Defining conservation priorities in a global biodiversity hotspot

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Introduction

In the late 1980s, the publication of a relatively simple study forever changed the science of conservation. Norman Myers (1988, 1990) looked at where the world's plants occur to see if some places had more species than others did. Indeed, he found that the world's diversity of plants has a very biased distribution. Most of them are concentrated in a few areas scattered around the globe. Later studies went on to find that many vertebrates concentrate in the same areas, but the basic conclusions were unchanged. Most of nature's diversity lives on a relatively small part of the Earth's surface.

The implications of this are enormous. Conservation constantly struggles with how to allocate its limited resources to different needs. There are always more places under threat than resources to protect them. However, if some places are more diverse than others are, then perhaps it is more efficient to protect those places rather than the species poor ones.

Myers' studies were among the first steps in an ongoing global effort to decide what places on the planet are most important for protecting biodiversity. In an unfortunate coincidence, many of the same places with the most species, also suffer severe habitat destruction. These places Myers termed hotspots – they are the intersection of a high concentration of species found nowhere else and unusually high levels of habitat destruction. By acting in the hotspots, conservation groups could save more species, in less area, and presumably for lower cost, than in other places. Myers had shown that some places really are more important for conservation than others are.

What Myers did not answer was what to do within the hotspots. They are far too large to protect in their entirety. The average size of a hotspot is about 0.7 million km^2 (Myers et al. 2000), larger than all but two of the world's protected areas (World Database on Protected Areas, http://sea.unep-wcmc.org/wdbpa/). Unfortunately, those two largest of protected areas are in very biodiversity poor places (North-East Greenland and Ar-Rub'al-Khali, Saudi Arabia). As well, the hotspots are generally heavily populated and subject to intense economic development (Cincotta et al. 2000). Protection of the hotspots will likely only come one small piece at a time.

Since the original hotspots study, the field of priority-setting science has shifted toward finer scales to try to define those smaller pieces. The ultimate goal is to identify the most important areas for conservation, and do so at a scale practical for implementing conservation actions. Most of these studies use the same basic approach. They use maps of species distributions to identify a set of places containing the most species in the smallest area. For a review, see Cabeza & Moilanen (2001) and Pimm and Lawton (1998). Unfortunately, the development of analysis methods is far ahead of the data to drive those analyses. For only a few places in the world (e.g., New South Wales, Australia; Cape Floristic Region, South Africa), do we know enough about species distributions to make this approach work.

In this chapter, we briefly discuss what scientists currently know about species distributions, and the limits of those data for defining conservation priorities. We then focus on the task of refining conservation priorities to a scale practical for conservation actions. Our first method refines existing maps of bird distributions and then identifies priority regions using conventional techniques. Our second method uses only maps of general habitat change, which are simpler to create than maps of individual species distributions. Surprisingly, this simpler approach gives nearly the same answer as that from the improved species distribution maps. This begs the question of whether we really need more knowledge of species distributions to direct conservation action. Perhaps there is a simpler solution.

What we know about where species occur

For most species, we can summarize the world's knowledge of them in one word. Nothing. For 90% of the species, nobody has even formally described them (Wilson 2003). For the remaining 10% we know enough to give them a name, and maybe a little more. To illustrate, imagine selecting a random known species. If you asked an expert on that group of organisms to show you where it lives, the likely result would be a few dots, or even a single dot, on a map. If you were lucky, they would draw a crude shape on the map. Only for a tiny fraction of the world's species, could we get a good map and expect to find an individual of that species.

For select taxonomic groups, our knowledge is fairly good. The world's birdwatchers have rigorously tracked down nearly 10,000 species of bird in every corner of the planet. Birds are almost certainly the most studied taxonomic group, but even for them the available maps are rather crude. A study by Manne et al (1999) analyzed the distributions of over two thousand birds and had to use a grid cell size of one degree of latitude and longitude, or roughly 10,000 km^2 at the equator. At the time, this was the highest resolution dataset available. Since then, somewhat better maps have become available for birds, as well as for many mammals (e.g., www.NatureServe.org). For most other species, you are still lucky to find any map at all.

However, we can make some educated guesses about where the unknown species live. For example, many unknown species are probably insects. Of the insects we do know, most associate with specific plants. Botanists believe they have already described most of the plants, and find that most of them are in the biodiversity hotspots (Figure 1) (Myers 1988, 1990, Myers et al 2000, Myers 2003). Since most of the plants are in the hotspots, most of the insects are probably there as well. The difficulty is finding exactly where in the hotspots all these unknown species might occur.

