CHAPTER 3 Methods

Source: Global Gap Analysis: towards a representative network of protected areas: 31

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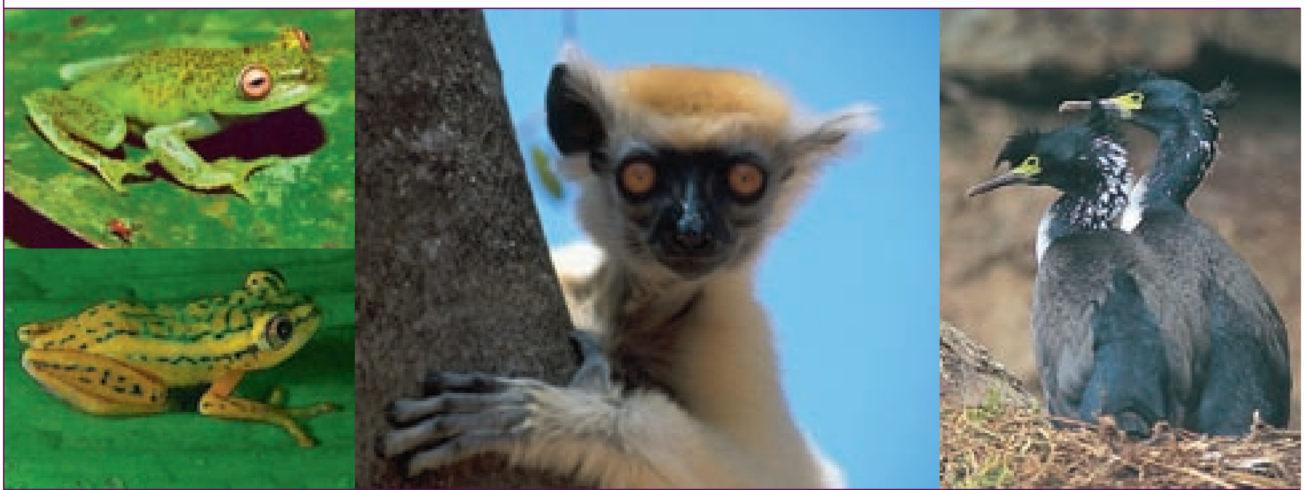
Global Gap Analysis: towards a representative network of protected areas



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All maps in this report, except where otherwise noted, were created using ArcView CIS 3.2a (ESRI 2000), using the data described in the report.

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We are thankful to the WCPA Steering Committee for its support of the partnership initiative on "Ecosystems, Protected Areas and People," which offered a framework for the global analysis as a major component of the theme on "Building a Comprehensive Global Protected Area System" of the Vth World Parks Congress.

Last but not least, we are grateful to the many individuals who contributed directly to this analysis and report, by providing technical and administrative support, data, expertise, advice, translation, photographs and/or comments on the manuscript: L. Allfree, T. Allnutt, J.L. Amiet, L. Andriamaro, L. Bennun, P. Benson, S. Blyth, C. Borja, L. Bowen, K. Brandon, A. Bruner, K. Buhlmann, N. Burgess, S. Butchart, F. Castro, H. Castro, D. Church, N. Cox, M. Denil, E. Dinerstein, I. Dodds, R. East, J. Fanshawe, M. Foster, G. Gillquist, J. Gittleman, E. Granek, L. Hannah, F. Hawkins, C. Hilton-Taylor, D. Hubbard, D. Iskandar, K. Jones, R. Kiester, S. Krogh, J. Lamoreux, P. Langhammer, R. Livermore, C. Loucks, G. Mace, D. Maestro, L. Manler, M. Martinez, K. Meek, R. Mittermeier, J. Morrison, P. Moyer, J. Musinsky, C. Nielsen, S. Olivieri, B. Phillips, G. Powell, J.C. Poynton, S. Quesada, C. Razafintsalama, S. Richards, T. Ricketts, R. Ridgely, M.O. Roedel, C. Rondinini, A. Rosen, P. Ross, A. Rylands, P. Salaman, C. Simmons, M. Sneary, L. Sørensen, A. Stattersfield, G. Stichler, R. Thomas. L. Suárez, P.P. van Dijk, J.-C. Vie, C. Vynne, C. Wilson, B. Young. All of their contributions were invaluable. We also thank M. Martínez and C. Razafintsalama for, respectively, the translations of the executive summary to Spanish and to French.

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TO THE READER

PROTECTED AREAS ARE THE SINGLE MOST IMPORTANT TOOL for addressing the global challenge of conserving biological diversity. However, until now, the nations of the world have had a difficult time making maximum use of protected areas for this purpose because we have lacked a comprehensive, consistent measure of how much diversity is represented in existing protected areas systems. Furthermore, there have been no blueprints to guide where new protected areas might be established to maximize biodiversity impact.

The World Parks Congress, convened by the IUCN World Commission on Protected Areas and held but once a decade, is one of the most influential gatherings of the conservation community and has always set standards and determined new directions for the world's protected areas. The 1992 Caracas Congress, for example, came up with the target of protecting 10 percent of the land area of each country, which has been very influential in stimulating the creation of new protected areas over the past decade. However, the 10 percent target is problematic in that it does not take into account one of the most fundamental laws of ecology, that biodiversity is not evenly distributed over the surface of our planet. This simply means that some regions require much more protected area coverage than others to ensure that their full range of life forms is represented. With this new global analysis of gaps in the protected areas system, prepared especially for the Durban World Parks Congress, we have taken a big first step toward resolving this issue.

This gap analysis mobilizes four unprecedented datasets, all compiled by enormous networks of specialists under the umbrella of the IUCN. Three of these are biological, compiled by BirdLife International and by the IUCN Global Mammal and Amphibian Assessments, and they provide the broadest, finest resolution, and the most accurate assessment of global biodiversity available to date. The fourth dataset is the World Database on Protected Areas, now also globally comprehensive. These data are analyzed using advanced techniques of systematic conservation planning.

The results of this analysis are cautiously optimistic. The great majority of the species analyzed are represented in the protected areas system, and the amount of land required to produce a much more comprehensive system is very small. Nevertheless, this analysis also demonstrates that the global network is far from complete, even for birds and mammals – the two taxonomic groups that have always received the greatest conservation attention – and that a number of major challenges remain. First of all, the world's small island nations emerge as seriously underprotected, and are a major priority for future protected area investment, and the same is true of the continent of Asia, which is also underrepresented. Second, simple representation of biodiversity in protected areas does not ensure its persistence. Concerted conservation efforts at the landscape level will be necessary for our protected areas to be viable. Finally, it is clear that much further work is necessary to address aquatic systems, both freshwater and marine, which are currently grossly underrepresented and are the biggest issue that we have to face over the next decade.

We have every hope that the results of this analysis will be far-reaching. They should provide a global blueprint of how well the protected area systems of the world are doing in representing biodiversity, what would be necessary to produce a truly representative system, and where the next steps should be in making this a reality. Furthermore, they should guide the investments of governments and civil society in those places where better protected area coverage is most urgently needed, and also those of multilateral and bilateral agencies, corporations, and foundation donors interested in this issue. We believe that it is only through this kind of rigorous, ecologically-sound planning that the countries of the world be successful in conserving the full scope of their natural heritage, and very much hope that this publication will be a significant contribution to making this noble and essential goal a reality.

Russell A. Mittermeier
President, Conservation International

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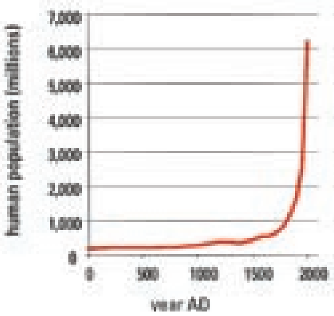
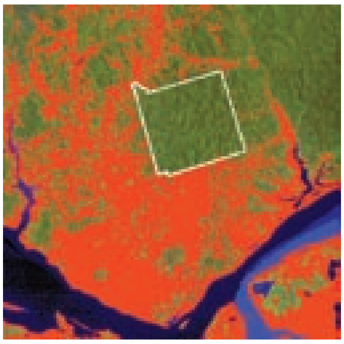
GLOBAL GAP ANALYSIS – EXECUTIVE SUMMARY

The problem

Increasing human pressure on natural resources is transforming our planet's ecosystems and leading to irreversible biodiversity loss.



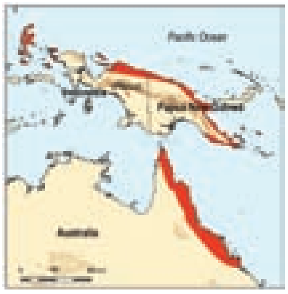


The opportunity

Governments worldwide acknowledge the value of protected areas as conservation tools, and so set land aside for this purpose. An assessment of the completeness of the current global network of protected areas is a critical tool needed to strategically expand and strengthen the coverage of protected areas.

The data

Four remarkable datasets have just become available that allow a first attempt at this assessment. The World Database on Protected Areas holds more than 100,000 spatial records of protected areas. Distribution maps produced through the IUCN Red List partnership now cover 11,171 species: 1,183 globally threatened birds, 4,734 mammals (978 threatened), and 5,254 amphibians (1,467 threatened).

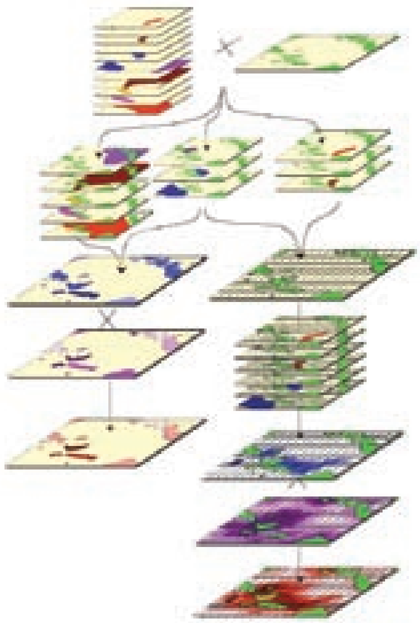


The analysis

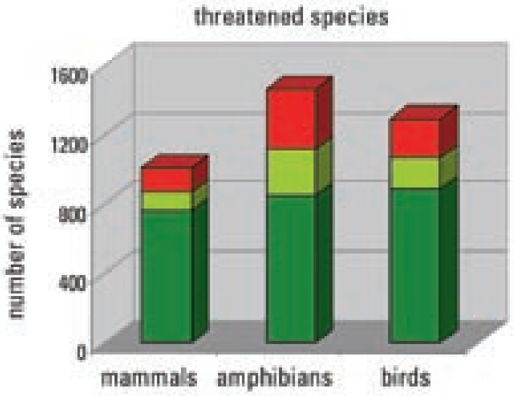
This project overlaid species distribution maps onto protected area maps using Geographic Information Systems to assess how well each species is represented in protected areas.

Assessment of the highest priority areas for consolidating and expanding the protected area network requires information on irreplaceability and threat. Irreplaceability measures how options for achieving species representation targets are reduced if a site is not conserved. Threat can be calculated as the number of threatened species present at a site, weighting those with higher extinction risk.

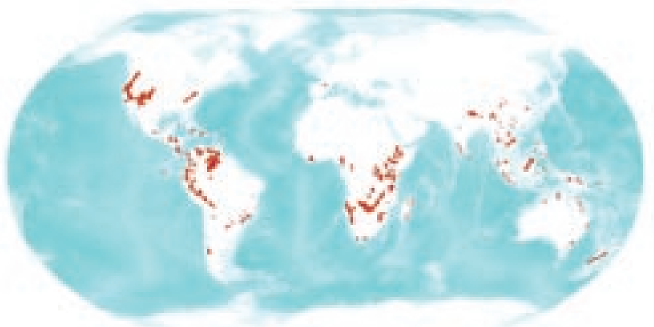
Sites of exceptional irreplaceability and threat were identified as the most urgent conservation priorities. These include currently protected sites – priorities for strengthening the existing global network of protected areas – and unprotected sites – priorities for the expansion of the global network.



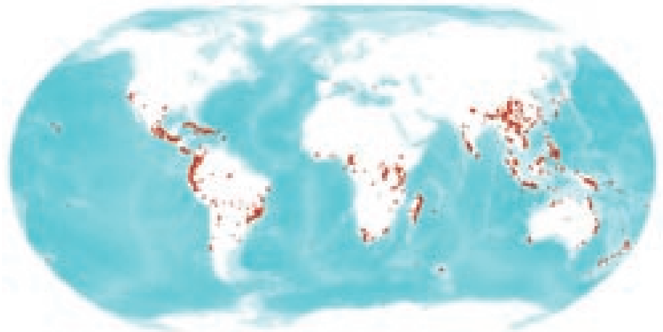
The results



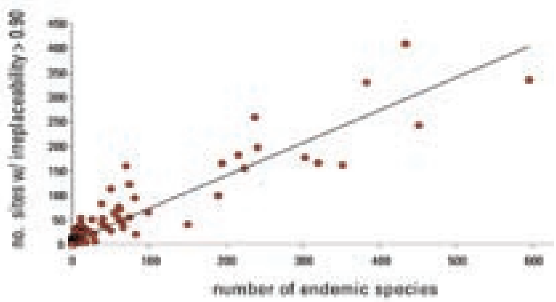
At least 1,310 species (831 at risk of extinction) are not protected in any part of their ranges. Amphibians, overall, are less well covered than birds or mammals.



Areas identified as urgent (both for strengthening and for the expansion of the global network) are mainly concentrated in tropical forests, especially in areas of topographic complexity, and on islands.

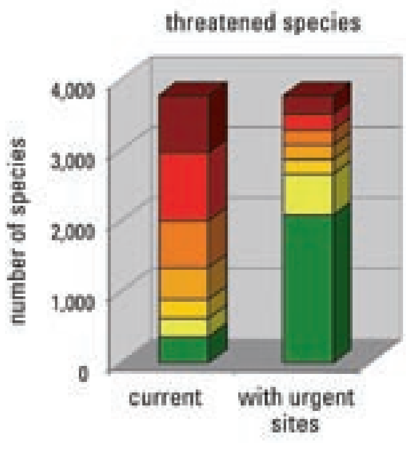


Proportionally, Asia is a higher priority for the expansion of the global network of protected areas, while the need for strengthening the existing network is mainly emphasized in Africa and South America.



The percentage of area already protected in a given country does not inform how much more protection is needed – the level of endemism is a much better predictor.

The implications



The current global network of protected areas is far from achieving a complete coverage of vertebrate species.

The expansion of the global protected area network cannot be based on area targets (10 percent or otherwise): it must instead be based on biodiversity information.

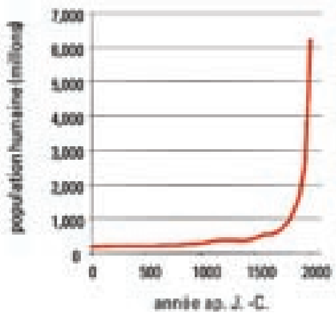
Many unprotected regions are highly irreplaceable and threatened – it is essential to ensure that they are adequately protected as soon as possible. Likewise, many existing protected areas urgently require increased investment.

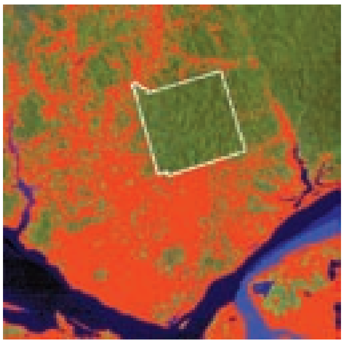
This analysis does not cover aquatic biodiversity, nor address issues of the persistence (only of the representation) of biodiversity. Nevertheless, expanding the global network of protected areas into the regions highlighted as urgent priorities in this global gap analysis would go a long way towards the conservation of bird, mammal, and amphibian species, and provide a first step towards a truly representative protected area system.

ANALYSE GLOBALE DES LACUNES “GLOBAL GAP ANALYSIS” – RÉSUMÉ

Le problème

L’augmentation de la pression humaine sur les ressources naturelles transforme les écosystèmes de notre planète et entraîne une perte irréversible de la biodiversité.



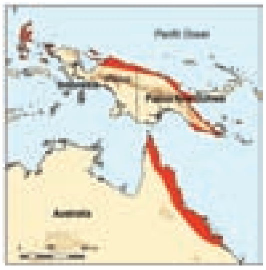


L’opportunité

Les Gouvernements du monde entier reconnaissent la valeur des aires protégées comme outil de conservation et ont désigné des terres dans ce but. Une évaluation de la couverture du réseau mondial d’aires protégées est ainsi devenue une urgente nécessité afin de guider son renforcement stratégique et son expansion.

Les données

Quatre ensembles remarquables de données viennent d’être mis à disposition et rendent possible une première tentative d’évaluation. La Base de Données Mondiale des Aires Protégées (World Database on Protected Areas) contient plus de 100 000 données géographiques relatives aux aires protégées. Les cartes de distribution produites grâce au partenariat pour la Liste rouge des espèces menacées de l’UICN couvrent maintenant 11 171 espèces: 1 183 espèces d’oiseaux globalement menacées, 4 734 espèces de mammifères (dont 978 menacées) et 5 254 d’amphibiens (dont 1 467 menacées).

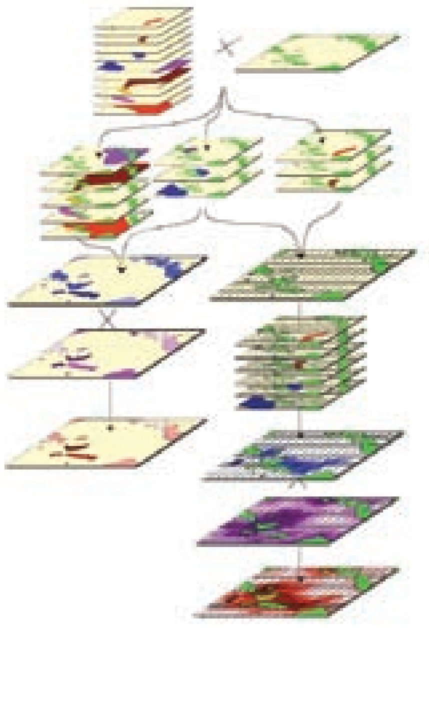


L’analyse

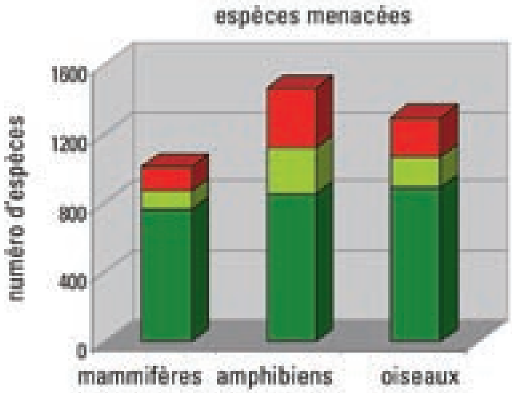
Ce projet a superposé les cartes de distribution des espèces et les cartes des aires protégées, en utilisant des Systèmes d’Information Géographique, dans le but d’évaluer à quel point chaque espèce est représentée dans les aires protégées.

Une évaluation des zones prioritaires pour une consolidation et une expansion du réseau d’aires protégées nécessite des informations sur l’irremplaçabilité et la menace. L’irremplaçabilité mesure la façon selon laquelle les options pour parvenir aux objectifs de représentation des espèces sont réduites si un site n’est pas conservé. La menace peut être simplement calculée comme le nombre d’espèces menacées présentes sur un site, en attribuant un coefficient de pondération aux espèces comportant un plus grand risque d’extinction.

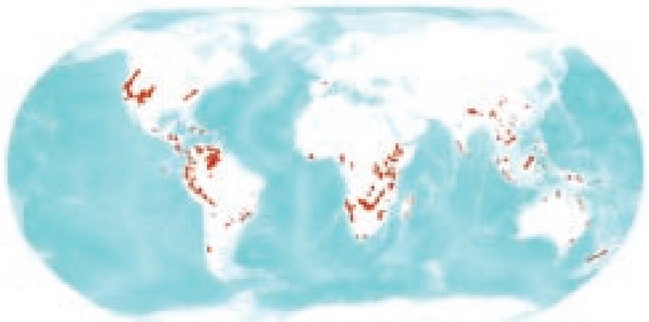
Les sites de menace et irremplaçabilité exceptionnelles ont été identifiés comme priorités premières en terme de conservation. Ceux-ci incluent des sites actuellement protégés – priorités pour le renforcement du réseau mondial d’aires protégées existant – et des sites non protégés – priorités pour l’expansion du réseau mondial.



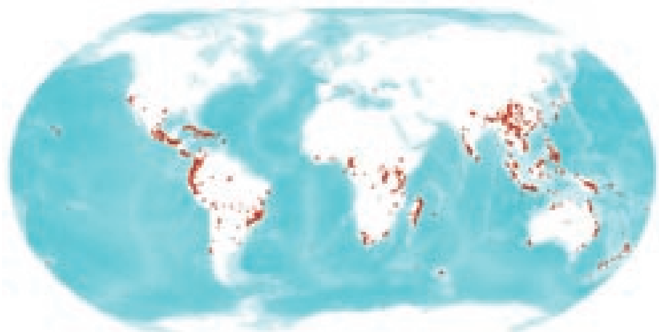
Les résultats



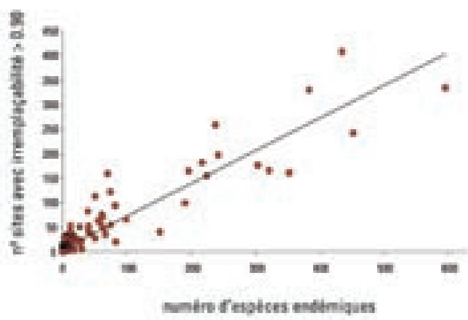
Au moins 1 310 espèces (dont 831 font face à un risque d'extinction) ne sont protégées dans aucune partie de leur aire de répartition. Généralement, les amphibiens sont moins bien couverts que les oiseaux et les mammifères.



Les zones identifiées comme urgentes (à la fois pour le renforcement et l'expansion du réseau mondial) sont essentiellement concentrées dans les forêts tropicales, plus particulièrement dans les régions à topographie complexe, et sur les îles.



Proportionnellement, l'Asie est une plus grande priorité pour l'expansion du réseau mondial d'aires protégées, alors que le besoin de renforcement du réseau existant est plus important en Afrique et en Amérique Latine.



Le pourcentage de surface déjà protégée pour un pays donné ne permet pas de connaître le degré de protection additionnelle nécessaire – le degré d'endémisme est un bien meilleur indicateur prévisionnel.

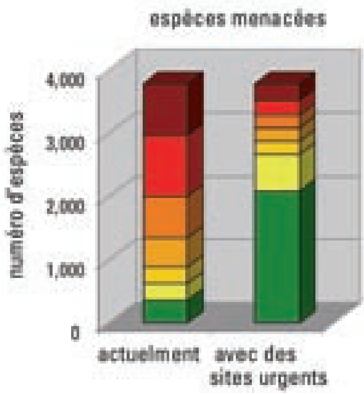
Les implications

Le réseau mondial d'aires protégées actuel est loin d'assurer une couverture complète des espèces de vertébrés.

L'expansion du réseau mondial d'aires protégées ne peut pas être basée sur des objectifs en terme de surface (10 pourcent ou autre) mais doit être basée sur une information relative à la biodiversité.

De nombreuses régions non protégées sont hautement irremplaçables et menacées; il est essentiel d'en assurer une protection adéquate aussi vite que possible. De même, de nombreuses aires protégées existantes nécessitent urgemment davantage d'investissement.

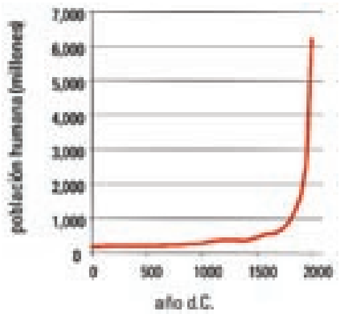
Cette analyse ne couvre pas la biodiversité aquatique et ne traite pas les questions relatives à la persistance (seulement représentation) de la biodiversité. Néanmoins, élargir le réseau mondial d'aires protégées dans les régions mentionnées comme priorités urgentes, dans cette analyse globale des lacunes, contribuerait grandement à la conservation des espèces d'oiseaux, de mammifères et d'amphibiens et constituerait une première étape vers un système d'aires protégées réellement représentatif.

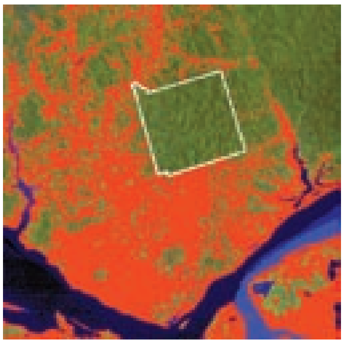


ANÁLISIS GLOBAL DE OMISSIONES DE CONSERVACIÓN "GLOBAL GAP ANALYSIS" – RESUMEN EJECUTIVO

El problema

El aumento de presiones humanas sobre los recursos naturales está transformando los ecosistemas de nuestro planeta y conduciendo a una pérdida irreversible de biodiversidad.



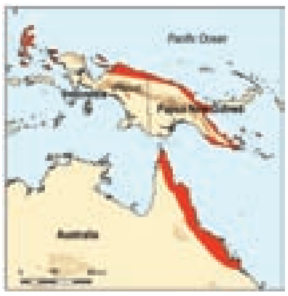


La oportunidad

Los gobiernos alrededor del mundo reconocen el valor de las áreas protegidas como herramientas de conservación y por ello designan tierras para este propósito. Por lo tanto, se requiere urgentemente una evaluación de qué tan completa es la red global de áreas protegidas para guiar estratégicamente su fortalecimiento y expansión.

Los datos

Recientemente se han puesto a disposición de usuarios cuatro excelentes conjuntos de datos que permiten un primer intento de tal evaluación. Uno de ellos es la Base de Datos Mundial sobre Áreas Protegidas (World Database on Protected Areas), que contiene más de 100,000 registros geográficos de áreas protegidas. Los mapas de distribución producidos a través de la red de socios de la Lista Roja de UICN actualmente abarcan 11,171 especies: 1,183 aves globalmente amenazadas, 4,734 mamíferos (978 amenazados), y 5,254 anfibios (1,467 amenazados).

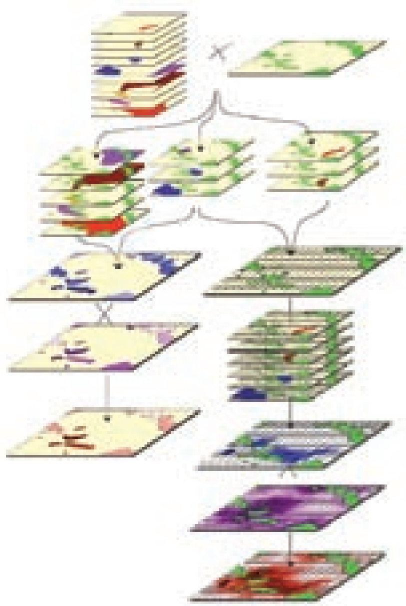


El análisis

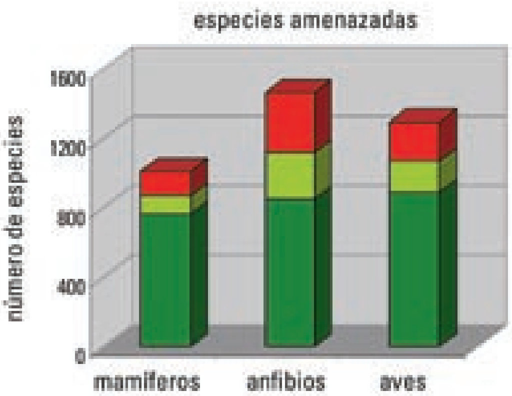
Este proyecto combina los mapas de distribución de especies con los de áreas protegidas utilizando Sistemas de Información Geográfica para evaluar la representación de cada especie en las áreas protegidas.

La evaluación de las áreas de más alta prioridad para consolidar o expandir la red de áreas protegidas requiere información sobre irremplazabilidad y amenazas. La irremplazabilidad mide cómo se reducen las opciones para lograr la representación de especies objetivo si un sitio no es conservado. El nivel de amenaza puede calcularse simplemente como el número de especies amenazadas presentes en el sitio, dando un mayor valor a aquellas que corren riesgo de extinción.

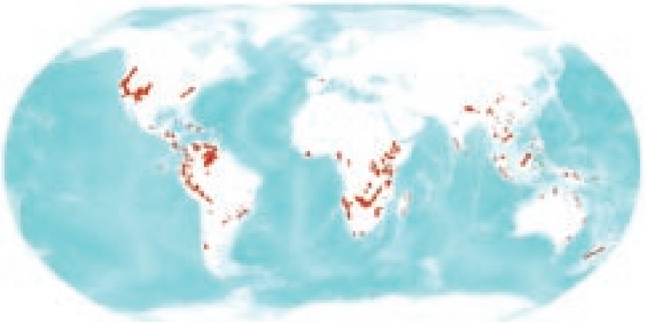
Los sitios con un excepcional nivel de irremplazabilidad y amenaza se identificaron como las prioridades de conservación más urgentes. Estos incluyen sitios actualmente protegidos – como prioridades para reforzar la red de áreas protegidas existentes – y sitios no protegidos – como prioridades para la expansión de la red global.



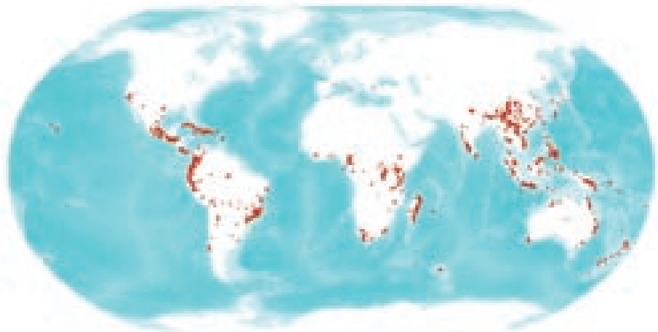
Los resultados



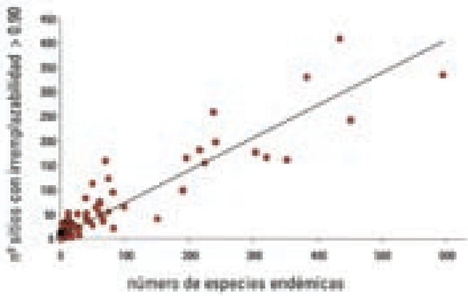
Por lo menos 1,310 especies (831 en riesgo de extinción) no están protegidas en ninguna parte de sus distribuciones. En general, los anfibios están menos protegidos que las aves o los mamíferos.



Las áreas identificadas como urgentes (tanto en cuanto a fortalecimiento como en cuanto a expansión de la red global) se concentran principalmente en los bosques tropicales, especialmente en áreas de compleja topografía y en islas.

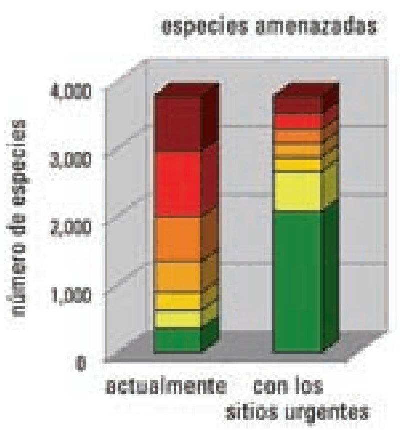


Proporcionalmente Asia tiene una prioridad más alta para la expansión de la red global de áreas protegidas, mientras que la necesidad de fortalecer la red existente se concentra en África y América del Sur.



El porcentaje de superficie ya protegida en un país no determina cuánta protección adicional se necesita – el nivel de endemismo sirve mucho mejor como indicador.

Las implicaciones



La actual red de áreas protegidas está lejos de abarcar una cobertura completa de especies de vertebrados.

La expansión de dicha red no puede basarse en metas de superficie (como el 10 porciento nacional); por el contrario, debe estar basada en información sobre la biodiversidad.

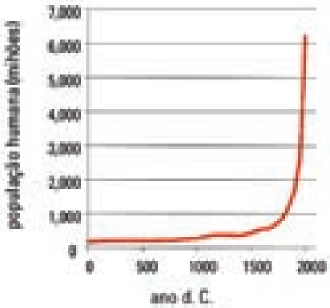
Muchas regiones que carecen de protección son altamente irremplazables y amenazadas; es esencial asegurar su protección lo más pronto posible. Igualmente, muchas áreas protegidas existentes requieren urgentemente de una mayor inversión.

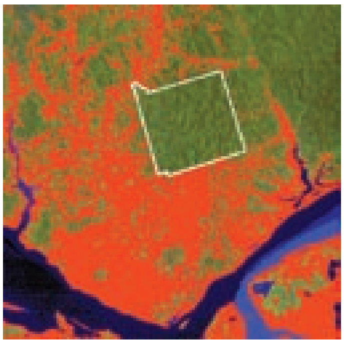
Este análisis no abarca la biodiversidad acuática, ni hace referencia al tema de la persistencia (apenas de la representación) de la biodiversidad. No obstante, la expansión de la red global de áreas protegidas a las regiones marcadas como prioridades urgentes en este “gap analysis” global significaría un gran avance hacia la conservación de especies de aves, mamíferos y anfibios, y proporcionaría un primer paso hacia un sistema de áreas protegidas realmente representativo.

ANÁLISE GLOBAL DE LACUNAS
"GLOBAL GAP ANALYSIS" – SUMÁRIO EXECUTIVO

O problema

A crescente pressão humana sobre os recursos naturais está transformando os ecossistemas do nosso planeta, e causando perdas irreversíveis de biodiversidade.



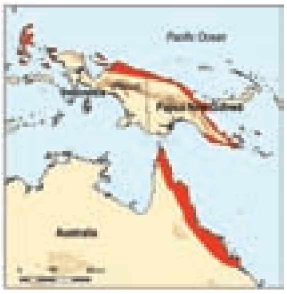


A oportunidade

Governos do mundo inteiro reconhecem o valor das áreas protegidas como ferramentas de conservação, e como tal continuam a designar áreas do seu território com esse propósito. Portanto, torna-se urgente uma avaliação do grau de adequação da rede mundial de áreas protegidas, que permita guiar estratégicamente a sua consolidação e futura expansão.

Os dados

Acabam de ser disponibilizadas quatro bases de dados extraordinárias, que tornam possível uma primeira tentativa de avaliação. A Base de Dados Mundial da Áreas Protegidas (World Database on Protected Areas) inclui mais de 100.000 registros geográficos. Mapas de distribuição produzidos pela parceria da Lista Vermelha da UICN abarcam atualmente 11.171 espécies: 1.183 aves mundialmente ameaçadas, 4.734 mamíferos (978 ameaçados) e 5.254 anfíbios (1.467 ameaçados).

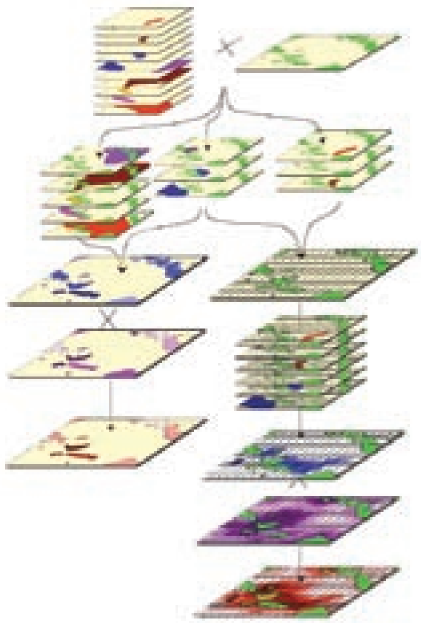


A análise

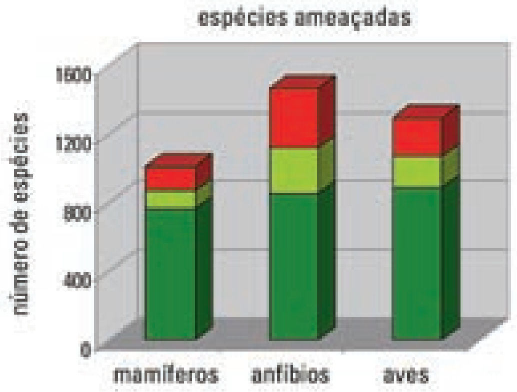
Este projeto combinou os mapas de distribuição das espécies com os mapas de áreas protegidas, utilizando Sistemas de Informação Geográfica para analizar o grau de representação de cada espécie em áreas protegidas.

A avaliação de quais áreas têm mais prioridade para o fortalecimento e expansão da rede de áreas protegidas requer informação sobre o quanto essas áreas são insubstituíveis e sobre o grau de ameaça a que estão sujeitas. O conceito de área insubstituivel estima o quando seria perdido, em termos de opções para alcançar os objetivos de conservação das espécies, se o local não for conservado. O grau de ameaça pode ser calculado simplesmente através do número de espécies ameaçadas presentes no local, com maior peso para as espécies com risco de extinção mais elevado.

