PHILOSOPHICAL
TRANSACTIONS
OF
THE ROYAL
SOCIETY B

Phil. Trans. R. Soc. B (2007) **362**, 169–174
doi:10.1098/rstb.2006.1976

Biodiversity hotspots through time: an introduction

International targets set for reducing the rate of biodiversity loss—the 2010 target—and ensuring environmental stability (Millennium Development Goals) have helped to focus the efforts of the scientific community on providing the data necessary for their implementation. The urgency of these goals, coupled with the increased rate of habitat alteration worldwide, has meant that actions have largely not taken into account the increasing body of data about the biodiversity change in the past. We know a lot about how our planet has been altered and recovered in the past, both in deep time and through prehistory. Linking this knowledge to conservation action has not been widely practised, by either the palaeoecology or the conservation communities. Long-term data, however, have much to offer current conservation practice, and in the papers for this volume we have tried to bring together a variety of different perspectives as to how this might happen in the most effective way. We also identify areas for productive collaboration and some key synergies for work in the near future to enable our knowledge of the past to be used for conservation action in the here and now. Lateral thinking, across knowledge systems and with open-mindness about bridging data gaps, will be necessary for our accumulating knowledge about our planet's past to be brought to bear on our attempts to conserve it in the future.

Keywords: 2010 target; biodiversity; conservation; paleoecology; evolution; prehistoric human impact

1. BIODIVERSITY CONSERVATION TARGETS: THE TEMPORAL DIMENSION

At the World Summit for Sustainable Development in Johannesburg in 2002, the assembled parties endorsed the 2010 target, earlier agreed by the Conference of the Parties to the Convention on Biological Diversity (CBD 2002), to 'achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on Earth'. This bold target directly contributes to the Millennium Development Goal of ensuring environmental sustainability (see http://www.un.org/millenniumgoals/#), via reducing the loss of environmental resources, all of which are built on biodiversity. As we write this in 2006, 2010 seems impossibly close—how can we achieve anything like this target in only 4 years? This time-frame is one of urgency and speed, one that almost invites remedial, quick actions that do not rest on long-term studies that can span decades. The achievement of the 2010 target is not long-term, but this does not preclude long-term data being important to help us reach the goal.

Spatial patterns in biodiversity are well recognized, and form the basis for many conservation strategies—most notably the biodiversity hotspots approach has been used by conservation agencies as a way of effectively targeting conservation resources at areas of greatest diversity, and the highest levels of endemism and threat (Myers *et al.* 2000; Mittermeier *et al.* 2005). The temporal dimensions of biodiversity are less well studied, however, and it is the aim of this special issue on 'Biodiversity hotspots through time: using the past to manage the future' to explore the dynamic nature of vegetation in Earth's most biodiverse landscapes. In this volume, we present examples of the use of palaeoecology and other techniques in understanding processes of vegetation change over time, and discuss how this knowledge can be integrated into conservation practice and policy.

Why explore hotspots through time? In addition to being spatially patterned, biodiversity is patterned temporally; the diversity of life on Earth is not static in space or in time (Knapp 2003). Climate has varied throughout the past, influencing the extent and area of particular ecosystems and habitats, and species have not always occupied the same regions or habitats they do today. It is clear that understanding how patterns of distribution of diversity, be it in habitats or species, have changed can help us predict what might happen in the future. But there is often a mismatch between the temporal scales of past data and the ecological processes that are of interest to conservationists. This need not be so, and the papers we have collected for this volume demonstrate a wide variety of approaches for exploring the issue of not only how we use data through time to demonstrate what has happened in areas of high biodiversity and to predict what might happen in the future, but also how these data can be used to inform conservation actions in the here and now.

In crafting this volume, we have defined hotspots very broadly, not intending to select areas that are more or less important for conservation, but rather to explore the issues of landscape level diversity through time in areas where species level diversity is also high.