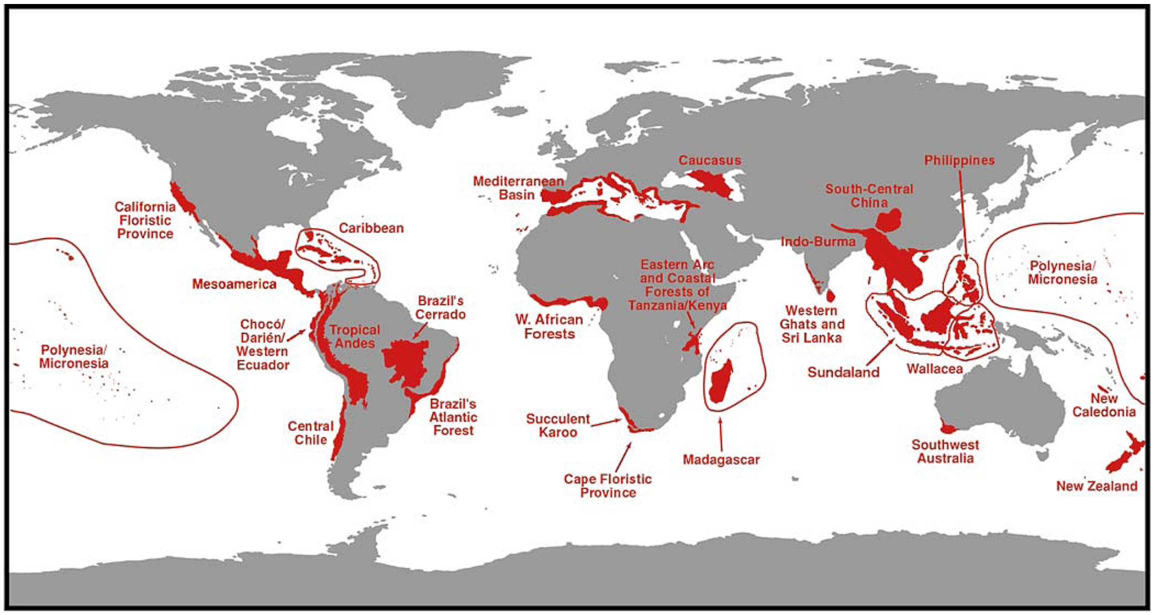

Figure 1 – Map of the world's biodiversity hotspots (Myers et al 2000, reprinted with permission from Nature Publishing Group).

The scientific community is continuing to improve our knowledge of species' distributions. In the past, naturalists necessarily did this using a brute force approach. People went outside, looked for things, and plotted their locations on a map. It is an effective, but slow and costly approach. Moreover, the smaller the species, the harder it is to find, and the remaining species are almost certainly on the small end. We already found all the large species first because they were easy.

Scientists increasingly use computerized models to improve on those earlier efforts. Advances in remote sensing and Geographic Information Systems now allow us to extend limited information from the field across landscapes too large to survey in detail. The results of those models can then provide input for finer-scale hotspot analyses.

These models generally fall into one of three categories that we refer to as: simple, statistical, and black box. Simple models are precisely what the name suggests, simple. They have few variables and few rules for each species under study. Such models have the distinct advantage of requiring few input data, making them applicable to many species. As an example, Harris et al (in press) use only elevation and forest cover to refine hundreds of bird distribution maps in the Atlantic Forest hotspot. Such data are available, or we can easily create them, for most parts of the world.

Many distribution models use statistical algorithms such as linear or logistic regression (e.g., Gibson et al 2004, Guisan & Zimmermann 2000). These approaches require more data, but usually represent the distribution of a species better than simple models. The advantage is the more accurate results. The disadvantage is that only for a few species do we have sufficient data for such models. Most statistical models require a list of locations where a species occurs, plus measurements of relevant environmental variables, to use in deriving ecological rules for the species' distribution. For example, with enough surveyed locations, it is easy to define elevational or climatic limits within which a species occurs. However, even for species we know well, the locality data are not always precise, often having errors of several kilometers. This could place a point in a completely different habitat than its true location. Unfortunately, we usually do not even have this quality of data. For most species, we know only a single or at most a few locations. That situation is unlikely to change soon. There are simply too many species and too few people searching for them.

