Future habitat loss and the conservation of plant biodiversity

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ABSTRACT

Rapid land-use and climate changes are projected to cause broad-scale global land-cover transformation that will increase species extinction rates. We assessed the exposure of globally threatened plant biodiversity to future habitat loss over the first half of this century by testing country-level associations between threatened plant species richness and future habitat loss owing to land-use and climate changes, separately. In countries overlapping Biodiversity Hotspots, plant species endangerment increases with climate change-driven habitat loss. This association suggests that many currently threatened plant species will become extinct owing to anthropogenic climate change in the absence of potentially mitigating factors such as natural and assisted range shift, and physiological and genetic adaptations. Countries rich in threatened species, which are also projected to have relatively high total future habitat loss, are concentrated around the equator. Because poverty and poor governance can compromise conservation, we considered the economic condition and quality of governance with the degree of plant species endangerment and future habitat loss to prioritize countries based on conservation need. We identified Angola, Cuba, Democratic Republic of Congo, Ethiopia, Kenya, Laos, Madagascar, Myanmar, Nepal, Tajikistan, and Tanzania as the countries in greatest need of conservation assistance. For conservation endeavors to be effective, the conservation capacity of these high-need countries needs to be improved by assisting political stability and economic sustainability. We make policy recommendations that aim to mitigate climate change, promote plant species conservation, and improve the economic conditions and quality of governance in countries with high conservation need.

1. Introduction

Human-driven land-use and climatic changes are perhaps the greatest threats to terrestrial biodiversity (Millennium Ecosystem Assessment, 2005a; IPCC, 2007) given the mounting empirical evidence that these anthropogenic forcings substantially exacerbate species' endangerment (Brook et al., 2003; Sodhi et al., 2008). As these environmental changes are likely to continue into the future (Millennium Ecosystem Assessment, 2005b), it is important to assess their impacts on biodiversity for effective prioritization of conservation efforts (Lee and Jetz, 2008).

In particular, the impacts of land-use and climatic changes on plant biodiversity will have extensive ramifications on other taxa and human society given that plants are fundamental structural and nutrient-sequestering components of most ecosystems. Not only do plants produce resources that support non-plant biodiversity (Huston, 1994; Primack and Corlett, 2005), they also provide food and materials essential for human existence (Kier et al., 2005), and are involved in many ecological processes necessary for the persistence of life (Hamilton and Hamilton, 2006). Several studies have predicted the future extinction patterns of plant species based on land-use and climate change projections (Thuiller et al., 2005; Van Vuuren et al., 2006), but none has explicitly examined the association between the current endangerment and future habitat loss (e.g., Lee and Jetz, 2008 for vertebrates). Threatened plant species are more likely to be driven toward extinction by future habitat loss than non-threatened species because the former are generally restricted in range and consist of fewer individuals. We can therefore determine whether future land-use and climatic changes exacerbate extinction risk predictions by testing whether these will have the greatest negative influences in areas already characterized the highest number of currently threatened species. Therefore, realistic projections of conservation impact should not

only consider the magnitude of predicted habitat loss and degradation, they must also take into the account the distribution of species currently threatened with extinction.

Here we assessed the exposure of threatened plant biodiversity to land-use and climate change-driven habitat loss up to year 2050 by testing the hypothesis that countries with higher threatened plant species richness (after controlling for the effect of area) are likely to suffer from greater relative habitat loss given recent historical trends. We estimate country-specific plant species endangerment by (i) using the number of endemic plant species per country as a proxy for the number of threatened species (see Section 2.1. and Appendix A, Supplementary Methods) and (ii) using the residuals in the power-law endemic species-country area relationship as an index of endangerment. We then quantified the potential extent of future habitat loss owing to land-use and climate changes up to 2050 in each country (data from Lee and Jetz, 2008) derived from the Millennium Ecosystem Assessment (2005b). To determine which countries are most prone to plant biodiversity loss, we produced rankings for future plant species endangerment by relating the current degree of plant species endangerment with the amount of projected total habitat loss (Lee and Jetz, 2008). To evaluate the efficacy of the current prioritization pattern of IUCN species assessments under future scenarios, we tested the association between the proportion of species assessed in a country and future plant species endangerment. We considered countries that overlap with Biodiversity Hotspots (Myers et al., 2000; Mittermeier et al., 2004) separately to those that do not because Biodiversity Hotspots are considered urgent conservation priorities owing to high plant endemicity (~150,000 endemic species in total) and high historical habitat loss (Myers et al., 2000; Mittermeier et al., 2004). Like Biodiversity Hotspots, tropical regions are focal areas for conservation because they are highly biodiverse, but at the same time, threatened by high rates of habitat loss and degradation (Laurance, 2007; Bradshaw et al., 2009). We therefore considered tropical countries separately from temperate countries in our analyses.