Locais considerados altamente insubstituíveis e com graus de ameaça excepcionais foram identificados como sendo as prioridades de conservação mais urgentes. Estes incluem locais atualmente protegidos – que são prioridades para a consolidação da rede global de áreas protegidas atual – e locais não protegidos – que são prioridades para a expansão da rede global.

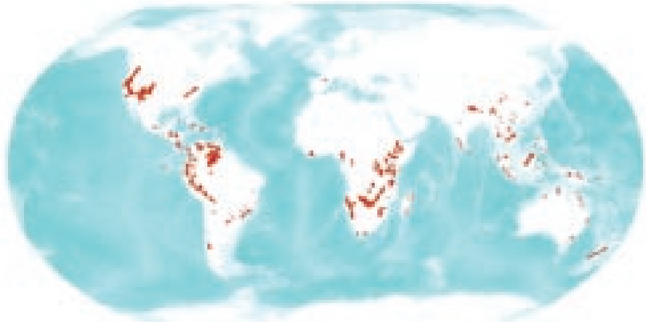


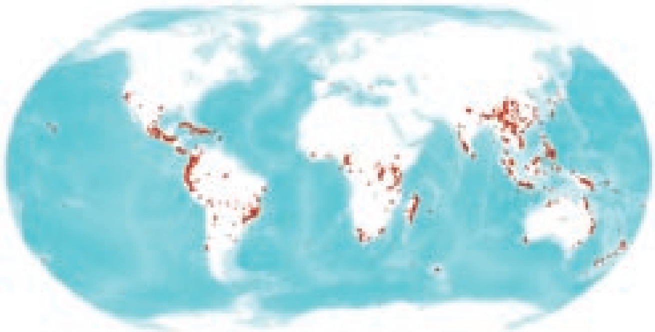
Os resultados



Pelo menos 1.310 espécies (831 das quais em risco de extinção) nao estão protegidas em nenhuma parte da sua área de distribuição. Em geral, os anfíbios estão em menos cobertos em áreas protegidas do que os mamíferos ou aves.

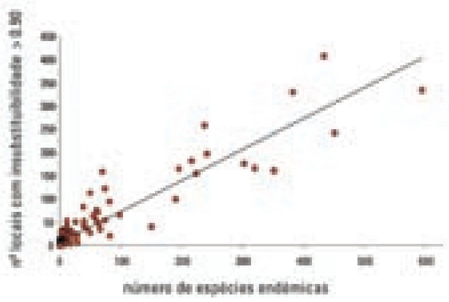
As áreas identificadas como sendo urgentes (quer para a consolidação quer para a expansão da rede global) estão majoritariamente concentradas em florestas tropicais, particulamente em regiões de grande complexidade topográfica, e em ilhas.





Em comparação, a Ásia surge como sendo uma prioridade mais elevada para a expansão da rede mundial de áreas protegidas, ao passo que o enfoque na consolidação da rede já existente é maior na África e na América do Sul.

O percentual da área que cada país possui atualmente dedicado a áreas protegidas não é um indicador preciso sobre o quanto mais é necessário proteger – o nível de endemismo é um indicador muito mais adequado.

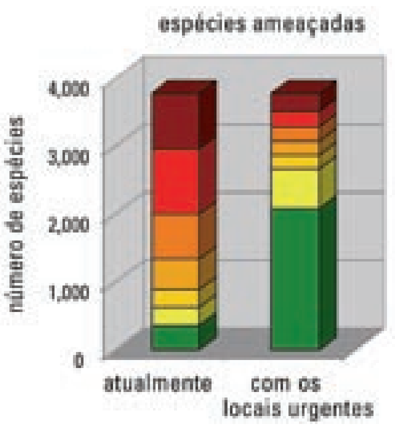


As implicações

A rede mundial de áreas protegidas está longe de atingir uma cobertura completa das espécies de vertebrados.

A expansão da rede mundial de áreas protegidas não pode ser baseada em metas associdas a área total a ser conservada (tais como 10 porcento do território nacional); em vez disso, deve ser baseada em informacão sobre biodiversidade.

Muitas regiões são altamente insubstituíveis e estão altamente ameaçadas – é essencial assegurar que essas regiões são protegidas de forma adequada o mais rapidamente possível. Da mesma forma, muitas áreas protegidas já existentes requerem urgentemente maior investimento.



Esta análise não abrange biodiversidade aquática e não trata da persistência (apenas da representação) da biodiversidade a longo prazo. Ainda assim, a proteção das regiões identificadas como sendo prioridades urgentes nesta análise global de lacunas significaria um grande avanço para a conservação das espécies de aves, mamíferos e anfíbios, proporcionando um primeiro passo em direção a um sistema mundial de áreas protegidas verdadeiramente representativo.

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CHAPTER 1

Introduction

James Nations

Governments throughout the world have recognized the importance of designating protected areas for the conservation of biodiversity.

THE PROBLEM: BIODIVERSITY AT RISK

The 20th century witnessed an extraordinary growth of the world's human population – from 1,650 million to 6,000 million people, with almost 80 percent of that increase occurring since 1950 (UN 2001). We now live in a human-dominated planet (Figure 1.1). Our population density is more than 30 times that predicted for an omnivorous mammal of our size and one-third to one-half of the land surface has been transformed by human action. Humans use about 40 percent of the planet's gross terrestrial primary productivity and 8 percent of the primary production of the oceans, 35 percent in temperate continental shelf systems. Sixty-six percent of recognized marine fisheries are fully exploited, overexploited, or depleted. The carbon dioxide concentration in the atmosphere has increased by nearly 30 percent since the beginning of the industrial revolution and more atmospheric nitrogen is fixed by humans than by all natural terrestrial sources combined. Humans use more than half of the runoff water that is fresh and reasonably accessible, with 70 percent of this for agriculture (Vitousek *et al.* 1997, Woodruff 2001).

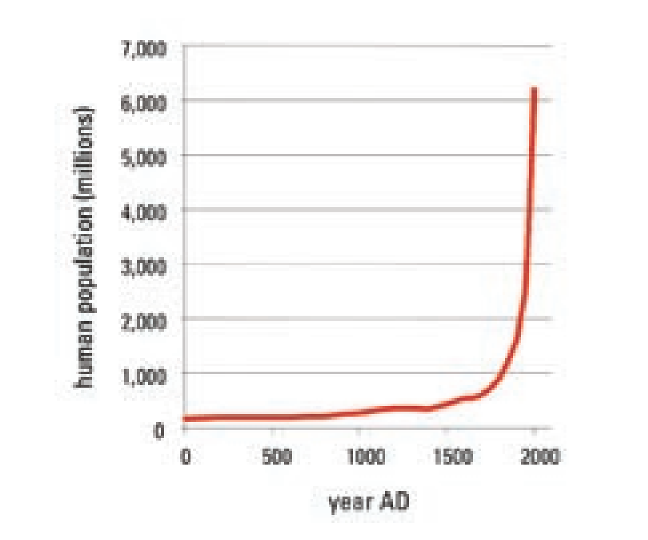

Figure 1.1 Variation in human population over time (US Census Bureau, http://www.census.gov/), showing exponential growth. The human population increased from 2,500 to more than 6,000 million people within the last 50 years.

Such increasing human pressure is severely impacting biodiversity, which is now in deep trouble. Ecosystems of all kinds are under pressure worldwide (WRI 2000): forest cover has been reduced by at least 20 percent and perhaps by as much as 50 percent; some forest ecosystems, such as the dry tropical forests of Central America, are virtually gone; more than 50 percent of the original mangrove areas in many countries is gone; wetlands have shrunk by about half; and natural grasslands have been reduced by more than 90 percent in some areas. Only tundra, arctic, desert, and deep-sea ecosystems remain so far relatively unscathed. These widespread transformations result in current species extinction rates at least one thousand times higher than the rates typical through Earth's history (Pimm *et al.* 1995), a pace unprecedented since the last mass extinction event, 65 million years ago (Jablonski 1995). Approximately 20,000 species are now listed as "threatened" with a high probability of extinction in the wild in the medium-term future, according to the Red List of The World Conservation Union Species Survival Commission (IUCN/SSC, IUCN 2002). This encompasses only well-studied groups such as many vertebrates and some plants, so the number in reality is much higher. Species populations are being lost at an even faster rate (Hughes *et al.* 1997). This extinction crisis is causing dramatic and often irreversible reduction in the economic, environmental service, option and aesthetic values of biodiversity (Chapin *et al.* 2000, Balvanera *et al.* 2001, Balmford *et al.* 2002, Collar 2003). Increased conservation efforts are essential to stem and reverse this crisis.

THE CHALLENGE: BUILDING THE GLOBAL NETWORK OF PROTECTED AREAS

The most effective way to conserve biodiversity is to maintain native species in natural ecosystems: extinction can be fought with less expense and more chance of success in the long term by maintaining self-sustaining populations in their native habitats (Balmford *et al.* 1996). This approach requires that areas are set aside where conservation is a priority over other land uses. The term 'protected area' was defined at the IV[th] World Congress on National Parks and Protected Areas (Caracas, Venezuela, 1992) as

> "An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means."

The practical value of protected areas in shielding areas of land from destructive use has been clearly demonstrated (Chomitz & Gray 1996, Deininger & Minten 1997, Bruner *et al.* 2001, Sánchez-Azofeifa *et al.* 2003; Figure 1.2). In regions of intense human occupation, protected areas are often the only remaining patches of native vegetation, holding the last examples of the native species communities (e.g., van Schaik *et al.* 1997, Dourojeanni 1999, Sánchez-Azofeifa *et al.* 2003), with the species abundance and diversity in many protected areas being markedly higher than in the surrounding landscape (e.g., Sinclair *et al.* 2002). Many species' extinctions have been prevented by the strategic creation of new protected areas in their last remaining habitats (e.g., the White Rhino *Ceratotherium simum* at the Umfolozi Game Reserve in South Africa; Emslie & Brooks 1999) and, conversely, many species are currently restricted to protected areas (e.g., the Whooping Crane *Grus americana*, which breeds in Wood Buffalo National Park, Canada, and winters at and near Aransas National Wildlife Refuge, USA; BirdLife International 2000).

If reinforced on the ground, protected areas are therefore an effective (albeit frequently not sufficient) way of addressing habitat loss – the main threat to biodiversity conservation (Hilton-Taylor 2000). Protected areas, particularly large ones, also buffer their communities from direct exploitation (Woodroffe & Ginsberg 1998). Nevertheless, some threats to biodiversity, such as disease (e.g., Jarvis *et al.* 2001) and introduced species (e.g., Hulme 2003), cannot be addressed simply by the creation of protected areas. Yet, having protected areas in place is often key to being able to implement measures needed to deal with these threats (e.g., Myers *et al.* 2000a). Climate change is an emerging threat (Parmesan & Yohe 2003) that may cause the loss of populations even in protected areas that retain otherwise pristine habitat (e.g., Pounds *et al.* 1999). While ultimately this threat can only be addressed at the scale of the entire planet (IPCC 2002), on a landscape level the creation of networks of protected areas retaining habitat connectivity is fundamental to accommodate shifts in species ranges and ecosystem boundaries (Hannah *et al.* 2002). Protected areas also provide numerous economic benefits including sources of water for agriculture, fertilization of crops, tourism, and sustainable direct extraction of resources (Beattie & Ehrlich 2001, Balmford *et al.* 2002, Carret 2003).

Protected areas have therefore received wide recognition as core components of conservation strategies, and their designation is a requirement of several multilateral environmental agreements (e.g., the Convention on Biological Diversity, http://www.biodiv.org/; the Ramsar Convention on Wetlands, http://www.ramsar.org/), as well as national and international legislation (e.g., the United States Endangered Species Act, http://endangered.fws.gov/esa.html; the European Birds and Habitats Directives, http://europa.eu.int/comm/environment/).

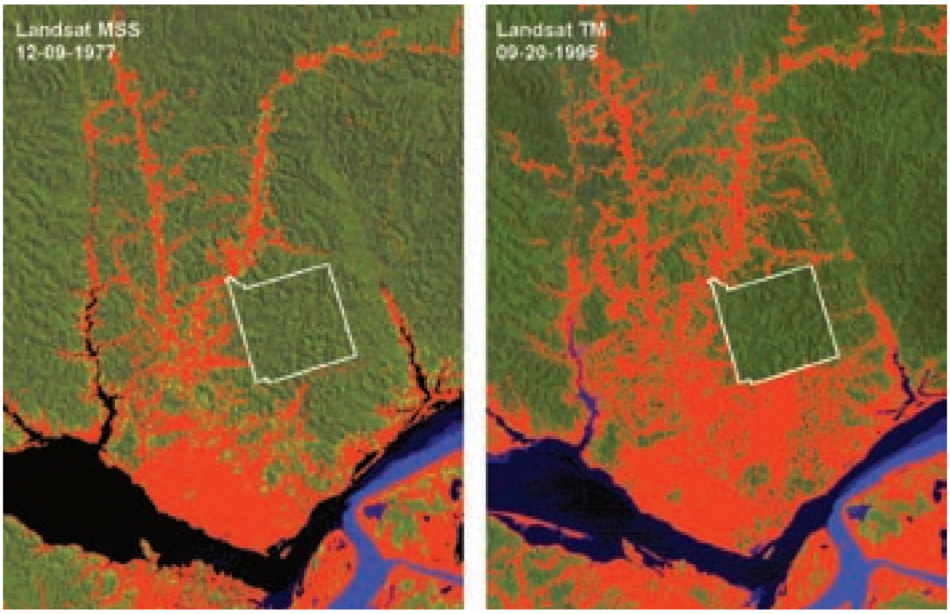

Figure 1.2 Expansion of deforestation around the Adolpho Ducke Forest Reserve, Manaus, Brazil. Mature forest appears as varying tones of green. Water appears as black to blue. Deforestation was estimated by spectral classification and is displayed in red. The Reserve totals 100 km^2 and its borders are shown in white. Despite the intense deforestation in the region, the Reserve is proving effective in retaining forest cover. Data provided by M. K. Steininger. Code 923 NASA Goddard Space Flight Center.

Throughout the world, governments have invested in the creation of protected areas, and currently most nations have set aside some of their territory for conservation purposes. The 1997 United Nations List of Protected Areas recognized nearly 13,000 protected areas, in 225 nations or territories, occupying about 8 percent of the land surface (UNEP-WCMC 1997). Nevertheless, numerous regional analyses over the last decade have revealed that the coverage of biodiversity in protected areas is woefully inadequate (e.g., Castro Parga *et al.* 1996, Pressey *et al.* 1996, Williams *et al.* 1996, Nantel *et al.* 1998, Scott *et al.* 2001b). Furthermore, many currently existing networks of protected areas are highly biased towards particular ecosystems, often those habitats that are less economic valuable and species poor, leaving other more important ecosystems inadequately protected (Pressey 1994). While it is likely that each individual protected area has significant biological value, the overall biological value of current protected area systems is likely to be significantly overestimated by the hectares they occupy (Pressey & Cowling 2001).

There is an obvious need to set aside additional protected areas. But, to be effective, these require restrictions to destructive activities. Consequently, the task of setting aside protected areas becomes increasingly difficult as competition for land use becomes more intense (Musters *et al.* 2000). The human population is expected to continue growing until the end of the 21st Century (UN 2001), with recent projections indicating a peak of 9,000 million people by 2070, 50 percent more than today (Lutz *et al.* 2001). Additionally, increase in per capita resource consumption means that pressure on natural resources will keep increasing at a rate faster than population growth. Indeed, while already one-third of the Earth's land area has been converted to agriculture and urban or built-up areas, projections suggest that an additional one-third could be converted within the next 100 years (WRI 2000). These trends suggest that designating new protected areas is not only an urgent task, but also one which needs to be carried out as efficiently as possible, making the best possible use of the scarce resources available to maximize the return in terms of biodiversity conservation.

In a few regions, comprehensive analyses of the current status and future needs of the regional networks are well under way (e.g., Pressey *et al.* 1996, Scott *et al.* 2001b, Cowling & Pressey 2003). At the global scale, however, we do not know how much of the world's biodiversity is covered by the existing global network of protected areas. The accumulating evidence from regional analyses (e.g., Castro Parga *et al.* 1996, Pressey *et al.* 1996, Williams *et al.* 1996, Nantel *et al.* 1998, Scott *et al.* 2001b) indicates that the current global network is wholly insufficient, but conservation science has struggled to provide an answer to the question of how many, and where, new protected areas should be added to move towards complete coverage of biodiversity worldwide. The recognition of the dire need to create protected areas has led to the emergence of generic, area-based targets for protected areas (e.g., the IUCN call for the near-term protection of 10-12 percent of the total land area in each nation or each biome). However, these area-based targets, although politically expedient, are unhelpful in that they are blind to both the distribution of biodiversity and the area required to conserve it (e.g., Soulé & Sanjayan 1998, Rodrigues & Gaston 2001).

THE OPPORTUNITY: GLOBAL DATA, ROBUST METHODOLOGIES, IDEAL TIMING

A convergence of three critical factors now makes it possible, for the first time in the history of conservation science, to have an overview of the coverage provided by the global network of terrestrial protected areas. First, comprehensive global data on protected areas and species distributions are now available.

Second, robust methodologies for systematic conservation planning are now well-developed and ready for use. Third, the international conservation agenda has reached an ideal time to evaluate global protected areas.

The global gap analysis presented here is a snapshot of an ongoing process to understand how adequate the global network of protected areas is, and to highlight areas where it should be urgently expanded. This analysis will be followed by others, with more refined and focused as data becomes more complete, tools become yet more powerful, and international attention to the need for protected areas rises to a critical mass.

Global Data

Advances in information technology and management have now reached the point where data are available on the geographical distribution of thousands of species across entire higher-taxa (classes) and around the entire globe, in formats useful for analysis. Specifically, draft distribution maps have been compiled for all mammal and amphibian species by the IUCN/SSC Global Mammal and Amphibian Assessments, with input from hundreds of specialists. These maps will be formally published over the next few years, as publicly and freely available electronic data. Distribution data for all bird species are not yet available, but maps for all threatened species have already been published (BirdLife International 2000). In addition, the World Database on Protected Areas has been wholly updated over the last year. The data used in this analysis are described in detail in Chapter 2.

Robust Methodologies

Gap analysis is a method for identifying 'gaps' in the network of conservation areas. The term was coined by J. Michael Scott in the 1980s with the initial purpose of providing "a quick overview of the distribution and conservation status of several components of biodiversity" (Scott *et al.* 1993). The concept grew into a comprehensive methodology that is now applied by the United States Geological Survey National Gap Analysis Program (USGS GAP program, Box 1.1). The term also became a popular way to refer to assessments of networks of protected areas.

In this report, 'gap analysis' refers to a two-stage process:

- Stage 1: Identify the gaps by analyzing the adequacy of the existing global network of protected areas in representing biodiversity targets.

- Stage 2: Fill the gaps, highlighting the most urgent regions for the expansion of the global network.

The methodology used in this analysis is rooted in two lines of research: the USGS GAP program (Box 1.1), and systematic conservation planning methods for protected area selection (Box 1.2). Although developed independently, these two planning procedures merge naturally into one another (Pressey & Cowling 2001). Indeed, the main differences between the GAP and systematic conservation planning methods also make them complementary approaches. The main empha-

BOX 1.1: THE USGS NATIONAL GAP ANALYSIS PROGRAM (GAP)

GAP originated in an application developed by J. Michael Scott in the 1980s for Hawaiian bird conservation (http://www.gap.uidaho.edu/). Later, he and other researchers at the University of Idaho Cooperative Fish and Wildlife Research Unit initiated Idaho GAP as the first pilot study under the U.S. Fish and Wildlife Service. GAP has since evolved into a U.S.-wide effort conducted at the state level and coordinated by the USGS Biological Resources Division (e.g., Scott *et al.* 1993, Caicco *et al.* 1995, Strittholt & Boerner 1995, Kiester *et al.* 1996, Wright & Scott 1996, Scott *et al.* 2001b). Projects to map terrestrial vertebrates have been planned or implemented in each of the 50 states. In addition, aquatic, regional, and international projects have been planned (Jennings 2000).

GAP has four basic steps:

1. Create a map of land use/land cover that maps vegetation at the level of natural assemblages of plant species (e.g., alliance level).
2. Map predicted distributions of vertebrate species, modeled by extrapolation from known point records using GIS data sets that include the vegetation map obtained above and other environmental information (e.g., elevation, soils).
3. Classify the study area according to type of land stewardship and management status.
4. Analyze the representation of vertebrate species and vegetation alliances in areas managed for conservation. Usually, this emerges from a table showing the land area (and percent of area) of each element (land cover classes and species ranges) within each stewardship and management status category.

Due to the importance of vegetation maps in the GAP process, a significant part of each study deals with how these were derived and concerns relating to their accuracy (see Jennings 2000 for a review of the GAP method). The issue of how much of any element's distribution needs to be represented in conservation areas is unresolved, with suggested levels such as 10 to 50 percent, recognized as arbitrary but no better solution presented, and recognition that it may require some estimation of risk on a case-by-case basis (Jennings 2000).

The GAP approach is gaining popularity outside the USA as a planning tool for networks of protected areas, for example, in Brazil (Fearnside & Ferraz 1995), Costa Rica (Powell *et al.* 2000), Ecuador (Sierra *et al.* 2002) and Europe (Smith & Gillett 2002).

sis of GAP has been on analyzing the existing network coverage (Stage 1 above), and it has been developed from the beginning as a GIS-based tool. Systematic conservation planning, on the other hand, has focused on the development of analytical procedures for selecting additional areas to fill the gaps (Stage 2 above). However, the boundaries between both approaches have been blurring, as algorithm-based analyses have started relying more on spatial tools (e.g., CODA, Bedward *et al.* 1992; WORLDMAP, Williams 1996; C-Plan, Pressey 1998) and GAP has started incorporating protected area selection algorithms (e.g., Kiester *et al.* 1996, Clark & Slusher 2000). The global gap analysis presented in this report is a combination of the two approaches.

Ideal Timing

Although the datasets and techniques on which this global gap analysis is based will continually improve – and, in the case of biological data, expand taxonomically – the upcoming World Parks Congress presents a tremendous opportunity to disseminate this initial analysis. Specifically, the V^{th} World Parks Congress in Durban in September 2003, hosted by the IUCN World Commission on Protected Areas (WCPA), offers an ideal venue for launching the global gap analysis concept, and for engaging the global conservation community.

Held once every 10 years since 1962, the IUCN World Parks Congress (WPC) is an assembly of the global conservation community, who assess achievements, problems, and issues, and chart goals for the world's protected area network. The V^{th} WPC has as one of its technical components a Workshop Stream on "Building Comprehensive Protected Area Systems," where a global agenda for addressing protected area coverage will be discussed. The timing of this World Parks Congress is also extremely fortuitous, in that it immediately precedes the ninth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice to the Convention on Biological Diversity (CBD) in November 2003, which will be specifically addressing the issue of protected areas in preparation for the Conference of the Parties of the CBD. Thus, the global gap analysis has an unprecedented opportunity to feed directly key results into these policy frameworks following the World Parks Congress.

BOX 1.2: SYSTEMATIC CONSERVATION PLANNING

Systematic conservation planning methods for the selection of networks of protected areas have been developed since 1983 (Kirkpatrick 1983) as a response to the recognition that resources for protecting biodiversity need to be allocated as efficiently as possible (Margules & Pressey 2000). The aim of systematic conservation planning is to produce a network of protected areas that, together, can assure the preservation of a maximum of biodiversity elements or features (such as species, communities, or land systems). The conservation value of any individual site is, therefore, the extent to which it complements the other sites in the network, by contributing to the achievement of the conservation goals pre-defined for the network. Thus, a core principle of systematic conservation planning is 'complementarity' (Pressey *et al.* 1993, Margules & Pressey 2000).

The six main stages in the systematic conservation planning methodology are (Margules & Pressey 2000):

1. Compile and review new and existing data on the biodiversity of the planning region, particularly data on the biodiversity features (e.g., species, land systems) that will be used as surrogates for biodiversity across the planning region.
2. Identify conservation goals for the planning region, setting explicit representation targets for the biodiversity features that are analyzed.
3. Review existing conservation areas, measuring the extent to which the representation targets have been achieved by existing conservation areas and mapping future land use pressures and threats.
4. Select additional conservation areas, identifying new conservation areas as potential additions to the established protected area system.
5. Implement conservation actions by deciding on the most appropriate or feasible form or management to be applied to individual areas.
6. Maintain the required value of conservation actions, by setting conservation goals for individual conservation areas to retain the biodiversity features for which the area is important, implementing management actions to achieve these goals, and monitoring key indicators.

This process is iterative and typically includes much feedback and many reasons for altering decisions.

The activity of identifying the conservation goals (Stage 2) is central to this process. In this stage, the overall goals of conservation planning (representativeness and persistence of biodiversity) are translated into more specific, preferably quantitative, targets for operational use. These targets allow clear identification of the contribution of existing protected areas to the overall goals (Stage 3) and provide the means for measuring the conservation value of different areas during the area selection process in Stage 4. Stage 4 typically makes use of iterative selection algorithms to the selection of areas that efficiently complement existing protected area networks (e.g., Rebelo & Siegfried 1992, Williams *et al.* 1996, Lombard *et al.* 1999, Balmford *et al.* 2001). The combination of Stages 3 and 4 is what makes this process, effectively, a gap analysis.

OBJECTIVES OF THE GLOBAL GAP ANALYSIS

This analysis has two objectives:

1. To provide an assessment of the effectiveness of the global network of terrestrial protected areas in covering the analyzed vertebrate species.

2. To highlight regions that are priorities for expanding and consolidating the global network of terrestrial protected areas, as a means of improving coverage to the analyzed vertebrate species.

Given the global scale of this analysis, and associated spatial uncertainty, the regions highlighted under the second objective will require finer-scale assessments, to investigate the feasibility for the expansion and consolidation of the global protected area network.

CHAPTER 2

Data

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Okinawa Rail *Gallirallus okinawae,* endemic to Okinawa Island, Japan. This Endangered species has been declining as a result of habitat loss, but is protected in Yambaru National Park.

The global gap analysis combines four extraordinary datasets that are the culmination of the information gathering efforts of thousands of individuals and dozens of institutions. These four datasets are the World Database on Protected Areas (WDPA), and datasets on the distributions of globally threatened bird species, all mammal species, and all amphibian species.

These combined data allow researchers, for the first time ever, to have an overview of species distributions within the global network of protected areas. This groundbreaking effort marks the beginning of an ongoing process to match protected areas with species distribution at the global scale. Nevertheless, each of these datasets has limitations, described in detail in this chapter, that must be taken into account in interpreting the results of this analysis. The data will be continually reviewed as it is updated and used in future iterations of the global gap analysis.

This chapter first describes the four datasets and how each has been used in this analysis. We then describe the limitations of the data that are most relevant to the interpretation of our results.

WORLD DATABASE ON PROTECTED AREAS

The World Database of Protected Areas (WDPA) consortium was created in 2002 to review and update previously existing data on the global coverage of protected areas. The WDPA was built on Version 5 of the database on protected areas compiled by the United Nations Environment Program's World Conservation Monitoring Centre (UNEP-WCMC). The aim of the WDPA project is to create a freely available, accurate and up-to-date database that will be accepted and used as the global standard by all stakeholders. Organizations currently involved in the consortium include: BirdLife International, Conservation International, Fauna & Flora International, The Nature Conservancy, UNEP-WCMC, the World Resources Institute, the Wildlife Conservation Society, and the World Wildlife Fund. This group is open to others committed to developing the WDPA, by pooling and ensuring free and open access to their protected area data.

The WDPA Process

The process of constructing the WDPA database, as approved by the Steering Committee of the World Commission on Protected Areas (WCPA), includes two phases. The first phase pooled and integrated all existing datasets from the consortium organizations. During this phase, the consortium also asked governments around the world to submit the official version of their protected areas system and related data. The second phase, still ongoing, involves consolidating and reviewing the resulting integrated dataset, drawing upon the expertise available through the extensive membership of the WCPA. The WDPA data will be made publicly available at the World Parks Congress in September 2003. After that point, the database will be updated as part of an ongoing process, changing as countries create new protected areas and/or alter the status and/or extent of existing areas.

The version of the WDPA used in this analysis was released on May 12, 2003 (henceforth, May '03 version). Because the WDPA database is being continually updated and consolidated, the version released at the World Parks Congress will be a significantly improved version of that which has been used for this analysis.

The WDPA Data

Protected areas in the WDPA are recorded either as polygons (60,160 records) or as points (102,341 records, of which 70,831 records have no associated area information). Protected areas with polygon data have had their boundaries digitized. Protected areas recorded as points have only a single set of latitude and longitude coordinates marking their geographical location.

Both types of data were provided as ArcView shapefiles (ESRI 2000), with associated tables of attributes (Figure 2.1). Data for each protected area includes a unique site code, protected area name, country, geographical coordinates, designation (e.g., Nature Reserve, National Park), IUCN categories,

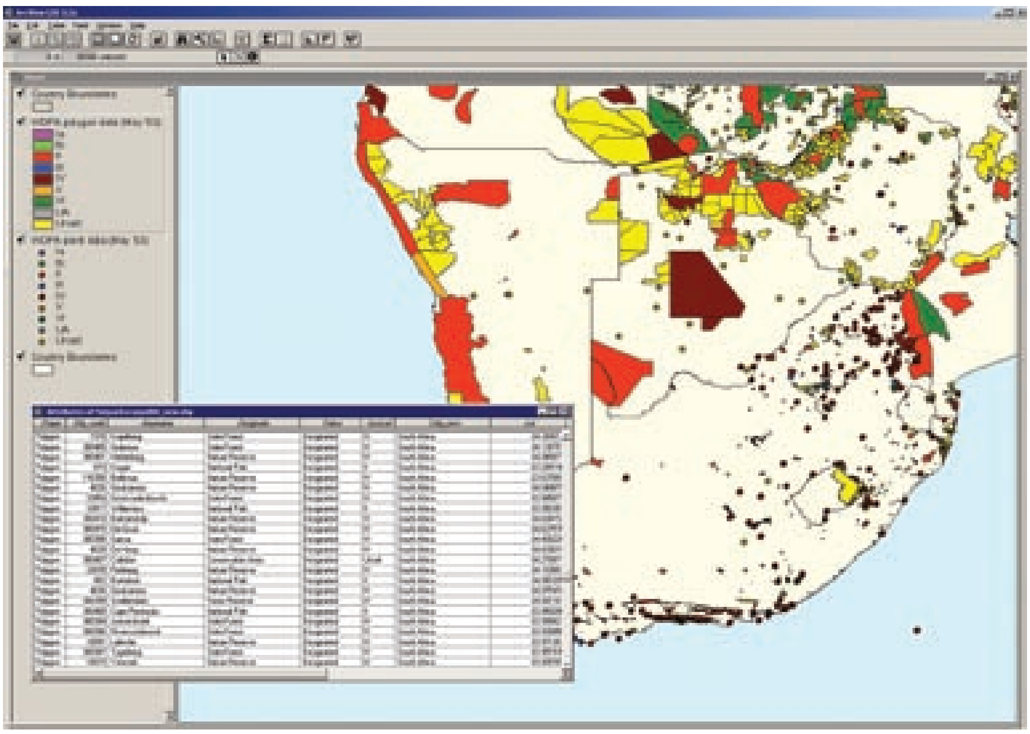

Figure 2.1 World Database on Protected Areas records for part of Southern Africa, including both polygon and point data. Color codes refer to IUCN management categories (see IUCN 1994a): Ia, Strict Nature Reserve; Ib, Wilderness Area; II, National Park; III, Natural Monument; IV, Habitat/Species Management Area; V, Protected Landscape/Seascape; VI, Managed Resource Protected Area; UA, sites that do not qualify for any IUCN category; Unset, sites for which the appropriate IUCN category, if any, is not known. The table in the left corner shows a portion of a table of attributes associated with the protected area polygon data.

and status (e.g., Designated, Proposed, Degazetted). Additionally, the WDPA includes data on protected areas with international status (e.g., UNESCO Man and the Biosphere Reserves, World Heritage Sites, Ramsar Wetlands), but this information was included in this analysis only when the area was also designated at a national level.

For purposes of the global gap analysis, the following records were eliminated from the WDPA:

- Records with both *Lat* and *Lon* as zero (30 polygons and 21,944 points), that is, those with no information on the exact geographical location of an area.

- Records that do not seem to correspond to established protected areas, including those with *Areaname* recorded as "Area Not Protected" (2,956 polygons), or *Status* recorded as "Adjustment (exact nature unknown)," "Degazzeted," "Proposed," "Recommended," or "Unset" (1,507 polygons and 3,731 points).

For the remaining records, we kept the maximum level of geographic data provided by the WDPA. Point records with no information on area were kept in a separate point shapefile (10,995 records). Point records with associated area information were converted into circular shapes of the same area (centered on the coordinates provided for the point) and merged with the polygon records into a common polygon shapefile (total number of records: 91,702).

All protected area data have been used in this global gap analysis irrespective of IUCN management category (Figure 2.1), although we recognize that protected areas vary widely in terms of management effectiveness, as discussed below.

As described in Chapter 3, this analysis explores two scenarios. In Scenario A, all protected area information was used, while in Scenario B, very small protected areas and point records with no area data were excluded.

GLOBALLY THREATENED BIRDS

The data on the world's globally threatened bird species were compiled by the BirdLife International partnership (BirdLife International 2000), and reviewed by hundreds of experts. This data includes assessments of threat for each species, strictly following the IUCN Red List criteria (version 3.1, IUCN 2001, www.redlist.org) and, of crucial importance here, range (or distributional) maps.

Where possible, these range maps were based on locality records that included sightings and specimen records (ideally recent sightings although, for some species, old records are the only records). A species' *known range* was derived from these records, using additional habitat and topographical information to aid range definition. For some species, a *projected range* was added to the known range to reflect areas between well-spaced localities of suitable habitat, and areas close to known localities that are likely to hold the species. Known and projected ranges have been combined to give an estimate of *extent of occurrence* for each threatened species (Gaston 1994; also see following section on Data Limitations). For some species, possible and historical ranges were also mapped, but these were not included in this analysis.

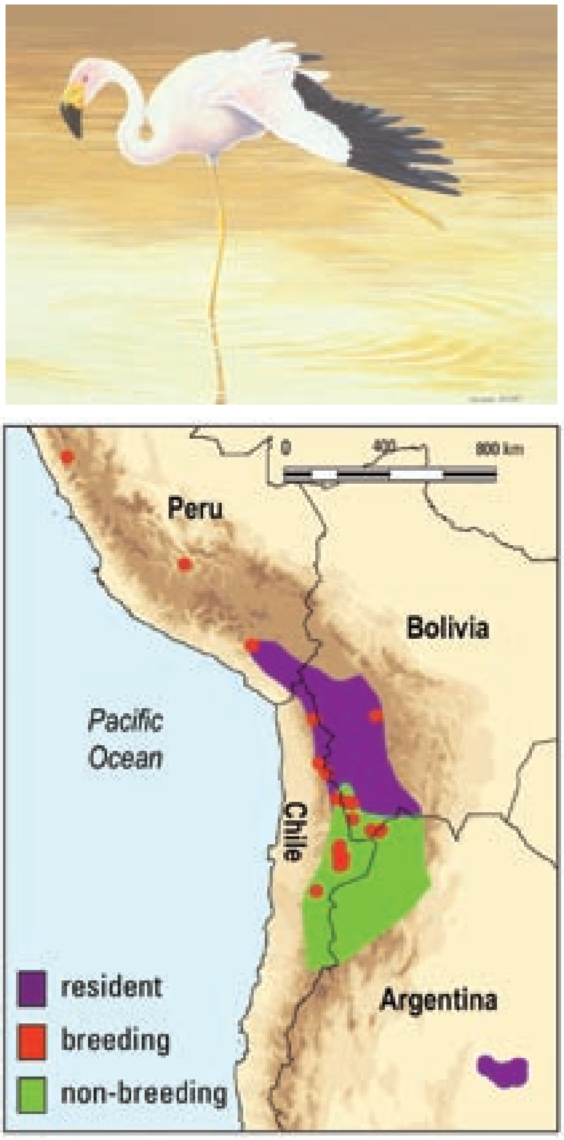

Figure 2.2 Extent of occurrence of the Andean Flamingo *Phoenicoparrus andinus* according to season of occurrence. BirdLife International classified this species as Vulnerable according to IUCN criteria. Darker shades of brown indicate higher elevation. Illustration © Norman Arlott, Rare Bird Club.

Additionally, each polygon included within a species' extent of occurrence has been coded according to the season of occurrence of the species: *breeding; non-breeding;* or *resident* (Figure 2.2). For marine species (those with a mainly oceanic non-breeding range) only breeding range was considered. For two species (Slender-billed Curlew *Numenius tenuirostris*, and Streaked Reed-warbler *Acrocephalus sorghophilus*) only non-breeding range is known (BirdLife International 2000).

The taxonomic classification used followed BirdLife International (2002). Of the 1,183 globally threatened birds included in this analysis, 182 are Critically Endangered, 321 are Endangered, and 680 are considered Vulnerable species. The three species classified as Extinct in the Wild were excluded from the analysis. In order to match the available distribution maps, we retained for each species the threat categories as published in the 2000 assessment (BirdLife International 2000), even though a more recent threat assessment is available (www.birdlife.net).