As the papers in this volume suggest, we can identify some areas we feel are ripe for collaboration. These are by no means the only ways in which data from the past can be used to help conservation practice, but we feel it

---

One contribution of 14 to a Theme Issue 'Biodiversity hotspots through time: using the past to manage the future'.

is these areas where significant progress can be made soon, and where it will have greatest effect.

- Linking proximal palaeoecology to conservation action in specific areas of concern.
- Using phylogeny to inform palaeoecology and the conservation of evolutionary potential.
- Linking spatial and temporal patterns and scales of disturbance for ecosystem management.
- Understanding the continuous role of changing climate and human activities in shaping vegetation change in the biodiverse landscapes.

2. HOTSPOTS, BIODIVERSITY CONSERVATION AND METHODS OF MEASUREMENT

The diversity of life is not spread evenly over the face of the globe. A latitudinal gradient exists in species richness, with a marked decrease from tropical to polar regions. Explanations for this pattern are many and competing, but that a pattern exists is widely recognized (Dobzhansky 1950; Hutchinson 1959; Wright *et al.* 2006). This pattern of species richness distribution, coupled with concern about the rate of biodiversity loss and the need to prioritize actions for its conservation, has led to many proposals of how to define and delimit the areas where high biodiversity and high threat coincide. Endemism, or range size rarity—the distribution of rare species in limited areas—is also of interest to those seeking to conserve diversity; those species or groups that are distributed in only one place are of conservation concern, regardless of whether they occur in an area of high species richness. The complex interplay of patterns of species richness and endemism means that priority setting for conservation action to implement the CBD using these criteria can be incredibly difficult, and at times contentious.

The metaphor of hotspots—hot areas being those more biodiverse—has an immediate and almost visceral appeal; the idea, first proposed by Myers (1988), has become part of the vernacular. Using data drawn primarily from flowering plants, Myers *et al.* (2000) formalized the concept as an intersection of areas of high endemism and threat. Others have used the concept slightly differently (e.g. Fjeldså *et al.* 1997), or used different criteria (Olson & Dinerstein 1998; Spector 2002), but hotspots are what most people use to describe those areas on the globe where diversity is highest. Just what or where the hottest spots are is often hotly contested, in part due to conflict over how the millions spent on conservation worldwide should be distributed, both among conservation organizations and over places on the globe.

Biodiversity conservation itself is a dynamic concept and is evolving in response to changing perceptions of diversity and landscape history. In this issue Callicott *et al.* (2007) use the concept of biocomplexity to explore how connectivity between human and natural systems can be understood through an understanding of landscape history, and how this knowledge can inform conservation and land-use decisions. Biodiversity seems an easy concept, but its broad definition (see below) can open new lenses through which to explore ways of implementing conservation, or even to explore what we mean by conservation itself.

Biodiversity is broadly defined in the CBD as 'the variability of living organisms from all sources, including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems'; it is more than just species diversity or endemism. This broad definition means that surrogates are often used to describe or document biodiversity; one type of measurement or pattern can be a useful descriptor of a pattern at a different scale (Williams 1996). For example, family-level taxonomic diversity has been used as a surrogate for overall richness in flowering plants worldwide (Williams *et al.* 1994), birds are often used as a surrogate for all groups of terrestrial organisms (Important Bird Areas concept, http://www.birdlife.org/action/science/sites/index.html), and vascular plant and insect diversity are correlated in the tropics (Barthlott *et al.* 1999), but indicator or surrogate groups do not always accurately predict results for other sets of organisms (e.g. Prendergast *et al.* 1993).

Crucially important for the use of indicators or surrogates is the definition of clear objectives for their use and specification of clear criteria for the selection of the surrogate (Caro & O'Doherty 1999). Using data from the past, the list of indicators or surrogates ranges from fossil proxies (e.g. fossil pollen, plant macrofossils, microfossil charcoal, sediment geochemistry) and molecular phylogenies, to records contained in old maps, aerial photographs, early traveller's diaries and archival records. But similar to the spatial record, an understanding of questions being asked is essential in order to select the most appropriate surrogate. In this issue Weng *et al.* (2007), for example, show how pollen diversity can be used as a surrogate for species level diversity in the Colombian Andes, and provide linkage between today's and past patterns. They stress the need for integrated data management strategies in order to make long-term data useful in the context of conservation policy. A number of other papers in this volume (e.g. Behling & Pillar 2007; Bush *et al.* 2007) use the microfossil charcoal record contained in sedimentary sequences to reconstruct past burning regimes, and thus assess past human influence on the environment and vegetation composition.