Less wealthy countries have limited financial means for conservation projects such as the enforcement and monitoring of protected-areas (Bruner et al., 2004). Hence, species there might be at greater risk from habitat loss, direct harvesting, and encroachment of invasive alien species. Poverty can also lead to unsustainable exploitation of resources (Kerr and Currie, 1995) and could therefore exacerbate species loss through direct harvesting. Poor enforcement of existing legislation, weak governance, lack of political will and corruption can result in the degradation of biodiversity owing to ineffective biodiversity management (O'Connor et al., 2003) and high deforestation rates in developing countries (Geist and Lambin, 2002). In addition, conservation efforts might be compromised by decision-making processes in other sectors (Deutz, 2005), such as economic and residential land-use planning in the absence of effective high-level coordination within and between national ministries (Bojö and Chandra Reddy, 2001). As poverty and poor governance have adverse impacts on biodiversity conservation, we identified countries of high conservation need by considering their wealth and quality of governance with the future plant species endangerment ranks. Poor countries with low-quality governance and high future plant species endangerment were identified as having the highest conservation need. We are aware that the relationship between biodiversity threat and governance is not new *per se* but it has never been applied to guide conservation efforts in the global context we present here. Considering the negative impact of corruption and ineffective governance on biodiversity in many local case-studies (e.g., Welp et al., 2002; Smith et al., 2003), our approach of incorporating governance quality with endangerment levels to assess conservation need of nations is therefore novel and much needed.

We provide the first global-scale assessment of the association between threatened plant species and future land-use and climate change-driven habitat loss, and present plausible policies toward plant species conservation. By considering these projected impacts together with governance quality and poverty, our system of conservation ranking allows national lawmakers and the international community to prioritize conservation efforts.

2. Methods

2.1. Estimating number of globally threatened plant species per country

We used the number of endemic species as a proxy for the number of threatened species because the large taxonomic gap in the current (post-1997) IUCN Red List – where only about 12,000 species out of a total flora of 223,300–422,000 species were assessed – limits its use to infer global patterns of extinction risk (Pitman and Jorgensen, 2002). Our two main sources of country-level data on the number of endemic plant species were datasets from Pitman and Jorgensen (2002) and United Nations Environment Programme's World Conservation Monitoring Centre (UNEP-WCMC) (World Resources Institute, 2007). For countries with missing data, we used values in national biodiversity reports and Floras wherever possible (Appendix A, Supplementary References).

Although the number of endemic species is correlated with the number of threatened species (Pearson's $R = 0.78$, in European countries with reliable threatened species data, Pitman and Jorgensen, 2002), using endemism as a proxy for endangerment can be confounded by differences in the size of each country. For instance, it is logical to posit that species endemic to a large country are less likely to be endangered because their potential range size is larger than that of species endemic to a smaller country. To test for this possible bias, we constructed a set of generalized linear models (GLM) with a binomial error distribution and logit link function. Our results suggested that the potential bias owing to country area is absent or weak (Appendix A, Supplementary Methods). We therefore argue that the number of endemic species is an adequate proxy for the number of threatened species when accurate endangerment data are absent across countries, with the assumption that the correlation between endemic and threatened plant richness in European countries is representative of that in other countries (cf. Pitman and Jorgensen, 2002).

2.2. National index of relative plant species endangerment

Among-country comparisons of the raw number of globally threatened species cannot be made owing to differing land areas; therefore, we fitted the power-law species-area relationship (SAR) ($S = cA^z$, where S = endemic species richness as a proxy for number of threatened species, A = country area, z = the power coefficient and c = a constant; Arrhenius, 1921) to 196 countries and considered the residuals as a proxy of relative species endangerment. Country-area data were obtained from the World Resources Institute (2007) EarthTrends database (http://earthtrends.wri.org). We are cognizant that the curvilinear form of the SAR is likely to provide a more realistic detection of the hotspots of endangerment compared to the linearized form (Fattorini, 2007); hence, we first fitted the curvilinear form of the power-law SAR using the nls function in R v.2.8 (R Development Core Team, 2008). We calculated starting parameter values based on standard procedures described in Ratkowsky (1990). However, the curvilinear model was untenable because the residuals were non-Gaussian and heteroscedastic via visual inspection of the residual plots. We then reverted to fit the linearized SAR model ($\log_e$ [number of endemic species + 1] ~ $\log_e$ [country area]) (e.g., Balmford and Long, 1995; Lee

and Jetz, 2008) using glm in R. Log-transformed area explained ~25.5% of the deviance in the log-transformed number of endemic species. The residuals of this model were taken as an index of plant species endangerment controlling for country area.