Some scientists are attempting to go around the insufficient data problem. This often involves what we refer to as a 'black box' approach. The black box is usually a powerful computer with complex things happening inside it. As an example, genetic algorithms are a recent favorite. By combining species locality data, usually from museum specimens, with spatial environmental data, the algorithms calculate the ecological niche for a species (Stockwell & Peters 1999, Peterson et al 2002, Raxworthy et al 2003). The rules for this niche are then used in creating a distribution map.

The advantage of such an approach is the ability to model any species for which we have locality data. In some cases, the results are compelling, and have even led to the discovery of new species (Raxworthy et al 2003). The disadvantages involve three factors. First, locality data are not always precise, causing the same problems we described above with the statistical models. Second, deforestation and other landcover changes have destroyed many of the places where museum specimens were originally collected. An estimate of environmental conditions there today may not be the same as when the specimen was collected. These first two factors could both result in predictions of species in habitats where they do not really occur.

The third disadvantage is more subtle. The algorithms generally arrive at the rules for ecological niches through random searching and testing. The rules found do not necessarily conform to ecological reality, although the hope is that they do. This is the black box aspect. The computer (black box) gives an answer and you trust it, with or without fully understanding how it found that answer. It is a tradeoff between minimizing user input, and trusting the black box to yield a correct answer.

All of these approaches, and others we do not discuss, are useful. They increase our knowledge of where species are, and the methods are improving. Once we have that knowledge, we can then use it to improve our maps of conservation priorities. We, along with our colleagues, have done this using the simple model approach in the Atlantic Forest hotspot.

The next section describes the methods and results of those models to refine distribution maps of birds in the Atlantic forest. We then use those maps to identify specific conservation priorities in the Atlantic Forest. In the following section, we explore an alternative method to using species distribution maps. This method uses only maps of habitat change, ignoring the specific species those habitats might contain. Surprisingly, it gives nearly the same answer, suggesting that detailed information on species distributions may not be the only, or the best, method to identify conservation priorities.

Method 1: The answer that birds tell us

Most of the Atlantic Forest is in Brazil with small parts in Argentina and Paraguay. It is species-rich, unique, and highly threatened (Myers 1988, 1990, Myers et al 2000, Olson & Dinerstein 1998). At the coarsest scale of knowledge is the entire hotspot (red in Figure 2A). Its total area is just over one million square kilometers but about 90% of that area has already lost its forest (Myers et al 2000). Most of the human population (>100 million) and most of the economic activity of Brazil occur within the Atlantic Forest as well, presenting substantial obstacles to conserving what forest remains (www.biodiversityhotspots.org). This full hotspot level of knowledge is clearly insufficient to direct specific conservation actions. It merely defines an important region for more detailed study.