3. EVOLUTIONARY TIME, SPECIATION AND CLIMATE CHANGE

A distinction is often made between evolutionary and ecological time—with evolutionary time being defined as the long time-scale reaching back into the origins of life. The concept of evolutionary time as 'deep time' has its origins in Darwin's original concept of evolution by natural selection occurring very slowly and over extremely long time-scales (Darwin 1859). Thus, evolutionary time is often seen as being very ancient and perhaps not necessarily relevant to the urgency of the crisis affecting the biodiversity today. The mass extinctions of the Permian and Cretaceous/Tertiary boundary have had profound effects on the composition and diversity of life on Earth (Erwin 1993; Jablonski 2001), one causing the extinction of 96% of all skeletonized marine life and the other causing the final extinction of the dinosaurs, but neither apparently impeding the continued change and diversification of life on Earth. Using these sorts of very ancient events to inform conservation practice is difficult, except in the predictive sense that extinction is a phenomenon that has occurred throughout history.

Long-term data, however, have numerous potential applications in conservation approaches to extinctions. Diversification is the flip side of extinction and the result of the evolutionary process. But diversification can occur at taxonomic and ecological levels, with habitat or landscape level diversity being another important indicator of biodiversity a variety of scales. Phylogeny describes taxonomic diversification, and the linking of phylogenetic diversity to conservation priority could help us to conserve a broader and more evolving set of taxa and habitat than does focusing on species or regions that are isolated or at the end of a diversification path (Vane-Wright *et al.* 1991). Long-term data can provide an alternative perspective on how conservationists view extinctions. Faced with mass extinctions and limited conservation budgets, a long-term perspective on the process of extinction can provide a possible line on how best to focus conservation efforts in order to preserve evolutionary potential (Willis *et al.* 2007).

Willis *et al.* (2007) also describe how a long-term perspective can suggest possible goals for conservation by providing a description of the variability in species distribution in response to changing climate and introduce the use of corroborated uncertainty measures into scenario building. Palaeodata can be used to explore species' climate requirements, and to test how accurately species–climate models are able to predict how species distribution responds to changing climate. This approach is central to the success of climate-integrated conservation strategies (Hannah *et al.* 2002*a*,*b*).

Similarly, Young & León (2007) explore how tree lines respond to changing climate and disturbance patterns. Their study indicates the importance of morphological plasticity as an important source of diversity, thereby demonstrating how rapidly diversification can occur. Diversification time is not necessarily long: both taxa and habitats are known to have diversified rapidly, the latter through catastrophic events such as volcanic eruptions or earthquakes, rather than the slower process of continental drift, and the former through processes such as speciation.

Speciation and how it works has been a topic of interest since Darwin first articulated the concept of evolution by natural selection—he and other nineteenth century biologists were fascinated by what they called the 'species problem'. Just what constitutes a species has also been a topic of much debate and research (Mallet 2005); there are almost as many species concepts as there are biologists studying the speciation process! Species distributions and richness are both extremely important for conservation practice, both as the taxonomic category about which legislation is made (see Mace 2004) and as surrogates for genetic or ecosystem diversity. Lack of parity in species designations across taxa or through time can both cause problems for conservation (Isaac *et al.* 2004)—is a bird species the same level of genetic distinctness or variation as is a plant species or a species of micro-organism, are species of plants identified from pollen the same as those identified using current populations? It may be that the focus on species richness and range size rarity inherent in the traditional formulation of the hotspot metaphor may be impeding the integration of temporal data into the study of biodiversity.