2.3. Future habitat loss from land-use and climate changes

The Millennium Ecosystem Assessment (2005a) developed four socioeconomic scenarios that delineated possible future outcomes of terrestrial ecosystem change up to 2050 (Adapting Mosaic [AM], Global Orchestration [GO], Order from Strength [OS], and Techno-Garden [TG]). Land-cover projections in the MEA were made based on the IMAGE v. 2.2 model (Image-Team, 2001), which provided current and projected areal distributions for 18 land-cover classes at 0.5° resolution. The IMAGE model generates explicit forecasts of land-cover using a set of linked and integrated socioeconomic, climate and environmental models (described in Alcamo et al. 1998; Millennium Ecosystem Assessment, 2005b). We obtained raw data from Lee and Jetz (2008) who calculated the percentage of area subjected to land-cover transformation in 174 countries owing to land-use and climate changes over the four MEA socioeconomic scenarios from 2000 to 2050. Lee and Jetz (2008) classified transformation from natural- to human-induced land-cover types as land-use-driven (e.g., pristine forest converted to agricultural land), and change from one natural land-cover category (e.g., pristine forest converted to savanna) as driven by climate change. Thus, our metric for climate change-driven habitat loss was the average area projected to undergo transformation from one natural land-cover category to another under the four socioeconomic scenarios to the year 2050 expressed as a percentage of the total land area of a country, and the metric for future habitat loss owing to land-use change was the average area projected to be converted via human land-use change divided under the four scenarios to year 2050 expressed as a percentage of total land area. We used the percentage land-cover transformations averaged over all four scenarios for our main analyses because the 'real' future is likely to fall in between the four scenarios (Millennium Ecosystem Assessment, 2005b). We also conducted additional analyses using land-cover transformation data from each of the four scenarios to examine the sensitivity of our results towards the dominance of any one particular scenario. We used Spearman's ρ rank-order correlation to test the correlation between the index of species endangerment and future habitat loss owing to land-use and climate changes.

2.4. Future plant species endangerment

By relating the current degree of plant species endangerment to total future habitat loss (loss due to both climate and land-use change averaged over four scenarios), we ranked 163 countries (with data available for future habitat loss and current endangerment index) according to their future degree of plant species endangerment (Lee and Jetz, 2008). Each country was separately ranked in terms of total future habitat loss (from both land-use and climate changes) and current species endangerment. We averaged the percentile rank values of these two measures and re-ranked the derived value in descending order to obtain a global ranking of future plant species endangerment (cf: Lee and Jetz, 2008).

2.5. Current species endangerment prioritization

The IUCN Red List categorizes species into relative threat categories and provides information on the reasons for the categoriza-

tion. Currently, the IUCN is undertaking a global preliminary assessment of all plant species. To quantify current effort in assessing species endangerment, we calculated the proportion of the number of plant species assessed in each country up to year 2008 in the current (post-1997) Red List (www.iucnredlist.org). The total number of plant species in each country was the average of the numbers collated from Pitman and Jorgensen (2002), and UNEP-WCMC (World Resources Institute, 2007). We used Spearman's ρ rank-order correlation to test the concordance between the current effort in assessing species endangerment and future plant species endangerment.

2.6. Wealth, governance quality and future conservation need

We adopted per capita gross national income adjusted for purchasing power parity (GNI-PPP) averaged from 2003 to 2007 as a measure of a country's relative wealth. Per capita GNI-PPP data were collated from the World Bank World Development Indicators database (www.worldbank.org/data). We obtained governance quality data from the 2008 Worldwide Governance Indicators (WGI) project (Kaufmann et al., 2008) that appraised countries using indicators of six dimensions of governance: voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption. For each of the six indicators, a score of −2.5 (lowest quality of governance) to 2.5 (highest quality of governance) was allocated to each country. We calculated average values of each of these six dimensions for each country from 2003 to 2007 to obtain an estimate of the relative current governance quality of each country. We used principal component analysis to extract only one component (explaining 86.8% of the variance) consisting of all six dimensions because of strong inter-correlations. Human population increase (Davies et al., 2006) was excluded in our analyses for conservation need because it was used to model land-use change in IMAGE 2.2.

By relating the future plant species endangerment to economic wealth and governance quality, we took into account the exacerbating effects of poverty and poor governance on biodiversity and identified countries with the greatest need for conservation efforts. Our analysis of future conservation need included 145 (using economic wealth as a metric) and 157 (using governance quality as a metric) countries after removing 18 countries with unavailable wealth data and six countries with unavailable governance quality data. Like previous studies (e.g., Myers et al., 2000), we introduced quantitative thresholds for the designation of high-priority ecoregions. This multiple-threshold method ranked countries in five categories of decreasing future conservation need. We assigned countries ranked in the top 20% in future plant species endangerment, and the bottom 20% in governance quality or per capita GNI-PPP, as those having the greatest conservation need (Category 1). We placed countries ranked in successive 20% increments in future plant species endangerment and governance quality or wealth in categories of decreasing conservation need (e.g., 60%, Category 2; 40%; Category 3).

We recognize that the economic condition and governance quality of countries can change quickly especially in politically turbulent regions (e.g., sub-Saharan Africa) and might affect the accuracy of our predictions. However, because future economic condition and governance quality cannot be quantified with certainty, and the effects of economic condition and governance quality on species endangerment is currently on-going, we argue that there is adequate merit in using present-day wealth and quality of governance data to guide future conservation efforts.

3. Results

3.1. Patterns of current plant species endangerment

Endemic species richness data were available for 196 countries. One hundred forty-three countries overlap with the network of Biodiversity Hotspots and they contain a total of 206,905 endemic plant species which represent ~64.1% of the global flora based on the mean of the estimated lower (223,300; Scotland and Wortley, 2003) and upper limits (422,000; Govaerts, 2001; Bramwell, 2002). In contrast, the remaining 53 non-Hotspot countries contain only 7812 endemic species.