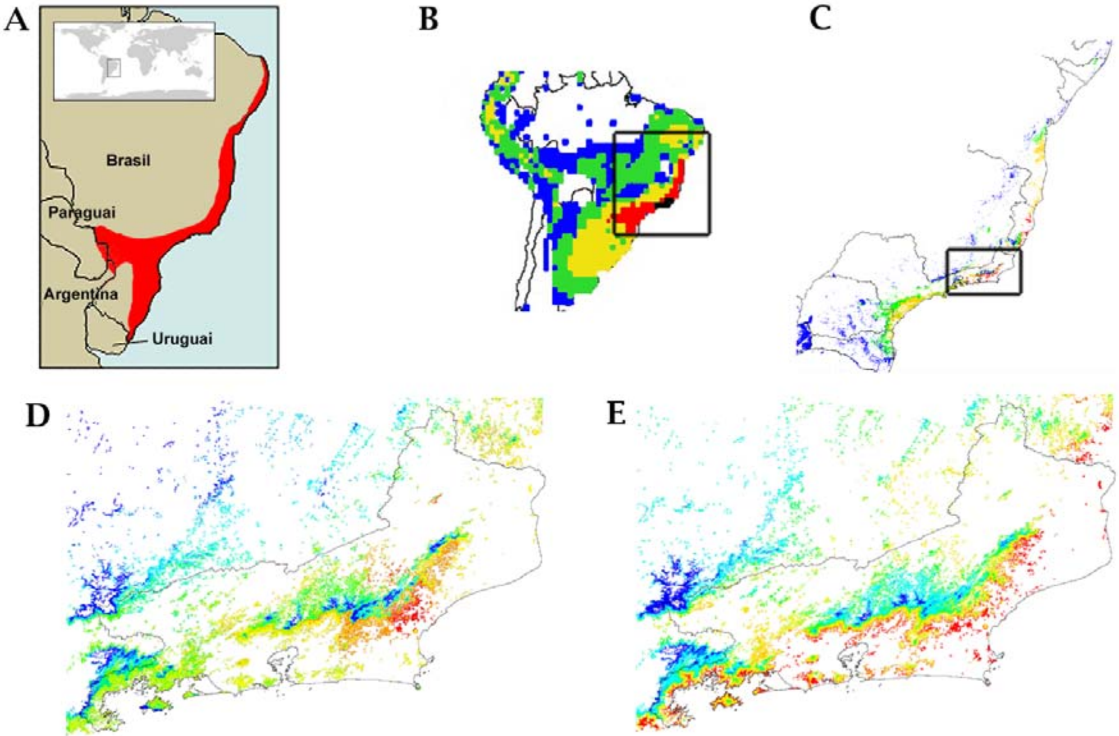

Figure 2 – A progressive series of conservation priority maps for the Atlantic Forest hotspot (red in A, drawn by authors). In maps B through E, priority levels increase as follows: blue (lowest), green, yellow, red, and black (highest). Map B is from Manne et al (1999) and has a 1-degree lat/long resolution. Map C is from

Harris et al (in press) and has a 1-km^2 resolution. Maps D and E are from the authors and have a resolution of ~0.001 km^2. The individual maps use different sets of species, and so the numbers of species are not directly comparable. The relative priority of regions, however, is comparable. Only B has a black category. The color schemes in B and C are modified from their original sources. The boxes in B and C outline the equivalent areas shown in C and D respectively.

We can get a somewhat finer level of detail by analyzing already available species' distribution maps. These are of the type generally found in field guides for well-known taxa. Manne et al (1999) did just that using passerine birds. They again found the Atlantic Forest to be of high conservation importance (Figure 2B), just as Myers did when using plant distributions. The Atlantic Forest has more birds in danger of extinction than any other region in the Americas. More interesting is that the map from Manne et al (1999) highlights a relatively small area (black in Figure 2B) that holds an exceptional number of threatened birds within the larger hotspot. While the entire hotspot is important, this central part seems to be even more so.

The black area in Figure 2B roughly corresponds to the state of Rio de Janeiro. It has many endangered birds, but it also has many people (>14 million, Noble et al. 2002). It is also mostly deforested, and so most of the black area in reality has no forest to protect. In many respects, this mini-hotspot has the same problems as the larger hotspot. We still need further refinement to define priority areas practical for conservation action.

Harris et al (in press) take a logical next step. They use simple models to refine the existing maps of bird distributions. Details of their methods are described in two papers (Harris & Pimm 2004, Harris et al *in press*), but a brief summary is as follows. They evaluated 174 of the forest-dependent endemic birds, excluding only species not dependent on forest or thought to already be extinct. For each species, they obtained the most recent digital range map (from Mehlman et al. 1999 or BirdLife International 2001). They then used a Geographic Information System (GIS) to remove areas considered unsuitable, but still within the range of that particular species. In this case, unsuitable areas are those at an unsuitable elevation for the species or with no forest (mapped with Landsat satellite imagery). For most birds in this region, elevational limits are in Parker et al (1996), an essential resource for studying Neotropical birds.

The results of this process are maps of the actual habitat for each species, rather than the maps of maximum range used by Manne et al (1999). By then following much the same idea as Manne et al (1999), we arrive at Figure 2C. At first glance, this refined priority map looks substantially different from the equivalent region outlined in Figure 2B. The high priority areas in Figure 2B (red and black) are mostly blank in Figure 2C. And that is exactly the point! Most of the hotspot is not a priority because it no longer has any forest to protect.

If we zoom in closer, we can begin to see other important patterns not apparent in the coarser scale priority maps. In Figure 2D, we have extended the same methods used by Harris et al (in press) to an even finer scale (~$0.001km^2$) using Landsat satellite imagery and elevation data. The area mapped includes most of Rio de Janeiro state, Brazil, with small parts of São Paulo, Espírito Santo, and Minas Gerais states. At this level of detail, we can now see that within the former high priority area (black in Figure 2B), there is actually substantial variation. Many areas are blank, because there is no forest, while other areas range from low priority (blue, few threatened species) to high priority (red, many threatened species).