4. ECOLOGICAL TIME

Ecological time is often linked to the generation time of the organism under study. The generation time of organisms differs radically; some trees can live for thousands of years, and the composition of a forest today will be the result of processes occurring decades or even hundreds of years ago. This creates a challenge when setting conservation goals, because our human perspective of time is inextricably linked to our own generation time; we sometimes see phenomena that occur over longer time-scales than a single research career or study season as intractable or opaque to study. Temporal data are often collected for species of commercial value (see Hutchings & Baum 2005), but for much of wild nature, no such data exist. Various techniques are available, however, which allow conservation ecologists to understand the dynamics of long-lived species like trees. For example, Chazdon *et al.* (2007) explore the effects of rates of change in tree communities following major disturbances. They study tree community attributes following abandonment of agricultural fields or pastures, using both chronosequence and annual tree dynamics studies, and find that rates of change in tree communities are determined by a complex set of interactions between local site factors, landscape history and structure, regional species pools, and species life histories.

One of the central ecological questions in invasive species research is determining what makes certain habitats more susceptible to invasion by non-indigenous species and, conversely, what enables certain species to become effective invaders. The importance of using the long-term record, in understanding particularly anthropogenic and natural disturbance histories, is fundamental to addressing such questions. Species attributes for invasiveness are difficult to define (Cox 2004), but habitat traits appear to better predict invasiveness (Jenkins & Pimm 2003); knowledge of how habitats have altered and perhaps coped in the past could help us predict where to focus efforts in the present.

Disturbance is a recurring theme in the study of biodiversity, both past and present, and studying the effects of long-term disturbance patterns can provide information on the processes that drive changes in ecological variability. Disturbance is usually characterized as either natural (hurricanes, landslides, earthquakes and the like) or human (e.g. fire, deforestation, agriculture), but it is clear from examination of the past that humans have been an integral part of many ecosystems for about 100 000 years—human disturbance is a kind of natural disturbance (Willis *et al.* 2004).

It is the scale and scope of this disturbance that in recent years has become of great concern. The ecosystem approach adopted by the CBD as the best way in which to integrate the three objectives of the Convention—conservation of biodiversity, sustainable use of its components and the fair and equitable sharing of the benefits arising out of the use of genetic resources—explicitly recognizes humans as an integral component of these systems. A recurring theme of papers in this volume is that many of the landscapes today considered as important for conservation owe much to human intervention in the past (e.g. Haberle 2007; Heckenberger *et al.* 2007).

That ecosystems have been resilient to human intervention in the past (see Brncic *et al.* 2007) does not mean they will continue to be in the face of increasing and dramatically altered human impact. Furthermore, not all landscapes have been impacted or altered by humans; strategies for management need to explicitly take past use or non-use into account (Mayle *et al.* 2007). The complex mosaic nature of most landscapes and vegetation types in areas of high diversity is highlighted by all of the papers in this volume—there will be no easy answer or simple formula. The potential interplay between climatic and human disturbance can profoundly affect how ecosystems and vegetation change, and it is clear that the human societal behaviour and the responses of vegetation communities to disturbance might change in response to changing environmental conditions. It is also suggested that some of the past methodologies used for creating these landscapes might be recreated in order to manage the biodiverse landscapes in a more sustainable manner (Glaser 2007).

Information on past disturbance and variability links long-term datasets with current conservation objectives, and is critical to the development of effective management and restoration techniques. Gillson & Duffin (2007), for example, use palaeoecological data to investigate long-term changes in tree density in savannas, and integrate these data within an ecosystem management approach based on thresholds of potential concern. This approach uses the knowledge of past variability in order to decide when ecosystem changes are unprecedented, or are approaching thresholds not compatible with conservation goals. In this way, management interventions can be planned which are based on knowledge of the variability and resilience of ecosystems.