Species-area regression residuals revealed the highest relative index of plant species endangerment in tropical America, tropical Asia, and Southern Africa (Madagascar and South Africa) (Appendix A, Fig. S1a). In general, Hotspot countries (Fig. S1b) have a higher degree of current plant species endangerment than non-Hotspot ones (Fig. S1c). In the tropics, countries in Central and South America, and Southeast Asia generally have a higher degree of plant species endangerment than African countries (Fig. S1d), while among temperate countries, South Africa, China and Australia had a high plant species endangerment (Fig. S1e). The five countries with the highest endangerment are (in descending order): Papua New Guinea, New Caledonia, South Africa, Indonesia, and Colombia (full list in SM, Table S1).

3.2. Exposure of threatened plant biodiversity to future habitat loss

3.2.1. Habitat loss owing to climate change

In 118 Hotspot countries where data on future habitat loss and endemism were available, the index of current plant species endangerment was positively correlated with future climate change-driven habitat loss averaged across the four scenarios (Spearman's ρ = 0.294, P = 0.001) (Fig. 1a). The plant species endangerment index was also positively correlated with climate change-driven habitat loss projected under each of the four separate scenarios (Spearman's ρ = 0.232 to 0.330, all P < 0.011; Table S2). However, among 45 non-Hotspot countries, endangerment was negatively correlated with the climate change-induced loss averaged across the scenarios (Spearman's ρ = −0.284, P = 0.059) (Fig. 1b), as well as, projected under each scenario (Spearman's ρ = −0.337 to −0.271, all P < 0.088; Table S2).

In 86 tropical countries, the plant endangerment index increases with the average future climate change-driven habitat loss (Spearman's ρ = 0.253, P = 0.019) (Fig. 1c) and that projected in each of the four scenarios separately (Spearman's ρ = 0.172 to 0.272, P = 0.011 to 0.114; Table S2). Among 77 temperate countries, endangerment was neither correlated with average climate-change-driven habitat loss (Spearman's ρ = −0.148, P = 0.200) (Fig. 1d) nor that projected under each scenario (Spearman's ρ = −0.173 to −0.124, P = 0.133 to 0.283; Table S2).

Combining all countries did not demonstrate any evidence of a correlation between endangerment and average habitat loss (Spearman's ρ = −0.013, P = 0.870) or habitat loss projected under each scenario (Spearman's ρ = −0.024 to −0.11, P = 0.764 to 0.912; Table S2).

3.2.2. Habitat loss owing to land-use change

Current plant species endangerment was not correlated with the degree of future habitat loss among Hotspot countries (averaged across four scenarios: Spearman's ρ = −0.053, P = 0.568 [Fig. 2a]; projected under each scenario: Spearman's ρ = −0.064 to 0.045, P = 0.494 to 0.676 [Table S2]). Among non-Hotspot countries, plant endangerment was not correlated with future habitat
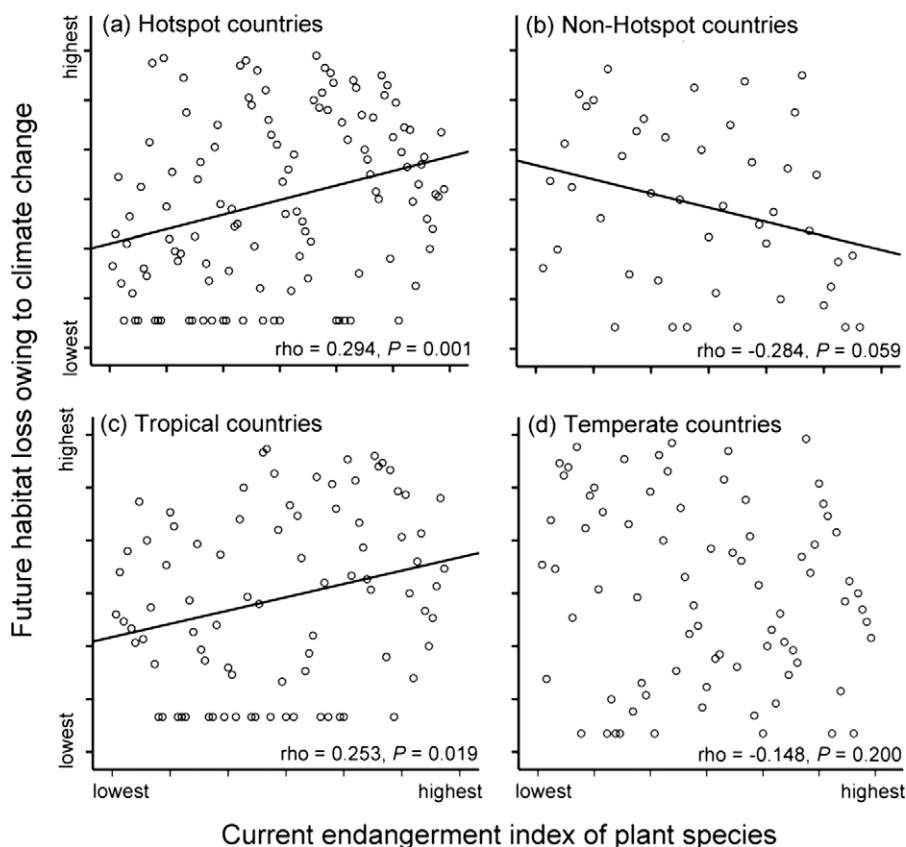