MAMMALS

Distribution maps for all mammal species were compiled, as part of the IUCN Global Mammal Assessment, by Wes Sechrest (W. Sechrest, *unpublished*), Luigi Boitani (Boitani *et al.* 1999, for large mammals of Africa; L. Boitani and G. Amori, *unpublished* for rodents of Africa), Marcelo Tognelli (Patterson *et al.* 2003, for rodents of South America), and Gerardo Ceballos (Patterson *et al.* 2003, for bats of Central America). Because all of these maps are still being formally reviewed, only draft maps (of variable accuracy) were available for this global gap analysis.

The taxonomic classification of all species used in this analysis followed the second edition of *Mammal Species of the World* (Wilson & Reeder 1993, http://nmnhwww.si.edu/msw/), with some modifications from draft chapters of the third edition made to incorporate the latest taxonomic information (Reeder & Wilson, *unpublished*). Spatial data (Figure 2.3) were compiled from primary and secondary literature (e.g., taxonomic accounts, regional atlas projects, Mammalian Species Accounts), museum records, and other scientific reports and documents. Over 1,700 sources were consulted for information on species distributions. Preference was given to more recent sources, as well as sources that have comprehensive information for the entire species' range.

Similar to the database on bird species, data on the extent of occurrence of mammal species were composed of polygons that corresponded to different levels of certainty about the species presence, to differences between historical and current range, and to difference in where species were either native or introduced. For this analysis, only polygons where the species was both reported as *Native* and with presence coded as *Extant* or *Possibly present* were used, thus excluding historical and introduced ranges. In addition, no information was available on migratory mammal species (e.g., Wildebeest *Connochaetes taurinus*) to distinguish between seasonal ranges. Marine mammals were also excluded from the analysis (i.e., Cetacea, Sirenia, and marine species in the Order Carnivora). In total, 4,734 species were analyzed. According to the 2002 IUCN Red List (www.redlist.org) these include 131 Critically Endangered species, 229 Endangered, and 618 Vulnerable species. However, a perfect match between the IUCN assessment and the distribution maps was not possible due to minor differences in the taxonomic classification. The majority of these species have been assessed in 1996 (Baillie & Groombridge 1996) using version 2.3 of the IUCN criteria (IUCN 1994b, now supplanted by version 3.1, IUCN 2001).

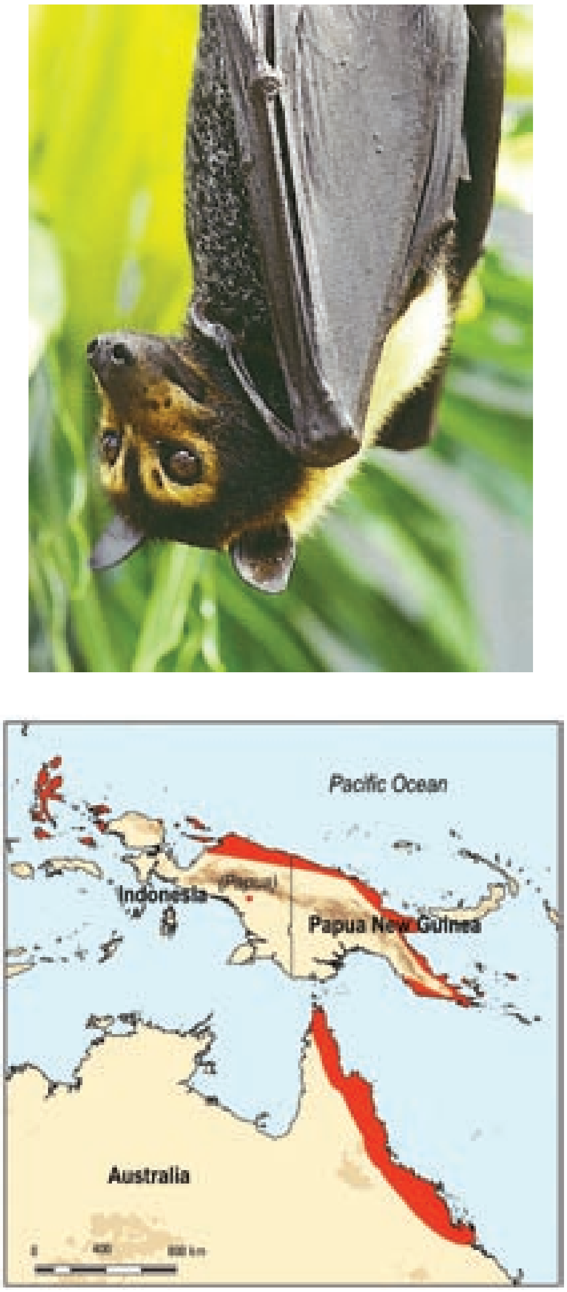

Figure 2.3 Extent of occurrence of the Spectacled Flying Fox *Pteropus conspicillatus,* a species assessed as Least Concern according to IUCN criteria (for more information, see Bonaccorso 1998). Darker shades of brown indicate higher elevation. Photo © Lubee Foundation.

AMPHIBIANS

With the exception of North America (see below), amphibian maps have been taken from the ongoing IUCN Global Amphibian Assessment. Distribution maps (e.g., Figure 2.4) are being created for all species in two stages. First, an expert on amphibians in each of 33 designated regions collected data on all species in the region. Each of these experts was responsible for collating information on species taxonomy, geographic range (including a preliminary distribution map), population status, habitat preferences, trade status, and major threats and conservation measures that are needed or are currently in place. Each regional expert also provided a preliminary assessment of threat for each species according to the IUCN Red List categories (IUCN 2001). All of the data collected in this initial stage is being reviewed either through expert workshops (usually for the more species-rich regions), or by leading herpetologists.

The global gap analysis used the most up-to-date data available including reviewed maps of species distributions for Mesoamerica, Russia and the Confederation of Independent States, China, New Guinea and the Solomon Islands, Southeast Asia, South Asia, and half of the African species. Distribution maps for South America, Europe, West Asia, Japan, Madagascar and the Seychelles, and New Zealand, as well as

Figure 2.4 Extent of occurrence of the Casque-headed Tree Frog *Triprion petasatus*, assessed as Least Concern by the Global Amphibian Assessment (for more information, see Galindo-Leal 2003). Darker shades of brown indicate higher elevation. Photo © Peter Weish 2003.

the remaining species of Africa, have not yet been formally reviewed. However for some regions, such as Europe and West Asia, much of the data comes from reliable published sources.

NatureServe, a non-profit organization that provides scientific information and tools related to conservation, provided the distribution maps for species in North America (US and Canada). The main source for these maps was a database on county of occurrence developed by Mike Lannoo at Ball State University (Blackburn *et al.* 2001). These maps feed into the Global Amphibian Assessment as part of the process for the Red List assessment of North American species.

When complete, the results of the Global Amphibian Assessment will be freely available through the IUCN Red List web site (www.redlist.org), AmphibiaWeb (www.amphibiaweb.org), and the American Museum of Natural History Amphibian Species of the World web site (http://research.amnh.org/herpetology/amphibia/index.html).

The taxonomic classification used followed Frost (2002), with modifications where deemed necessary by the experts involved in the Global Amphibian Assessment. After excluding 21 extinct species, 5,254 amphibians were included in this global gap analysis. Based on the currently available assessment of threat for each species (unreviewed for the regions mentioned above), this included 291 Critically Endangered, 494 Endangered, and 682 Vulnerable species.

DATA LIMITATIONS

The global gap analysis is based on comparison between mapped data of protected areas and mapped data of species ranges. This comparison may be affected by limitations in both sets of data, which can result in two types of error:

- *Omission errors*, which occur when a given species is not considered covered by a protected area when, in fact, it is covered, and
- *Commission errors*, which occur when a given species is considered covered by a protected area when, in fact, it is not covered.

For conservation purposes, it is more important to minimize commission errors than omission errors, because ignoring a species that is genuinely not represented in protected areas may result in species extinction. Unfortunately, the current data are much more prone to commission errors.

Limitations in Protected Area Data

This section describes limitations in the May '03 version of the WDPA that are considered most likely to have an effect on the results. Some of these limitations will have been minimized or corrected in the version of the WDPA released at the WPC, while others will be addressed afterwards. Despite these limitations, this version of the WDPA is currently the best global dataset on protected areas, and is substantially better than previously available datasets.

Missing Records

The WDPA does not include all existing protected areas. The database is incomplete both because there are gaps in information about existing protected areas, and because the global network is dynamic and changing. This may become a source of omission errors in the global gap analysis, as some species may be considered uncovered by the global network when in reality they are covered by unmapped protected areas. Missing records are particularly problematic if concentrated in a few countries or regions, and if these regions are rich in species, particularly endemics.

Although the magnitude of the problem of missing records in the May '03 WDPA is difficult to assess, some insight is provided by the above-mentioned nearly 22,000 records that have no associated geographical information (no recorded latitude or longitude). These correspond to protected areas known to exist, but, given that they were excluded from the analysis, they were treated in practice as missing records. As expected, these records were heavily biased towards small protected areas (nearly 12,000 records < 100 ha), which are less likely to influence the results, although a few were of very large areas (18 records ≥ 1,000,000 ha).

The WDPA is also likely to be less complete in terms of mapping of less traditional but important protected areas such as indigenous and private reserves, as well as areas classified at the sub-national level (e.g., provincial or state-level reserves).

Incorrect Records

The results of the global gap analysis will be sensitive to records that include incorrect information about protected areas. Major inaccuracies in the location of protected area boundaries (e.g., if the extent of the protected area has been reduced or increased) or changes in status of an area (e.g., from “Proposed” to “Designated” or from “Designated” to “Degazetted”) may result in either commission or omission errors in the analysis. These problems arose in part as new datasets were integrated into the WDPA, which sometimes involved adding protected areas without eliminating earlier records, resulting in “ghost areas” represented by obsolete polygons. These problems could not be corrected because the May ’03 version of the WDPA does not include information on the last date of revision or source data for each record. Future releases of the WDPA will address this issue, and will also be greatly improved by revisions of the protected area data at the national or regional scales.

Protected Areas with Point Data Only

Nearly half of the records used in this analysis were point data (47,000 records). For 36,005 of these, some data on area were available, and these were represented as circles centered on the respective latitude and longitude coordinates. The remaining 10,995 were represented as points. When compared with maps of species’ extents of occurrence, protected areas records represented as points can lead to omission errors, while protected areas represented as circles can lead to both omission and commission errors (Figure 2.5). In most cases, the magnitude of errors will be much higher when using point data only. The protected areas more likely to be affected by these errors are those that are larger (which overlap many species distributions) and those that are more elongated (for which true shape is poorly represented by a circle/point).

Point records are heavily biased toward the representation of smaller protected areas, reducing the predicted magnitude of errors created by these data. For example, about 57 percent of all point records with area information are smaller than 100 ha, although some records correspond to very large protected areas (e.g., 18 records larger than 1,000,000 ha). Additionally, many protected areas are elongated and not well represented by circles, for example in mountainous areas or along country borders (e.g., Figure 2.6).

Uneven Global Coverage

As with the biological data (see below), the quantity and quality of data in the WPDA are unevenly distributed across countries (e.g., Figure 2.6), which will result in discrepancies in the results of the global gap analysis.

Lack of Data on Management Effectiveness of Protected Areas

One of the major limitations of the WDPA data for the purposes of the global gap analysis is the scarcity of information regarding the management effectiveness of each protected

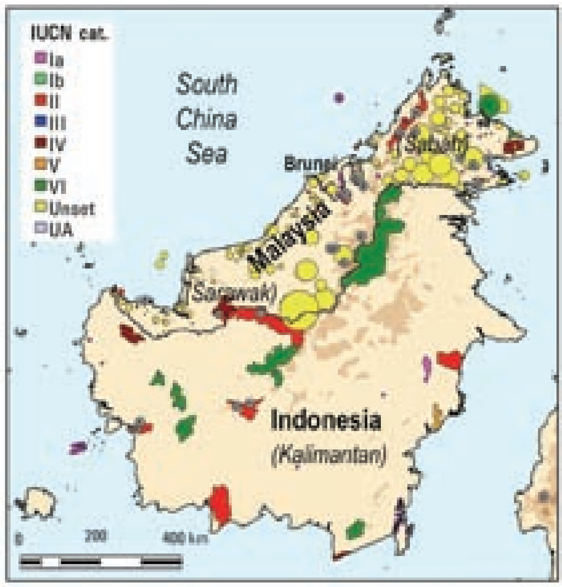

Figure 2.6 WDPA records for the trinational island of Borneo, Southeast Asia. Data quality differs between Brunei and the Malaysian section of the island (Sarawak, Sabah) and the Indonesian section (Kalimantan). In the Indonesian part, most data were available as polygons with associated IUCN I to IV categories, while north in Malyasia and Brunei, most data were provided as points of Unset category. The large circle in the center of the island is an example of a protected area whose true shape is badly represented as a circle, as the area is exclusively in Malaysian territory.

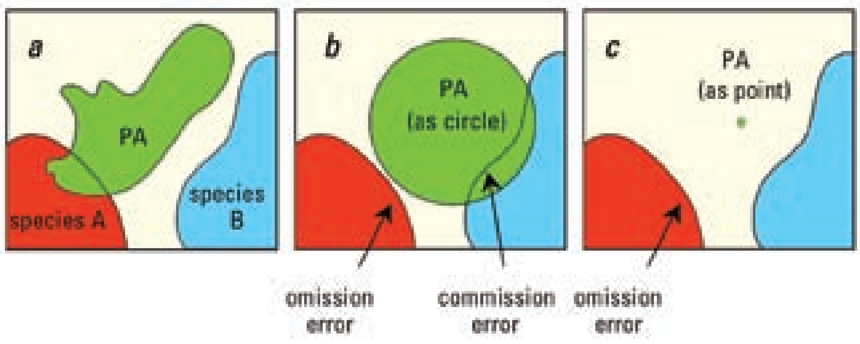

Figure 2.5 Omission and commission errors can result from circle and point representations of protected areas: *a*) the true shape of a protected area PA is represented as a green polygon; *b*) a circle representation can result in both omission (species A) and commission (B) errors; *c*) point representations may result in commission errors (species A). The magnitude of errors is higher when using point data only.

area, i.e., the degree to which a protected area is likely to succeed in preserving the biodiversity values it contains. Without this information, any evaluation of the coverage of the global network of protected areas is necessarily an approximation. Indeed, even in situations where researchers know that a species is currently present in a given protected area, the species could still be extirpated in the near future. For example, direct habitat destruction (e.g., fires, logging, human settlement), species exploitation (e.g., bushmeat hunting), or presence of invasive species can all be responsible for the local extinction of species inside protected areas. Many protected areas do not prevent biological degradation within their borders both because they are not effectively managed (Brandon *et al.* 1998) and because they are subject to many internal and external pressures from human activities (e.g., Janzen 1983b).

IUCN management categories I to VI (IUCN 1994a) provide some information on the level of management of individual protected areas, but for a large number of protected areas this information is not available (Figure 2.7). Additionally, not all countries have systematically applied IUCN categories. Among those that have, the classification has not been applied consistently, so that protected areas classified under the same category are not necessarily similar in terms of management. Furthermore, categories I-VI are more likely to reflect the legal status of a reserve (intended level of management) than its real management effectiveness. The real effectiveness of a protected area in preserving biodiversity depends not only on its management level but also on the nature of the biodiversity values being preserved (e.g., species more or less sensitive to habitat disturbance) and the social and economic context (e.g., level of human pressure inside and around the protected area).

Given these difficulties, IUCN categories were not used in this analysis to distinguish between management levels. Instead, all protected areas were used regardless of IUCN management category.

However, including all protected areas in the WDPA irrespective of management effectiveness creates a significant source of commission errors, because many of these areas do not provide effective protection to the species whose ranges they overlap. This is more likely to be the case with very small protected areas, which are the majority of records in the WDPA. Indeed, more than 50 percent of the records for which area information was available are smaller than 100 ha (Figure 2.8). Although these are frequently designated to conserve tiny habitat fragments, often essential for preventing the loss of remnant populations (Turner & Corlett 1996), many protected areas this small are highly unlikely to be able to retain their current species diversity over the long term (Diamond 1975).

As the WDPA develops, much work will be done to create more complete information on the management of protected areas in the database. The task of creating a classification system for the management effectiveness of protected areas, one that can be applied systematically and coherently across the world, is not trivial. The issue is of such importance that it is being addressed in a Workshop Stream ("Management Effectiveness") at the 2003 World Parks Congress.

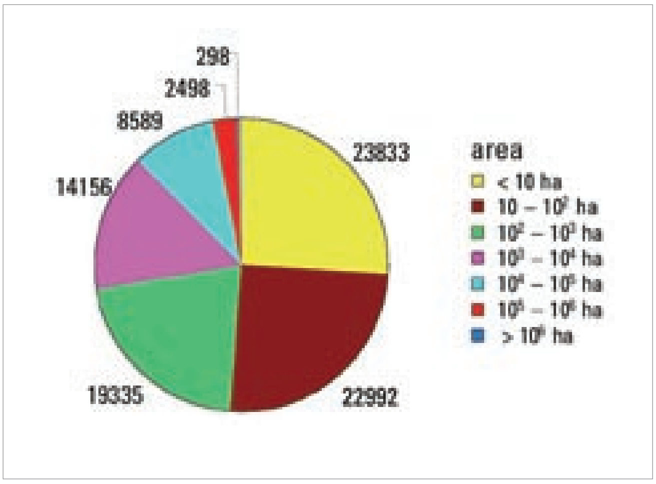

Figure 2.8 Distribution of area values for protected areas mapped as polygons (including point data converted to circles). More than half of these records correspond to very small (< 100 ha) protected areas.

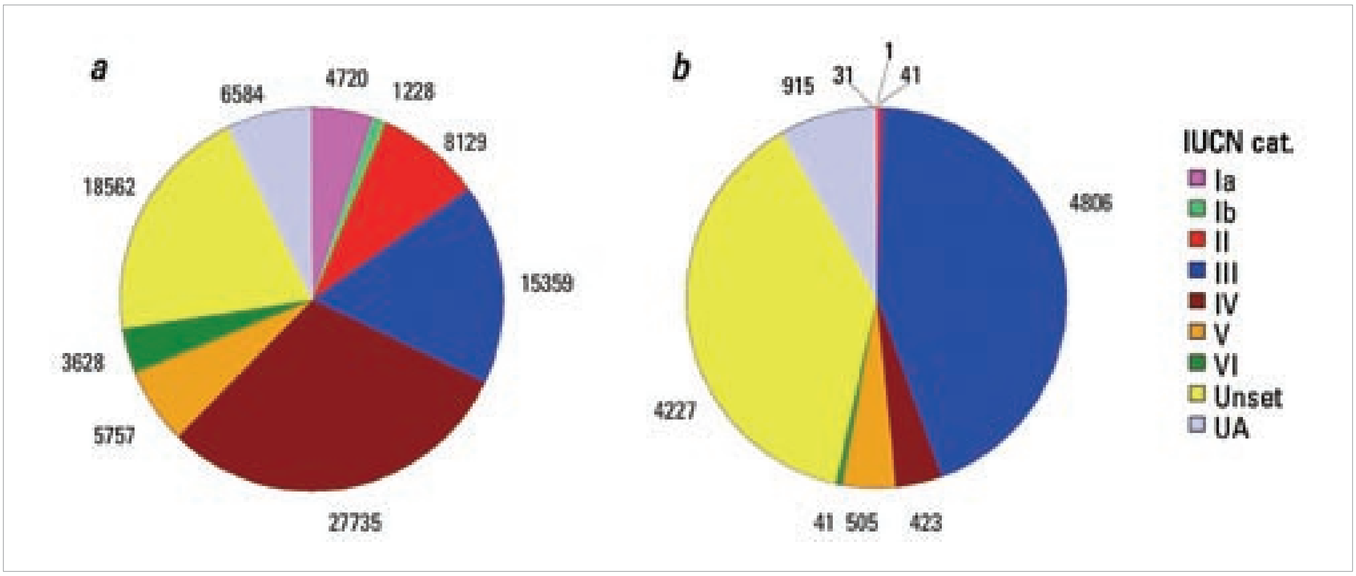

Figure 2.7 Classification of polygon records (*a*) and point records (*b*) according to IUCN management categories. Point records (*b*) are those for which no area information was available (other points were converted to circles and are included in *a*). IUCN category is not known (Unset) for 20 percent of polygons and 39 percent of points.

Limitations in the Biological Data

Narrow Taxonomic Scope

The global gap analysis included only those taxonomic groups for which it was possible to obtain compilations of maps of global coverage in digital format: mammals; amphibians; and globally threatened birds. No attempt was made to collect species distribution maps for other taxa.

These species are analyzed here as conservation targets on their own right. While other taxa would certainly benefit from the conservation of the regions highlighted by the results of the global gap analysis (e.g., Howard *et al.* 1998), no assumption is made that a network of protected areas adequate for the representation of mammals, amphibians, and threatened birds is sufficient for other taxonomic groups. Indeed, previous studies have demonstrated that vertebrate species are not likely to be adequate surrogates for other groups, particularly those with more species and high levels of endemism, such as plants and invertebrates (e.g., Rodrigues & Gaston 2001).

Missing Species and Incomplete Species Maps

Even though the taxa considered in the global gap analysis correspond to the best-known fraction of the world's biodiversity, many vertebrate species are still unknown to science. The recent discovery of more than 100 new species of frogs from Sri Lanka testifies to this (Meegaskumbura *et al.* 2002). Additionally, many known species have not been formally described or mapped (e.g., for new Sri Lankan frog species, only around 30 have been mapped by the IUCN Global Amphibian Assessment). The problem of missing and incomplete species maps will disproportionately affect the results of the gap analysis in poorly known regions such as tropical forests, and for less well-known taxa such as amphibians and small mammals. Such species and regions are more likely to be true gaps in the coverage of the current global protected area network, because they tend to occur in nations with less tradition of and fewer resources for biodiversity conservation.

Even where distribution maps are available, many are incomplete in the sense that they do not include areas where a species is actually present but has never yet been recorded. Again, poorly known species and poorly known regions are most likely to be affected by these kinds of limitations of biological data (Figure 2.9).

Many species included in this analysis (particularly, but not only, amphibians) have only been reported from a single or a few locations, with insufficient data to estimate potential range. In general, these are mapped as having very small ranges, approaching point distributions. While conservation of these species should preferably be based on better data, for the purpose of the global gap analysis it is preferable to err on the side of considering these species unprotected in areas where they are present (omission error), rather than incorrectly considering them protected in places where they are absent (commission error), particularly because such species are often threatened.

Species Ranges Mapped as Extent of Occurrence

For the majority of species, mapped ranges (e.g., Figure 2.2, Figure 2.3, Figure 2.4) are gross overestimates of locations where species truly occur, as they generally correspond to *extent of occurrence* range maps, rather than *area of occupancy* (Gaston 1994; Figure 2.10). Most of these ranges were obtained as "envelopes" including original records (point data) and through extrapolation (using, for example, habitat information) from original records (e.g., BirdLife International 2000). They are likely to include more or less extensive areas from where the species is absent (Figure 2.10)

These overestimates of species locations are a substantial source of commission errors in this analysis, as species may be

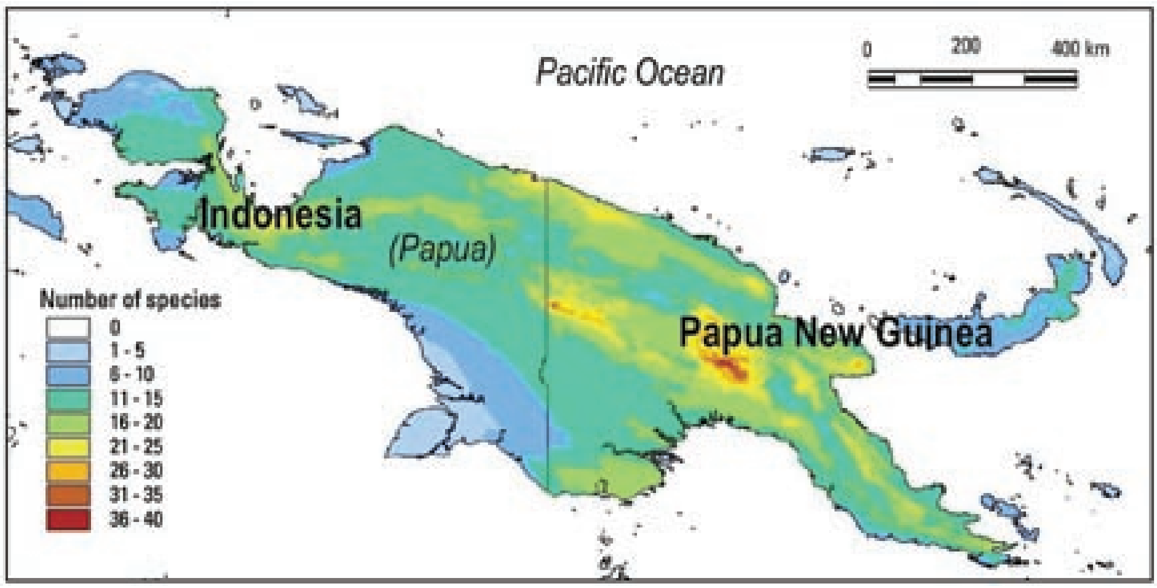

Figure 2.9 Richness of amphibian species in New Guinea, as mapped by the IUCN Global Amphibian Assessment, illustrating variable degrees of knowledge of biological data. While the entire island is poorly known, the contrast between species richness in Papua New Guinea and Papua, Indonesia is an artifact resulting from the almost complete lack of knowledge from the Indonesian side. For example, a one-month Rapid Biological Assessment (RAP) expedition to the Wapoga River area (northwestern Papua) discovered 29 new species of frogs, corresponding to more than 50 percent of the frog species recorded (Mack and Alonso 2000).

listed as present in protected areas that overlap their mapped extent of occurrence but where they do not occur (Figure 2.10). Indeed, this is probably the most serious source of errors for the global gap analysis, which can result in a severe overestimation of the coverage of the existing reserve network, with significant influence on the overall results. Species for which there is a larger degree of mismatch between area of occupancy and extent of occurrence, such as habitat specialists, are more likely to be affected. Smaller protected areas, which tend to encompass less habitat diversity, are also expected to be more prone to this error.

Uneven Global Coverage

As with the protected area data described above, the quality and quantity of biological data is unevenly distributed across the world. Well-known regions are less likely to have missing species, and maps of individual species from these regions will tend to show greater accuracy and levels of detail, even approaching the area of occupancy in a few cases. For the lesser-known taxa, the contrast between regions or even neighboring countries can be significant depending on the level of sampling effort invested in each (Nelson *et al.* 1990, Figure 2.9). This data artifact will inevitably influence the results of the global gap analysis, although the net effect will depend on the particular circumstances. On one hand, less sampled regions will have more species with incomplete maps (e.g., only known from a few records), a source of omission errors. On the other hand, distribution maps will tend to be broader generalizations (less detailed), and therefore will include larger fractions of unoccupied habitat, a source of commission errors.

Lack of Data on Species Viability Across the Range

The effectiveness of protected areas in retaining their biological resources and value depends on management effectiveness, which is in turn determined by management levels and structures, social and economic context (conditioning levels of human use inside and around protected areas), and protected area design (size, shape, connectivity). In addition to these factors, species ecology is also critical in determining which species can or cannot be protected by a given protected area.

As discussed earlier, large areas of each species' mapped range (extent of occurrence) are likely to be unoccupied. However, even those portions of the range where the species is truly present are not all equivalent (Figure 2.11), and so it is relevant in which of those portions protected areas are located. As widely reported in the published literature, the current presence of a species in a protected area is not a guarantee of its future persistence, even on a time scale of a few years or decades (e.g., Newmark 1987, 1996, Nicholls *et al.* 1996, Woodroffe & Ginsberg 1998). Consequently, the complete list of species reported from a given protected area is likely to be a considerable overestimate of those species whose long-term persistence can actually be effectively ensured by the protected area.

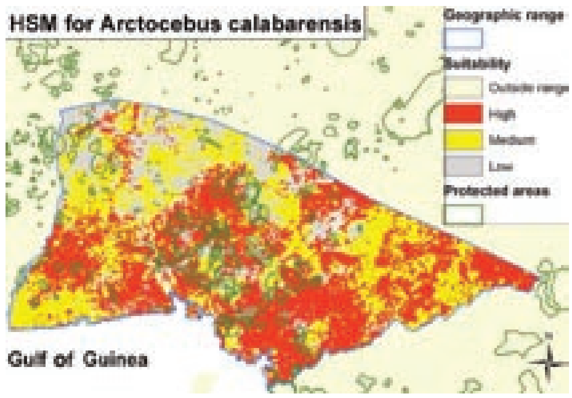

Figure 2.11 Variation in habitat suitability across the range of the Calabar Angwantibo *Arctocebus calabarensis* in West Africa (Boitani *et al.* 1999). Habitat suitability models (HSMs) integrate environmental and biological data to gain insight into the structure of species' ranges, and have now been developed for hundreds of vertebrate species in Africa (Biotani *et al.* 1999). Currently being integrated into regional gap analyses, it is likely that future global gap analyses will make use of this type of data as well. Map by by C. Rondinini and L. Boitani.

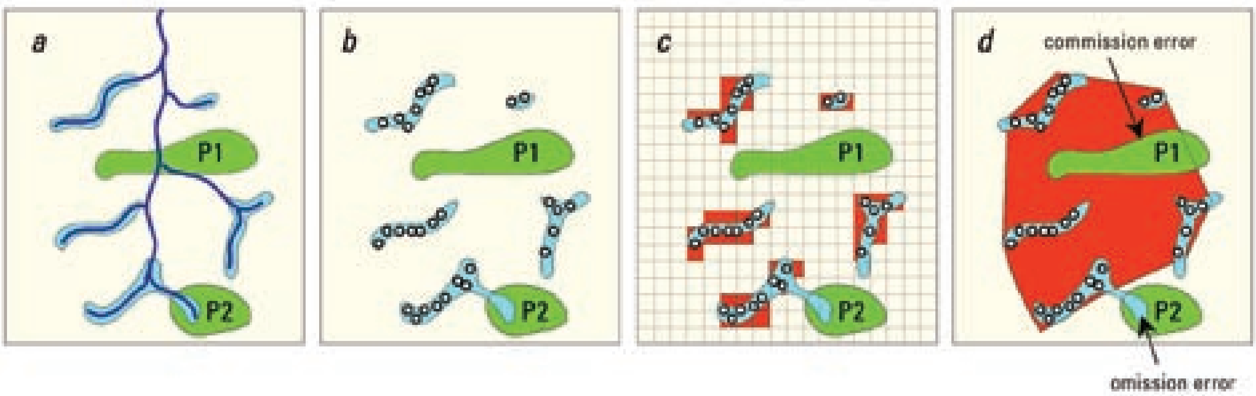

Figure 2.10 Both commission and omission errors can derive from mapping species ranges as extent of occurrence. *a*) The true range of a hypothetical species, distributed along portions of a river system, is represented in light blue. Two protected areas (P1 and P2) exist in the region. *b*) The species is only known from records (white dots) that cover part of its range. *c*) A possible representation of the species' area of occupancy is given by the squares that overlap known records (red squares). *d*) A possible representation of the extent of occurrence is given by the envelope that encompasses all records (red polygon). When represented as extent of occurrence, the species would not be detected in area P2, where present (omission error), and would be considered covered by area P1, where absent (commission error).

Indeed, the abundance pattern of most species over their geographic range is characterized by the existence of many sites of low abundance and just a few peaks where abundance can be orders of magnitude higher (Brown *et al.* 1995). The long-term effectiveness of reserve networks in retaining species can on average be improved by targeting these peaks of abundance for inclusion (Rodrigues *et al.* 2000), but for the vast majority of species no such information is available on the structure of abundance across their ranges.

Also, species ranges are naturally dynamic, especially at their edges (Hengeveld 1990). As a result, a species may occur only intermittently at a given place, which is not unusual for those with high dispersal abilities such as birds. In extreme situations, the species may simply be a vagrant to a given protected area, but it may also occur more or less regularly in response to variable ecological conditions (e.g., changes at the edges of bird ranges following harsh winters; Mehlman 1997).

For some species, especially those depending on ephemeral habitats, population extinction and recolonization within short time frames may be part of their natural population/metapopulation dynamics, as individuals track the most favorable habitat patches (e.g., Ehrlich 1992). Such dynamics may lead to an intermittent pattern of occupation of some protected areas by some species, unless the protected areas are sufficiently large to encompass a 'sustainable landscape' that maintains the ecological processes (e.g., fire, hurricanes) responsible for such dynamics (Baker 1992).

Implications of Data Limitations

Overall, the coarseness of the biological data and the broad definition of protected area used in this analysis mean that commission errors (considering species covered in protected areas from which they are either absent or that provide no guarantees of the species' long term persistence) are much more likely to occur than omission errors (failing to recognize that the species is truly covered by a protected area).

These limitations do not reduce the significance of this first global assessment of the global network of protected areas in covering species diversity, but they are important to understand how the results can be interpreted, and the limits to what it is possible to extract from those results.

The following chapter describes the methods employed to make the best use of the available data in this global gap analysis.

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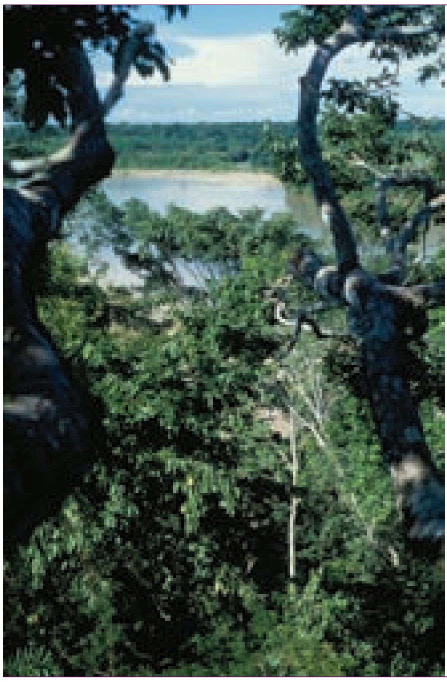
CHAPTER 3

Methods



Haroldo Castro

View of forest canopy at La Collpa, Tambopata River, Peru, Andes.

The global gap analysis is a two-stage process. The first stage – *identifying the gaps* – is an overview of the coverage of the analyzed species (threatened birds, all mammals, and all amphibians) by the global network of protected areas. The second stage – *filling the gaps* – provides recommendations regarding priority new areas that need conservation attention in order to fill the gaps in the current network.

The results of each stage critically depend on the criteria applied to consider a species either *covered* or a *gap*. In theory, the minimum requirement for a species to be considered covered by the global network of protected areas is if at least one viable population is protected. This requirement includes not only a minimum number of individuals sufficient to prevent the effects of genetic and demographic stochasticity (Soulé 1987), but also includes all the ecological infrastructure necessary for species persistence in the long-term, with allowance made for the natural variability of environmental conditions (environmental stochasticity) and natural or anthropogenic change (such as climate change). These prerequisites for survival vary considerably and idiosyncratically among species.

In practice, the information upon which the global gap analysis is based – extent of occurrence of species and polygons of protected areas – does not allow such complexity to be taken into account. Therefore, any criteria applied to these data to distinguish between covered and gap species is inevitably an approximation only. Two main sets of criteria were explored here, henceforth referred to as Scenarios A and B. In Scenario A, the requirement for considering a species covered is simply that its range overlaps with a protected area. Scenario B is more demanding, with a species considered covered only if a predefined percentage of its range overlaps with protected areas.

This chapter describes how the data were analyzed under Scenarios A and B to identify the gaps in the global network of protected areas, and to highlight regions that require additional conservation investment.

SCENARIO A

Scenario A makes the fewest possible assumptions about the data. The scenario does, however, make two very strong (and unrealistic, see previous chapter) assumptions:

a) That all protected areas are equally adequate for the protection of each species and

b) That species can be equally well protected in any part of their range, and by the protection of fraction of that range.

Under Scenario A, a species is therefore considered to be covered if any protected area overlaps its range. A gap species is one that is not overlapped by any of the protected areas considered in this analysis.

For migratory species, the criterion for coverage was that at least one protected area overlaps each of the breeding and non-breeding ranges of the species (migratory range *per se* was not considered). Hence, for the purpose of this analysis, each migratory species was converted into two *species-ranges* (breeding and non-breeding), which may or may not overlap (Figure 3.1). For marine species, only breeding ranges were considered.

To identify covered and gap species, the Geographic Information System (GIS) software ArcView (ESRI 2000) was used to overlap protected area data with each of the mapped species' distributions (Figure 3.2). The distribution of all gap species was then mapped to highlight areas recommended as priorities for the expansion of the global network of protected areas.

To test the sensitivity of the results obtained in Scenario A to the data characteristics of the WDPA, we also investigated the number of covered species that overlap only with protected areas:

- other than those classified under IUCN categories I to IV (which correspond to higher levels of legal protection).

- either represented as points or as polygons ≤ 1000 ha. This was used to evaluate the effects of point data and very small protected areas (the majority of the records in the WDPA, Figure 2.8) in the results.