5. SYNERGIES: WORKING TOWARDS A 2010 TARGET

The time is right for a coming together of those working in conservation practice and those working on long-term phenomena in order to bring the broadest set of data to bear on the 2010 target of reducing the rate of biodiversity loss. Creative thinking and synthesis are both required if our objective is to conserve the diversity of life on Earth. But conserving a dynamic Earth, capable of responding to future challenges and changes, requires knowledge of the past as well as action in the present. Synthesis is also essential, as all scientific communities involved in the measurement of biodiversity need to think about how to join forces to allow data from as many sources as possible to inform our progress towards the 2010 target. It will require action from all sides to bring together studies over a variety of time-scales.

Some specific examples of how these kinds of data can be used in conservation targets include:

(i) *Establishing baselines* is critical to achieving the 2010 target (Dobson 2005), as is monitoring of change into the future. Studies of biodiversity through time can contribute a unique and important element; a sampled baseline that transects different landscape factors in a way not possible with shorter-term datasets (Gillson & Willis 2004; Willis *et al.* 2005). Watson (2005) rightly asks 'is a 30 year record of species population really meaningful when there may be long-term trends in populations that have not been taken into account?'—we would argue that a 30-year record is relevant, but that coupled with long-term trends that can be elucidated from studies into the past, such a record really becomes a basis for action. Baselines and indicators, taken in the right context, are critical to being able to measure any sort of progress towards reducing the rate of biodiversity loss.

(ii) *The Global Strategy for Plant Conservation (GSPC)*. One area where such studies could contribute is the GSPC (see http://www.plants2010.org/). The GSPC is a strategic framework with a series of targets under the categories of (i) understanding and documenting plant diversity, (ii) conserving plant diversity, (iii) using plant diversity sustainably, (iv) promoting education and awareness of plant diversity and (v) building capacity for the conservation of plant diversity. The GSPC is currently being driven forward through the efforts of the botanical gardens community (see http://www.plants2010.org/). There is no reason, however, why palaeoecological studies could not contribute to the implementation of Target 4 'at least 10% of each of the world's ecological regions effectively conserved'—where knowledge of the effectiveness of today's protected areas under a variety of scenarios may depend on data from the past. Archaeological studies could also contribute to the achievement of Target 7, '70% of the genetic diversity of crops and other major socio-economically valuable plant species conserved, and associated indigenous and local knowledge maintained', where local concepts of biodiversity and its importance are of critical concern. That human populations have had a profound impact on the plant diversity of many of today's forests means that it is imperative that communities of scientists connect this knowledge with current work on the targets of the GSPC. Plants are the basis for landscapes, and being able to study their past distributions and reactions to perturbation will certainly help us to plan future actions for their conservation.

(iii) *Measuring biodiversity for conservation.* A Royal Society working group recommended that a simple framework be used in designing measurements of biodiversity, and that the framework could be applied to long-term and rapid-response situations (Royal Society 2003; http://www.royalsoc.co.uk/document.asp?id=1474). Their recommendations explicitly include long-term studies with a temporal element.

(iv) *Climate change-integrated conservation strategies.* There has been a specific call for the integration of insights about the biotic impacts of climate change from palaeoecology, and an integration of these insights into climate change-integrated conservation strategies (Hannah *et al.* 2002*b*).

(v) *IUCN Red Lists.* More challenging for temporal studies are linkages to current taxon-focused conservation practices such as the IUCN Red Lists or CITES legislation. Imaginative thinking about how to use the IUCN criteria to allow 'preliminary' conservation status to be assessed for taxa in the past might be a way forward. Red List Indicators (RLI) or sampled RLIs (Butchart *et al.* 2005), where the conservation status of a selection of taxa is tracked through time could then be applied retrospectively to assess those types of organisms that have declined the most.

It is often argued by those working with palaeoecological data that temporal studies are the 'Cinderellas' of conservation and are left out of current conservation concern. It is true that the urgency of the problem of biodiversity loss and the time-scale of action required to achieve the 2010 target means that those currently engaged in conservation practice do not necessarily go to long-term or time-spanning studies to solve problems of immediate concern. Conversely, it is often true that those working in time-spanning studies do not examine current conservation relevant objectives to examine how they might contribute effectively. Creative thinking and synthesis are both required if our objective is to conserve the diversity of life on Earth; conserving a dynamic Earth, capable of responding to future challenges and changes, requires knowledge of the past as well as action in the present.