Fig. 1. Relationship between the ranks of current endangerment index and ranks of future habitat loss owing to climate change among Biodiversity Hotspot countries (a), non-Hotspot countries (b), tropical countries (c), and temperate countries (d). Trend lines represent analyses with evidence for Spearman's rank-order correlations.
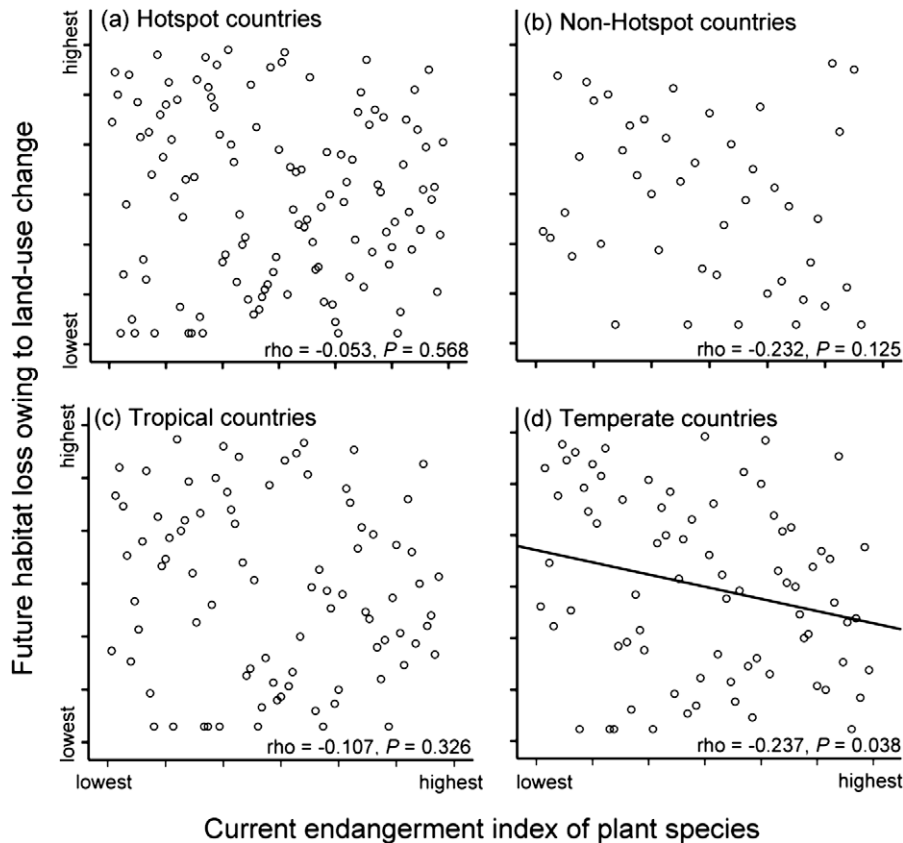
Fig. 2. Relationship between the ranks of current endangerment index and ranks of future habitat loss owing to land-use change among Biodiversity Hotspot countries (a), non-Hotspot countries (b), tropical countries (c), and temperate countries (d). Trend lines represent analyses with evidence for Spearman's rank-order correlations.

loss averaged over the four scenarios (Spearman's $\rho = -0.232$, $P = 0.125$ [Fig. 2b]) and that projected under three of the four scenarios (i.e., GO, OS, and TS; Spearman's $\rho = -0.259$ to -0.143, $P = 0.086$ to 0.349 [Table S2]). There is evidence of a negative correlation between plant endangerment and habitat loss projected under the AM scenario (Spearman's $\rho = -0.296$, $P = 0.048$; Table S2).

Among the tropical countries, plant endangerment was not correlated with the average future habitat loss (Spearman's $\rho = -0.107$, $P = 0.326$; Fig. 2c) and the loss projected under each scenario (Spearman's $\rho = -0.126$ to 0.062, $P = 0.249$ to 0.572; Table S2). Among the temperate countries, plant endangerment was negatively correlated with average future habitat loss (Spearman's $\rho = -0.237$, $P = 0.038$; Fig. 2d) and habitat loss under the AM scenario (Spearman's $\rho = -0.224$, $P = 0.050$; Table S2).

There was no evidence of a correlation between plant endangerment and future habitat loss among all 163 countries (habitat loss averaged across four scenarios: Spearman's $\rho = -0.074$, $P = 0.350$; loss projected under each scenario: Spearman's $\rho = -0.110$ to -0.010, $P = 0.162–0.897$ [Table S2]).