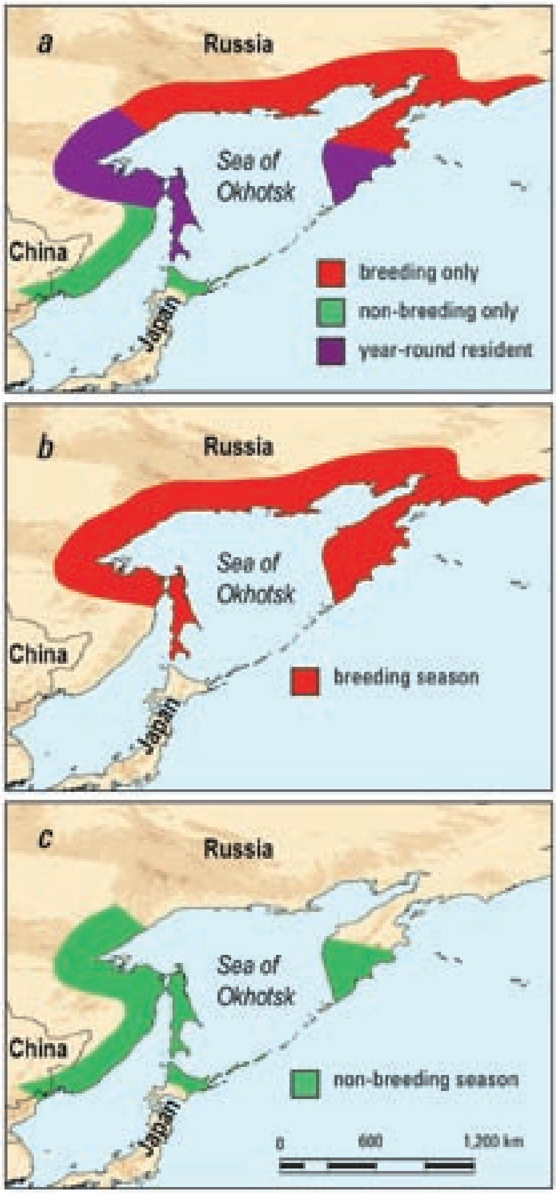


Figure 3.1 Example of the definition of two *species-seasons* for a migratory bird. Darker shades of brown on the map correspond to higher altitude. Steller's Sea-eagle *Haliaeetus pelagicus* is a Vulnerable species. Its range (*a*) includes areas where it occurs only during the breeding season (red), areas where it occurs only during the non-breeding season (green), and areas where the species is a year-round resident (purple). In order for this species to be considered *covered* under Scenario A, at least one protected area needs to touch the species' range during each of the breeding (*b*) and non-breeding (*c*) seasons. This can be achieved by a single protected area in the year-round resident range, or else a protected area in each of the breeding and non-breeding portions of the range. For the purposes of the global gap analysis, this species was treated as having two *species-seasons*, with ranges as mapped in (*b*) and (*c*), both classified as Vulnerable.

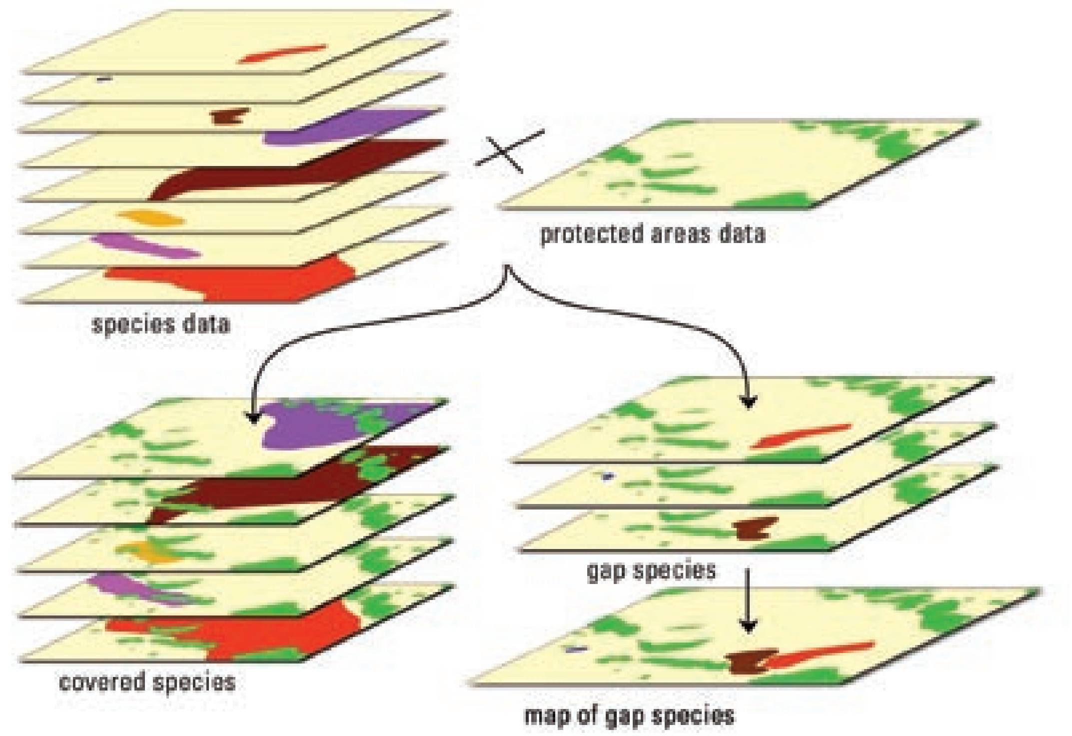


Figure 3.2 Illustration of the method followed in Scenario A. Data on species' distribution were overlaid with protected areas data, and a species was considered a *gap* if its range did not touch any protected area; otherwise the species was considered *covered*. An overlay of distributions of gap species provides a map of gap species and highlights regions of the world that require additional protected areas.

SCENARIO B

Under Scenario A, a species is considered to be covered if any protected area (point or polygon) overlaps its range, regardless of the size of the protected area and the fraction of the range that is covered. Given that for many of the species large fractions of the extent of occurrence are unsuitable for the conservation of the species (e.g., Figure 3.3), this Scenario clearly produces an overestimate of the number of species covered by the global network of protected areas.

Scenario B attempts to provide a more realistic assessment by using more demanding criteria for considering a species covered, and by allowing a species to be considered a *partial gap* if these criteria are only partially met. However, given the nature of the data, even Scenario B assessments must still be regarded as crude approximations, as they certainly underestimate the coverage needed for the majority of species.

Criteria for Considering a Species Covered

For the purposes of Scenario B, only protected areas larger than 100 ha have been considered, therefore excluding all point records with no associated area (10,995 records), as well as polygons with area ≤ 100 ha (46,825 records). The rationale for this decision is that very small protected areas alone cannot be expected to hold viable populations of the vast majority of the vertebrate species analyzed. Indeed, literature on the effects of habitat fragmentation provides abundant evidence of dramatic changes in composition and structure of vertebrate communities in very small habitat fragments, shortly after isolation, including those of small-bodied species (Terborgh *et al.* 2001). Some species, particularly generalists well-adapted to disturbed and secondary habitats, may increase in abundance and diversity in such small habitat fragments (Malcolm 1997). However, for the majority of the species, the reverse happens: many studies have reported a decrease in both overall species diversity and the abundance of individual species when they are confined to very small areas (see Laurance & Bierregaard 1997).

The 100 ha threshold is well below most estimates of the minimum area needed to support intact communities of vertebrate species. For example, Gurd *et al.* (2001) estimated the minimum area to be approximately 5,000 km^2 for mammal assemblages in eastern North America, while Brito and Figueiredo (2003) suggest 250 ha for demographic stability and 2,500 ha for genetic stability of the Atlantic Forest Spiny Rat *Trinomys eliasi*. We established the 100 ha threshold very conservatively, to exclude protected areas that are very likely not relevant for the conservation of the analyzed vertebrate species (although recognizing that they may play other important conservation roles).

Excluding these small protected areas reveals an increase of about 7 percent in the number of gap species not detected by Scenario A. This is not a dramatic change to the overall results because most protected areas represented as points or polygons ≤ 100 ha are located in northern temperate regions with highly fragmented habitats. Indeed, about 50 percent of all such protected areas are concentrated in Europe. The widespread species that are predominant in these regions are covered by other protected areas as well, and do not become gaps when these protected areas are excluded.

Much more serious sources of commission errors occur when Scenario A analyses indicate that a species' extent of

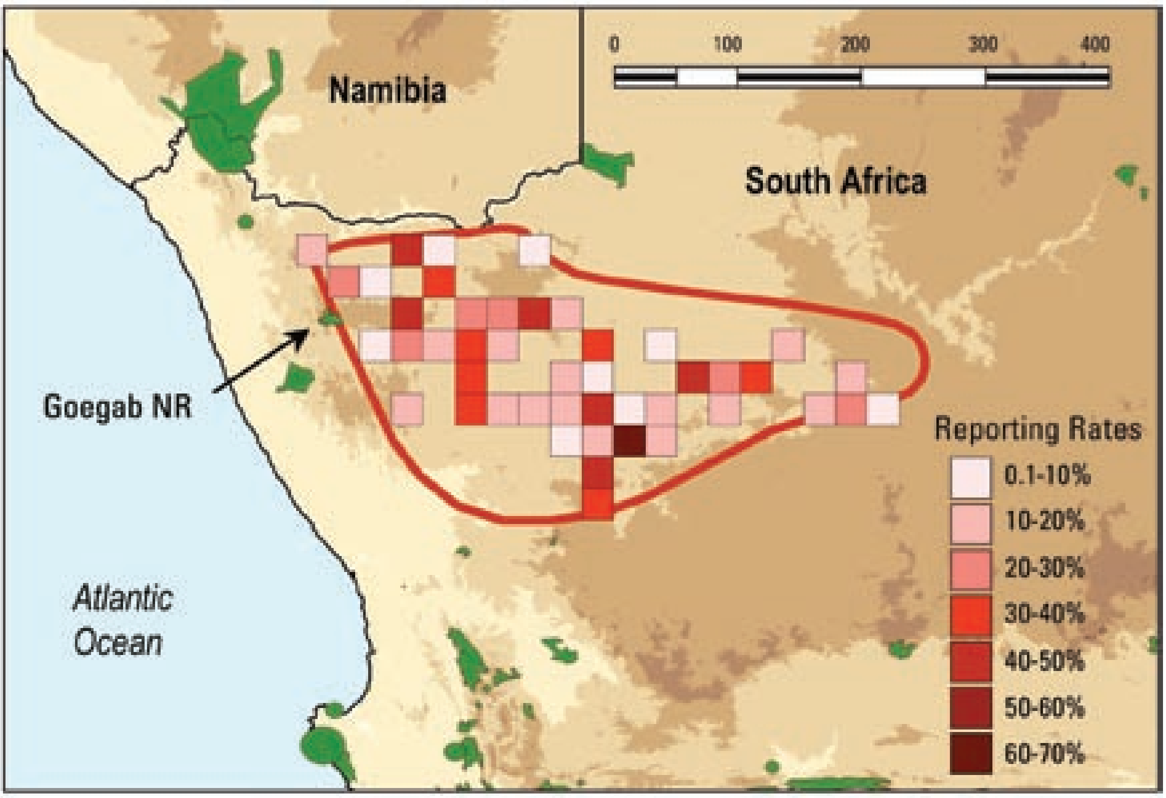


Figure 3.3 Example of a commission error under Scenario A due to habitat fragmentation/specialization inside the species mapped extent of occurrence. Darker shades of brown on the map correspond to higher elevation, and green polygons correspond to protected sites. The Red Lark *Certhilauda burra* is a Vulnerable species endemic to South Africa. The red line on the map indicates the boundaries of the species' extent of occurrence as mapped by BirdLife International (2000). These boundaries are marginally overlapped by the Goegab Nature Reserve, hence the species is considered covered under Scenario A. However, this is a species whose habitat is naturally patchy, such that only about 5 percent of its extent of occurrence contains suitable habitat. Additionally, most of this habitat has been overgrazed and degraded, meaning that the species only occupies about 1,000 km^2 out of the 72,000 km^2 mapped (BirdLife International 2000). Data from a different source provides further insights. The area of occupancy of this species (squares of variable shades of red, representing quarter degree grid cells) has been obtained by the Southern African Bird Atlas Project (Harrison *et al.* 1997). These data confirm that most of the species' extent of occurrence is not occupied. Additionally, reporting rates (percentage of times a species was recorded in each cell in relation to the number of visits, positively related to relative abundance across the species' range; Robertson *et al.* 1995) demonstrate that the grid cells occupied are not all equivalent in terms of conservation value. Furthermore, these data indicate that the species is likely to be absent from Goegab Nature Reserve, being therefore a commission error under Scenario A. Accordingly, BirdLife International (2000) reports that the Red Lark is not covered in any area protected by the state, although important populations are found in private reserves.

occurrence is covered by protected areas (of any size) when in fact the species is either absent from those areas or is covered very poorly. Some of these situations correspond to cases where the boundaries of species' ranges have been drawn too coarsely and hence have included peripheral protected areas where the species does not occur (Figures 3.3 and 3.4). Other commission errors occur in situations where protected areas are located in unsuitable regions within the species' extent of occurrence (Figure 3.5).

All these situations are impossible to predict with the available data. Nevertheless, the larger the proportion of a species' range that is overlapped by protected areas, the higher the likelihood that a species is truly covered. A possible criterion for considering a species covered is therefore that a given percentage of its range overlaps with protected areas.

Hence, the approach adopted in this analysis was to establish a *representation target* for each species, defined as the percentage of the species' extent of occurrence that must overlap protected areas in order for the species to be considered *covered*. A species not represented at all in the protected areas considered for this Scenario is a *gap*, while a species that meets only a portion of its representation target is a *partial gap* (Figure 3.6).

More demanding targets (larger percentages of the range) were set for species with more restricted ranges. To set a constant representation target (for example, 15 percent) would favor wide range species in relation to narrow endemics: 15 percent of a wide range is still a large area, while 15 percent of a small range is tiny. Furthermore, species with small ranges tend to be rare, not only in terms of range size but also in terms of local abundance (Hanski 1982, Brown 1984, Gaston *et al.* 1997). Therefore, the number of individuals protected in 15 percent of the range of a narrow endemic is *disproportionately* smaller than the number of individuals protected in the same fraction of the range of a widespread species – what Lawton (1993) called the double conservation jeopardy of rare species. All else being equal, species with small ranges are more vulnerable to stochastic events, including natural events (such as climate variation) as well as anthropogenic activities (e.g., habitat degradation, introduced species). These factors explain the well-known negative relationship between species' range size and extinction risk (e.g., Purvis *et al.* 2000). Setting higher representation targets for species with restricted ranges corresponds therefore to adopting a more precautionary approach

Figure 3.4 Example of a commission error under Scenario A due to coarsely drawn extent of occurrence maps. Darker shades of brown correspond to higher elevation, and green polygons correspond to protected sites. The Silvery-brown Bare-face Tamarin *Saguinus leucopus* is endemic to northern Colombia. The species is considered Vulnerable under IUCN criteria, as most of its geographic range has been deforested for livestock farming, agriculture, and by the construction of the Medellín-Bogotá highway (Vargas & Solano 1996). It has been considered covered under Scenario A due to a marginal overlap of its range with Los Nevados Natural National Park (NNP). However, this is a lowland rainforest species (Emmons & Feer 1990), while Los Nevados NNP is a highland area (2,600 to 5,300 m) of Andean cloud forest, páramo, and snowy peaks (www.parquesnacionales.gov.co). This is therefore a commission error, and indeed the species has been reported not to occur in any protected area (Vargas & Solano 1996, Defler *et al.* 2003). Coarsely drawn range boundaries are the most likely explanation for this commission error – in a region of such complex topography, a subtle boundary misplacement corresponds to a radical change in habitat type. Serranía de San Lucas (northern portion of the species' range) has been identified as an important site for the establishment of a National Park, which would confer protection to several other threatened primate species (Vargas & Solano 1996, Defler *et al.* 2003). Photo by F. Medem.

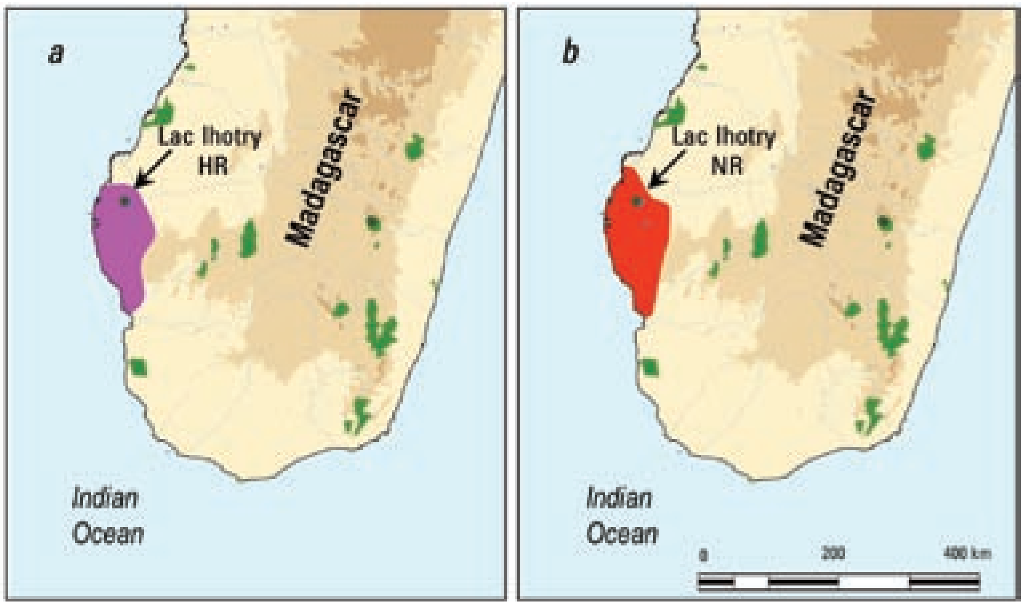


Figure 3.5 Example of commission errors under Scenario A due to protected areas that cover unsuitable habitat inside species' extents of occurrence. Darker shades of brown correspond to higher elevation, and green polygons correspond to protected sites. The Long-tailed Ground-roller *Uratelornis chimaera* (*a*) and the Subdesert Mesite *Monias benschi* (*b*) are both Vulnerable species endemic to the spiny-forest of south-west Madagascar (BirdLife International 2000). These were considered covered by Scenario A, due to overlap with Lac Ihotry Hunting Reserve (represented as a point), but this is a wetland, which is inappropriate habitat for these species. Accordingly, BirdLife International (2000) reports that both species are entirely unprotected.

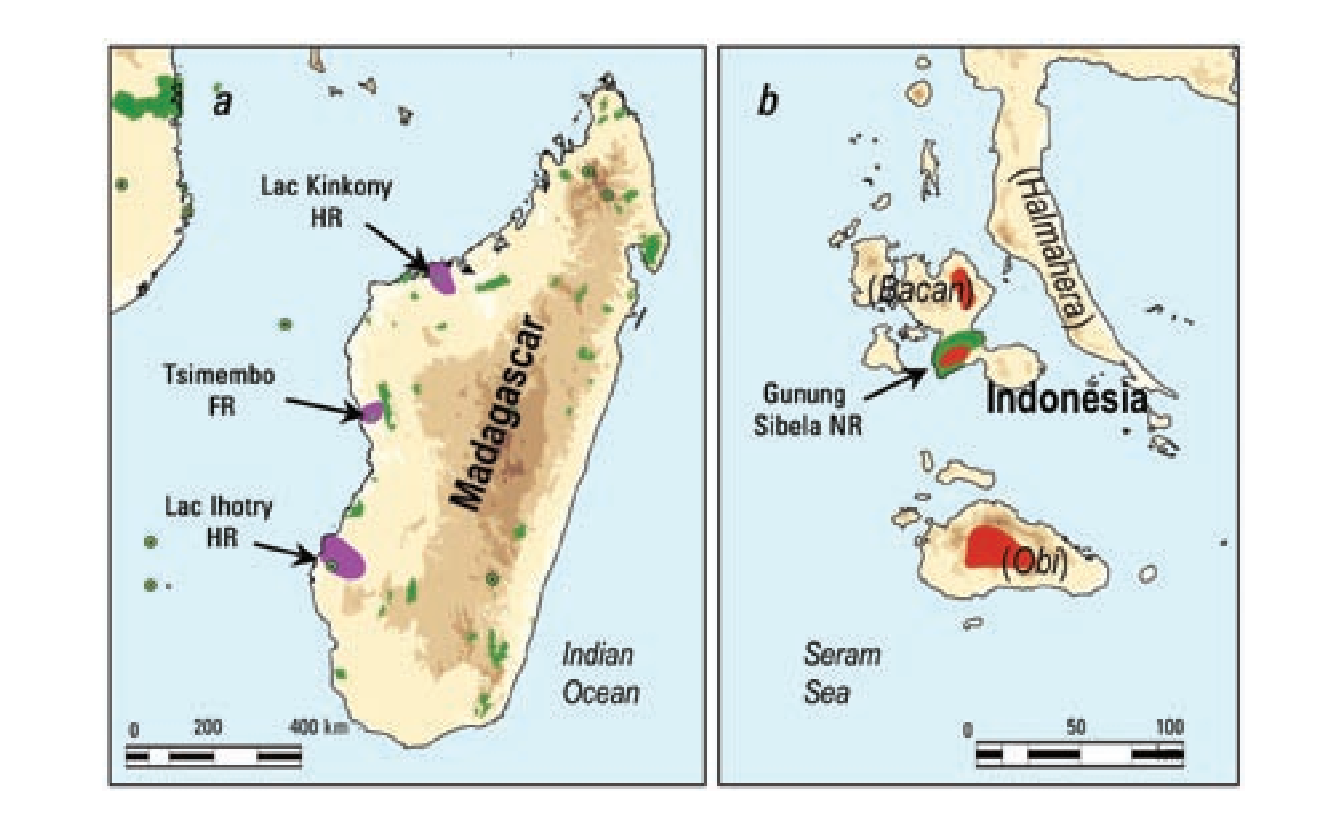


Figure 3.6 Example of species identified as *partial gaps* by Scenario B but considered *covered* by Scenario A. Darker shades of brown correspond to higher elevations, and green polygons correspond to protected sites. *a*) Sakalava Rail *Amaurornis olivieri*, a Critically Endangered species, is only known from three widely separated areas in lowland western Madagascar (BirdLife International 2000). It is considered covered under Scenario A due to overlap with Tsimembo Forest Reserve and Lac Kinkony and Lac Ihotry Hunting Reserves. However, these reserves do not meet the representation target established for Scenario B (60 percent of the species' 11,300 km^2 extent of occurrence) as they cover only 3 percent of the species range. *b*) Moluccan Woodcock *Scolopax rochussenii*, a Vulnerable species, is endemic to the islands of Obi and Bacan (North Maluku), Indonesia, with a mapped extent of occurrence of only 680 km^2 (BirdLife International 2000). It is considered covered by Scenario A, due to overlap with Gunung Sibela Nature Reserve, but this protected area covers only 13 percent of the species' mapped range, insufficient to satisfy the 100 percent target established for Scenario B.

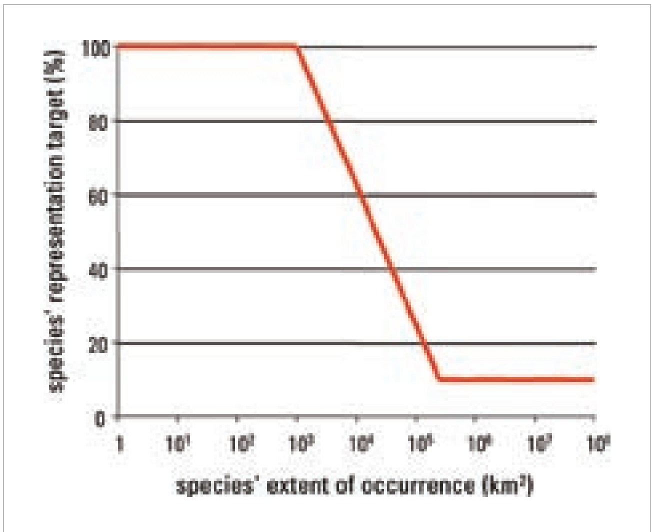


Figure 3.7 Relationship between each species' extent of occurrence and its required representation target in Scenario B (percentage of range that ought to be overlapped by protected areas in order for the species to be considered covered). For very narrowly distributed species (extent of occurrence < 1,000 km^2), the target is to represent 100 percent of the range; for very widespread species (> 250,000 km^2), the representation target equals 10 percent. For species with ranges in between, the target was interpolated between these two extremes, using a logarithmic transformation.

towards restricted-range species in assessing whether they should be considered covered or not.

Figure 3.6 illustrates the method used to calculate the representation target of each species based on its extent of occurrence. All species with ranges ≤ 1,000 km^2 were required to have 100 percent of their range covered, while species with ranges ≥ 250,000 km^2 were required to have at least 10 percent of their range covered. Targets for species with intermediate range sizes were defined by interpolation using a log transformation (Figure 3.7). For example, species with ranges occupying 50,000 km^2 (the threshold for considering a species as "restricted-range" adopted by Stattersfield *et al.* 1998) require 36 percent of their range covered.

As in Scenario A, targets for migratory bird species were defined separately for breeding and non-breeding ranges, given that each of these may have different conservation requirements. For example, the Hooded Crane *Grus monacha* has a breeding range of approximately 1,600,000 km^2 (southeastern and southcentral Siberia, Russia), but a non-breeding range about 14 times smaller (135,000 km^2, in Japan, South Korea, and China). The main threat to this species, which justifies its classification as Vulnerable, is habitat destruction in its wintering grounds, where the population is spatially concentrated (BirdLife International 2000). The representation targets for each of this species' seasonal ranges are, respectively, 10 and 22 percent for the breeding and non-breeding ranges.

The method for establishing each species' representation target is based on a strong assumption: that restricted range species require a more precautionary approach. Logic suggests that very localized species should have their entire range reserved: as the size of species' ranges approaches the size of functional protected areas, species tend to be either totally covered or totally absent from protected areas. The 10 percent representation target for widespread species is also a logical one: in practice, it means that these species are on average neutral to the analysis, as 10 percent is approximately the total area of the planet covered by protected areas. However, the 1,000 km^2 and 250,000 km^2 thresholds are, admittedly, somewhat arbitrary, and the results of Scenario B need to be interpreted accordingly.

Unlike Scenario A, the results of Scenario B do not provide a clear boundary between gap and covered species (except for the situations where species representation in protected areas is zero percent, when both scenarios become equivalent). Instead, they provide a qualified measure of the confidence in the statement that the species is covered or not.

Accordingly, Scenario B results were not used to create a global map of gap species. Instead, they were used to calculate the likelihood that particular sites are needed for achieving each species' representation targets, following the methodology described below.

Spatial Units

For this analysis, we divided the world's land area into non-overlapping spatial units, henceforth referred to as one of two types of *sites*, protected and unprotected (Figure 3.8). Protected sites may correspond to individual protected areas or clusters of overlapping or continuous polygons representing several protected areas, that were merged together to create a single protected site.

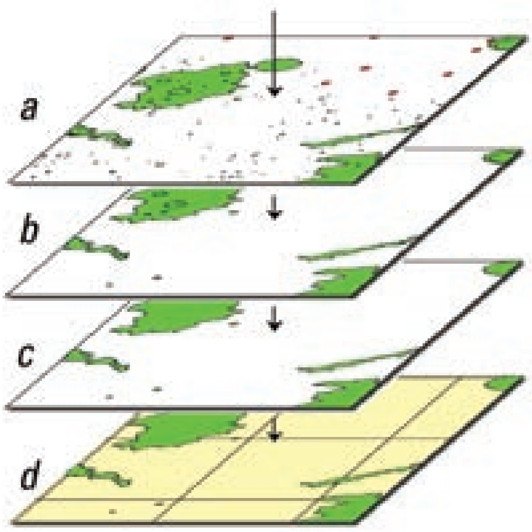


Figure 3.8 Preparing the data for Scenario B of the global gap analysis. The original set of protected areas (*a*, green polygons and red dots) was filtered to exclude all point data (red dots) as well as protected areas smaller than 100 ha. The remaining protected areas (*b*) were merged together to obtain a map in which each patch of protected land is an individual *protected site* (*c*). The area outside protected sites was divided based on a ½ degree grid, across which each grid cell or part of a grid cell represents an *unprotected site* (*d*, in yellow).

Unprotected sites were obtained by splitting the remaining land area using a half degree grid. A half degree cell has an area of about 3,090 km^2 near the Equator, with the area of each cell decreasing towards the poles (for example, about 2,850 km^2 at the Tropics of Cancer or Capricorn). The resulting map of sites is therefore composed of units of different shapes and sizes. There were 95,661 sites with data for at least one species; of these, 29,764 corresponded to protected sites and 65,897 to unprotected sites.

Each one of the species distribution polygons was overlaid with the map of sites, producing a matrix of species by both protected and unprotected sites. The first use of this matrix was to calculate the percentage of the species' range falling inside each of the sites, and hence whether each species meets its representation target, and therefore whether it is a covered species, a partial gap species, or a gap species. The matrix was then used to calculate site irreplaceability.

Site Irreplaceability

The concept of *irreplaceability* has been proposed by Pressey and colleagues (Pressey *et al.* 1993, 1994) as a tool for managers that makes explicit the spatial options for achieving a desired set of outcomes in planning new protected areas or managing existing ones. First developed in the context of conservation planning in Australia (e.g. Pressey 1998, 1999), it has since been applied to many other regions (e.g., Guyana, Richardson & Funk 1999; South Africa, Cowling *et al.* 1999, Cowling & Pressey 2003; U.S., Davis *et al.* 1999) and has became a central concept of systematic conservation planning (Pressey *et al.* 1993; Margules & Pressey 2000).

Irreplaceability is defined as the likelihood that a given site will need to be protected to achieve a specified set of targets or, conversely, the extent to which options for achieving these targets are reduced if the site is not protected (Pressey *et al.* 1994). Irreplaceability ranges from zero percent (if a site is not needed to achieve target goals) to 100 percent (sites for which there are no replacements – the targets cannot be achieved without protection of that specific site). Areas with progressively lower irreplaceability have progressively more options for replacement (Figure 3.9).

For this analysis, the irreplaceability of each site for achieving the representation targets defined for each species depends on:

- The species occurring in the site
- The conservation targets set for each of those species
- How many other sites contain each of the species occurring in the site, and
- The percentage of each species' range that is within the site in relation to the other sites where the species occurs.

In theory, irreplaceability could be measured by examining all the combinations of sites such that each species achieves its repersentation target (referred to as *representative combinations*). The irreplaceability of a given site, *x*, is obtained by dividing the number of representative combinations that includes site *x* but that no longer would be representative

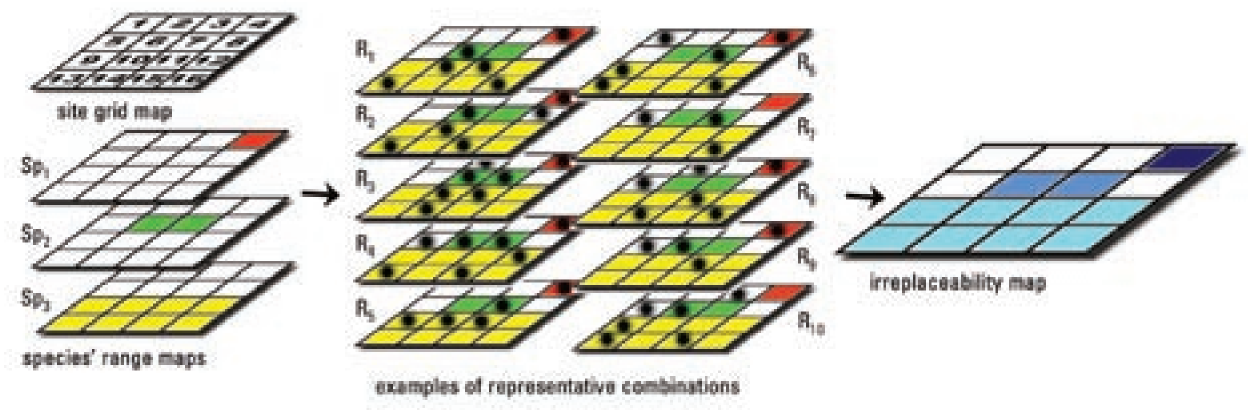


Figure 3.9 Illustration of the concept of irreplaceability (adapted from NSW-NPWS 2001). Consider three species, Sp_1, Sp_2 and Sp_3. Sp_1 (red) occurs in a single site, (#4 in grid map); Sp_2 (green) occurs in two sites, (6 and 7); Sp_3 (yellow) occurs in eight sites (9–16). For simplicity, let us assume that for each of these species the representation target is the same, 30 percent of each of their ranges. A *representative combination* (such that representation targets are met for all species) requires representing Sp_1 in site 4, Sp_2 in at least one of sites 6 and 7, and Sp_3 in at least three of sites 9 to 16. There are 65,534 combinations of the sixteen sites in the site grid map, ten of which are illustrated here (a black dot indicates that the site is selected). Of these combinations, only 21,024 are representative (e.g., R_1 to R_6), the remaining 44,511 do not meet the representation target for at least one species (e.g., R_7 to R_{10}). To calculate the irreplaceability of, for example, site 6, we need to know how many of the representative combinations include site 6. There are 14,016 such combinations (e.g., R_1 to R_4), but site 6 is fundamental for ensuring a representative combination in only 7,008 of these combinations (e.g., R_1 and R_2; site 6 is redundant in R_3 and R_4). The irreplaceability of site 6 thus equals 0.33, obtained by dividing the number of combinations where the site's presence is fundamental by the total number of representative combinations (7,008/21,024). Using the same rationale, the irreplaceability of sites 9 to 12 is 0.10. Site 4, which is present in all representative combinations (never redundant), has irreplaceability 1. Site 3 (with no species) is always redundant and has therefore zero irreplaceability.

if site *x* were removed by the total number of representative combinations, that is, the proportion of representative combinations where site *x* plays a critical role for achieving one or more species representation targets (NSW-NPWS 2001). In practice, the number of possible representative combinations increases exponentially with the number of sites and species analysed, making impossible the calculation of true irreplaceability using arithmetic indices, except for very simple scenarios (e.g., Figure 3.9).

Irreplaceability was estimated in this analysis using the statistical techniques proposed by Ferrier *et al.* (2000). These were implemented by the software C-Plan, developed by the New South Wales National Parks and Wildlife Service (NSW-NPWS 2001).

Irreplaceability cannot be used as a ranking system in which sites are selected in decreasing order of their irreplaceability values. In fact, both sites of high irreplaceability and low replaceability are needed when creating a representative network of protected areas that achieves all the pre-defined conservation targets. But the fraction of sites within a given range of irreplaceability values that are needed in the representative network increases for higher irreplaceability, as there are fewer options for representing their biological values elsewhere (e.g., Figure 3.9).

Irreplaceability was calculated for both protected and unprotected sites (Figure 3.10). The irreplaceability of a particular protected site, calculated using data on covered species and partial gaps, indicates the extent to which options are reduced if the biological values of the protected site are lost, providing a measure of its overall importance for the representation of the vertebrate species analysed within the current global network of protected areas. The irreplaceability of unprotected sites, calculated using data on species that are gaps or partial gaps, indicates the likelihood that these sites would be needed in an expanded protected area network that represents all species to their predefined representation targets.

Irreplaceability was calculated separately for each of the higher taxa analyzed: threatened birds; all mammals; and all amphibians.

Threat

Area threat, or vulnerability, is a measure of the likelihood that the area will be disturbed or destroyed (Pressey & Taffs 2001). Threat information, which has been measured in a variety of ways, is frequently applied to assessing conservation priority. Commonly used measures include human density (e.g., Cincotta *et al.* 2000, Balmford *et al.* 2001) or levels of human activity, variables such as land development/degradation (e.g., Abbitt *et al.* 2000, Myers *et al.* 2000b), presence of roads (e.g., Reyers *et al.* 2001), and potential for agriculture/forestry (e.g., Pressey & Taffs 2001). The recently published global "human footprint" map (Sanderson *et al.* 2002a) uses a combination of measures of human impact. The use of such measures of threat is justified by their relationship with species extinction risk (e.g., Brooks *et al.* 1997, Rivard *et al.* 2000, McKinney 2001 for human population).

Measures based on human influence typically underestimate threat levels in arid regions (Sanderson *et al.* 2002a). They are also poor in detecting those threats that are not necessarily associated with intense human use, most noticeably the effect of introduced species. A more direct measure of threat for a given taxonomic group is the number of threatened species in a region (e.g., Dobson *et al.* 1997) or a combination of the levels of threat of different species (e.g., Lombard *et al.* 1999).

