ****$P<0.0001$.
[c] Percent Agreement is the number of shared megadiversity countries in the top five ranks of both rankings, expressed as a percentage of 5.

the biodiversity of these countries would be given greater priority upon consideration of the threats to each one's biodiversity.

Furthermore, the DRC was not revealed as a hotspot (i.e. large positive residual) in any of the four univariate regressions of Fig. 5, yet it emerged as the top-ranked hotspot in the full regression model. This top ranking may be due to it having the greatest L_{pgr} combined with L_{pgr} being the most influential variable in the full regression model. This study specifically pinpoints population growth rate as a potential threat that is highly influential in ranking the megadiversity countries (see also Kerr & Currie, 1995). More generally, this study suggests that highly influential variables—and the threats they represent—should be incorporated into the analysis of hotspots.

Finally, for a given regression model, the megadiversity countries tended to be ranked in the same way regardless of whether the response variable was endemic vertebrate, endemic plant, total vertebrate, or total plant species richness (see Table 2). It is reassuring that the ranking of hotspots based on either endemic vertebrate or endemic plants species richness are similar to one another and similar to rankings based on total vertebrate and plant species richness. However, perfect agreement (100%) on the very top ranks should not be expected and was not obtained.

Table 3
Sperman rank correlation coefficients (r_s) of the rankings derived from the full model compared to either the debt-excluded, population growth rate-excluded, or area-only models.

Comparison	Species[a]	r_s[b]	Percentage Agreement on Top 5 ranks[c]
Debt-excluded vs. Full	EV	0.86****	80
	EP	0.80***	80
	TV	0.88****	80
	TP	0.83***	100
Populations Growth Rate-exculded vs. Full	EV	0.06	20
	EP	0.17	40
	TV	0.39	40
	TP	0.15	40
Area-only vs. Full	EV	0.24	40
	EP	0.13	20
	TV	0.4	40
	TP	0.3	60

[a] The abbreviations correspond to the following species groups: EV = endemic vertebrates, TV = total vertebrates, EP = endemic plants, and TP = total plants.
[b] Significance indicated as follows: $^{*}P<0.05$, $^{**}P<0.01$, $^{***}P<0.001$, and $^{****}P<0.0001$.
[c] Percentage Agreement is the number of shared megadiversity countries in the top five ranks of both rankings, expressed as a percentage of 5.

Using multiple regression for hotspot analysis

Multiple regression can be used to conduct a comprehensive hotspot analysis where the goal is to rank or identify hotspots based on several variables. However, when the variables are correlated, multiple regression should not be used to test the significance of the full regression model. That is, a stepwise regression model may exhibit an increasingly better fit to the response variable (and greater statistical significance) as more predictor variables are added for the sole reason that the predictor variables are correlated with one another (Sokal & Rohlf, 1995). In addition, species load variables may often be correlated with the response variable (species richness), given that the denominator of the load variables is species richness. Again, this autocorrelation suggests caution in assessing the statistical significance of any relationship between species richness and a species load variable. Despite these obstacles to significance testing, standardized residuals for each observation or country can be obtained from regression and used to rank the countries.

A positive aspect of using multiple regression in hotspot analysis is that many variables can be used to fit the line and hence rank the residuals of each observation. That is, the hotspot analysis can be very comprehensive. Of course, the number of variables used should be far less than the number of observations (or countries). Multiple regression also indicates which variables most influence the ranking of hotspots. That is, variables with large regression coefficients determine the values of the residuals more than do the variables with small coefficients. In all the multiple regression models used in this study, population growth rate (L_{pgr}) had the largest (or most negative) coefficients (see Table 1). Also note that L_{pgr} regressed against species richness had the most negative slope of all the univariate regressions (see Fig. 5).