3.3. Future plant species endangerment and the current distribution of species assessments

Countries with the highest future plant species endangerment are concentrated around the equator (Fig. S2). Madagascar was projected to experience the highest plant species endangerment, followed by Sri Lanka, Georgia, Panama, and Costa Rica in descending order. The current species assessment effort (measured as the proportion of species assessed in all post-1997 IUCN Red Lists up

to 2008) was positively correlated with future highest plant species endangerment (Spearman's $\rho = 0.328$, $P < 0.001$, $n = 163$).

3.4. Countries with the greatest conservation need

Seven countries were ranked in the category of greatest conservation need based on economic condition (Category 1: top 20% for future plant species endangerment and bottom 20% in terms of wealth) (Fig. 2a). These countries are Democratic Republic of Congo, Ethiopia, Kenya, Madagascar, Nepal, Tanzania, and Tajikistan. Nine countries were classed in the category of greatest conservation need based on quality of governance (Category 1: the top 20% for future plant species endangerment and bottom 20% in terms of governance quality), namely, Angola, Cuba, Democratic Republic of Congo, Ethiopia, Laos, Myanmar, Nepal, Tajikistan, and Venezuela (Fig. 2b). Twenty and 19 countries were classed in Category 2 based on economic condition and quality of governance, respectively (Fig. 3).

We found high overlap between the countries prioritized based on economic condition and those prioritized based on quality of governance. After excluding countries with unavailable wealth and governance data, ten countries qualified for Category 1 based on economic condition or governance quality. Of these ten countries, four countries were prioritized based on both economic condition and governance quality. Out of 33 countries prioritized in Categories 1 and 2 based on economic condition or governance quality, 20 countries were prioritized based on both criteria. The country rankings for conservation need (and raw data used in the analyses) are available in Appendix A (Table S3). We also found a high positive correlation between economic condition and the quality of governance (Spearman's $\rho = 0.761$, $P < 0.001$, $n = 145$).
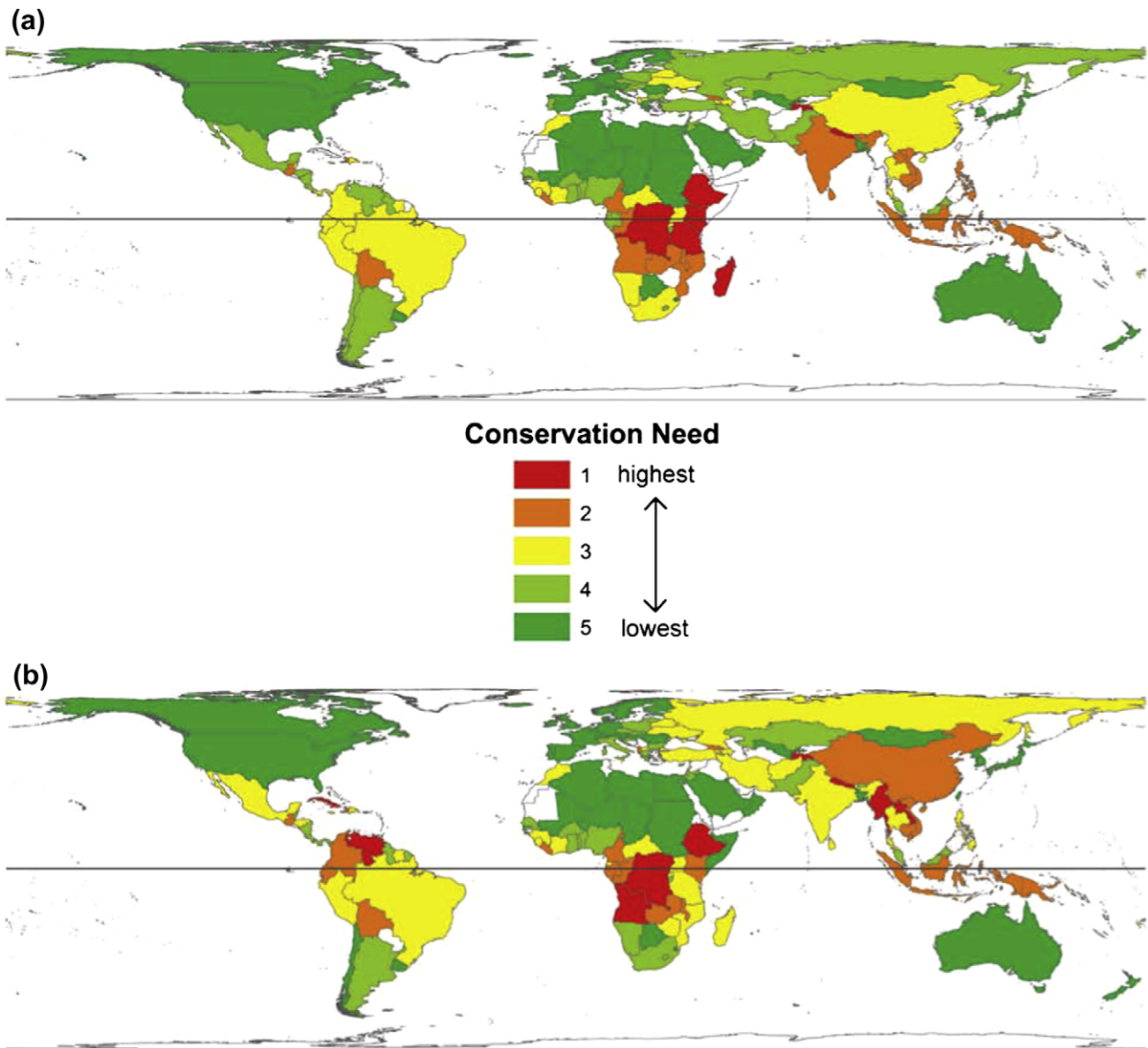
(a)