As a first approach, threat levels were measured in this analysis as the weighted number of threatened species per site. Weights were defined according to IUCN threat categories: 3 for Critically Endangered, 2 for Endangered, and 1 for

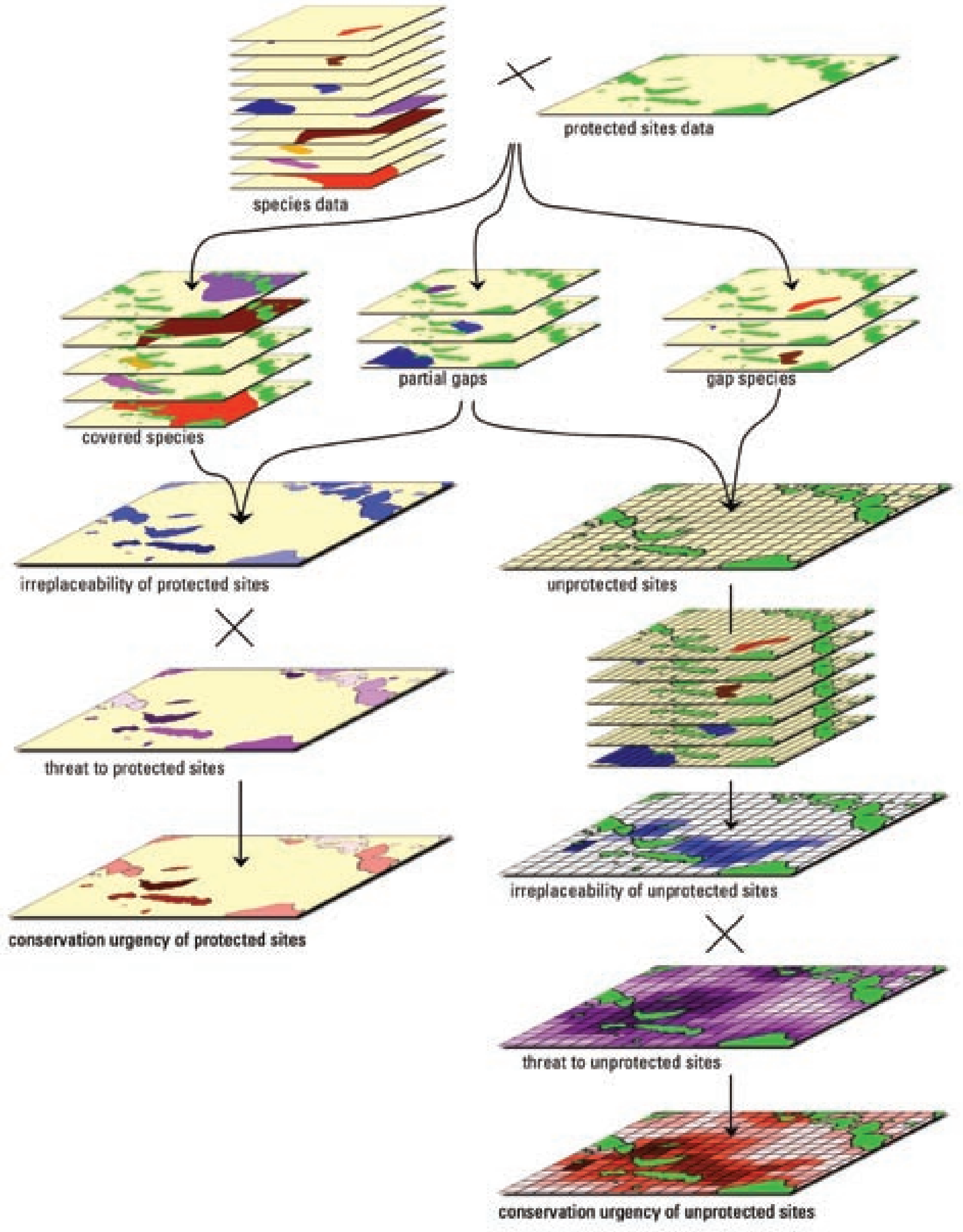


Figure 3.10 Illustration of the method followed in Scenario B. Data on species' distribution were overlaid with protected sites data to determine how much of each species' range is protected. A species protected by a percentage of range larger than its predefined representation target was considered *covered*. A species whose range overlaps protected sites by less than its representation target was a *partial gap*. A species whose range does not touch any protected site was a *gap*. Data on partial gaps and covered species was combined to produce a map of the irreplaceability of each protected site for representing these species. When combined with threat, a map of the urgency for the conservation of protected sites was obtained. The area outside protected sites was divided into unprotected sites using a ½ degree grid. Data on gap and partial gap species were combined to produce a map of the irreplaceability of each one of these sites for filling the gaps in the protected area network (i.e., representing all species to their predefined targets). Combined with information on threat, a map of the urgency for expanding the existing network of protected areas was obtained.

Vulnerable species. While these values are arbitrary, they follow the assumption that site threat increases both with the number of threatened species present at the site and with the levels of threat of individual species. Threat levels were calculated separately for each of the higher taxa analyzed: threatened birds; all mammals; and all amphibians.

Conservation Urgency

Irreplaceability highlights regions for which there are few options for replacement elsewhere. Threat, on the other hand, highlights regions for which there are few opportunities for conservation in the future unless urgent action is taken. Neither of these variables alone adequately predicts which areas should be given priority in the allocation of conservation resources. Hence, a site with high irreplaceability and low threat, while important and perhaps a good conservation bargain, is not necessarily a high priority in terms of conservation investment, because options for conservation will still be available in the future. Correspondingly, a site with high threat and low irreplaceability is not a high priority because other spatial options are likely to be available for the conservation of the same biological values.

Sites of high spatial irreplaceability and high threat are those where options for replacement are not available either spatially or temporally: these sites require immediate conservation attention in order to prevent the loss of unique biodiversity values. These correspond therefore to the highest conservation priorities (Pressey & Taffs 2001; Figure 3.11).

Areas of high urgency for the expansion of the global network of protected areas were highlighted by choosing the higher classes of irreplaceability and threat values for unprotected sites. These corresponded to all sites included in the top 5 percent in terms of weighted numbers of threatened species, and with irreplaceability ≥ 0.9. The same procedure was applied to protected sites, in order to highlight protected areas that require special attention to ensure that their management is adequate for the maintenance of the biological values they hold.

Figure 3.11 After assessing the irreplaceability and threat values of each protected and unprotected site, sites that combine higher values for both variables were highlighted as being high priorities for the expansion/consolidation of the global protected area network.

This procedure was applied separately to each of the higher taxa analyzed. Final maps of urgency across all taxa for protected and unprotected sites were then obtained by combining the respective maps obtained for each of the three taxa.

Given the scale of this assessment, and the coarseness of the data, the areas identified as urgent by this global gap analysis are, above all, regions that deserve immediate finer-scale assessments to investigate the feasibility of the expansion and consolidation of the global protected area network.

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CHAPTER 4

Results and Discussion

Pygmy Hog *Sus salvanius*, the world's smallest pig and a Critically Endangered species. Formerly occurred throughout the Terai region of India, Bhutan and Nepal, but it is now found only in northwest Assam, India, virtually restricted to Manas Wildlife Sanctuary.

In this chapter we present and discuss the significance of the results obtained in the global gap analysis. We begin by presenting and analyzing species coverage in protected areas, as obtained in the two scenarios explored. The subsequent three sections present and interpret the results for globally threatened birds, for mammals, and for amphibians. Each of these sections starts by assessing the importance of the existing protected area network for each of the analyzed taxa, a useful product possible under Scenario B, in terms of irreplaceability, threat, and – building from these – urgency for increased conservation action. Each section then presents and discusses the results for the unprotected 90 percent of the planet, both in terms of species wholly unrepresented in protected areas (Scenario A) and of irreplaceability, threat, and urgency (Scenario B). Following the discussion on individual taxa, we present a geographical overview of the overall maps of urgency obtained across all taxa, for both protected and unprotected sites, discussing the implications of these findings for global conservation planning. Finally, in the closing section, we discuss the relationships between the global gap analysis and global prioritization analyses.

SPECIES COVERAGE

A central question underlying this global gap analysis is how much of the diversity of the vertebrate species analyzed is covered by the global network of protected areas? As discussed in Chapter 2, limitations in the data preclude any straightforward answer to this question. With the data currently available, all that is possible is to provide estimates based on more or less strict criteria for considering a species as either covered or a gap. Scenarios A and B differ in these criteria, and consequently provide two different outlooks on the extent of coverage by the global network.

Scenario A

The relative proportions of gap and covered species according to Scenario A are presented in Figure 4.1. Covered species that were only represented in protected areas smaller than 1,000 ha and/or only by protected areas other than those classified as IUCN Categories I-IV are presented separately.

Because only threatened bird species were analyzed, the results for this group are always presented in comparison to threatened species of mammals (IUCN 2002) and amphibians, based on draft results of the Global Amphibian Assessment (Figure 4.1b). Additionally, results for threatened birds refer to numbers of species-seasons that are either covered or gaps, given that these were the unit used in the analysis. In any instance, the overall proportions change little if threatened bird species are considered instead of species-seasons (assuming that a migratory bird species is a gap if it is not represented in protected areas anywhere in its range, the ratio of gap to covered species would become 19 percent to 81 percent instead of the current 17 percent to 83 percent).

Overall, Scenario A identified 1,310 gap species: 225 threatened bird species-seasons (equivalent to 223 species), 260 mammals (140 of them threatened), and 825 amphibians (346 threatened). These correspond to 12 percent of all the species analyzed, distributed as 17 percent of all threatened bird-seasons, 6 percent of all mammals, and 16 percent of all amphibians. Additionally, 1,034 of the covered species were only represented in protected areas smaller than 1,000 ha and/or only by protected areas other than those classified as IUCN I-IV. Mammals were the group best covered, both when comparing results obtained for all species of mammals and amphibians (Figure 4.1a) and when comparing the results across birds, mammals, and amphibians for threatened species (Figure 4.1b).

Scenario B

In Scenario B, the distinction between gap and covered species is not so abrupt as in Scenario A, and is best understood by analyzing the pattern obtained for the majority of species that were classified as partial gaps (Figure 4.2).

Numbers of gap species (those not represented in the protected area network) are naturally comparable to those obtained in Scenario A, but slightly larger because Scenario B excluded all protected areas represented as points or as polygons smaller than 100 ha.

Overall, Scenario B identified 1,652 gap species (15 percent of all the species analyzed), distributed as:

- 263 (20 percent) threatened bird species-seasons (equivalent to 261 species, 22 percent),
- 507 (11 percent) mammals (166 threatened, 16 percent), and
- 882 (17 percent) amphibians (375 threatened, 26 percent).

As for the species identified as fully covered, Scenario B identified 2,613 (23 percent of all species analyzed), including:

- 104 (8 percent) of all threatened bird species-seasons (95 species, 8 percent),
- 1,612 (34 percent) of all mammals (171 of the threatened species, 17 percent), and
- 897 (17 percent) of all amphibian species (83 of the threatened species, 6 percent).

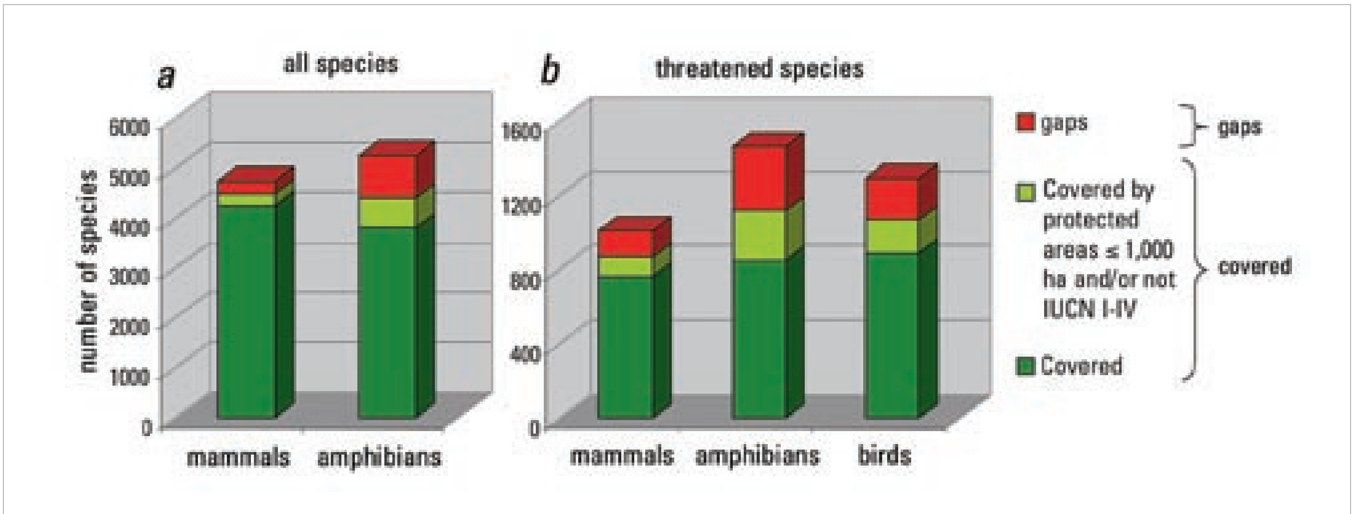

Figure 4.1 Numbers of gap and covered species found under Scenario A for (a) all species of mammals and amphibians and (b) threatened species of mammals, amphibians, and birds (species-seasons). Species covered only in protected areas smaller than 1,000 ha and/or other that those classified as IUCN I-IV are presented separately.

Most species (either considering all or just threatened species) are partial gaps, with a general bias towards species that meet smaller fractions of their representation targets (Figure 4.2). As with Scenario A, mammals are the best covered of the three higher taxa analyzed.

Analyzing the distribution of different classes of representation for threatened species of each IUCN threat level (Figure 4.3), it becomes obvious that for all groups the level of representation is worse for higher degrees of threat.

Comparison of Coverage Estimates for Scenarios A and B

Scenarios A and B differ in the criteria applied in considering a species to be a gap, and consequently they provide two different perspectives on the degree of species coverage by the global network. Certainly, neither of them is 'the correct answer.' The requirements for considering a species covered in Scenario A are so trivial that it must be considered a serious overestimate of the coverage provided by the global network of protected areas. Indeed, assuming that species become adequately covered if their ranges overlap any extension of any protected area is likely to result in many commission errors (e.g., Figure 3.3, Figure 3.4, Figure 3.5, Box 4.1).

Scenario B, on the other hand, is likely to be too strict for a number of species, while being too lax for others. On one extreme, if the criteria stipulate that a species is covered by protected areas in 100 percent of its range, then it is obvious that if the species meets that requirement it must be represented in the global network (with a few exceptions for species with ranges that are either not well-known or incorrectly mapped). As the representation target becomes less strict, the confidence that the species is truly covered by at least one protected area decreases. It is likely that for some of the species analyzed, the representation targets are stricter than needed – the species may already be adequately covered in protected areas that overlap a fraction of the species' range that is smaller than the required target.

At the other extreme, there are species for which the representation criteria set in Scenario B are obviously meaningless. "Landscape species" (Sanderson *et al.* 2002b), such as top predators and migratory species, frequently have wide distributions (and therefore small representation targets in Scenario B) but demanding habitat and protected area requirements (Figure 4.4). Many top predator species, for example, require

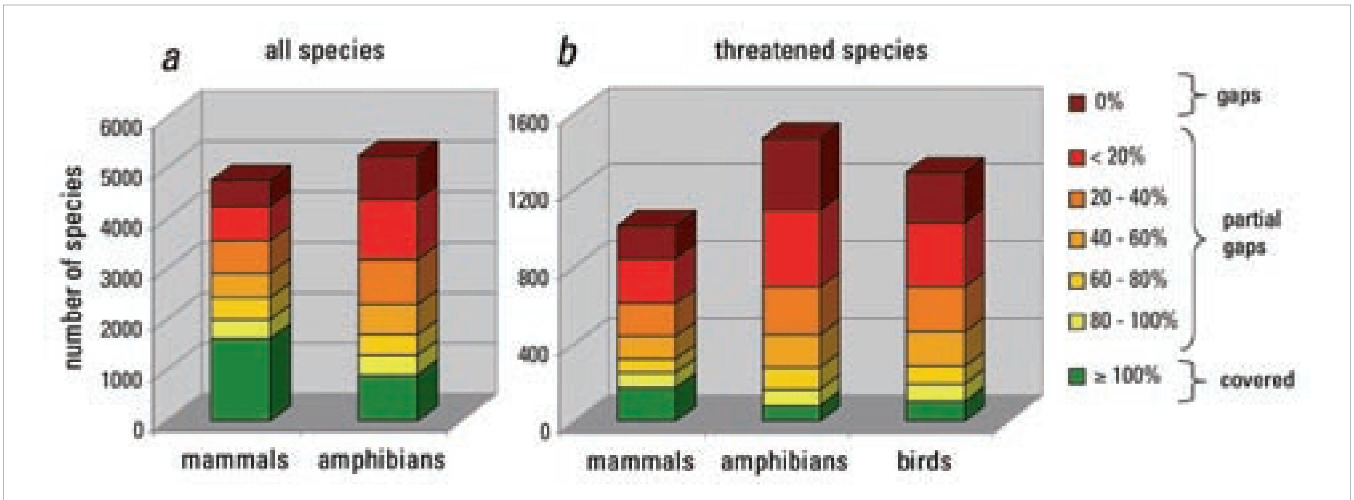

Figure 4.2 Numbers of gap and covered species found under Scenario B for: (*a*) all species of mammals and amphibians; and (*b*) for threatened species of mammals, amphibians, and birds (species-seasons). Species are categorized into gaps, partial gaps and covered according to the percentage of representation target that is covered by protected areas.

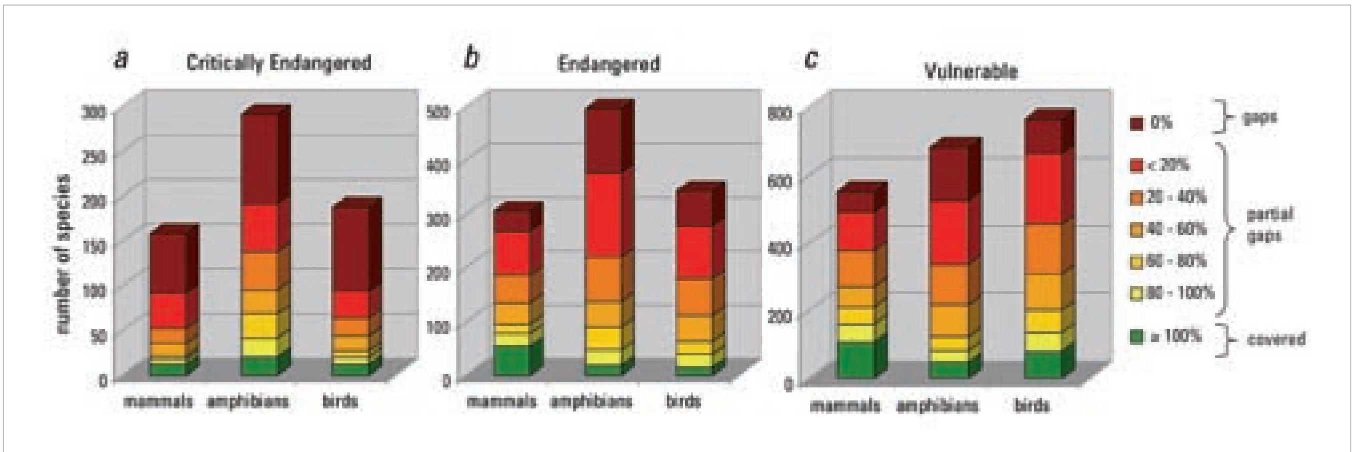

Figure 4.3 Numbers of gap and covered species found under Scenario B for threatened species of mammals, amphibians, and birds (species-seasons), according to IUCN threat level: (*a*) Critically Endangered; (*b*) Endangered; (*c*) Vulnerable. Species are categorized into gaps, partial gaps and covered according to the percentage of representation target that is covered by protected areas. Species of higher levels of threat are disproportionally poorly covered.

very large contiguous protected areas of relatively undisturbed habitat (Woodroffe & Ginsburg 2000).

For most migratory species, the simple additional requirement that species are covered during both the breeding and the non-breeding seasons is also likely to be insufficient for accommodating the particular conservation needs of many of these species. Many of them have high requirements for protection during migration, for example, to ensure adequate stopover habitat (e.g., Moore *et al.* 1995). In some migratory species, different populations follow different migratory routes, with different breeding and non-breeding ranges (e.g., Rubenstein *et al.* 2002), which means that even if protected areas cover both types of range they may not be covering the same population throughout the year.

Even for very localized species, conservation requirements may be quite large in spatial terms. For example, it may be tempting to assume that for most amphibian species the protection of a single population in adequate habitat is enough coverage. However, many of these species are associated with freshwater habitats that can only be protected by considering entire watersheds, for example to prevent the effects of upstream pollution in otherwise undisturbed sections of rivers (e.g., Bury 1988, Trauth *et al.* 1992).

Therefore, while it is likely that Scenario B is too strict in the representation requirements set for some of the species, overall it is still likely to be a crude underestimate of what would be needed to complete the global network of protected areas, even if only considering the needs of mammals, amphibians, and birds.

Regardless of their differences, Scenarios A and B both suggest a pattern in which amphibians are significantly less well covered than the other taxa, with mammals the best covered group and threatened birds in an intermediate position (Figure 4.1, Figure 4.2). Why should amphibians be so much more poorly covered by the protected areas system than mammals and birds? There are several, non-mutually exclusive, possible explanations. The most likely of these is simply that amphibians have, on average, much smaller range sizes, and so are likely to be less well-represented in protected area systems by chance alone than either mammals or birds. Indeed, the median range size of all amphibians in the datasets used in this analysis was 7,034 km^2 (1,003 km^2 for threatened amphibians) compared to 244,157 km^2 for all mammals (20,359 km^2 for threatened mammals) and 5,450 km^2 for threatened birds.

Other explanations include habitat preference – amphibians tend to be associated with freshwater habitats, which are not particularly well addressed by the terrestrial network of protected areas – and taxonomic bias – few protected areas were created with any consideration of amphibian distributions.

Why threatened mammals should be better represented than threatened birds is less obvious. Again, it may be a result of the larger ranges of mammals, although these may in part be due to an artifact of the coarser quality of the mammal distribution data. Additionally, we suspect that the high proportions of island endemic threatened birds – few mammals, and hence few threatened mammals, occur on islands – may provide some of the explanation, given that islands are a habitat poorly

Figure 4.4 The results of the global gap analysis are not adequate for assessing the conservation status of many species with demanding habitat and area requirements such as: (*a*) Orangutan *Pongo pygmaeus*, Endangered; (*b*) Tiger *Panthera tigris*, Endangered; (*c*) African Elephant *Loxodonta africana*, Endangered; (*d*) Harpy Eagle *Harpia harpyja*, Near-threatened. For these and many other species, simple presence in a protected area does not guarantee that the species' conservation requirements are being met. Photos: [a and b] Haroldo Castro; [c] Russell Mittermeier; [d] Conservation International.

BOX 4.1 OMISSION AND COMMISSION ERRORS FOR THREATENED AMPHIBIANS OF MESOAMERICA

In addition to species range maps, the Global Amphibian Assessment collected a diversity of other data (Chapter 2), including information on conservation measures currently in place for each species, such as presence or not in protected areas. These data provide an opportunity for evaluating the accuracy of the results obtained by Scenario A based on information provided by regional experts with field knowledge of both the species and the protected areas.

The 280 threatened species of amphibians of the Mesoamerican region (from Mexico to Panama) were analyzed as a preliminary case study. A comparison of the lists of species considered covered by Scenario A of the global gap analysis with those reported as covered in the Global Amphibian Assessment (Figure A), found: 71% match (species reported by both assessments as either covered or gaps); 9 percent omission error (species reported as gaps by the global gap analysis but as covered by the Global Amphibian Assessment); and 19 percent commission error (species reported as covered by the global gap analysis but as gaps by the Global Amphibian Assessment).

Hence, overall, the global gap analysis underestimated the number of gap species: 38 percent, as compared to 48 percent reported by the Global Amphibian Assessment. Furthermore, for about 10% of the covered species, the text notes entered by experts when describing the conservation status of each species indicate that presence in protected areas is no guarantee of the species' persistence, due to habitat degradation or because the species has not been registered in the protected areas recently despite searches.

For the majority of the species, it was possible to determine the most likely source of the omission and commission errors (Table I, Figure A). As predicted in Chapter 2, most errors are due to the spatial representation of species' ranges as extent of occurrence, which overestimate the species' true area of occupancy and result in commission errors.

The spatial implications of these commission and omission errors were evaluated by comparing maps of density of gap species found, respectively, by the global gap analysis (Figure B [a]) and by the Global Amphibian Assessment (Figure B [b]). The overall pattern is similar, indicating that the regions highlighted by the global gap analysis correspond to true gaps in the protected area network. However, the results using data from the Global Amphibian Assessment produced a wider gap area, increased the species density in the previously existing peaks and highlighted a new area (in Costa Rica) with a concentration of gap species. This reinforces the prediction that Scenario A of the global gap analysis underestimates the magnitude of the gaps in coverage of the global network of protected areas.

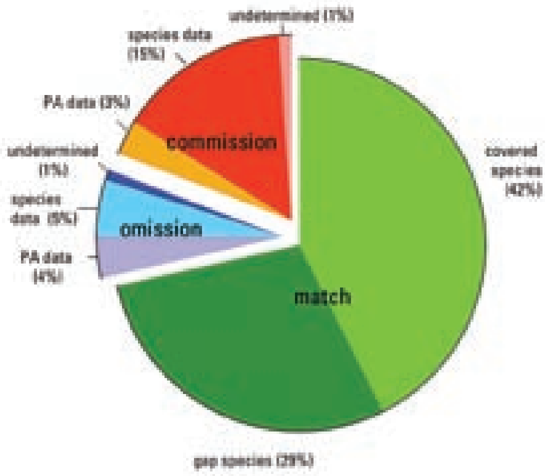

Figure A. Sources of omission and commission errors obtained by comparing the lists of species considered covered by Scenario A of the global gap analysis with those reported as covered in the Global Amphibian Assessment.

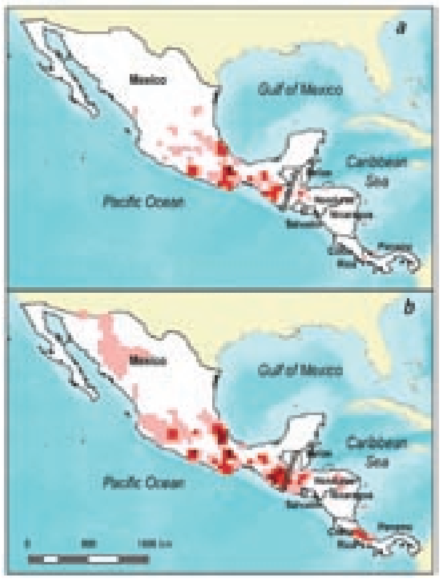

Figure B. Distribution of gap species found by Scenario A of the global gap analysis (a) and by the Global Amphibian Assessment (b). Darker shades of red correspond to higher species density.

Table I. Likely source of omission and commission errors.

Error type	Error source	%	Explanation
omission errors	protected areas data	4%	- protected area(s) not mapped - protected area(s) mapped in the wrong place - protected area(s) represented as points - protected area(s) represented as circles
	species' distribution data	5%	- incomplete species' range maps
commission errors	protected areas data	3%	- protected area(s) mapped in the wrong place - protected area(s) represented as circles
	species' distribution data	15%	- species' range maps include unoccupied areas

represented in the global protected areas system. Another possible explanation resides in differences between the criteria applied to assessing threat in birds and mammals. Hence, while all birds have been assessed following the new IUCN criteria (IUCN 2001), most mammals were assessed in or before 1996 (Baillie & Groombridge 1996). Additionally, the bird assessment is more comprehensive and probably a more reliable reflection of threat status in birds, while for mammals current threat status is probably unreliable for many of the small, poorly known, species.

The finding that species with higher levels of threat are more likely to be underrepresented, found in both scenarios, are expected. The smaller average range size of threatened species (see above) is again a likely explanation, as it implies that they are more likely to be missed by the network of protected areas (even though protected areas are sometimes created with threatened species in mind). For Scenario B, this effect is also confounded by the fact that the criteria adopted for considering a species covered were stricter for restricted-range species, which are frequently threatened.

There are two other explanations for the poorer coverage of threatened species. First, while presence in or absence from protected areas is not a criteria applied by IUCN to define the threat status of a species (IUCN 2001), it is more likely that species whose populations are not protected trigger the criteria for IUCN classification, such as population decline. Second, threat to species frequently results from widespread habitat destruction in biomes and geographical regions most intensively used by people – and these are also the regions where the creation of protected areas is socially and politically more contentious (Balmford *et al.* 2001).

The following sections delve further into these explanations by exploring the geographical patterns of covered and gap species for each taxonomic group individually.

RESULTS FOR GLOBALLY THREATENED BIRDS

The data for threatened birds is the most accurate of the biological datasets used in the global gap analysis. It is also the smallest of the three datasets, with only the 1,183 globally threatened bird species covered (BirdLife International 2000). Here, we examine in detail the results of the gap analysis for threatened birds, providing a geographic overview of the results in terms of irreplaceability, threat, and urgency, for both protected and unprotected sites.

The interpretation of all results for threatened birds should be made in the light of several overarching issues. First is the simple fact that, having the power of flight, birds are extremely good dispersers; over evolutionary time, they have dispersed to many remote regions, and currently inhabit nearly all land on the planet's surface. Those birds that reach isolated oceanic islands often face selective pressures different from those on continents, most notably a lack of predation, and so many have lost defensive adaptations (such as flight) which leaves them particularly vulnerable to extinction with the arrival of humans (Diamond 1991). Another important implication of flight is the ability of birds to migrate long distances (Salathé 1991). While most migratory birds are widespread throughout their life cycles, some species (especially seabirds) face constraints, such as the availability of inaccessible breeding sites (Croxall 1991), which have implications for their representation in the global protected areas system. Finally, birds adhere well to the general pattern of a steep latitudinal gradient of increasing species richness away from the poles (Blackburn & Gaston 1996), with the direct implication that, other things being equal, most gaps in avian coverage by the global protected area system will lie in the tropics.

Protected Sites

The irreplaceability of the world's protected sites (individual protected areas, or conglomerations of adjacent protected areas) for threatened bird species is mapped in Figure 4.5a. Clearly, irreplaceability is not wholly independent from protected area size – large conglomerations of protected areas will tend to be more irreplaceable, other things being equal. But we argue that, given the wide range of variation in the size of individual protected areas, presenting this real effect is much more important than producing a result that is comparable by unit area – everything else being equal, large protected areas are truly more irreplaceable than small ones. However, presentation of this map at the global scale does have another complication, in introducing a visual bias towards large protected area conglomerations – many tiny protected areas will simply be invisible on a global scale, even if highly irreplaceable. Nevertheless, a number of significant patterns can be discerned from this map.

Most obviously, highly irreplaceable protected sites for threatened birds are generally concentrated in tropical regions. Asia appears to have rather less highly irreplaceable protected sites than the other two tropical continents, although this is largely a visual artifact of the small size of Asian protected sites (see below). In Africa, highly irreplaceable protected sites are largely concentrated in the drylands of East and Southern Africa, a result driven partially by the large size and connectivity of protected areas in this region (IUCN 1992). In Latin America, irreplaceable protected areas are concentrated in the Guayana Shield, particularly the Venezuelan Tepuis (Mayr & Phelps 1967), and Amazonia – partly a product of the large size of Amazon protected areas (Rylands & Pinto 1998). Many Andean protected areas also have high irreplaceability, due to the exceptional number of threatened bird species with tiny ranges here (Fjeldså & Krabbe 1990). Numerous Atlantic Forest protected areas are highly irreplaceable too, but again many of these are tiny (Parker & Goerck 1997) and the region does not stand out on a global scale map. Islands generally feature rather poorly, partly because of the tiny size of many islands, partly because islands are generally underrepresented in the global protected area system (Moors 1985).

Surprisingly, there are also several obvious high latitude irreplaceable protected areas. The bulk of these are triggered by the breeding grounds of migratory species: two excellent examples are Wood Buffalo National Park in Canada, for Whooping Crane *Grus americana*, and Chaigurgino Nature Sanctuary in Siberia, for Siberian Crane *G. leucogeranus* (Meine & Archibald 1996). In only a very few cases is the irreplaceability of high latitude protected areas determined by genuinely restricted range species, such as Austral Rail *Rallus antarcticus* in Chile's Pali Aike and Torres del Paine National Parks (Imberti & Barnett 1999), and a number of species in New Zealand's Fiordland and Kahurangi National Parks (Clout & Craig 1995).

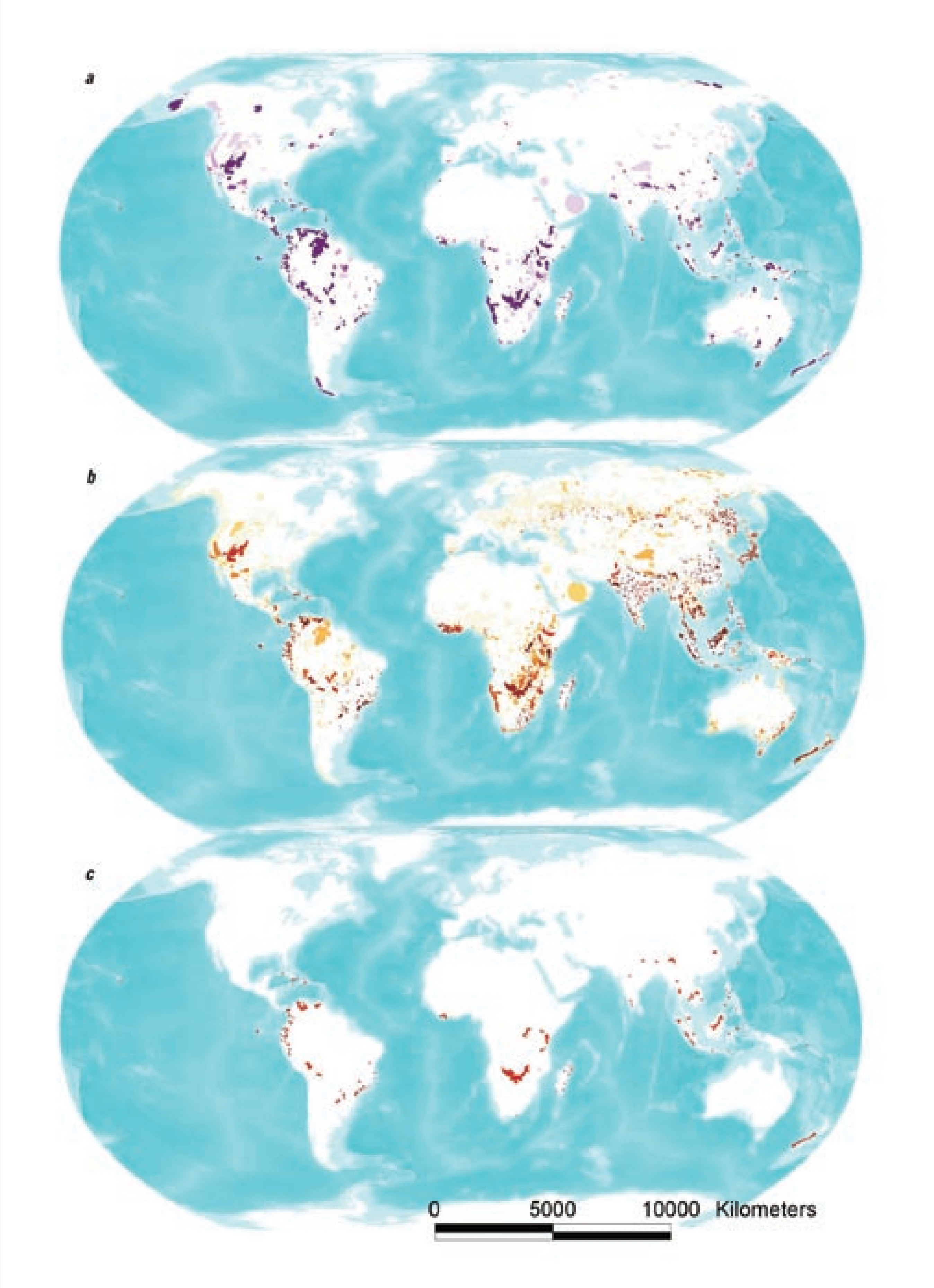

Figure 4.5 Global distribution of (*a*) irreplaceability, (*b*) threat, and (*c*) urgency for the conservation of threatened birds among protected sites, as obtained in Scenario B. Darker shades in (*a*) and (*b*) correspond to higher values of irreplaceability and threat.

Considering existing protected areas in terms of their richness of threatened bird species (weighted, as explained in Chapter 3), we find a rather stronger pattern of increasing richness towards the equator (Figure 4.5b). None of those parks holding the most threatened species are particularly large on a global scale. Examples include Parque Estadual do Desengano in Rio de Janeiro (Bencke & Maurício 2002), Zahamena National Park in Madagascar (Project ZICOMA 1999), and Mt Kitanglad National Park on Mindanao in the Philippines (Mallari *et al.* 2001). Nevertheless, there are some effects of park size here, with most large park complexes holding at least intermediate numbers of threatened species: the miombo protected area complex of central southern Africa is an excellent example, due largely to the number of widespread threatened species occurring in the region (Barnes 1998). Islands are again not well represented here, despite the large number of threatened island species, because most islands individually are rather species poor (and therefore threatened species poor).