Comparison of multiple regression to other priority-setting approaches

This study used multiple regression as a form of hotspot analysis only to rank hotspots (i.e. the megadiversity countries) previously identified by Mittermeier et al. (1997). However, multiple regression could be used in the initial step of identifying hotspots from among a larger group of candidates, such as all tropical countries; hotspots would simply be the highest-ranking countries. Multiple regression as a form of hotspot analysis is not limited to analysing well-defined political units such as countries. Indeed, the same sort of analysis could be conducted for the 25 transnational ecoregional hotspots identified by Mittermeier, Myers, Mittermeier and Gil (2000). The primary difference is that country-based socioeconomic data for a given ecoregion would need to be weighted according to the relative area each country 'contributes' to the total area of the ecoregion. Most importantly, hotspot analysis, as described here, can be applied to any spatial scale.

Hotspot analysis based on multiple regression can also incorporate other types of relevant data in addition to biodiversity threats. Other index-based approaches to setting priorities for conservation distinguish between stock variables (e.g. total species, endemic species, threatened species), pressure variables (e.g. threats to biodiversity), and 'response' variables (e.g. conservation effort, number of preserves) (Dinerstein & Wikramanayake, 1993; Sissy, Launer, Switky, & Ehrlich, 1994; Reyers et al., 1998; Reyers & James, 1999). Other variables to use in a hotspot analysis might include the economic value or the potential for conservation efforts to succeed (political and social feasibility) and the monetary cost of conservation efforts (McNeely, 1994; Moran, Pearce, & Wendelaar, 1997; Balmford et al., 2000a). Of course, obtaining reliable data for all these variables may be difficult. An inherent danger in using 'response' variables is that governments could be penalized (denied funds) because of previous success in conserving biodiversity. That is, countries with high response may be assumed to be less in need of assistance than countries with low response. In addition, incorporating 'economic value' variables into a hotspot analysis can lead to super-diverse countries being underfunded because of unstable political and social conditions (Mittermeier, Myers, Thomsen, & da Fonseca, 1998) and a lack of economic return on investment. Mittermeier et al. (1998) argue that the biologically richest regions should be given priority regardless of their political or socioeconomic status. Any attempts to include factors other than biological diversity should come after an initial hotspot analysis has identified those regions having high biodiversity (Mittermeier et al., 1998).

Many of the various approaches to determining priorities for conservation agree on which countries or ecological regions are identified as hotspots (Reyers et al., 1998). However, the ranking of the hotspots can differ substantially depending on the approach used (Reyers et al., 1998). Some index-based approaches (Reyers et al., 1998; Reyers & James, 1999) oddly rank many European countries at the top. These ranking indices usually involve threat and 'response' variables that often derive from composite and indexed data themselves. This makes it difficult to determine the most influential factors affecting the index (Given & Norton, 1993) unless complex multivariate statistical comparisons are used a posteriori (e.g. Reyers et al., 1998). The index-based approach is perhaps most suited to prioritizing areas within specific geographical regions in which specific threats can be analysed using quantitative data that are commensurate among countries (e.g. Dinerstein & Wikramanayake, 1993).

Multiple regression as a form of hotspot analysis evaluates biodiversity (i.e. stock variables) at a given level of a particular threat (i.e. pressure variables) that has been standardized to the number of species within the region (hotspot) (Figs 2 and 3) such that the hotspots with greater biodiversity, for a specific level of threat, are given priority. Regions with roughly equal biodiversity are prioritized based on threat. Therefore, this multiple regression approach always gives biodiversity greatest weight while the index-based approaches sometimes do not provide a clearly discernible relationship between the relative importance of biodiversity and socioeconomic variables in setting conservation priorities.