Katherine J. Willis[1,*]
Lindsey Gillson[2]
Sandra Knapp[3] *May 2006*

[1]*Long-term Ecology Laboratory,*
Oxford University Centre for the Environment,
South Parks Road, Oxford OX1 3QY, UK
[2]*Leslie Hill Institute for Plant Conservation,*
Botany Department, University of Cape Town,
Private Bag X3, Rondebosch 7701, South Africa
[3]*Department of Botany, The Natural History Museum,*
Cromwell Road, London SW7 5BD, UK
Author for correspondence (kathy.willis@ouce.ox.ac.uk)

REFERENCES

Barthlott, W., Kier, G. & Murke, J. 1999 Globale Artenvielt und ihre ungleiche Verteilung. *Cour. Forsch. Inst. Senck.* **215**, 7–22.

Behling, H. & Pillar, V. D. P. 2007 Late Quaternary vegetation, biodiversity and fire dynamics on the southern Brazilian highland and their implication for conservation and management of modern Araucaria forest and grassland ecosystems. *Phil. Trans. R. Soc. B* **362**, 243–251. (doi:10.1098/rstb.2006.1984)

Brncic, T. M., Willis, K. J., Harris, D. J. & Washington, R. 2007 Culture or climate? The relative influences of past processes on the composition of the lowland Congo rainforest. *Phil. Trans. R. Soc. B* **362**, 229–242. (doi:10.1098/rstb.2006.1982)

Bush, M. B., Silman, M. R., de Toledo, M. B., Listopad, C., Gosling, W. D., Williams, C., de Oliveira, P. E. & Krisel, C. 2007 Holocene fire and occupation in Amazonia: records from two lake districts. *Phil. Trans. R. Soc. B* **362**, 209–218. (doi:10.1098/rstb.2006.1980)

Butchart, S. H. M., Stattersfield, A. J., Baillie, J. E. M., Bennun, L. A., Stuart, S. N., Akçakaya, H. R., Hilton-Taylor, C. & Mace, G. M. 2005 Using Red List Indices to measure progress towards the 2010 target and beyond. *Phil. Trans. R. Soc. B* **360**, 255–268. (doi:10.1098/rstb.2004.1583)

Callicott, J. B., Rozzi, R., Delgado, L., Monticino, M., Acevedo, M. & Harcombe, P. 2007 Biocomplexity and conservation of biodiversity hotspots: three case studies from the Americas. *Phil. Trans. R. Soc. B* **362**, 321–333. (doi:10.1098/rstb.2006.1989)

Caro, T. M. & O'Doherty, G. 1999 On the use of surrogate species in conservation biology. *Conserv. Biol.* **13**, 805–814. (doi:10.1046/j.1523-1739.1999.98338.x)

Chazdon, R. L., Letcher, S. G., van Breugel, M., Martínez-Ramos, M., Bongers, F. & Finegan, B. 2007 Rates of change in tree communities of secondary Neotropical forests following major disturbances. *Phil. Trans. R. Soc. B* **362**, 273–289. (doi:10.1098/rstb.2006.1990)

Cox, G. W. 2004 *Alien species and evolution: the evolutionary ecology of exotic plants, animals, microbes and interacting native species*. Washington, DC: Island Press.

Darwin, C. 1859 *On the origin of species*. London, UK: MacMillan and Co.

Dobson, A. 2005 Monitoring global rates of biodiversity change: challenges that arise in meeting the Convention on Biological Diversity (CBD) 2010 goals. *Phil. Trans. R. Soc. B* **360**, 229–241. (doi:10.1098/rstb.2004.1603)

Dobzhansky, T. 1950 Evolution in the tropics. *Am. Sci.* **38**, 208–221.