Urgency, as defined here, is represented by upper values of the product of irreplaceability and threat (Figure 4.5c). The most urgent protected areas for increased investment for threatened birds lie almost without exception in the tropical forests and woodlands, especially in regions of complex topography or on islands. The Caribbean, Andes, Atlantic Forest, Eastern Arc Mountains, Madagascar, IndoBurma, and Indonesia are all particularly obvious; most of these regions were ranked among the hottest biodiversity hotspots proposed by Myers *et al.* (2000b). Non-forest protected areas scored as urgent are few and far-between: Argentina's Iberá Natural Reserve and adjacent protected areas (Di Giacomo *et al.* 2001), a key stronghold for a number of threatened grassland species, is a rare example. Tropical islands are rather more obvious on this map than on the maps for irreplaceability and threat: those that do hold protected areas, such as the Galápagos National Park (Swash & Still 2000), tend to be both highly irreplaceable and threatened.

Unprotected Sites

The bulk of this analysis focuses on the large proportion of the planet's surface lying outside of protected areas. For these unprotected sites, our units of analysis are half-degree grid cells, and so we circumvent the issues of dealing with unequal-sized units that we faced in assessing the current protected areas system (unprotected sites vary in size, but the variation is much smaller when compared to protected sites). Several commonalities, as well as contrasts, emerge from the analysis of unprotected sites in comparison with those of protected areas. Above all, these results underscore the importance of the tropics, especially of tropical mountain and island forests, with only New Zealand as a significant consistent exception to this pattern.

Scenario A asks where the ranges of threatened bird species do not intersect with protected areas. As discussed above, this is a major oversimplification of identifying those areas in need of increased protection, for example because even tiny, non-viable protected areas can trigger the *covered* status of a species. Nevertheless, a number of interesting results emerge from this analysis.

Most striking is the small number and geographic extent of the threatened bird species that are apparently unprotected under Scenario A (Figure 4.6). Small tropical oceanic islands appear noticeably: Henderson Island (Brooke 1995), São Tomé (Atkinson *et al.* 1991), Socotra (Kirwan *et al.* 1996), the Solomon Islands and Vanuatu (Doughty *et al.* 1999), and New Zealand's Chatham Island (Holdaway 1994), for example, all hold multiple unprotected threatened bird species. Less isolated islands also figure prominently, with Madagascar, notably Lac Alaotra (Hawkins *et al.* 2000), and Sangihe (Riley 1997) and Halmahera (Poulsen *et al.* 1998) in Indonesia, holding numerous threatened species. The latter is a particularly interesting example, because nine currently "proposed" protected areas would represent all of Halmahera's threatened birds. The only continental area holding numerous wholly unprotected species is the tropical Andes (Terborgh & Winter 1983).

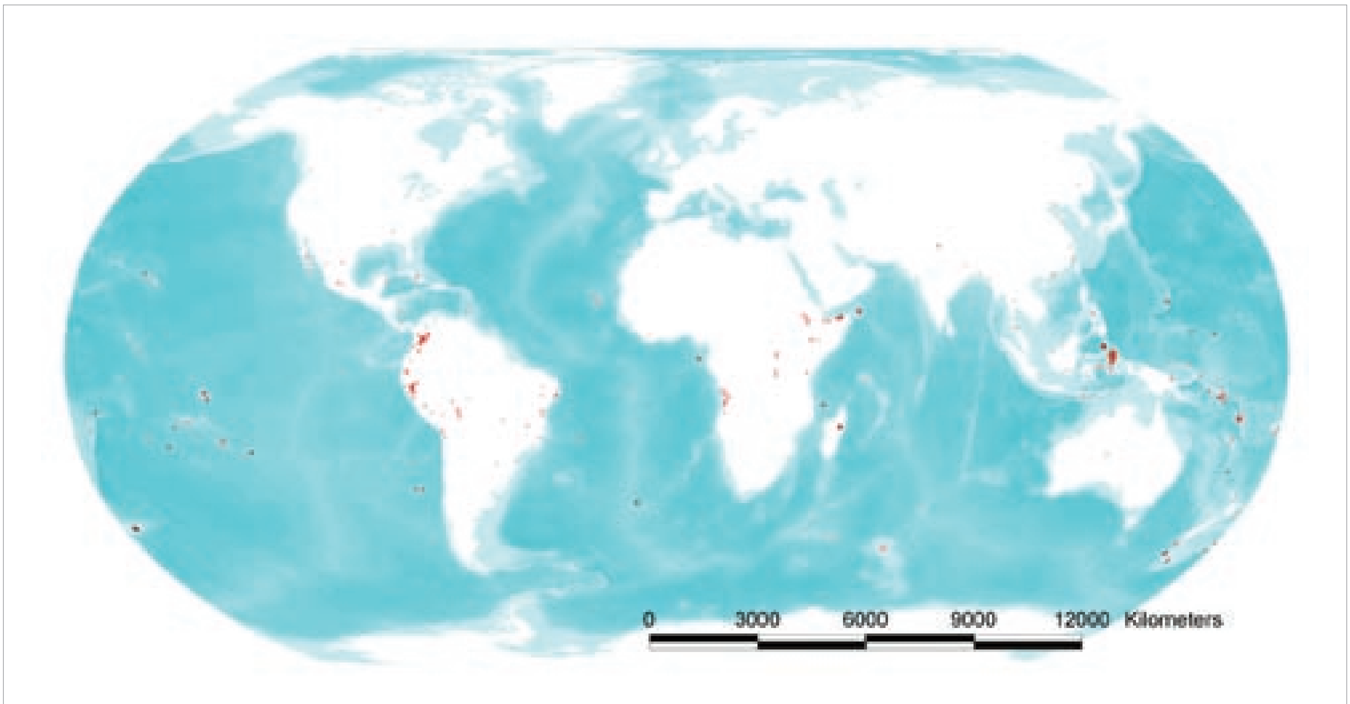

Figure 4.6 Distribution of threatened bird gap species-seasons identified in Scenario A. Darker shades of red indicate higher numbers of species-seasons.

As discussed earlier, various errors may cause us to identify some gaps incorrectly and miss other real gaps. Chile's Juan Fernández Islands demonstrate the former problem: their threatened bird species are formally protected in a National Park (Roy *et al.* 1999) but, although this is recorded in the WDPA, it was mapped as a circle between the islands, which misses land and therefore the islands' endemics (an extreme example of the problem of omission errors illustrated in Figure 2.5). Conversely, a few species such as Flores Hanging-parrot *Loriculus flosculus* and Flores Monarch *Monarcha sacerdotum*, endemic to the island of Flores in Indonesia, and known not to occur in any protected areas (Butchart *et al.* 1996), are incorrectly assumed to be protected (commission errors).

The irreplaceability map for unprotected threatened birds (Figure 4.7a) draws attention once again to the world's tropical mountains and islands. All of those islands identified as gaps under Scenario A are highlighted again, and a number of other islands with some – but inadequate – protection are also identified, for instance, the Philippines (Peterson *et al.* 2000). The real difference from Scenario A, however, comes in the continents, especially tropical mountains (Long 1994), where much larger areas are highlighted. Some regions that do not appear to have any gaps at all under Scenario A – such as the northern Central American highlands of Chiapas and Guatemala (Hernández-Baños *et al.* 1995), the Cameroon highlands (Stuart 1986), and Sri Lanka and the Western Ghats (Zacharias & Gaston 1999) – appear as highly irreplaceable here. The tropical Andes emerges once again as the most irreplaceable continental region (Renjifo *et al.* 1997).

As with Scenario A, some errors will doubtless creep into these results, although they should be much lessened here. For example, it appears surprising that Borneo features so little on the irreplaceability map, especially in comparison to Sumatra; both islands hold large numbers of threatened bird species, many with relatively small ranges (Brooks *et al.* 1999). The difference is presumably driven by the extensive coverage of protected areas running down Borneo's northern spine of mountains, including Mt Kinabalu (Davison 1992). Conversely, New Zealand appears more irreplaceable than expected given the extensive coverage of its threatened birds in protected areas (Lambert & Moritz 1995).

Clearly, the map of irreplaceability for threatened birds closely resembles existing global priority setting systems that are based on endemism and, to a lesser extent, threat. Most striking is the correspondence between this map and that of the Endemic Bird Areas of the World (Stattersfield *et al.* 1998). Even in comparison to studies based on plant endemism, rather than bird endemism, such as the hotspots of Myers *et al.* (2000b), only a few regions (such as Central Chile and the Caucasus) do not emerge as highly irreplaceable for threatened, unprotected birds. We discuss this further in our later discussion of the global gap analysis in the context of other global prioritization systems.

The species richness of the threatened birds of the world has been published before (BirdLife International 2000), and the weighting towards Critically Endangered species used here (Figure 4.7b) does little to change this overall pattern. The Philippines, Borneo, and Sumatra emerge as holding much the largest concentrations of globally threatened birds (Brooks *et al.* 1997). Only the Atlantic Forest, eastern Madagascar, and the eastern Himalayas rival these concentrations. The concentrations of threatened species in Southeast China, Japan, and in a band across the central Asian steppes is rather more surprising, a result driven by the large number of widespread East Asian threatened species (Collar *et al.* 2001). Oceanic islands, generally, do not stand out particularly dramatically: although islands overall hold many threatened birds, the low richness of most individual islands limits the number of threatened species of individual islands.

Interestingly, the last 500 years of bird extinctions (Brooks 2000) do not compare well with the distribution of unprotected, threatened bird species (Figure 4.7b). The vast majority of recent bird extinctions were on oceanic islands, especially in the Caribbean, Mascarenes, New Zealand, and Hawai'i and the Pacific generally. These islands do not stand out very clearly on the map of threatened bird species, because (even historically) they held so few species. This is doubly the case now that these islands have passed through an 'extinction filter' (Balmford 1996), losing all of their most vulnerable species and left with particularly depauperate, resilient avifaunas. Importantly, this effect is much more the case for birds – given their overwater dispersal capabilities and propensity to speciate on oceanic islands – than it is for mammals or, especially, amphibians.

The map of distribution of unprotected urgent sites (Figure 4.7c), building from the distributions of irreplaceability and threat among globally threatened birds to highlight areas where new protected areas are most urgently needed for the group, is best examined in comparison with its sister map for urgency of increased action in existing protected areas (Figure 4.5c). Again, the areas highlighted here are almost entirely tropical: very few areas emerge as the most urgent priorities for the establishment of new protected areas for threatened birds in the Holarctic, South America's southern cone, or Australia. The exceptions are the south Japanese islands (Itô *et al.* 2000) and, perhaps surprisingly, many sub-Antarctic islands, triggered largely by their colonies of seabirds – especially albatrosses – which are facing drastic declines due to longline fishing (Thomas 2000). New Zealand is certainly also an urgent priority, although maybe more for the maintenance of existing protected areas than for the establishment of new ones (see above).

Oceanic islands generally emerge much more urgently for unprotected than for protected areas, demonstrating again the precariously low level of protection of the world's islands. Hawai'i is an excellent example of an island group which, despite having an already extensive protected area coverage, urgently requires increased conservation attention, although much of this would be better targeted at the control of invasive species than at the establishment of new protected areas (Scott *et al.* 1986). The Caribbean, Madagascar, the Philippines, and the Solomon Islands all also emerge as urgent priorities for the establishment of new protected areas, as well as for the improvement of existing ones.

On the continents, we see largely similar patterns between the urgency maps for unprotected and protected areas. The Andes, Atlantic Forest, the Eastern Arc and Coastal Forests of Kenya and Tanzania, and IndoChina emerge as consistently high priorities. Maybe the clearest difference is in southern and eastern Africa, regions triggered as urgent for increased activity in existing protected areas (partially due to the large size of many protected areas here), but in which few threatened bird species are seriously underrepresented

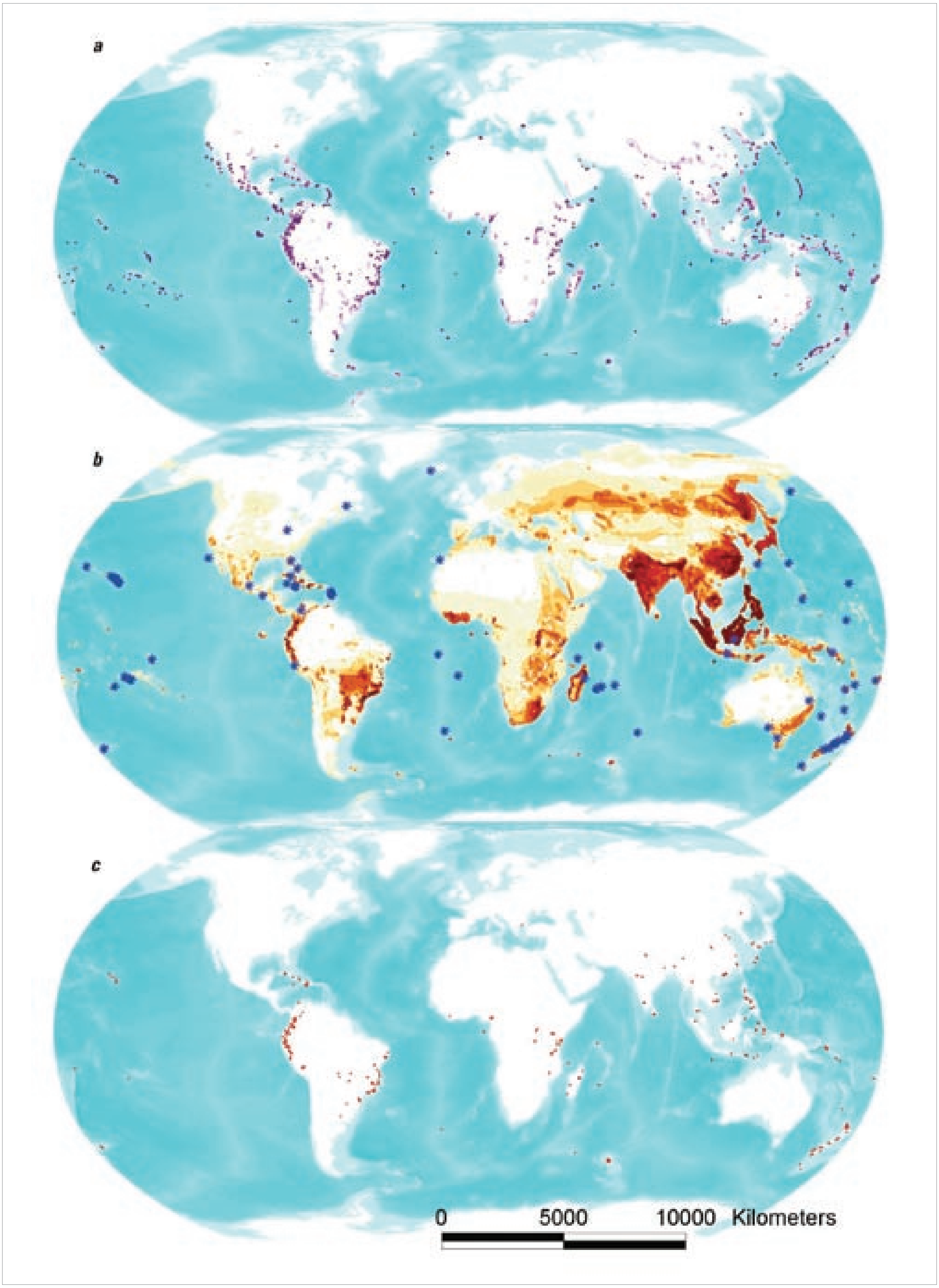

Figure 4.7 Global distribution of (*a*) irreplaceability, (*b*) threat, and (*c*) urgency for the conservation of threatened birds among unprotected sites, as obtained in Scenario B. Darker shades in (*a*) and (*b*) correspond to higher values of irreplaceability and threat. Asterisks in (*b*) represent the centers of ranges of extinct species, and are shown here for illustrative purposes only (have not been included in the measure of threat).

in protected areas. Another more surprising difference is the low degree to which unprotected areas in the Greater Sundas emerge as urgent. This is largely because of their existing extensive protected area coverage on paper – although these parks are in urgent need of increased conservation attention (Lambert & Collar 2002).

RESULTS FOR MAMMALS

Mammals are among the most successful species on the planet. Mammals inhabit every major realm on Earth (Nowak 1999), and include many ecologically and evolutionarily diverse species, including marine and aquatic species, as well as the volant bats. Over the course of their evolution, mammals have exhibited a vastly diverse array of forms and functions, with wide variation among species in body size, life history, and ecology. Like birds, they are endotherms ("warm-blooded"), and different species have adapted to live in different climates, although, as with most groups of species, the highest species diversity is concentrated in the tropics (e.g., Ceballos & Brown 1995, Gaston *et al.* 1995). Unlike birds, most mammals do not make large-scale migrations (Macdonald 2001), and even those that do, such as the Serengeti Wildebeest *Connochaetes taurinus* and Arctic Caribou *Rangifer tarandus*, pale in significance to the epic avian wanderings of species like the Arctic Tern *Sterna paradisaea* (Gochfeld & Burger 1996). Nevertheless, mammals have carved out niches in almost every ecosystem on the planet.

The mammalian class includes some of the most widespread species on earth. Species like the Grey Wolf *Canis lupus* and Red Fox *Vulpes vulpes* have circumpolar distributions, the former living throughout the northern hemisphere north of 15°N latitude, while the latter has a geographical range covering nearly 70 million km^2 (Sillero-Zubiri *et al.* in press). In the case of the red fox, anthropogenic expansion has contributed greatly to the ability of the species to increase its range (including introduction to Australia with devastating impacts on the native fauna). Indeed, many species have become commensal with man and colonized the farthest corners of the globe, often with detrimental impacts on their new environments (Ebenhard 1988, Alcover *et al.* 1998).

Nevertheless, most mammals also have small ranges, with more than half of all mammal species having ranges less than 250,000 km^2, roughly equivalent to an area the size of Italy. Perhaps more intriguingly, some 29 percent of mammals have range sizes less than 50,000 km^2 (with birds at 28 percent, Stattersfield *et al.* 1998). By far the highest number of such restricted-range mammals can be found in the large orders characterized by species with small body sizes including the rodents (Rodentia), bats (Chiroptera), and shrews and moles (Lipotyphla, ex "Insectivora"), all of which have more than one-third restricted-range species.

The distribution of restricted-range species also varies across continents, from 226 in Africa to only 58 in Australia. Islands, too, hold many restricted range species. Physical barriers and topography are the most important mechanisms that have served to confine mammalian distribution ranges.

Next to birds, mammals are the most well-studied group, including some of the most charismatic and appealing species on Earth. However, much of our knowledge about mammals is confined to the larger species. Many restricted-range species are poorly known, and many so-called endemics are merely artifacts of limited distributional or taxonomic knowledge. Indeed, many gap species identified here are known only from their type localities, and the description of new mammal species continues (Patterson 1996, 2001). These biases cannot be overcome until additional systematic and survey work has been conducted.

Finally, the strong relationship between endemism and threat holds true for mammals (Purvis *et al.* 2000). We know that about 25 percent of mammals are threatened with extinction, and that the two overarching threats facing mammals are habitat loss and exploitation, affecting 83 percent and 34 percent of mammals, respectively (Hilton-Taylor 2000). However, nearly 80 percent of mammals on the current IUCN Red List have not been assessed since 1996 (Baillie & Groombridge 1996), and, consequently, not assessed following Version 3.1 of the IUCN Categories and Criteria (IUCN 2001).

Protected Sites

Overall, the map showing irreplaceability of protected sites for mammals (Figure 4.8a) shows some similarities with those identified for birds (Figure 4.5a) and for amphibians (Figure 4.14a). This is unsurprising, given that irreplaceability throughout is being driven partly by protected area size, particularly for the large protected areas complexes in the western United States, Amazonia, and the drylands of southern and East Africa. However, these same large protected areas complexes show very little congruence with restricted-range species. For example, the huge protected site in the miombo-mopane woodlands region of southern Africa that includes the proposed "Okavango-Upper Zambezi" Transfrontier Conservation Area (TFCA), holds only a single restricted-range species, Shortridge's Multimammate Mouse *Mastomys shortridgei* (Skinner & Smithers 1990). However, the same site is triggered as being irreplaceable, because it overlaps the ranges of around 230 mammals, and includes large parts of the ranges of species such as the Lechwe *Kobus leche* (East 1999; Figure 4.9).

A similar example is the 150,000 km^2 cluster of protected areas in northeastern Canada and southwestern Alaska, which comprises a network of 29 conservation units ranging in size from areas smaller than one square kilometer to as large as 67,400 km^2. All told, a little more than 50 mammal species are represented in this complex, but the overwhelming majority have ranges larger than one million km^2.

As already noted for birds, viewing this map from a global perspective introduces a perception bias towards these large protected areas complexes, whereas many small and endemic-rich protected areas that are also highly irreplaceable are not so visible. For example, four protected areas complexes in southwestern India are nearly invisible on the map, yet their high irreplaceability levels are triggered by the inclusion of substantial portions of the ranges of threatened restricted-range species like the Nilgiri Tahr *Hemitragus hylocrius*, Nilgiri Marten *Martes gwatkinsii*, Malabar Civet *Viverra civettina*, Jerdon's Palm Civet *Paradoxurus jerdoni*, Hooded Leaf Monkey *Trachypithecus johnii*, and Sri Lanka Highland Shrew *Suncus montanus*. For example, Anamalai and Parambikulam Wildlife Sanctuaries and Eravikulam National Park have about 70 percent (2,000 animals) of the total population of the Endangered

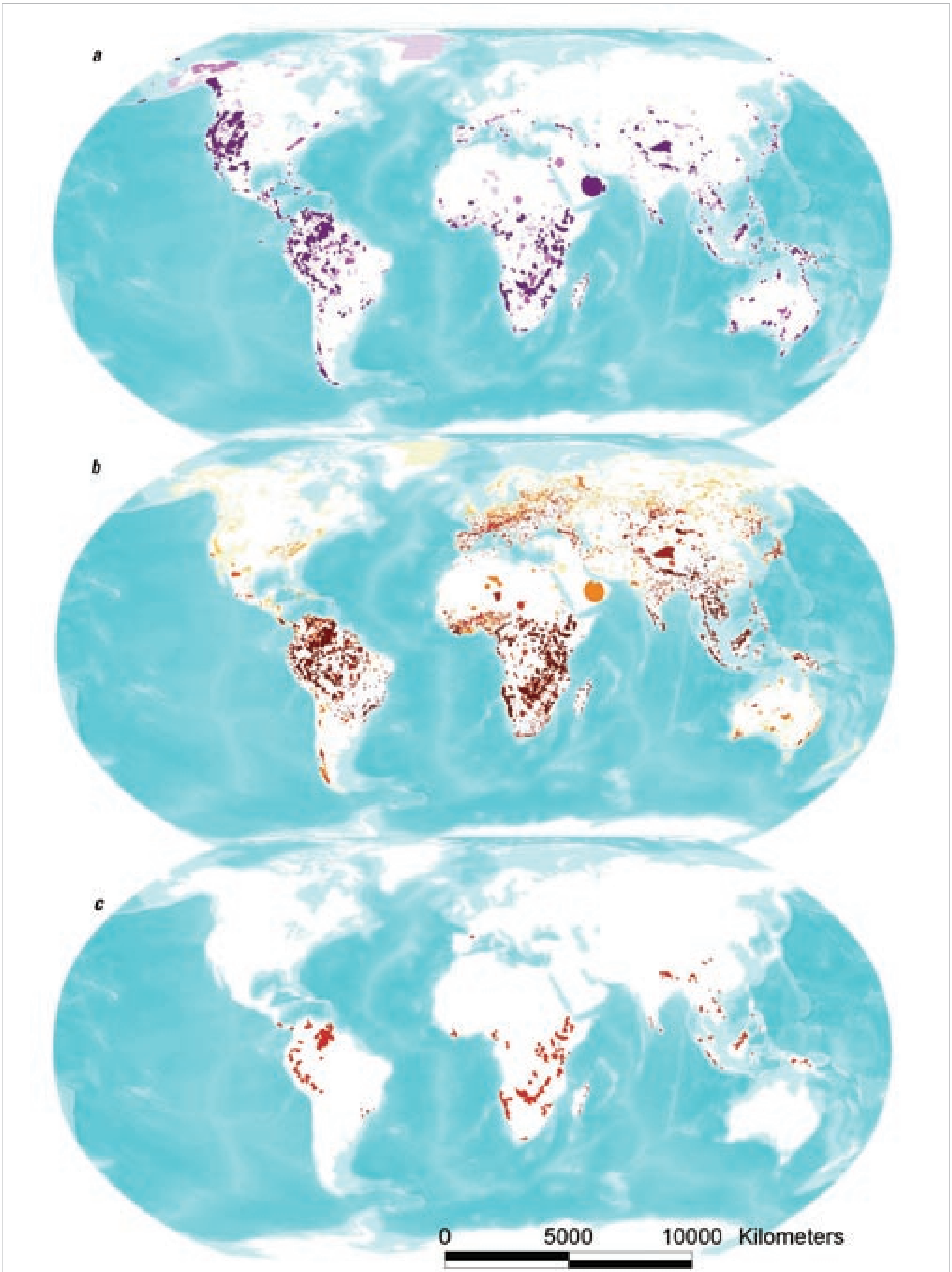

Figure 4.8 Global distribution of (*a*) irreplaceability, (*b*) threat, and (*c*) urgency for the conservation of mammal species among unprotected sites, as obtained in Scenario B. Darker shades in (*a*) and (*b*) correspond to higher values of irreplaceability and threat.

Figure 4.9 The large network of existing protected areas at the borders of Botswana, Namibia, Angola, Zambia, and Zimbabwe, emerge as high urgency in this analysis. This network area includes the Okavango Delta – one of the largest wetlands in the world – and is home to important populations of bird species such as the Wattled Crane *Grus carunculatus* (Vulnerable), as well as more than 100,000 Africa Elephants *Loxodonta africana* (Endangered). Some progress is already being made with linking up part of this vast network of protected areas to create the proposed Okavango-Upper Zambezi Transfrontier Conservation Area. Photos [top] Haroldo Castro; [bottom] Jeff Gale.

Nilgiri Tahr (Stuart & Johnsingh 2003). Other, even smaller, protected areas that have high levels of irreplaceability can be found throughout the tropics.

Many small protected areas triggered by high levels of endemism are found on islands, because they hold many restricted-range mammal species. For example, Pico Basile Forest Preserve on the island of Bioko in the Gulf of Guinea holds approximately 40 species and represents important habitat for six restricted-range species, among them Eisentraut's Mouse Shrew *Myosorex eisentrautii* and Isabella Shrew *Sylvisorex isabellae* (Eisentraut 1973). Bushmeat hunting in Bioko is having a devastating impact on its populations of primates, which are being hunted to dangerously low levels (Fa *et al.* 2000).

Similarly, mainland examples of small sites with high irreplaceability are also insular in nature, commonly occurring in mountainous regions such as the Bale Mountains in Ethiopia, which includes the majority, and in some cases the entire range, of species such as Ethiopian Wolf *Canis simensis*, Bale Monkey *Chlorocebus djamdjamensis*, Bale Shrew *Crocidura bottegoides*, Big-headed Mole Rat *Tachyoryctes macrocephalus*, and Mountain Nyala *Tragelaphus buxtoni* (Yalden & Largen 1992). This area is becoming increasingly insular, due to the impacts of livestock and settlement around the park (Stephens *et al.* 2001).

Finally, the huge protected area between southern Saudi Arabia, eastern Yemen, and western Oman, Ar-Rub'al-Khali (meaning "the empty quarter"), the largest sand desert in the world, deserves discussion. The area, while remarkably large (some 640,000 km^2 in extent), is notable for its limited floristic diversity: only 37 species of higher plants occur, of which 17 are known mostly from around the outer margins (Mandaville 1986). Similarly, mammalian diversity and endemism is also low, although the area does include most of the range of the Endangered Arabian Jird *Meriones arimalius* (Harrison & Bates 1991). Consequently, it does not stand out in a global map of threat for protected areas (Figure 4.8b).

As is the case for birds (Figure 4.5b), the most threatened protected areas (Figure 4.8b) are centered in the tropics, where the effects of habitat loss and deforestation are being felt the hardest, and where the impacts of exploitation are greatest. Most large high latitude protected area complexes hold only intermediate numbers of threatened mammal species. Even though areas such as the miombo-mopane woodlands appear striking on the global map, they hold significantly lower numbers of threatened species than areas such as the Ethiopian Highlands. Important regions where protected sites are triggered by their representation of threatened species include: eastern Costa Rica/western Panama; some Andean regions of Ecuador and Peru; Manu and Alto Purus in west Amazonia; some isolated sites in the Atlantic Forest of southern Brazil; the Ethiopian Highlands (Arsi Controlled Hunting Area and Bale National Park); East Africa east of the Gregory Rift; the Albertine Rift (mainly the Virunga and Ruwenzori Mountains National Parks); the Cross-Sanaga Rivers region of Cameroon and Nigeria; forested regions of eastern Madagascar; the southern Himalayas (Quomolangma in Tibet); Indo-Malaysia (e.g., Gunung Leuser and Kerinci Seblat NPs on Sumatra, much of northern Borneo); and the central highlands of New Guinea. Oceanic islands generally are poorly represented, because (as with birds), despite the fact that islands often have a high proportion of threatened species, the level of diversity on individual islands is low.

A number of protected areas holding threatened mammals are large when considered on a global scale: the most obvious examples include the Tsavo East and West/Mkomazi complex in Kenya and Tanzania (an area of almost 40,000 km^2 holding 21 threatened mammal species), the massive Selous ecosystem in southern Tanzania (50,000 km^2, holding 13 threatened mammals), and the Manu/Alto Purus complex in southern Peru (50,000 km^2, 15 threatened mammals). In general, these large areas contain widespread, threatened large mammal species. The single richest concentration of protected areas for threatened species (weighted as discussed earlier) are in northern Borneo, represented by multiple, small, protected areas notable for holding large numbers of threatened species, such as the Milian-Labau Virgin Jungle Reserve (22 species, less than 30 km^2).

Given the patterns observed for irreplaceability and threat, there are few immediate surprises when considering the results for protected sites of the highest urgency for the conservation of mammals (Figure 4.8c). Many of the large protected areas complexes in the Nearctic and Palearctic regions that appear so important when only irreplaceability is considered, fall out when threat is factored in. A similar scenario is evident for Australia, though this may be affected by the fact that more mammals have gone extinct from Australia than anywhere else in recent times – about one-third of all recent mammal extinctions – largely caused by exotic predators (Burbidge & Manly 2002).

The Andes, Tepuis, southern Atlantic Forest, the deserts of southwestern Africa, the miombo-mopane woodland, East Africa, the Albertine Rift, Ethiopian Highlands, and much of Southeast Asia, all stand out as areas of high urgency. Although some of these protected areas complexes are exceptionally large on a global scale, the level of actual protection is extremely variable. For example, of the 38 wildlife conservation areas in Ethiopia, only two are gazetted (EPA & MEDAC 1997) and active protection and management have occurred in only a few protected areas (East 1999, Jacobs & Schloeder 2001).

Perhaps the most eye-catching result of this analysis (at least by virtue of its isolation) is the small, protected area complex that shows up as high urgency in the Pyrenees between France and Spain. This site holds 68 species of mammals, 10 of them threatened, and is, in particular, an important area for the conservation of the restricted Pyrenean Chamois *Rupicapra pyrenaica* (Shackleton 1997, Mitchell-Jones *et al.* 1999).

Unprotected Sites

In a map representing the distribution of gap species as obtained for Scenario A (Figure 4.10), the region that stands out most prominently is Africa, and specifically northern Somalia, with species like Beira *Dorcatragus megalotis* entirely unrepresented in any formal conservation unit (East 1999, Laurent *et al.* 2001). Conversely, neighboring Ethiopia has some gap species, but does not stand out as being a gap region, because of its extensive reserve network, although few of its protected areas have legal status, active management, or infrastructure.

In contrast, other regions highlighted as gaps in Africa may show up as artifacts because we lack knowledge of the region. For example, several species throughout North Africa, particularly gerbils and some shrews, show up as gap species. Many of these species are known only from their type localities and are of doubtful taxonomic validity, and some of them have not been recorded for more than 50 years (Wilson & Reeder 1993). A number of these species may be more widespread, but there has been little survey work done in the region. The same holds true for some other areas, such as the Democratic Republic of Congo.

Despite these caveats, many of the smaller areas identified in Scenario A in Africa and elsewhere in the world are truly important gaps, including the Solomon Islands, East Sulawesi, the Sea of Cortez and Tres Marias islands off western Mexico, and, in Indonesia, North and South Pagai and Sipora Island off the west coast of Sumatra, and the Banggai Islands off eastern Sulawesi.

Surprisingly, the South American Andes and Atlantic Forest do not feature significantly in Scenario A (Figure 4.10). This may be an artifact of data quality, as the Andean species range data are relatively poor, but it is more likely to be the effect of commission errors caused by small, scattered protected areas that apparently cover the range of most species in these regions. Also, the existing small protected areas in regions that have undergone extensive habitat loss, such as in Madagascar and the Atlantic Forest, probably cover much less of species ranges than indicated by the analyses. Indeed, these same regions are prominent highlights in a map of irreplaceability according to Scenario B (Figure 4.11a). Here the regions that stand out most prominently are also those where species with restricted ranges occur together. Besides the Andes and the Atlantic Forest, these include the California Floristic Province, Mesoamerica, the Caribbean, the Fynbos and Succulent Karoo biomes of southern Africa, the Albertine Rift, the montane highlands of Kenya, Eastern Arc mountains and coastal forests, the Ethiopian highlands, the Marra Plateau in Sudan and the floodplains around Lake Chad, the Jos Plateau in Nigeria, the Cross-Sanaga River region in Nigeria/Cameroon, the low-lying regions of Madagascar, the Pyrenees, the Caucasus, the Zagros Mountains in western Iran, the Himalayas, western Ghats and

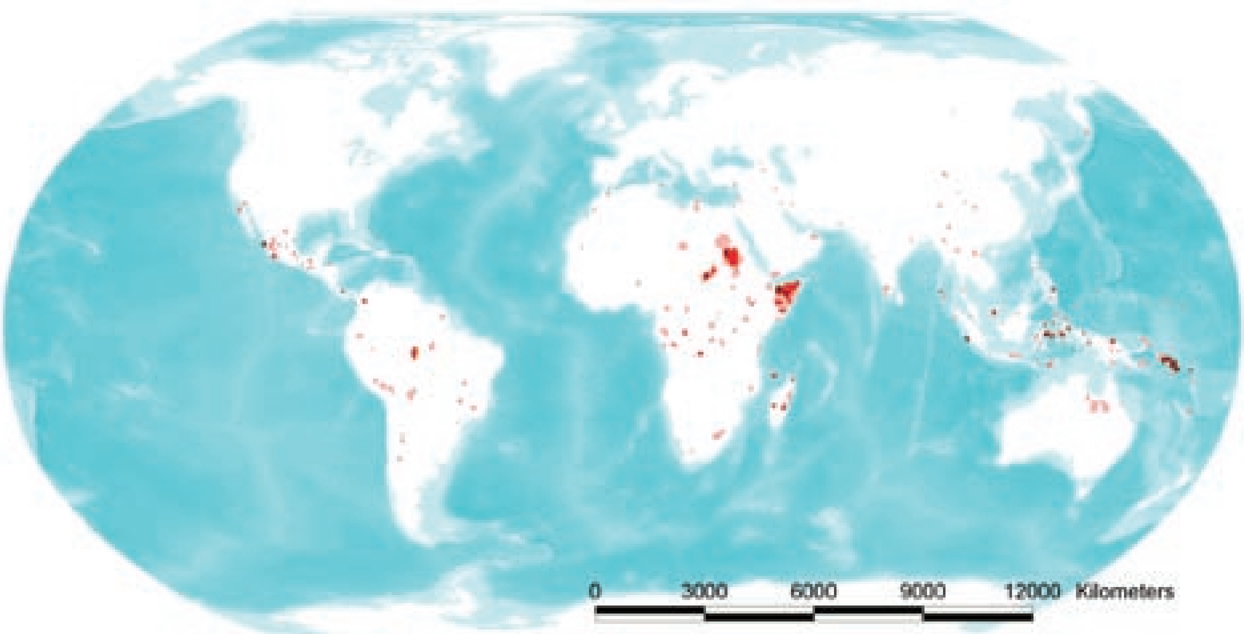

Figure 4.10 Distribution of mammal gap species identified in Scenario A. Darker shades of red indicate higher numbers of species.