The multiple regression approach to analysing hotspots utilizes data that are commensurate among the geographical entities being analysed. That is, the socioeconomic factors and the estimates of species richness are presumed to have been measured or assessed in roughly the same way in each country. This then allows for the countries to be compared. A disadvantage of these data (and the hotspot analysis presented in this study) is that they do not assess localized threats to biodiversity in specific areas. For instance, the multiple regression approach may identify the Democratic Republic of the Congo as a hotspot but is unable to assess the immediate threat to biodiversity within a given national park of that country. Deforestation is a major threat to biodiversity within tropical forests, yet even within a country the rate of deforestation can vary geographically depending on other factors such as local population size (Ochoa-Gaona & Gonzalez-Espinosa, 2000). The analysis of forest-cover data using GIS can provide estimates of local rates of deforestation but such analyses need to be interpreted carefully because estimated rates can be scale-dependent (Ochoa-Gaona & Gonzalez-Espinosa, 2000) or overestimated if some 'deforested' areas are actually natural grasslands (Apan & Peterson, 1998). However, if a particular threat variable (such as deforestation) can be accurately measured at a local scale then it does serve as a better indicator of the immediate threat to local biodiversity than does the ranking of the country proper as a hotspot. The problem is that it is difficult to obtain commensurate data on localized threats (e.g. deforestation) to enable the threat to local hotspots in different regions or countries to be compared, except at the level of the country (but see Harcourt, Parks, & Woodroffe, 2001).

Ranking hotspots and setting conservation priorities

There is a hidden assumption in hotspot analysis and all other methods for setting conservation priorities: that the opportunities for conservation outweigh the available funding, and hence some form of prioritizing or ranking is needed. This is not to say that the opportunities for conservation (i.e. establishment of new national parks and reserves) are numerous, but rather that funding is always in short supply. Funding for conservation is needed in many parts of the world, particularly developing countries; thus there is no shortage of potential recipients. Because of this, the entities that donate or lend financial resources (governments, financial institutions, non-governmental organizations) should base their decisions on a comprehensive assessment of need, urgency, and potential for success. The hotspot analysis described in this paper has only assessed urgency or threat, though the approach could be expanded and made even more comprehensive. Because each variable in the analysis is expressed on a per-species basis, this form of hotspot analysis will assist scientists, conservation-planners and financiers in allocating their efforts where the potential benefit per species is greatest.

Conclusion

There is no one correct way to identify or rank hotspots; this paper has not discussed several other methods for prioritizing geographic areas for conservation (see Reid, 1998 for a review; also Kershaw, Mace, & Williams, 1995; Beissinger, Steadman, Wohlgenant, Blate, & Zack, 1996; Kerr, 1997; Williams, Gaston, & Humphries, 1997; Olson & Dinerstein, 1998; Balmford, Lyon, & Lang, 2000b; Fjeldsa, 2000; Joly & Myers, 2001; Poiani, Merrill, & Chapman, 2001; Curio, 2002; and Margules, Pressey, & Williams, 2002, as examples of other methods). Some methods are explicitly geographical and spatial, such as those that use GIS and gap analysis to identify biodiversity hotspots and evaluate their need for protection (McKendry & Machlis, 1993). All the methods that include a quantitative assessment of threats to biodiversity, efforts to preserve biodiversity, and potential for successful conservation are commendable for attempting to be comprehensive and objective. Yet conservation biologists, economists, and geographers have not thoroughly analysed the ways in which different socioeconomic factors threaten biodiversity and influence the success or failure of preservation efforts (Tisdell, 1994; Reyers et al., 1998). Because of this lack of knowledge, it may be premature to completely endorse hotspot analyses or biodiversity risk assessments that are highly comprehensive and dependent on the uncertainties of numerous socioeconomic variables, particularly when the identification or ranking of hotspots is based as much on those variables as on the actual biodiversity of a country or region. In the present study, the ranking of hotspots was generally consistent among different regression models when those models shared the most-influential variable, population growth rate. However, the models were never in perfect agreement.

Perhaps the best approach to setting priorities for conservation and identifying hotspots consists of a first-order assessment of biodiversity, particularly endemism, as pioneered by Myers (1988, 1990), Mittermeier (1988) and their colleagues (Mittermeier et al., 1997, 2000). This assessment can be followed by an analysis of the hotspots so identified. Such a refined analysis ranks the hotspots based on variables that are indicative of a threat(s) to biodiversity. Many of these variables can be incorporated into the analysis as species loads and analysed simultaneously using multiple regression. This allows identification of the most threatened hotspots but also directs the attention of scientists, policy-makers and lenders towards an appreciation of the potentially destructive role of expanding human populations and their economic systems.

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