This fine scale variation primarily follows elevational gradients. The lowlands have by far the most species threatened with extinction, while the uplands have very few. The explanation for this becomes obvious when you consider the history of the area. The lowland forest has suffered the most severe deforestation, while the upland forest is still largely intact. By extension, this also means that species occurring in the lowlands have suffered the greatest habitat loss, and so face an increased risk of extinction. The priority is clear. Protecting the lowlands will protect the most threatened birds.

This pattern also opens up a new possibility. Since the most threatened habitat, the lowland forest, has the most threatened species, could we simply focus on mapping the habitats rather than individual species? This would be far simpler than mapping the distributions of all the individual species.

Method 2: The answer that habitat gives us

Forest once covered most of Rio de Janeiro state and the surrounding areas. To estimate which parts of this forest are most threatened, and thus likely to have the most threatened species, we did a simple comparison of the original and current forest cover. For an estimate of original forest cover, we used the WWF ecoregion map for the Atlantic Forest (Olson & Dinerstein 1998). For an estimate of current forest cover, we mapped forest from six Landsat 7 ETM+ satellite images (~year 2000).

We then calculated the percentage of forest lost within every 100-meter elevation bands and ranked them for priority (high loss = high priority, low loss = low priority). Figure 2E shows the results with oranges and reds being high priority, and blues lower priority. In general, the situation improves as you go up in elevation. For example, less than 20% of the forest below 200m remains, 20 to 30% remains between 200 and 700m, and more than 90% remains above 1300m.

This habitat-based map (Figure 2E) is surprisingly similar to the species-based map (Figure 2D). The high priority areas from species distributions (oranges and reds in 2D) are generally the same priority in the habitat-based map (2E). The habitat-based map does rank some areas in the southwest higher than in the species-based map, but the relative priorities within the maps are the same. Lowland areas consistently rank higher than their neighboring upland forest. The lower priority areas (blues) correspond even more closely.

Given either of these two priority maps, the recommendations on where conservation should act would be very similar. The lowland forest is almost gone. Protect what is left or the lowland species will go extinct. Adding species level information changes relatively little in the conservation recommendations.

Conclusions

A popular assumption is that better data on species distributions are necessary to make the best choices for conservation. If available, better species distribution data can help, but we find that they are not always necessary. The primary reason most species become threatened is habitat loss. It follows that most threatened species should occur in the threatened habitats. If one finds the most threatened habitat, it will be a high priority for conservation.

Scientists do still disagree about which data to use for defining conservation priorities. Recent discussions show that some strongly favor using species data

(Brooks et al 2004a,b), while others argue for including various measures of habitats or ecosystem services (Molnar et al 2004, Cowling et al 2004, Higgins et al 2004, Pressey 2004). The various views each have support, but conservation must still act before we have a final answer.

We do not presume to have the definitive answer for conservation priorities in the Atlantic Forest. We have looked only at birds and one measure of habitat change. However, studies have shown that diverse areas for some taxa do not overlap with others (e.g., van Jaarsveld et al 1998), suggesting that using single taxa is unwise. Would the map look the same for frogs or orchids? What if we used only the threatened species? The places with many frogs or orchids may be different from those with many birds, but perhaps the threatened frogs, orchids, and birds do occur in the same places. Will those priority areas also overlap with those from using habitats alone? These questions need answers.

The same data scientists use to model species distributions are also suited to mapping habitats. The satellite imagery, elevation maps, climate models, and soils data, are available for rapid analysis. We could use them to find the distribution of each species, one by one. Alternatively, we can map the world's habitats twice, once to show where habitat used to be, and once to show what remains. In our study, both approaches give similar answers. If true elsewhere, which we do not yet know, the habitat mapping approach might be a more efficient priority-setting method than using species distributions.

These conclusions may make some people uncomfortable, as they should. It conflicts with conventional wisdom. Scientists have spent centuries finding and cataloging where the world's biodiversity occurs. They may justly want to continue this. That does not mean the conservation community requires the information to move forward. We broadly know where the species are. We know that habitat loss threatens many with extinction. Finding every species is not necessary for conservation to act. Perhaps we need only find the places under greatest threat. Those places will have the species in need of protection.

References

BirdLife International. 2001. World bird database: the site for bird conservation. Version 1.0. BirdLife International, Cambridge, United Kingdom. Available from http://www.birdlife.net.

Brooks, T.M., G.A.B. Fonseca & A.S.L. Rodrigues. 2004a. Protected areas and species. Conservation Biology 18: 616-618.