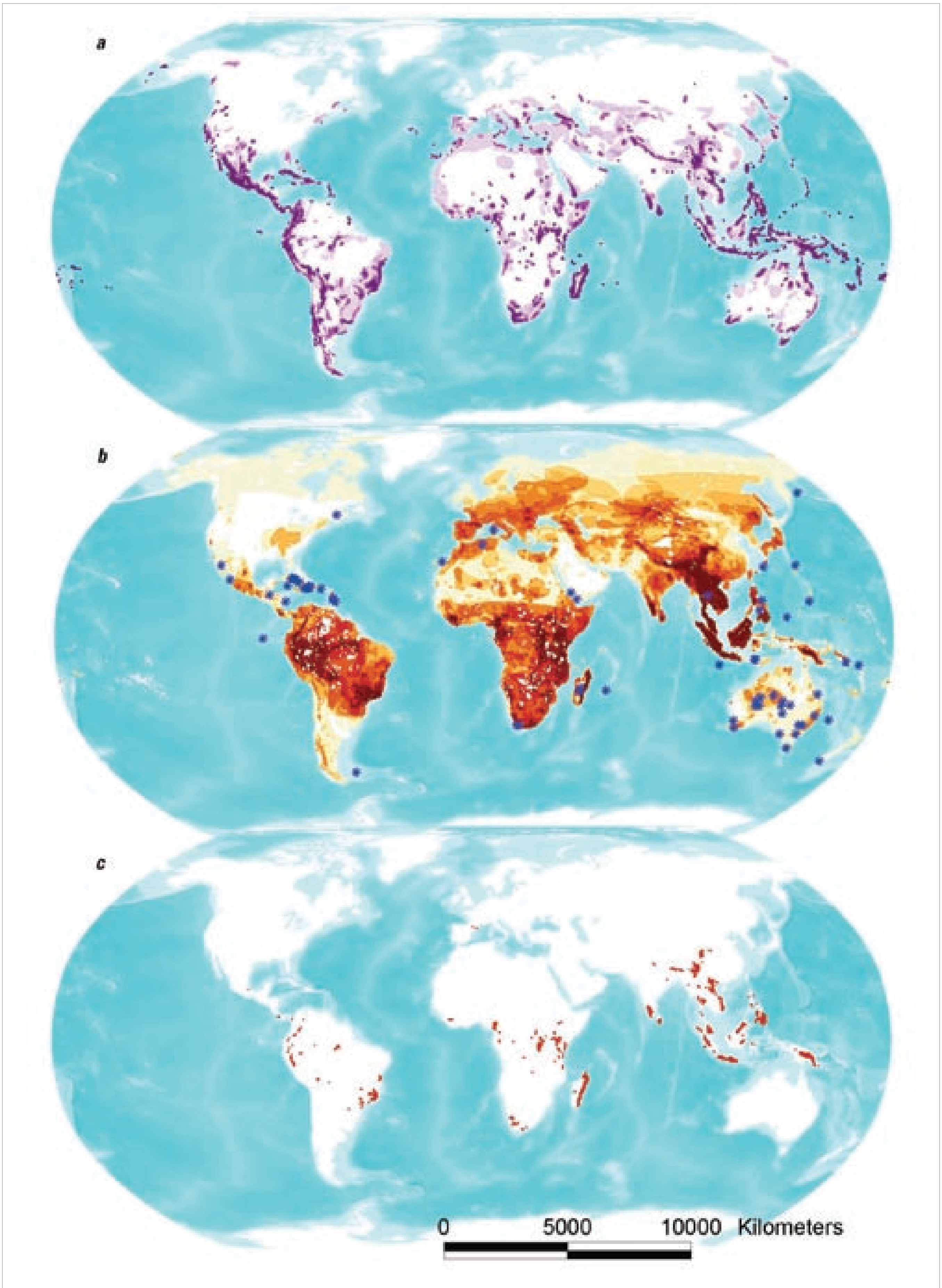

Figure 4.11 Global distribution of (*a*) irreplaceability, (*b*) threat, and (*c*) urgency for the conservation of mammal species among unprotected sites, as obtained in Scenario B. Darker shades in (*a*) and (*b*) correspond to higher values of irreplaceability and threat. Asterisks in (*b*) represent the centers of ranges of extinct species, and are shown here for illustrative purposes only (have not been included in the measure of threat).

Sri Lanka, central Honshu in Japan, southeast China, Indo-China, the upland regions of the Malaysian Peninsula, much of Indonesia and the Philippines, New Guinea, southwest Australia, the Kimberley region, Cape York Peninsula, and Tasmania. Nearly all of the biodiversity hotspots identified by Myers *et al.* (2000b) appear as highly irreplaceable regions in this map (even the Caucasus, which does not feature highly for other taxa, though not New Zealand, which has only two extant native bats among its terrestrial fauna), but other areas are added: the southwestern Arabian mountains, Jebel Marra in Sudan, the Albertine Rift, the Kenyan highlands, the Angola Scarp, East Melanesia, and Tasmania.

As noted for birds, the extent of 'gap regions' is much larger areas in Scenario B than in Scenario A (Figure 4.10). Extensive regions such as the Andes, Mesoamerica, Himalayas, Indo-Burma and southwest Australia, which do not appear as gaps at all in Scenario A, come out very strongly here (Figure 4.11a). Further, more so than in any other analysis for mammals, the high level of irreplaceability of oceanic islands is apparent, now including many islands in Micronesia/Polynesia and the eastern North Atlantic. Large numbers of restricted-range species are also found in New Guinea, the Solomon Islands, Madagascar, the Talamancan mountains, Ethiopian Highlands, Kenyan Highlands, and the Western Ghats. These can all be considered insular, whether actual islands or island habitat (i.e., mountain tops).

Regarding threat (Figure 4.11b), the highest levels for unprotected regions are in the Atlantic Forest of southern Brazil, the Cross-Sanaga region of Cameroon/Nigeria, the Albertine Rift, the montane forests of southwestern Kenya, eastern forested regions of Madagascar, the western Ghats, Sri Lanka, much of Indo-Burma, and the islands of Sumatra, Java, Borneo and New Guinea. As noted for protected sites, individual oceanic islands do not stand out because of their low mammalian diversity. Regions in high latitudes emerge because of the presence of large numbers of widespread threatened mammals. Main forces driving threat in these regions include the usual suspects: habitat loss and fragmentation (particularly in Brazil's Atlantic Forests, the forests of eastern Madagascar, and much of Indonesia). However, the increasing bushmeat trade is creating new threats, particularly in regions of Africa (Bakarr *et al.* 2001) and, to a lesser extent, in the Neotropics (Peres & Lake 2003) and Southeast Asia (Bennett *et al.* 2000). Rampant extraction of non-timber resource creates intact forests with no wildlife, the "Empty Forest Syndrome" (Redford 1992).

As with birds, when one considers the distributions of the 74 species of mammal that have gone extinct since 1500 (IUCN 2002, but see MacPhee & Flemming 1999), it is apparent that these, too, do not compare well with the distribution of unprotected threatened mammals. Since the oceanic islands of Polynesia/Micronesia hold few mammals, they are not highlighted as much as for birds, but the Indo-Malayan region, that comes out strongest for unprotected threatened mammals, is characterized by only a handful of extinct mammals. Instead, two clusters of mammalian extinctions stand out: Australia, which has lost 19 mammal species, and the Caribbean, in particular the oceanic islands of Cuba and Hispaniola, having lost five and ten species, respectively. Today, the Caribbean islands do not stand out on a list of threatened mammals, because they hold so few extant species, while, in the case of Australia, the degree of threat is relatively low when compared to regions such as eastern Madagascar or Southeast Asia.

Combining irreplaceability with threat for unprotected areas produces a map of sites that are currently unprotected, which represent the highest level of urgency for mammal conservation (Figure 4.11c). As with protected areas, unprotected sites of high urgency are centered on the tropics – particularly the Andes, Atlantic Forest, Albertine Rift, montane regions of Kenya, the Eastern Arc Mountains and Coastal Forests, eastern forests of Madagascar, Western Ghats and Sri Lanka, Indo-Burma, Indonesia, and New Guinea. Many of these sites are entirely complementary to existing protected area sites of high urgency. There is marked overlap here with the hotspots identified by Myers *et al.* (2000b), with the exception of the Albertine Rift, Kenyan highlands, and New Guinea. This overlap is more pronounced for mammals than for either birds or amphibians.

The high urgency identified for the Succulent Karoo biome of southern Africa (Figure 4.12) is of interest. The protected areas complex in South Africa is perhaps at its weakest in this biome (only 3.5 percent of the 112,000-km^2 biome is formally conserved), despite the fact that the biome holds more than 6,000 plant species, with 40 percent as endemics. Nine percent of approximately 70 mammals occurring in this biome are strict endemics, among them a number of golden mole species (Driver *et al.* 2003).

Figure 4.12 The Succulent Karoo biome in southern Africa is identified as an area of high urgency for the expansion of the network of protected areas. Less than 4 percent of this biome, about 112,000km^2, is currently protected, even though the biome holds more than 6,000 plant species, with 40 percent as endemics. The topic of expanding and creating linkages between existing protected areas in the biome has been the focus of recent priority-setting exercises (Cowling *et al.* 1999). Photo by Donovan Kirkwood.

As was the case for protected areas, sites in the Nearctic and Palearctic regions, and Australia emerge with a markedly low level of urgency – all areas with relatively low species diversity. The absence of New Zealand is unsurprising (just two indigenous mammals), but perhaps among the most noticeable omissions of all is the Caribbean. In contrast to the case with birds and amphibians, the low mammalian species diversity of the individual islands does not trigger high levels of urgency for mammals, even though there are at least 15 Critically Endangered and Endangered species confined to the Caribbean region (Woods & Sergile 2001). Although these islands were never as rich in mammal species as nearby continental regions, their current fauna is substantially poorer than it was before human colonization drove extinct the majority of non-volant mammals, including species ranging from solenodons and hutias to sloths and monkeys (Figure 4.11).

Figure 4.13 An undescribed species of frog, belonging to the genus *Litoria*, from Papua New Guinea. The level of available knowledge is much lower for amphibians than for either birds or mammals, with many new species still being described each year. Photo by Steve Richards.

RESULTS FOR AMPHIBIANS

The particular characteristics of amphibian ecology and physiology distinguish them from the other taxa analyzed in this study. Being ectothermic ("cold-blooded"), they are mainly associated with warm temperatures. Their water-permeable skin tends to restrict them to humid conditions, although a few are moderately tolerant of aridity. At a global scale, they are thus a taxon mainly associated with tropical regions, showing lower diversity in the polar and desert regions (Gaston *et al.* 1995, Duellman 1999a). At a local scale, they are highly associated with freshwater habitats, and are therefore particularly exposed to threats to these habitats. This preference for freshwater (and intolerance to seawater) explains the poor island colonization ability of amphibians, which results in lower levels of island endemism than those found for mammals or (especially) for birds.

The level of available knowledge is much lower for amphibians than for either birds or mammals (although some small mammals are as little known as amphibians). The Global Amphibian Assessment is proving crucial in compiling the currently scattered information on the distribution, population status and threats to these species, but is also highlighting how poorly known many of them truly are (see Section 2.4). More than 20 percent of the amphibian species evaluated so far have been classified as Data Deficient (i.e., the information available is inadequate to make a direct or indirect assessment of their risk of extinction, IUCN 2001), compared to 0.8 percent of birds and 5 percent of mammals. Many of these Data Deficient amphibian species are likely to be highly threatened. In addition, there are still very high rates of new species descriptions (Duellman 1999a), and many more species are awaiting description, particularly in Asia (e.g., Biju 2001, Meegaskumbura *et al.* 2002), New Guinea (S. Richards *pers. comm.*), tropical Africa (J.C. Poynton, J.L. Amiet, & M.O. Roedel *pers. comm.*) and parts of South America (Duellman 1999a). In some countries, such as Lao PDR, Cambodia, Bhutan, Myanmar, Democratic Republic of Congo, Angola and Papua New Guinea, exploration of the amphibian fauna is at such an early stage that it can hardly be characterized (Figure 4.13). In each of these countries, the species total will almost certainly more than double as exploration advances.

As mentioned above, in relation to birds and mammals, the typical range size of amphibian species is very small. The levels of endemism are particularly striking in tropical areas of complex topography, with species ranges often restricted to a particular slope of a particular mountain, which leaves species particularly vulnerable to habitat destruction and fragmentation (Duellman 1999a, Inger 1999). Other threats to amphibians include introduced species and direct exploitation (Kats & Ferrer 2003). However, there have been declines and even extinctions reported from apparently pristine areas, even in some cases within protected areas (Pounds *et al.* 1997). Increasing ultraviolet radiation, environmental contaminants and climate change have been suggested as possible explanations (Kiesecker *et al.* 2001). Additionally, there is increasing evidence that at least some of these declines have been caused by infectious agents, in particular the fungal disease amphibian chytridiomycosis (Berger *et al.* 1998). The highly permeable skin of amphibians, and their exposure to terrestrial and aquatic habitats at different stages of their life cycles, may make them more vulnerable than other vertebrates to environmental contaminants and changes in temperature and rainfall patterns.

The accumulating evidence for simultaneous declines of hundreds of amphibian species throughout the world (Alford & Richards 1999, Young *et al.* 2001) prompted the IUCN Species Survival Commission to establish a Declining Amphibian Population Task Force (DAPTF) in 1991 to assess the geography, extent, and causes of declines and disappearances of amphibians (http://www.open.ac.uk/daptf/).

We now move on to examining the results of the gap analysis for amphibian species. We start by examining regions of the world where protected sites stand out in terms of irreplaceability and threat, looking first at these variables separately, and then examining them together in a map of urgency. We follow the same procedure for unprotected regions of the world, starting with an overview of the spatial distribution of gap species that were identified in Scenario A.

Protected Sites

Very few protected areas in the world have been created or are being managed specifically for the conservation of amphibians, and the few exceptions are not in the most diverse regions (e.g., Denton *et al.* 1997). In some areas, wildlife management measures are actually adverse to the conservation needs of the amphibian fauna. For example, burning regimes in some

Indian parks, implemented to promote grassland regeneration and expansion for large herbivores, may reduce small-scale heterogeneity and cause direct mortality for amphibians. Nonetheless, many of the existing protected areas play a fundamental role in the conservation of amphibian species, mainly by retaining high quality natural habitat.

As noted for birds and mammals, the irreplaceability of protected sites is influenced by a combination of site size and high levels of endemism (4.15). High irreplaceability in temperate regions is mainly associated with very large protected sites, typically a contiguous set of many protected areas of different types. For example, a 130,000 km^2 cluster in the western United States is composed of 141 different protected areas. Thirty-seven amphibian species are represented in this protected site, which contains the bulk of the ranges of two Vulnerable species: Oregon Spotted Frog *Rana pretiosa* and Western Four-toed Salamander *Batrachoseps wrighti* (Nussbaum *et al.* 1983). Size is also the main cause for the irreplaceability of protected sites in Southern Africa, such as the the Okavango-Upper Zambezi TFCA. These areas overlap the range of 64 species, nearly encompassing the entire range of Laurent's Reed Frog *Hyperolius rhodesianus* (Schiøtz 1999).

In South America, the high irreplaceability of the aggregate of protected areas in the Tepuis (Figure 4.14) is partially because of its large size (440,000 km^2) but significantly because of high endemism (Duellman 1999b). These protected areas overlap the range of 186 species, encompassing the entire range of 39 of them.

Relatively small protected sites with high levels of irreplaceability are only possible in regions of extraordinary species endemism. In the western hemisphere, these include Mesoamerica, the Andes, the Atlantic Forest, and the Caribbean. For example, Las Orquídeas Natural National Park (320 km^2), on the western slope of the Cordillera Occidental, Colombia, overlaps the range of 31 species, eight of them with an extent of occurrence smaller than 1,000 km^2.

In Africa, protected sites of high irreplaceability and small size are concentrated in Madagascar, the Eastern Arc Mountains, and coastal Cameroon. While the former two are well-known for their levels of endemism (Howell 1993, Glaw & Vences 1994), the high levels of irreplaceability in protected areas of the latter in relation to the remaining Congo Basin may be at least partially boosted by higher sampling effort (e.g., Amiet 1983, also see below).

In Asia, small and highly irreplaceable protected areas are associated with mountainous areas in India's Western Ghats (Biju 2001), Sri Lanka (Meegaskumbura *et al.* 2002), southeastern China (Fei *et al.* 1999), and in Indonesia, Malaysia, and the Philippines (Inger 1999). For example, 77 amphibian species are recorded from Mount Kinabalu Park in north Borneo, Malaysia (800 km^2), including six species totally or mainly restricted to this protected area (Malkmus *et al.* 2002). Irreplaceable protected areas in Australia are mainly found in the Queensland Wet Tropics, and in the southwest (Tyler 1999).

As with irreplaceability, threat in protected sites tends to be higher for larger sites (Figure 4.14b). However, in this case very large protected sites reach at most moderately high levels of threat when compared with the relatively small sites holding the largest numbers of threatened species. Main regions concentrating reserves with high levels of threat – many of which are tiny and hard to discern at the global scale – are Mesoamerica, the Caribbean, Andes, Atlantic Forest, Western Ghats, Sri Lanka and southeastern China.

The single protected site with the highest weighted number of threatened species is a 11,000 km^2 set of protected areas in Costa Rica and Panama, around the transboundary park La Amistad. Of the 171 species present in this site, 12 are Critically Endangered, 15 are Endangered, 10 are Vulnerable, and a further 29 are Data Deficient. The main causes of threat here are disease, possibly in combination with climate change, leading to dessication. Most of Costa Rica's protected sites score high in terms of threat, including the Monteverde Cloud Forest Preserve. This protected area became world (in)famous for holding the only know population of the Golden Toad *Bufo periglenes*, a previously abundant but range-restricted species that declined and disappeared abruptly between 1977 and 1989, despite the fact that Monteverde Cloud Forest Preserve retains undisturbed, elfin cloud forest (Pounds & Crump 1994, Pounds *et al.* 1997). Evidence suggests that this mysterious disappearance may be associated with climate change - warming temperature resulting in a rising altitude of the orographic cloud bank that sustains the cloud forest habitat (Pounds *et al.* 1999).

After Costa Rica, Ecuador is the country with highest concentrations of protected sites with high levels of threat. Examples include the Cotopaxi (55 species, including 6 Critically Endangered, 10 Endangered, and 13 Vulnerable) and Sangay (76 species, 8 Critically Endangered, 11 Endangered) National Parks complexes. Infection by chytridiomycosis seems to be rampant in Ecuador, but perhaps the relatively lower levels of threat in adjacent Peru and Colombia may also be a reflection of the much lower levels of knowledge in these countries.

Perhaps the most striking example, given its tiny area, is Pic Macaya Natural National Park (55 km^2), Haiti (26 species, 9 Critically Endangered, 9 Endangered, 3 Vulnerable). The main threat to amphibian populations in Haiti, with less than 1 percent of its forest cover remaining, is habitat loss. The same is sadly true of other Caribbean countries such as Puerto Rico and Cuba (Hedges 1993).

In the eastern hemisphere, protected sites of high threat are scattered throughout southern China and northern, southwestern, and western Australia. By comparison, protected areas in Southeast Asia show comparatively low levels of threat – but this may be an artifact, as their amphibian faunas are so poorly known (and the better known species are the widespread, non-threatened, ones).

When irreplaceability and threat are combined to identify regions of high urgency for the conservation of amphibian species (Figure 4.14c), the protected sites that stand out include some very large site complexes (particularly those in the United States, and northern South America). The level of protection is highly variable among the different types of individual protected areas that comprise these sites, so caution is needed when interpreting these results, as they do not necessarily provide adequate protection to all the species.

However, the vast majority of protected sites of high conservation urgency are relatively small sites in areas of high species endemism and high threat. In the Western Hemisphere, the main ones are in Mesoamerica, the Andes, the Atlantic Forest, and the Caribbean. In the eastern hemisphere, they

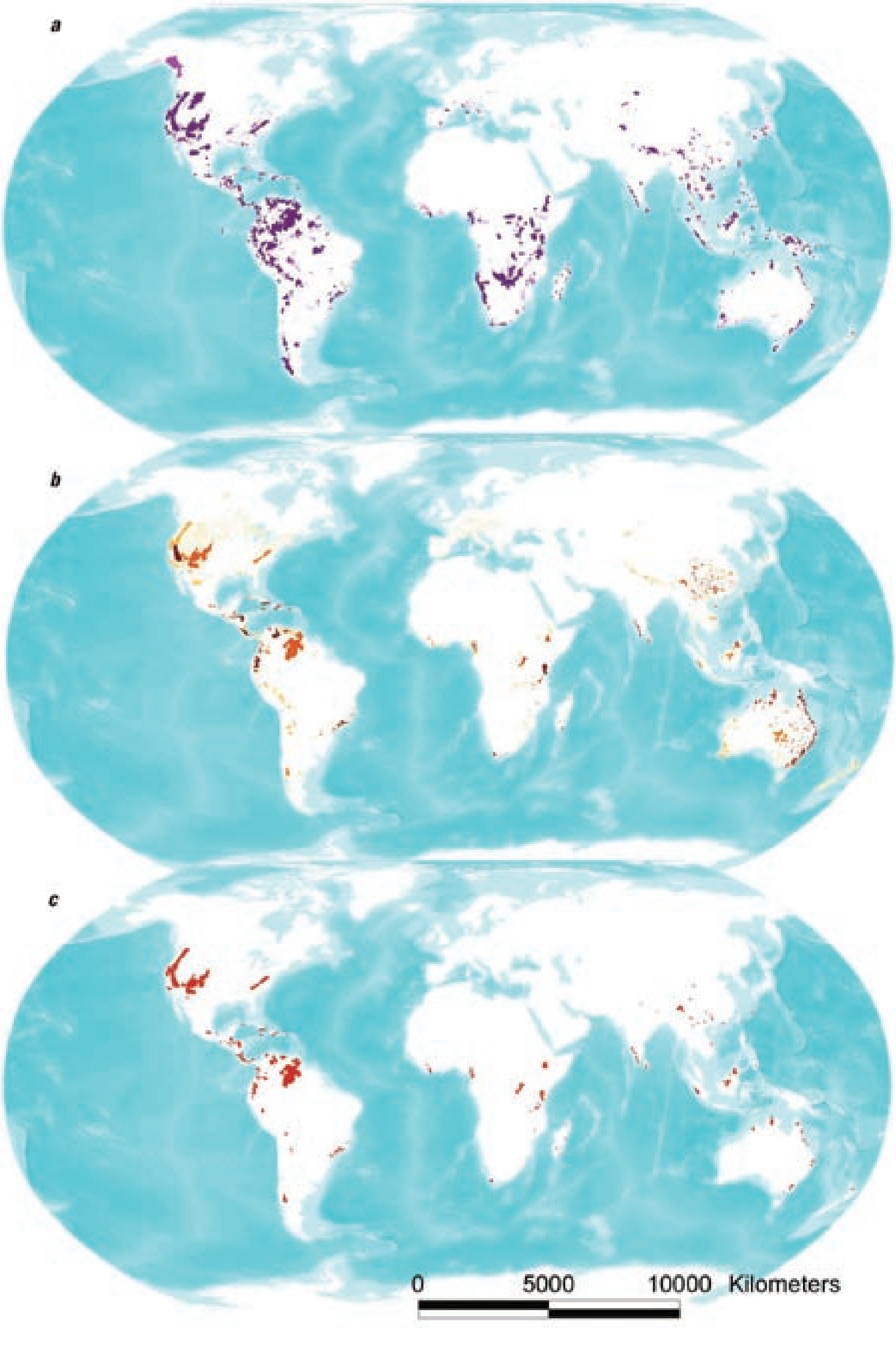

Figure 4.14 Global distribution of (*a*) irreplaceability, (*b*) threat, and (*c*) urgency for the conservation of amphibian species among unprotected sites, as obtained in Scenario B. Darker shades in (*a*) and (*b*) correspond to higher values of irreplaceability and threat.

Figure 4.15 Auyan Tepui, Gran Sabana, Canaima National Park, Venezuela. This is part of a vast complex of protected areas concentrated in the Guayana Shield, identified as urgent for both mammal and amphibian species. Photo by Russell A. Mittermeier.

include the Congo Basin, the Albertine Rift, the Eastern Arc mountains, Madagascar, the Western Ghats and Sri Lanka, as well as the western coast of Australia. These results become clearer in the context of unprotected sites, which we discuss below.

Unprotected Sites

Given the strict requirements applied to Scenario A for considering a species to be a gap, only species with ranges sufficiently small to fall outside any of the existing protected areas have been identified as gap species (Figure 4.16). In a few cases (particularly Somalia), the virtual absence of protected areas made it possible for a few species of moderate range size to show up as gaps. However, overall, Scenario A tends to highlight regions of exceptional endemism and species turnover, where ranges tend to be smaller. Areas where existing protected areas are very small and scattered, such as the Atlantic Forest and the Philippines, tend to be relatively underrepresented by Scenario A.

By comparison, these regions stand out in a global map of irreplaceability of unprotected sites for the representation of amphibian species (Figure 4.17a). Such a map accurately represents the distribution of areas holding significant species richness and/or endemism proposed by Duellman (1999a), which are mainly associated to tropical mountainous regions.

In some cases the effects of differential sampling effort are obvious in the irreplaceability results. For example, the contrast between Cameroon and surrounding countries is partially due to topography (the Cameroon highlands are known as a center of endemism for amphibians, Duellman 1999a), but also the result of the work of J.L. Amiet and J.L. Perret, who described over 60 species (ten percent of the currently known amphibian fauna of Africa), mainly from Cameroon, over the last 40 years. Better knowledge of the surrounding countries will probably reveal that some of the species currently only known from Cameroon are more widespread, and reveal new restricted range species endemic to those surrounding countries.

The northern Andes is the region of the world with the highest levels of amphibian endemism, with 1,000 species (nearly 20 percent of the world's amphibian fauna), and endemism levels of about 75 percent. The discovery rate of species in this region is still rapid, and many more endemic species will doubtless be described formally soon (Duellman 1999b). Peru, in particular, has been considerably less surveyed than Ecuador and Colombia, which is the only explanation for the fact that more species have been described from Ecuador (415 species, 161 endemics) than from Peru (355 species, 174 endemics), despite the fact that the latter is five times larger with a more complex topography. Other main areas of high endemism in the western hemisphere include Mesoamerica, the Atlantic Forest, the Caribbean region, and the Valdivian forests of southern Chile, as well as the Pacific Cascade-Sierra Nevada range, and the southern Appalachians in the United

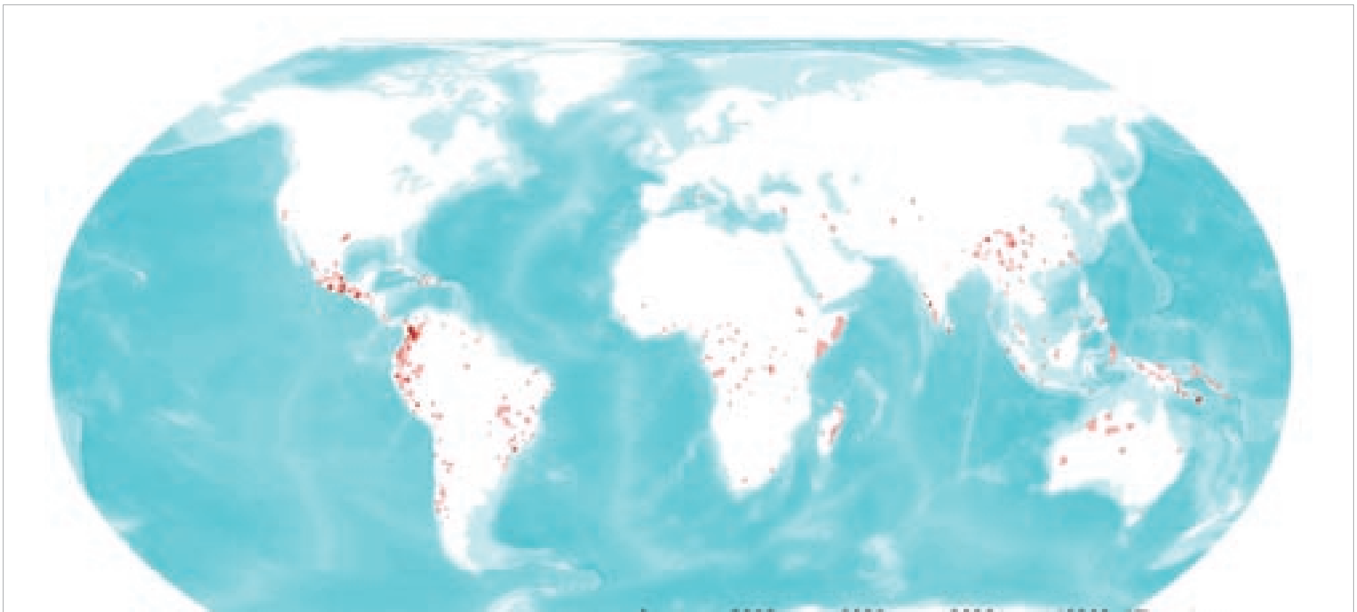

Figure 4.16 Distribution of amphibian gap species identified in Scenario A. Darker shades of red indicate higher numbers of species.

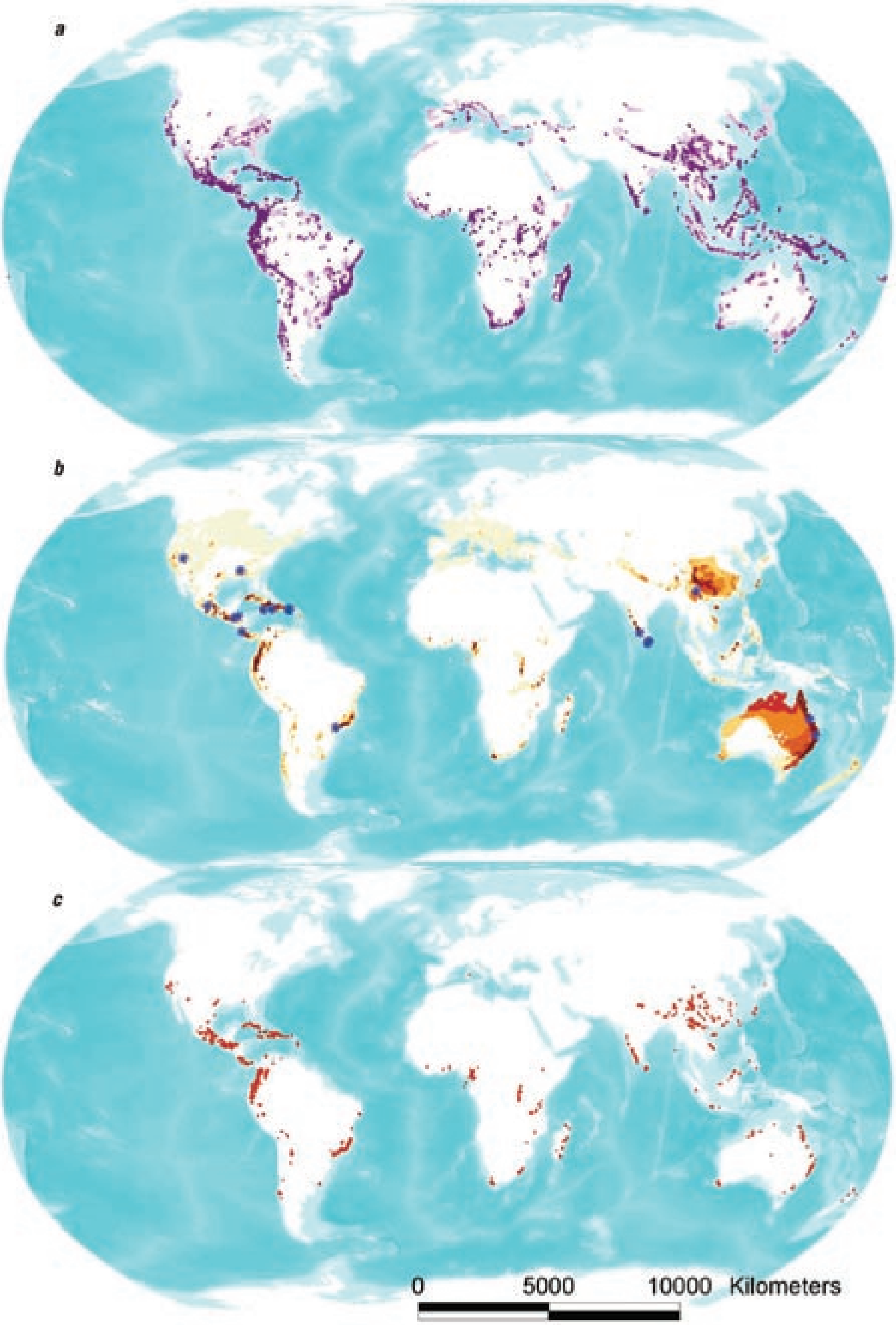

Figure 4.17 Global distribution of (*a*) irreplaceability, (*b*) threat, and (*c*) urgency for the conservation of amphibian species among unprotected sites, as obtained in Scenario B. Darker shades in (*a*) and (*b*) correspond to higher values of irreplaceability and threat. Asterisks in (*b*) represent the centers of ranges of extinct species, and are shown here for illustrative purposes only (have not been included in the measure of threat).

States (Campbell 1999, Duellman 1999b, Duellman & Sweet 1999, Hedges 1999).

In Europe, areas of high irreplaceability are found particularly in mediterranean islands (Sardinia, Sicily, Corsica, Balearics, and Crete) and highlands surrounding the Mediterranean Sea (Borkin 1999, Duellman 1999a). In Africa, Madagascar stands out (particularly the eastern mountains), with nearly 100 percent endemism among its 180 species (Poynton 1999). In fact, there is only one indigenous, non-endemic amphibian in Madagascar (Mascarene Frog *Ptychadena mascareniensis*). Tropical mountainous areas, such as the Cameroon Highlands, the Eastern Arc, and the Albertine Rift (Duellman 1999a, Poynton 1999), comprise most of the other concentrations of irreplaceability outside of protected areas. High irreplaceability is also found in a coastal strip of Southern Africa extending from the Succulent Karoo in southwest Namibia, though the Cape Floristic Region, eastwards to the Maputuland-Pondoland region in eastern South Africa and southern Mozambique (Poynton 1999). The contrastingly high irreplaceability of the lower section of the Congo river, and of isolated dots spread throughout the Congo basin, is probably an artifact of limited and localized sampling effort.

In Asia, high irreplaceability is again associated with high topographic variation (Duellman 1999, Inger 1999). The aforementioned Western Ghats and Sri Lanka hold 120 (75 percent endemics) and 80 species (80 percent endemic) respectively, although for each of these regions nearly 100 species currently await scientific description (Biju 2001, Meegaskumbura *et al.* 2002). Other areas of high endemism in continental Asia include the eastern Himalayas, the mountains surrounding the Sichuan basin, southcentral China, and Yunnan province in southern China. The sharp contrast between the Yunnan region and the adjacent Myanmar and Lao PDR is an artifact of the much better knowledge of the Chinese herpetofauna (Zhao & Adler 1993, Fei *et al.* 1999).

Nearly all of the islands of Southeast Asia have high irreplaceability, despite poor knowledge about the region's amphibian fauna (S. Richards *pers. comm.*, Figure 2.9). For example, New Guinea, Borneo, and the Philippines have, respectively, 85 percent, 60 percent, and 73 percent endemism. These values are likely to increase as the knowledge improves about this region. Other islands with high levels of irreplaceability include: New Zealand, Fiji, the Solomons, Taiwan, Hainan, the Japanese Ryukyu Islands, and the Andaman and Nicobar Islands.

Being mainly desert, Australia as a whole has only 210 amphibian species (although more than 90 percent endemism). The majority of these are concentrated in peaks of irreplaceability around coastal areas, particularly the Queensland Wet Tropics, the southeastern temperate forests, the Kimberley tropical savanna, and the southwest (Tyler 1999).

The Global Amphibian Assessment has recorded 21 extinct species so far, although many others have not been recorded for years despite searches (e.g., Young *et al.* 2001) and will probably be confirmed as extinct soon. The coincidence between their former distributions and the areas of high threat among unprotected sites (Figure 4.17b) demonstrates that many more species face real risk of extinction.

Unfortunately, for many of these species the causes of population decline seem to be independent of local habitat change, and are therefore difficult to prevent by creating new protected areas. While not yet well understood, evidence points to the effect of infectious agents and climate change, separately or in combination, as a main cause of threat of species in Australia and Mesoamerica and more recently in the Andes, especially Ecuador (Berger *et al.* 1998, Young *et al.* 2001).

Other threats, such as introduced species (Kats & Ferrer 2003), and pollution (Blaustein *et al.* 2003), are also difficult to combat by the mere creation of new protected areas. Nonetheless, having protected areas in place may be crucial in order to be able to implement measures needed to prevent and deal with these threats (Kats & Ferrer 2003). Australia is a major example of a region where introduced species are having a devastating effect on the native amphibian fauna (Tyler 1997).

In most regions, however, habitat loss is still the leading cause for species decline (Duellman 1999a, Hilton-Taylor 2000), and is particularly problematic in regions high species endemism (Brooks *et al.* 2002). The Caribbean region, with five species already extinct, is perhaps the most striking example. Other regions known for their high levels of habitat loss, and which have already suffered species extinctions, include the Western Ghats (Jha *et al.* 2000), Sri Lanka (Wickramagamage 1998), southeast China (Young & Wang 2001), and the Atlantic Forest of South America (da Fonseca 1985). While no extinctions have been reported from Madagascar or the Andes (but see Young *et al.* 2001), these regions have already suffered high levels of habitat loss (Ganzhorn *et al.* 2001, Armenteras *et al.* 2003) and accordingly hold many Critically Endangered species of restricted distribution.

Comparatively, many of the islands in Southeast Asia and the Mediterranean regions have low levels of threat, most likely a consequence of the low species richness of individual islands, as noticed for birds and mammals.