Conservation Need

⬛	1	highest
⬛	2	
⬛	3	
⬛	4	
⬛	5	lowest

(b)

Fig. 3. Countries classed into five categories of conservation need (Categories 1–5) based on economic wealth (A) and governance quality (B). Countries with the highest conservation need (Category 1: highest 20% in future plant species endangerment, and bottom 20% in economic wealth or governance quality) are shaded red. Countries with missing data and hence not considered in the analyses are unshaded. The map uses a cylindrical equal-area projection.

4. Discussion

We determined that the current endangerment level of plant species is positively correlated with projected climate change-driven habitat loss among countries that overlap with the Biodiversity Hotspots template (Myers et al., 2000; Mittermeier et al., 2004). The current endangerment level of plant species was also positively correlated with projected climate change-driven habitat among tropical countries. Our results were generally insensitive to scenario changes because plant endangerment was positively correlated with habitat loss projections under each of the four scenarios. This positive association suggests that climatic change is likely to exacerbate the current conservation crisis by having the greatest impact in areas with the highest level of endangerment. Our results provide yet more urgency to the imperative to reduce greenhouse gas emissions globally because plant biodiversity will otherwise be severely compromised.

Future land-use and climate changes must be considered together with the current distribution of threatened species to determine the locations most prone to high plant biodiversity losses (Lee and Jetz, 2008). Our rankings for future plant species endangerment revealed that countries most prone to high plant biodiversity losses are concentrated around the equator, thereby highlighting the continued importance of biological conservation in the tropics (Bradshaw et al., 2009). This positive correlation between future plant species endangerment and current species assessment effort suggests that species assessments are going in the right direction, with higher species assessment effort in countries likely to be more impacted by future changes. However, given that only about 12,000 of a total global flora of 223,300–422,000 species (~3–5%) have been assessed (IUCN, 2008), we urge the acceleration of species assessments in countries where the degree of future plant species endangerment is projected to be high. Completing assessments in these areas would provide a relatively inex-

pensive yardstick against which success of existing and future conservation efforts can be measured (Pitman and Jorgensen, 2002), as well as the responses of each species towards climate and land-use changes in this century.

Effective conservation of species can be thwarted by poor governance and poverty, (Geist and Lambin, 2002; O'Connor et al., 2003; Jha and Bawa, 2006; Sodhi et al., 2007), and constrained by the available financial resources, so it is important to prioritize conservation efforts in countries where the economic and political situation is most challenged. We classed each country into one of five categories of descending conservation need based on their economic condition and quality of governance. This multiple-threshold strategy of prioritizing conservation provided greater sensitivity compared to the binary (important versus unimportant) nature of existing templates such as the Global 200 Ecoregions (Olson et al., 2001), and Biodiversity Hotspots (Myers et al., 2000; Mittermeier et al., 2004). Politicians and conservation managers can therefore formulate better conservation policy – such as disbursement of financial aid and intensification of conservation efforts – based on the relative conservation need of countries.

Our approach of incorporating the economic condition to assess the relative conservation need of countries is instrumental to successful conservation of plant species. Poverty can exacerbate the impact of high habitat loss on the highly threatened plant biodiversity in these countries through unsustainable exploitation (Kerr and Currie, 1995). The paucity of funding for conservation projects (Kerr and Currie, 1995; Balmford et al., 2003; Bruner et al., 2004) can also compromise efforts in response to high future habitat loss. Although instruments for multilateral cooperation (most notably the Global Environment Facility) have been established, there is scarce funding available to poor countries (Brooks et al., 2006) because more than 90% of the total annual conservation funding (totaling US$6 billion) comes from and is spent on wealthier countries (James et al., 1999). Therefore, funds should be more readily transferred from wealthy countries with lower relative conservation need to poorer countries with higher conservation need.

Financial tools such as conservation trust funds, debt-for-nature swaps, and payment schemes for ecosystem services have been successful in financing conservation (Miles, 2005). Non-governmental advocacy groups such as Conservation International, Rainforest Coalition, The Nature Conservancy, and World Wildlife Fund have been facilitating such transfers by developing commercial–governmental and governmental–governmental partnerships and/or directing conservation projects using funds derived from individual and corporate donors as well international funding bodies such as the Global Environment Facility. While the work by these groups should be applauded and extended to shuttle a greater proportion of conservation funds into these countries, the coupling of anthropogenic climate change and biological conservation provide opportunities both for global reduction of carbon emissions, and more effective conservation endeavors in countries with high conservation need. For instance, under the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC), a north-south transfer of resources is facilitated by the Clean Development Mechanism (CDM) projects (Dechezleprêtre et al., 2007). However the inclusion of the REDD (Reducing Emissions from Deforestation in Developing Countries) mechanism in the new international framework can yield more benefits in terms of conservation (e.g., forest preservation and reforestation) and climate change mitigation (e.g., Venter et al., 2009). Developing countries with high conservation need can simultaneously increase economic revenue, prevent habitat loss, and mitigate future carbon emissions by protecting their forests.