Brooks, T., G.A.B. Fonseca & A.S.L. Rodrigues. 2004b. Species, data, and conservation planning. Conservation Biology 18: 1682-1688.

Cabeza, M. & A. Moilanen. 2001. Design of reserve networks and the persistence of biodiversity. Trends in Ecology & Evolution 16: 242-248.

Cincotta, R.P., J. Wisnewski & R. Engelman. 2000. Human population in the biodiversity hotspots. Nature 404: 990-992.

Cowling, R.M., A.T. Knight, D.P. Faith, S. Ferrier, A.T. Lombard, A. Driver, M. Rouget, K. Maze & P.G. Desmet. 2004. Nature conservation requires more than a passion for species. Conservation Biology 18: 1674-1676.

Gibson, L.A., B.A. Wilson, D.M. Cahill & J. Hill. 2004. Modelling habitat suitability of the swamp antechinus (*Antechinus minimus maritimus*) in the coastal heathlands of southern Victoria, Australia. Biological Conservation 117: 143-150.

Guisan, A. & N.E. Zimmermann. 2000. Predictive habitat distribution models in ecology. Ecological Modelling 135: 147-186.

Harris, G. M. and S.L. Pimm. 2004. Bird species' tolerance of secondary forest habitats and its effects on extinction. Conservation Biology 18: 1607-1616.

Harris, G.M., C.N. Jenkins & S.L. Pimm. (in press). Refining biodiversity conservation priorities. Conservation Biology.

Higgins, J.V., T.H. Ricketts, J.D. Parrish, E. Dinerstein, G. Powell, S. Palminteri, J.M. Hoekstra, J. Morrison, A. Tomasek & J. Adams. 2004. Beyond Noah: saving species is not enough. Conservation Biology 18: 1672-1673.

Manne, L.L., T.M. Brooks & S.L. Pimm. 1999. Relative risk of extinction of passerine birds on continents and islands. Nature 399: 258-261.

Mehlman, D., R. Roca, K. Smith, T. Brooks, and W. F. Limp. 1999. Conservation Priority Setting for Birds in Latin America. CD-ROM. The Nature Conservancy, Arlington, Virginia.

Molnar, J., M. Marvier & P. Kareiva. 2004. The sum is greater than the parts. Conservation Biology 18: 1670-1671.

Myers, N. 1988. Threatened biotas: "Hot Spots" in tropical forests. The Environmentalist 8(3): 187-208.

Myers, N. 1990. The biodiversity challenge: expanded hot-spots analysis. The Environmentalist 10(4): 243-256.

Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A.B. Fonseca & J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature 403: 853-858.

Myers, N. 2003. Biodiversity hotspots revisited. BioScience 53: 916-917.

Noble, J., A. Draffen, R. Jones, C. McAsey & L. Pinheiro. 2002. Brazil, 5th edition. Lonely Planet Publications Pty Ltd, Victoria, Australia. p. 232.

Olson, D.M. & E. Dinerstein. 1998. The global 200: A representation approach to conserving the Earth's most biologically valuable ecoregions. Conservation Biology 12: 502-515.

Peterson, A.T., M.A. Ortega-Huerta, J. Bartley, V. Sánchez-Cordero, J. Soberón, R.H. Buddemeier & D.R.B. Stockwell. 2002. Future projections for Mexican faunas under global climate change scenarios. Nature 416: 626–629.

Pimm, S.L. & J.H. Lawton. 1998. Planning for Biodiversity. Science 279: 2068-2069.

Pressey, R.L. 2004. Conservation planning and biodiversity: assembling the best data for the job. Conservation Biology 18: 1677-1681.

Raxworthy, C.J., E. Martinez-Meyer, N. Horning, R.A. Nussbaum, G.E. Schneider, M.A. Ortega-Huerta & A.T. Peterson. 2003. Predicting distributions of known and unknown reptile species in Madagascar. Nature 426: 837-841.

Stockwell, D. & D. Peters. 1999. The GARP modelling system: problems and solutions to automated spatial prediction. International Journal of Geographical Information Science 13: 143–158.

van Jaarsveld, A.S., S. Freitag, S.L. Chown, C. Muller, S. Koch, H. Hull, C. Bellamy, M. Krüger, S. Endrödy-Younga, M.W. Mansell & C.H. Scholtz. 1998. Biodiversity assessment and conservation strategies. Science 279: 2106-2108.

Wilson, E.O. 2003. The encyclopedia of life. Trends in Ecology and Evolution 18: 77-80.