Erwin, D. H. 1993 *The great Paleozoic crisis: life and death in the Permian*. New York, NY: Columbia University Press.

Fjeldså, J., Ehrlich, D., Lambin, E. & Prins, E. 1997 Are biodiversity "hotspots" correlated with current ecoclimatic stability? A pilot study using NOAA-AVHRR remote sensing data. *Biodiv. Conserv.* **6**, 401–422.

Gillson, L. & Willis, K. J. 2004 'As Earth's testimonies tell': wilderness conservation in a changing world. *Ecol. Lett.* **7**, 990–998. (doi:10.1111/j.1461-0248.2004.00658.x)

Gillson, L. & Duffin, K. I. 2007 Thresholds of potential concern as benchmarks in the management of African savannas. *Phil. Trans. R. Soc. B* **362**, 309–319. (doi:10.1098/rstb.2006.1988)

Glaser, B. 2007 Prehistorically modified soils of central Amazonia: a model for sustainable agriculture in the 21st century? *Phil. Trans. R. Soc. B* **362**, 187–196. (doi:10.1098/rstb.2006.1978)

Haberle, S. G. 2007 Prehistoric human impact on rainforest biodiversity in highland New Guinea. *Phil. Trans. R. Soc. B* **362**, 219–228. (doi:10.1098/rstb.2006.1981)

Hannah, L., Midgley, G. F., Lovejoy, T., Bond, W. J. & Bush, M. 2002*a* Conservation of biodiversity in a changing climate. *Conserv. Biol.* **16**, 264–268. (doi:10.1046/j.1523-1739.2002.00465.x)

Hannah, L., Midgley, G. F. & Millar, D. 2002*b* Climate change-integrated conservation strategies. *Global Ecol. Biogeogr.* **11**, 485–495. (doi:10.1046/j.1466-822X.2002.00306.x)

Heckenberger, M. J., Russell, J. C., Toney, J. R. & Schmidt, M. J. 2007 The legacy of cultural landscapes in the Brazilian Amazon: implications for biodiversity. *Phil. Trans. R. Soc. B* **362**, 197–208. (doi:10.1098/rstb.2006.1979)

Hutchings, J. A. & Baum, J. K. 2005 Measuring marine fish biodiversity: temporal changes in abundance, life history and demography. *Phil. Trans. R. Soc. B* **360**, 315–338. (doi:10.1098/rstb.2004.1586)

Hutchinson, G. E. 1959 Homage to Santa Rosalia. *Am. Nat.* **93**, 145–159. (doi:10.1086/282070)

Isaac, N., Mallet, J. & Mace, G. M. 2004 Taxonomic inflation: its influence on macroecology and conservation. *Trends Ecol. Evol.* **19**, 464–469. (doi:10.1016/j.tree.2004.06.004)

Jablonski, D. 2001 Lessons from the past: evolutionary impacts of mass extinctions. *Proc. Natl Acad. Sci. USA* **98**, 5393–5398. (doi:10.1073/pnas.101092598)

Jenkins, C. N. & Pimm, S. L. 2003 How big is the global weed patch? *Ann. Mo. Bot. Gard.* **90**, 172–178.

Knapp, S. 2003 Dynamic diversity. *Nature* **422**, 475. (doi:10.1038/422475a)

Mace, G. M. 2004 The role of taxonomy in conservation. *Phil. Trans. R. Soc. B* **359**, 711–719. (doi:10.1098/rstb.2003.1454)

Mallet, J. 2005 Species concepts. In *Evolutionary genetics: concepts and case studies* (eds C. W. Fox & J. B. Wolf). Oxford, UK: Oxford University Press.