In countries where high plant species endangerment and high future land-cover transformation risk are accompanied by poor governance, the risk of biodiversity losses increases. In Indonesia,

rampant illegal logging is made possible by implicit patronage from politicians, businesses, and the military (Welp et al., 2002; Smith et al., 2003; Sodhi et al., 2007) and this can result in higher habitat losses than predicted by the IMAGE model. In Myanmar, poor government regulation and enforcement of legislation can be inferred from grazing, hunting, fuelwood extraction, and permanent settlement in more than 50% of protected parks (Rao et al., 2002). In such countries where the quality of governance is low, the ease at which humans exploit natural capital is high, adding pressure to biodiversity. We suggest that nations with a better quality of governance (many of the developed countries) can assist countries with comparatively poor governance through training natural resource managers, and in improving various aspects of governance. The international community can supplement this 'soft' approach with an incentive- and penalty-based 'carrot-or-stick' strategy. For instance, only countries with sound governance in habitat management and biodiversity conservation can be allowed to apply for international development loans or aid. Conversely, the international community can exert pressure on countries with deteriorating governance by disabling their access to international development funds (Sodhi et al., 2007).

The high overlap between the countries prioritized based on economic condition, and those prioritized based on quality of governance is driven by the high positive correlation between GNI-PPP and quality of governance. The negative impact of poverty and poor governance is therefore likely to act in tandem to increase the threat to biodiversity in many countries. Our results demonstrated that in countries with high conservation need, ameliorated conservation outcomes are unlikely without concomitant improvements in economic condition and governance. The concept of local community-based conservation that emphasizes cooperation between local people and formal organizations such as national governments and foreign aid agencies (Berkes, 2007) represents a possible approach that might achieve positive outcomes with improvements in local economic condition and governance structure. First, by emphasizing social and conservation objectives, this deliberative approach bridges the differing local and global views (or "lens"; Berkes, 2007) of biodiversity as mainly a local commons for livelihoods and a global commons for ecosystem services and recreation. Second, by recognizing and deliberating with the local and/or traditional governance structure, this approach strengthens local environmental governance. The deliberation process decentralizes power, and hence, enables violation of the norm (e.g., good conservation practices) to be detected easily (Berkes, 2007). This helps to instill a sense of local stewardship by giving local people incentives, as well as moral justifications, for upholding the norm (Stern, 2005).

Our results depended on, amongst others, the assumption that the species in each country are most adapted to the natural land-cover at present. Changes from one land-cover type to another constitute habitat loss, and hence threat to species persistence. We also recognized that every species responds to habitat loss differently; the persistence of a species depends on factors such as the ability to migrate, the ability to evolve adaptations to new conditions and to altered inter-specific interactions. However, we did not consider the possibility of range shifts and the differential responses of each species to habitat loss because they are impossible to quantify with certainty for a large number of species assessed globally. We could not use a high-resolution spatial grid approach in our analyses because the exact global distribution of every plant species has yet to be mapped. Therefore, threatened species data could not be generated at these spatial scales. The relatively low-resolution of the land-cover data (0.5° grid squares) precluded the use of natural biogeographic units (e.g., ecoregions) as sampling units (Lee and Jetz, 2008). Moreover, threatened or endemic species data were not available at the ecoregion scale.

We recognized that using countries as sampling units is not ideal because national boundaries rarely reflect true ecological patterns. Large and ecologically varied countries like Brazil and China were treated as uniform, therefore potentially obscuring or confounding relationships. For example, a high number of threatened species and future habitat loss might be driven by high endangerment in only one small area within a large country, and a high future habitat loss in another non-overlapping part of that same country. However, our results showed that land-use- and climate change-driven land-cover transformations and areas of high plant species endangerment (surrogated by Biodiversity Hotspot areas) are not mutually exclusive; therefore, establishing the impact of land-cover transformations on biodiversity appears to be a robust approach (SM, Fig. S3).

Future land-use and climate change impacts must be considered together with the current distribution of threatened species for plant conservation endeavors. The inclusion of the REDD mechanism in the new UNFCCC might allow developing countries with high conservation need to increase economic revenue, prevent habitat loss, while mitigating carbon emissions and effects of climate change (Venter et al., 2009). Locally, community-based conservation initiatives might provide unique opportunities to improve governance, sustain livelihoods, and conserve biodiversity. While local conservation efforts must be prioritized in countries with high conservation need, a concerted global effort must be made by all countries to find biological and social solutions to the biodiversity crisis.

Author contributions

X.G. and N.S.S. designed research. X.G. performed research and analyzed data. X.G., C.J.A.B., N.S.S., and H.T.W.T. wrote the paper.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biocon.2010.04.019.

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