Mayle, F. E., Langstroth, R. P., Fisher, R. & Meir, P. 2007 Long-term forest–savanna dynamics in the Bolivian Amazon: implications for conservation. *Phil. Trans. R. Soc. B* **362**, 291–307. (doi:10.1098/rstb.2006.1987)

Mittermeier, R. A., Gil, P. R., Hoffman, M., Pilgrim, J., Brooks, T., Mittermeier, C. G., Lamoureux, J. & da Foncesca, G. A. B. 2005 *Hotspots revisited: Earth's biologically richest and most endangered terrestrial ecoregions*. Washington, DC: Conservation International.

Myers, N. 1988 Threatened biotas: "hotspots" in tropical forests. *Environmentalist* **8**, 187–208. (doi:10.1007/BF02240252)

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B. & Kent, J. 2000 Biodiversity hotspots for conservation priorities. *Nature* **403**, 853–858. (doi:10.1038/35002501)

Olson, D. M. & Dinerstein, E. 1998 The Global 200: a representation approach to conserving the Earth's most biologically valuable regions. *Conserv. Biol.* **12**, 502–515. (doi:10.1046/j.1523-1739.1998.012003502.x)

Prendergast, J. R., Quinn, R. M., Lawton, J. H., Eversham, B. C. & Gibbon, D. W. 1993 Rare species, the coincidence of diversity hotspots and conservation strategies. *Nature* **365**, 335–337. (doi:10.1038/365335a0)

Royal Society 2003 *Measuring biodiversity for conservation. Policy document 10/03*. London, UK: The Royal Society.

Secretariat of the Convention on Biological Diversity, 2002 *Global Strategy for Plant Conservation*. Quebec and London: Secretariat of the Convention on Biological Diversity and Botanic Gardens Conservation International.

Spector, S. 2002 Biogeographic crossroads as priority areas for biodiversity conservation. *Conserv. Biol.* **16**, 1480–1487. (doi:10.1046/j.1523-1739.2002.00573.x)

Vane-Wright, R. I., Humphries, C. J. & Williams, P. H. 1991 What to protect? Systematics and the agony of choice. *Biol. Conserv.* **55**, 235–254. (doi:10.1016/0006-3207(91)90030-D)

Watson, R. T. 2005 Turning science into policy: challenges and experiences from the science–policy interface. *Phil. Trans. R. Soc. B* **360**, 471–477. (doi:10.1098/rstb.2004.1601)

Weng, C., Hoogstriema, H. & Duivenvoorden, J. F. 2007 Response of pollen diversity to the climate-driven altitudinal shift of vegetation belts in the Colombian Andes. *Phil. Trans. R. Soc. B* **362**, 253–262. (doi:10.1098/rstb.2006.1985)

Williams, P. H. 1996 Measuring biodiversity value. *IUCN World Conserv.* **1/96**, 12–14.

Williams, P. H., Humphries, C. J. & Gaston, K. J. 1994 Centres of seed plant diversity: the family way. *Proc. R. Soc. B* **256**, 67–70.

Willis, K. J., Gillson, L. & Brncic, T. 2004 How virgin is virgin rainforest? *Science* **305**, 943–944.

Willis, K. J., Gillson, L., Brncic, T. & Figueroa-Rangel, B. 2005 Providing baselines for biodiversity measurement. *Trends Ecol. Evol.* **20**, 107–108. (doi:10.1016/j.tree.2004.12.003)

Willis, K. J., Araújo, M. B., Bennett, K. D., Figeroa-Rangel, B., Froyd, C. A. & Myers, N. 2007 How can a knowledge of the past help to conserve the future? Biodiversity conservation and the relevance of long-term ecological studies. *Phil. Trans. R. Soc. B* **362**, 175–186. (doi:10.1098/rstb.2006.1977)

Wright, S., Keeling, J. & Gillman, L. 2006 The road from Santa Rosalia: a faster tempo of evolution in tropical climates. *Proc. Natl Acad. Sci. USA* **103**, 7718–7722. (doi:10.1073/pnas.0510383103)

Young, K. R. & León, B. 2007 Tree-line changes along the Andes: implications of spatial patterns and dynamics. *Phil. Trans. R. Soc. B* **362**, 263–272. (doi:10.1098/rstb.2006.1986)