Obtained as a combination of threat and irreplaceability, the regions of the world where there is highest urgency for the creation of new protected areas for amphibians are predominately tropical mountain areas that are suffering high rates of habitat loss and/or being affected by chytridiomycosis. These areas include: Mesoamerica, the northern Andes, the Caribbean, the Atlantic Forest, African tropical highlands (Cameroon, Eastern Arc, Albertine Rift, and eastern Madagascar), tropical Asian mountains (in the Western Ghats, Sri Lanka, southeast China, Borneo, Philippines, and Vietnam), and temperate and tropical forests in coastal Australia. The poor ability of amphibians to colonize islands, and consequent low species richness in isolated islands, are the main reasons why few islands are highlighted as urgent, despite high levels of irreplaceability (e.g., the Solomon Islands).

Nearly all of the regions highlighted as urgent for amphibian conservation correspond to biodiversity hotspots, as proposed by Myers *et al.* (2000b).

For some other regions, changes in levels of knowledge are likely to reveal new areas of conservation urgency. For example, Sumatra and Kalimantan are essentially unexplored above 1,000 m, where very large numbers of micro-endemics are expected to occur. In Sulawesi, many new species are in the process of description (D. Iskandar, *pers. comm.*). In Maluku there have been almost no surveys in recent years due to the unstable political situation. The only parts of the islands of Southeast Asia where we have reasonable amphibian data are Java and the Malaysian parts of Borneo (D. Iskandar, *pers. comm.*, Inger 1999).

PRIORITIES ACROSS ALL THREE GROUPS

Now that we have assessed the urgency of conservation action for each of the taxonomic groups covered – mammals, amphibians, and threatened birds – we can go on to assess urgency for overall conservation action, and its derivation from the patterns for individual groups. We do this both for existing protected areas – where urgency should be interpreted as increase (or at very least continuation) of existing investment – and for unprotected half-degree grid cells – where urgency should be interpreted as the importance of establishing new protected areas. These two overall urgency maps are simply a combination of the urgency maps for the three taxonomic groups: anywhere mapped as a priority for at least one of the three groups is mapped here.

Geographic Overview of the Urgency of Protected Areas

The tropics hold the majority of the protected areas that are most important for mammal, amphibian, and threatened bird conservation (Figure 4.18). In this section, we assess this geography, analyzing how each taxonomic group contributes to specific patterns, and highlighting which protected areas are the most important for increased investment.

Quite extensive protected area complexes in Madagascar, and in western, eastern, and southern Africa appear as overall priorities (Brooks *et al.* 2001). Mammals contributes the bulk of this pattern, above all for protected areas in the montane forest conglomerations of the Cameroon Highlands (e.g., Mt Koupe in Cameroon, Cross River in Nigeria, and Pico Basile on Bioko), the Albertine Rift (e.g., the Virungas, Rwenzori, and Bwindi in Uganda, Nyungwe in Rwanda, and Ituri and Maiko in the DRC), the Eastern Arc (the Udzungwas, Ulugurus, and Usambaras in Tanzania, and the Taita Hills in Kenya), the Ethiopian Highlands (e.g., Bale and Yabello), and Madagascar (e.g., Marojejy, Masoala, Ankarafantsika, Zahamena-Mantadia, Ranomafana-Andringitra, and Isalo; Figure 4.19). The mammal data also highlight isolated lowland forests in Upper Guinea (Nimba and the Sapo-Taï complex on the Liberia-Cote d'Ivoire-Guinea border; Figure 4.20) and on the Kenyan coast (Arabuko-Sokoke), as well as some of the large dryland reserves (e.g., Tsavo East and West in Kenya, the Selous in Tanzania, the Okavango-Upper Zambezi TFCA, Namib Naukluft-Skeleton Coast in Namibia, and the "Greater Limpopo" Transfrontier Park between South Africa, Mozambique and Zimbabwe). Threatened birds show a not dissimilar pattern, albeit to a rather less dramatic extent. Amphibians contribute least of all, with only small protected areas in the montane forests – all areas also important for mammals or threatened birds – appearing as urgent. The low degree to which South African protected areas appear is surprising, given the enormous importance of these for plant conservation (Cowling *et al.* 1997). Neither of the two huge African wildernesses of the Congo forests (Aveling *et al.* 2002) and the Sahara desert (Muchoney *et al.* 2002) appear as holding urgent protected areas, given their relatively low threat.

The most urgent of the protected areas of Asia are smaller and more dispersed than those of Africa, a simple function of the small average size of Asian protected areas (see below). In South and East Asia, much the highest priority protected areas are those of the Western Ghats (e.g., Anamalai and Kudremukh) and Sri Lanka (e.g., Sinharaja), the eastern Himalayas (e.g., Royal Chitwan in Nepal), the southwestern Chinese provinces of Sichuan (e.g., the panda reserves of Wo Long, Wang Lang, and Jiu Zhai Gao), and the southern Japanese islands (Amami-Gunto and Okinawa Kaigan), with results for all these areas driven by all three taxa. Interestingly, a scatter of urgent protected areas also emerges in central (e.g., Liupanshan) and southeastern China (e.g., Yang Zi Er). IndoChina (e.g., Khao Yai in Thailand, Nakai-Nam-Theun in Lao PDR, Ngoc Linh in Vietnam, and Tonle Sap in Cambodia) is an important priority region for mammals and threatened birds, although not for amphibians – presumably an artifact of poor knowledge of the amphibian fauna here (e.g., Stuart 1999). The protected areas of Peninsular Malaysia (e.g., Taman Negara), Borneo (e.g., Kinabalu, in Sabah) and Sumatra (e.g., Gunung Leuser, Kerinci-Seblat, and Bukit Barisan) emerge as very high priorities for all three groups, but those of Java, Wallacea, and the Philippines scarcely show up – again, partially an artifact of small protected area size on these islands (Dinerstein & Wikramanayake 1993). New Guinea's protected areas (e.g., Lorentz, in Papua) appear not to be a high priority for amphibians (another instance of the paucity of amphibian data) and only slightly more so for birds; that they show up as clearly urgent for mammals (Flannery 1995) may at least partially be explained by differences in the criteria for assessing threat in mammals.

Moving to Latin America, we find that the protected areas of Mesoamerica (Peterson *et al.* 1993) – e.g., Sierra de las Minas in Guatemala, and El Triunfo in Mexico – and the Caribbean (Woods & Sergile 2001) – e.g., Cienaga de Zapata on Cuba, Blue Ridge/John Crow Mountain on Jamaica, Sierra de Bahoruco in the Dominican Republic, Caribbean National Forest on Puerto Rico, and Morne Trois Pitons on Dominica – important priorities for amphibians, barely register for mammals or for threatened birds. Only the highland protected areas of Costa Rica and Panama (e.g., Darién and La Amistad; Figure 4.21), appear as urgent for all three taxa (Janzen 1983a). The Andes from Venezuela (e.g., Perija) through Colombia (e.g., Sierra Nevada de Santa Marta, Tatamá, Munchique), Ecuador (e.g., Cotapaxi, Machalilla, Podocarpus), and Peru (e.g., Rio Abiseo, Huascarán, Manú, Bahuaja-Sonene) to Bolivia (e.g., Madidi; Figure 4.22) hold numerous exceptionally important protected areas for all three taxa (Mast *et al.* 1999), although the Galápagos appear for birds only (Swash & Still 2000). In contrast, protected areas in the larger blocks of intact lowland forest appear less urgent: those in the Guayana Shield (e.g., Canaima, in Venezuela) driven by mammals and amphibians, and those in Amazonia by mammals alone, especially primates (Rylands *et al.* 2000). The Brazilian Atlantic forest (Fonseca 1985) holds numerous protected areas important for all three taxa (e.g, Pedra Talhada, Sooretama, Serra do Mar, Iguaçu, Serra dos Órgãos; Figure 4.23), while the southern cone non-forest habitats of the Brazilian cerrado (e.g, Serra da Canastra), the Argentinian pampas (e.g., Iberá) and central Chile (e.g., Puyuhue) hold protected areas considered urgent for just one taxon (mammals, threatened birds, and amphibians, respectively).

Outside of the tropical continents, the bulk of the existing protected areas found to be urgent lie in Australia and New Zealand. The former results are driven almost exclusively by amphibians (Cogger 1992), with key protected areas in the Kimberley savannas (e.g., Kakadu), the Queensland Wet Tropics (e.g., Daintree) and on the New South Wales coast (e.g.,

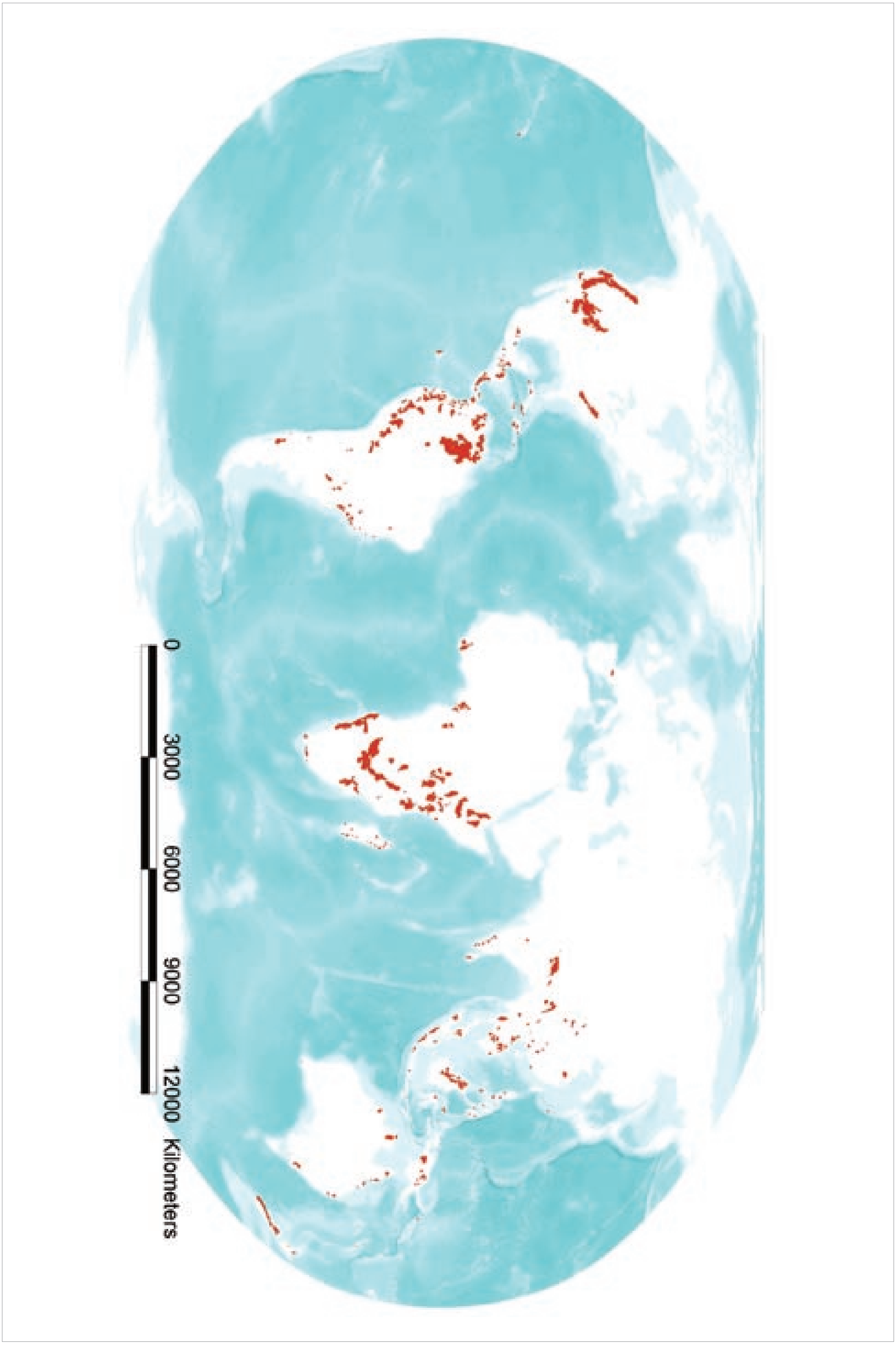

Figure 4.18 Global distribution of protected sites of high urgency for the coverage of mammals, amphibians and threatened birds.

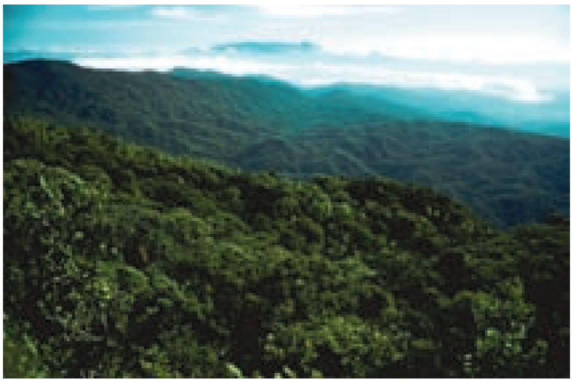

Figure 4.19 Marojejy National Park comprises the forested Marojejy massif in eastern Madagascar, and is more than 60,000 ha in extent. Fifteen threatened birds and 13 species of threatened mammals have their range overlapped by the protected area, highlighted as urgent for the consolidation of the global protected area network. Photo by Frank Hawkins.

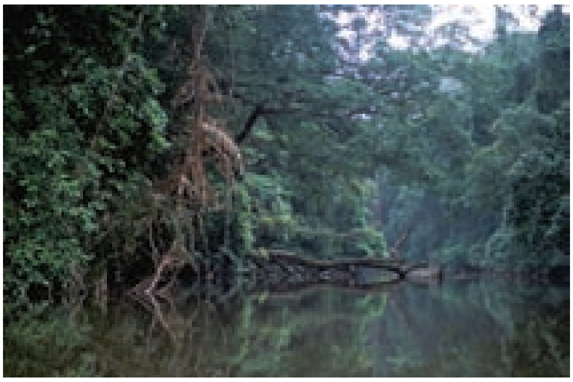

Figure 4.20 Sapo National Park, Liberia, designated in 1983, is mainly moist lowland rainforest. Together with the adjacent Krahn Bassa National Forest, it forms a complex of high urgency for both bird and mammal species, which overlaps the range of 8 threatened birds and 148 mammals (10 threatened). Photo by John Martin.

Figure 4.21 La Amistad Biosphere Reserve, Costa Rica, also designated as a National Park and a World Heritage site, is part of a large complex of protected areas across a boundary of Panama and Costa Rica. Nearly two hundred mammals (11 threatened) and 170 amphibians (37 threatened, as well as four species known only from this site) highlight it as an area of high urgency for the consolidation of the global protected area network. Unfortunately, amphibian populations in this area are being highly affected by disease. Photo by Guido Rahr.

Figure 4.22 Madidi National Park, Bolivia, is part of a transboundary corridor of protected areas that ranges from the Bolivian Amazon into the Peruvian Andes. This corridor, which includes also the Ulla Ulla Natural Fauna Reserve (Bolivia), the Bahuaja-Solene National Park, and the Tambopata-Candamo Reserve (Peru), was identified as urgent for the protection of mammals and threatened birds. Photo by Haroldo Castro.

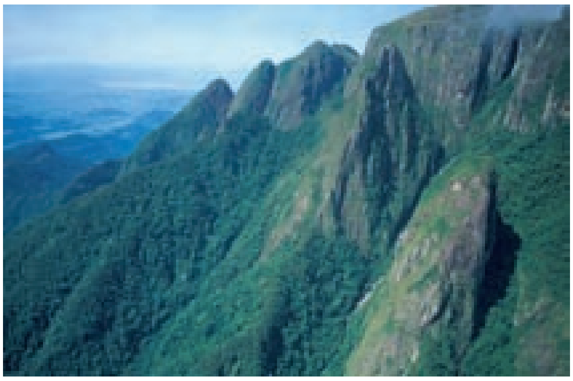

Figure 4.23 The Serra dos Órgãos National Park (Rio de Janeiro State), was the third National Park to be designated in Brazil (1939). Together with other protected areas in the Atlantic Forest region, it was identified as urgent for the consolidation of the existing protected area network. Photo by Haroldo Castro.

Kosciusko). Likewise, the importance of Coromandel Forest Park on New Zealand's North Island is driven by amphibians (Bell 1996), although the urgency of the Fiordland complex on South Island is due to its threatened bird species (Clout & Craig 1995). Only one protected area appears as urgent in Eurasia: Pyrénées Occidentales, triggered by the presence of Pyrenean Chamois *Rupicapra pyrenaica* (García-Gonzales *et al.* 1985). Quite large areas of the western USA (e.g., Yosemite, Grand Canyon), and the Appalachians (e.g., Great Smoky Mountains, Shenandoah) appear on the final map of protected area importance, all determined wholly by amphibians (Drost & Fellers 1996). Finally, Hawai'i (e.g., Hawai'i Volcanoes) appears on the map because of its threatened birds (Scott *et al.* 2001a); as a general rule, the absence of the rest of the Pacific from this map is more due to the lack of protected areas here than it is to any lack of irreplaceability or threat.

As this discussion makes clear, most of those protected areas identified as urgent overall are actually identified by multiple of the terrestrial vertebrate groups that we examine here. We can quantify this level of cross-taxonomic surrogacy (Table 4.1) as the proportional overlap between sets of protected sites highlighted as urgent for threatened birds, mammals, and amphibians (Figure 4.7c, Figure 4.11c, Figure 4.17c). Proportional overlap between each of these sets was calculated as a modification of the Jaccard coefficient rescaled as a proportion of the maximum possible overlap. Hence, the proportional overlap between two sets A and B is given by

$$O = \frac{\dfrac{c}{a+b+c}}{\dfrac{\mathrm{Min}\,(a,b)}{\mathrm{Max}\,(a,b)}} \times 100$$

where a is the number of sites in set A, b is the number of sites in set B, and c is the number of sites in common between A and B. This index varies between zero (no common sites) to 100 (maximum possible overlap). For sets of different sizes, maximum possible overlap takes place when the smallest set is a subset of the largest; for sets of equal size, this index is equivalent to the Jaccard coefficient. The significance of the overlap obtained in each case was tested using

Table 4.1 Cross-taxonomic congruence between sets of protected sites highlighted as urgent for threatened birds, mammals, and amphibians. O is the proportional overlap between sites, varying from zero (no common sites) to 100 (maximum possible overlap); CI is the 95% confidence interval obtained from deriving this overlap at random 10,000 times.

	O **(%)**	**CI**
threatened birds × mammals	19.4	[0.31, 0.33]
threatened birds × amphibians	21.2	[0.77, 0.79]
mammals × amphibians	22.1	[0.73, 0.76]

the *bootstrap* technique (Efron 1982). Ten thousand pairs of sets of the same size as the ones being tested were randomly selected from all protected sites, and proportional overlap between each pair was calculated as explained above. Confidence intervals (*CI*) were obtained from these replicates, and the probability (p) of obtaining the observed overlap O from the data was calculated as the fraction of times values ≥ O were found among the replicates. In each case, the overlap between urgent protected areas for each of the taxa was much higher than expected due to chance: in 10,000 random replicates, the extent of overlap found was always smaller than the observed values ($p = 0.0000$).

Geographic Overview of the Urgency of Unprotected Areas

Examination of the overall urgency map for unprotected areas reveals a number of important differences from that for existing protected areas. Most dramatically, islands appear much more strongly as priorities for areas that are currently unprotected. Asia, too, appears much more important as a priority for new investment (as opposed to for continuation of existing investment), with the Americas and Africa less so. This is largely a product of the fact that wilderness areas (Mittermeier *et al.* 2003) in the latter two continents appear as much less important for unprotected than for existing protected areas. The degree to which urgent unprotected areas is concentrated in the tropics is even greater than that seen for important existing protected areas.

For Africa, the highest priority regions for new conservation investment lie almost exclusively in the continent's centers of endemism (Kingdon 1989). All three taxa identify urgent regions for new protected areas in Upper Guinea, the Cameroon Highlands, the Albertine Rift, the Ethiopian Highlands, the Eastern Arc and coastal forests, eastern Madagascar, Maputaland-Pondoland, and the Cape Fynbos. The Succulent Karoo is an outlier, appearing on the overall priority map, but driven by mammals only: this major plant center of endemism is also important for mammal species (Vernon 1999). The Kenyan Highlands are another surprise: these mountains are rather young and hold few endemics among most taxa, but emerge as urgent due to endemic mammals (Coe & Foster 1972). Islands emerge as uniformly urgent, largely due to their threatened birds: São Tomé e Príncipe, the Seychelles, Mauritius, the Comoros (Figure 4.25). In terms of omissions, the lack of areas in the miombo-mopane woodlands (See Figure 4.18 for highlighted complexes of large protected areas) is a reflection of the relatively good coverage afforded to these by existing parks. The lack of any urgent unprotected areas in the Congo or Sahara wildernesses is unsurprising, although one might have expected priorities to emerge in the Horn of Africa or Angola Scarp centers of endemism.

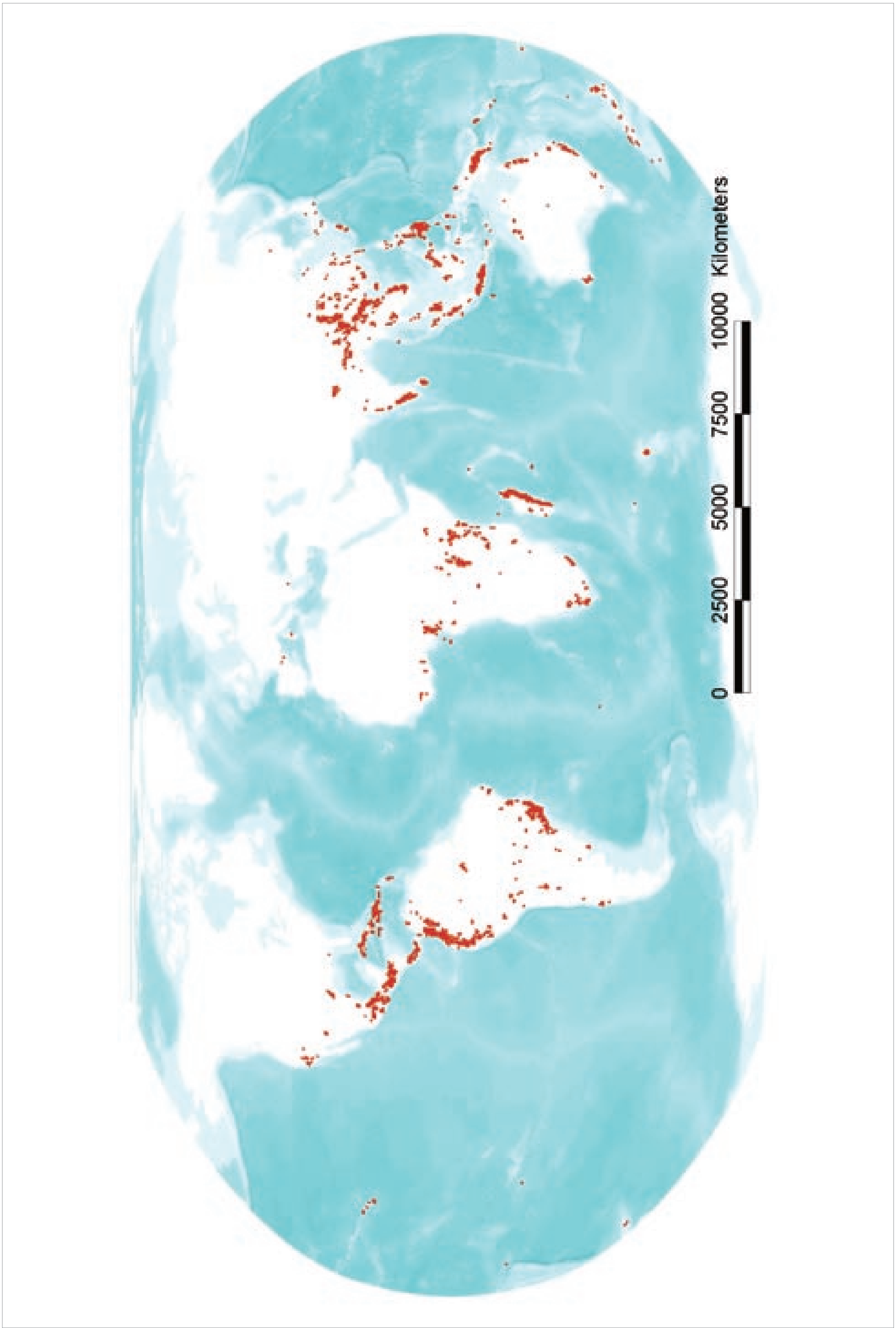

Figure 4.24 Global distribution of unprotected sites of high urgency for the coverage of mammals, amphibians and threatened birds.

Figure 4.25 The Union of Comoros, located between the north of Madagascar and East Africa, is one of the island territories identified by the global gap analysis as urgent for the expansion of the global network of protected areas. The country is suffering intense deforestation, yet here it has one single protected area – the Mohéli Marine Park – which offers no protection to the islands terrestrial vertebrates. Nine threatened birds occur on these islands, six of them endemics, including three Critically Endangered species of Scops-owl *Otus spp.* (one endemic to each of the islands of Mohéli, Anjouan and Grand Comoro; BirdLife International 2000). These islands also comprise the entire range of the Critically Endangered Comoro Black Flying Fox *Pteropus livingstonii* – one of the rarest fruit bats in the world with only around 1,000 individuals in the wild. The Action Comores program, a voluntary conservation organization supported by international organizations, is working with Comorien communities to develop locally based conservation and monitoring of the Comoro Black Flying Fox (http://ibis.nott.ac.uk.Action-Comores/). Photos © Elise Granek.

Asia emerges as an extremely high priority for new protected area investment. Few wholly new regions appear, in comparison to the map for urgent existing protected areas, but all of the regions mapped there expand. In South Asia, the specific priority regions are again the Western Ghats and Sri Lanka, and the eastern Himalayas. In East Asia, southwest, southeast, central, and, interestingly, eastern, China emerge as the highest priorities, along with the southern Japanese islands and Taiwan. The latter three regions are not priorities for mammals, but otherwise all three taxa contribute to these patterns. It is in Southeast Asia, though, that the densest concentrations of areas requiring urgent new investment emerge, especially in Vietnam, and on nearly all major Philippine and Indonesian islands. Northern Thailand and southern Peninsula Malaysia also appear as priorities for mammals (Lekagul & McNeely 1988). A few tiny outlying islands also emerge as priorities for just one of the higher taxa: India's Andaman Islands for amphibians, and Australia's Christmas Island (south of Java) for birds.

Moving east, congruence between the three major taxa breaks down. New Guinea emerges as a major priority for the establishment of new protected areas for mammals (Flannery 1995), but hardly at all for amphibians or threatened birds (again, this may be an artifact of our knowledge). Smaller Pacific islands are priorities for threatened birds (Pratt *et al.*, 1987): the Solomon Islands, Samoa, Fiji, French Polynesia, Norfolk Island, and, strikingly, New Zealand. Finally, Australia – as is the situation for existing protected areas – emerges almost exclusively as a priority for amphibians (Cogger 1992).

In Latin America, four regions capture the bulk of the area highlighted as urgent for establishing new protected areas. As is the result for existing protected areas, the Andes emerge as extremely important, including the lowland Pacific forests of the Chocó and Tumbes regions, driven by all three higher taxa. Similarly, the Atlantic Forest appears as urgent for mammals and for amphibians, as well as for threatened birds (Figure 4.26). To the north, the patterns are slightly less congruent. The Caribbean – both Greater and Lesser Antilles – is important for both amphibians and threatened birds, but not for mammals, largely because most of the Caribbean's mammal species are already extinct (Woods & Sergile 2001). Mesoamerica, an astoundingly high priority for amphibians (Flores 1993), mainly because of the high levels of amphibian threat in this region (Figure 4.17b), barely emerges for mammals or threatened birds. Elsewhere, limited urgent areas lie in other biomes – a few Amazonian sites for mammals, central Chile for amphibians, the Cerrado for threatened birds – but these are few and scattered. The Guayana Shield, so important for the maintenance of existing protected areas, does not show up at all as a priority for the establishment of new ones.

Only tiny regions of the Holarctic appear as priorities for the establishment of new protected areas, with very little cross-taxonomic congruence between these. In Eurasia, the Pyrenees and southeastern Greece are priorities for unprotected mammals (Mitchell-Jones *et al.* 1999) and Sardinia for two threatened *Hydromantes* salamanders (Gasc *et al.* 1997). Four regions of North America – the California Floristic Province, southern Arizona, the Edwards Plateau in Texas, and the Florida Panhandle – urgently require new protected areas for amphibians (Conant & Collins 1998, Stebbins 2003). Finally, Hawai'i again appears as a priority for threatened birds, although the issues here are as much the control of invasive species as of establishment of new protected areas (Scott *et al.* 2001a).

As with protected sites, there is a much higher degree of overlap than expected (Table 4.2) but, strangely, the mammals seem to overlap less than do threatened birds and amphibians. This may be a result of the fact that a higher proportion of restricted-range mammals than the other two taxa occur in xeric habitats (e.g., the Succulent Karoo).

What are the Characteristics that Distinguish Urgent Sites?

Now that we know the locations of areas that urgently require conservation actions, both for supporting existing protected areas and for establishing new ones, we can look for general characteristics of these areas.

Size of Protected Sites

Figure 4.18 clearly shows that some of the protected sites that are highlighted as urgent are very large. The range of sizes is very wide, from 1 km^2 to 439,104 km^2 . The smallest sites are not discernible on a global scale. Despite this variation, urgent sites tend to be much larger than the typical protected area within each realm in the planet (Figure 4.27, Figure 4.28). This is as expected, because, everything else being equal, large sites tend to have higher proportions of the species ranges (hence higher irreplaceability) and higher numbers of species (hence higher numbers of threatened species). Large protected areas are naturally desirable for the long-term preservation of species (Diamond 1975) and of ecological and evolutionary processes (Cowling *et al.* 1999). This said, small, strategically located, protected sites also play a fundamental role in regions of high endemism and are certainly better than no protected areas at all (Turner & Corlett 1996).

The distribution of large and small protected areas revealed as urgent is not homogenous across the planet. Across realms, urgent protected sites tend to be much larger for the Neartic than for any other region (the large protected sites in North America, Figure 4.18), followed by the Afrotropical and Paleartic realms. Regions with smallest median size of urgent sites are naturally those where islands dominate: Oceania, Australasia, and Indo-Malayan.

Certainly, not all regions have huge protected sites that can be highlighted as urgent to start with, but this cannot explain the variation among realms, because all regions do have small sites but these are not picked up everywhere. Hence, all sites selected for the United States are large, despite the fact that there are hundreds of small sites to choose from. Further, although they are larger than average within each region, urgent sites are still relatively small (64 percent are smaller than 1,000 km^2).

Geographic Location

Perhaps the most obvious property of protected (Figure 4.18) and unprotected (Figure 4.24) sites highlighted as urgent for the conservation of mammals, amphibians, and threatened

Figure 4.26 Atlantic Forest in Paraná State, Brazil. An important center of endemism for birds, mammals and amphibians alike, and one of the hottest hotspots for plant endemism (Myers *et al.* 2000b), the Atlantic Forest has suffered high rates of habitat loss. The entire coastal region from Santa Catarina to Espírito Santo States was identified as urgent, both for the consolidation and the expansion of the existing protected area network. Photo by Haroldo Castro.

Table 4.2 Cross-taxonomic congruence between sets of unprotected sites highlighted as urgent for threatened birds, for mammals, and for amphibians. *O* is the proportional overlap between sites, varying from zero (no common sites) to 100 (maximum possible overlap); CI is the 95% confidence interval obtained from deriving this overlap at random 10,000 times.

	O (%)	CI
threatened birds x mammals	12.7	[0.80, 0.81]
threatened birds x amphibians	23.7	[1.01, 1.09]
mammals x amphibians	13.2	[0.81, 0.82]

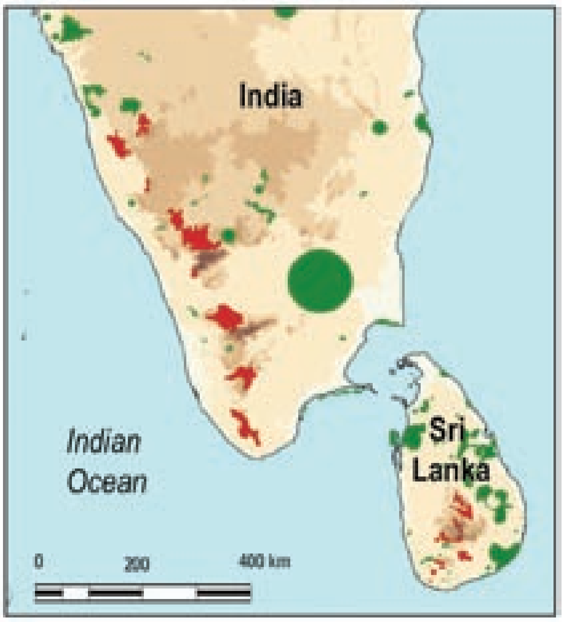

Figure 4.27 Protected sites of southern India and Sri Lanka. Darker shades of brown represent higher elevations. Sites highlighted as urgent are in red, others in green. The average size of all 153 protected sites is 234 km^2, while urgent sites occupy on average 437 km^2. Urgent protected areas are typically in mountainous regions.

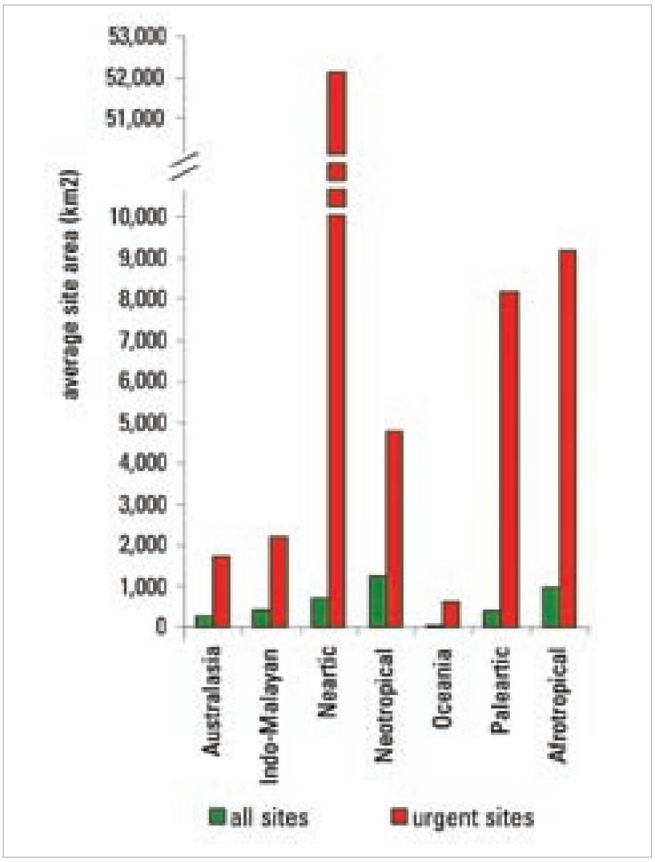

Figure 4.28 Average area of protected sites per realm, for all and for urgent sites (realms after Olson *et al.* 2001). Urgent sizes are generally much larger on average, particularly in the Neartic and Afrotropical realms.

birds is that most of them lie in the tropics: 77 percent of the area and 82 percent of the number of urgent protected sites, and 80 percent of the area and 87 percent of the number of urgent unprotected sites. By comparison, the fraction of the planet's land area in tropical regions is 39 percent, while current protected areas are mainly outside the tropics: 53 percent of the area and 74 percent of the sites.

The dominant biomes of the planet in terms of area are: *Deserts and Xeric Shrublands* (19 percent), *Tropical and Subtropical Moist Broadleaf Forests* (14 percent), and *Tropical and Subtropical Grasslands, Savannas and Shrublands* (13 percent, Figure 4.29a). The current network of protected areas represents each biome in similar proportions (Figure 4.29b) with *Temperate Coniferous Forests* and *Tropical and Subtropical Moist Broadleaf Forests* being the two biomes with higher percentage of their area protected (24.5 percent and 15.6 percent respectively), and *Lakes* and *Temperate Grasslands, Savannas and Shrublands* the biomes proportionally less represented (2.4 percent and 4.2 percent, respectively).

The distribution of protected sites revealed as urgent across biomes is a different picture (Figure 4.29c). Urgent protected sites lie disproportionately in tropical biomes, in particular *Tropical and Subtropical Moist Broadleaf Forests* (38.6 percent) and *Tropical and Subtropical Grasslands, Savannas, and Shrublands* (26.5 percent), and, to a lesser extent, *Deserts & Xeric Shrublands* (11.1 percent) and *Temperate Coniferous Forests* (10.0 percent). Species-poor biomes such as *Boreal Forests/Taiga*, *Temperate Grasslands, Savannas, and Shrublands*, *Tundra* and *Rock and Ice* are nearly absent. Most of the urgent protected area in *Tropical and Subtropical Grasslands, Savannas, and Shrublands* corresponds to the large protected sites in south-central Africa, the area of *Temperate*

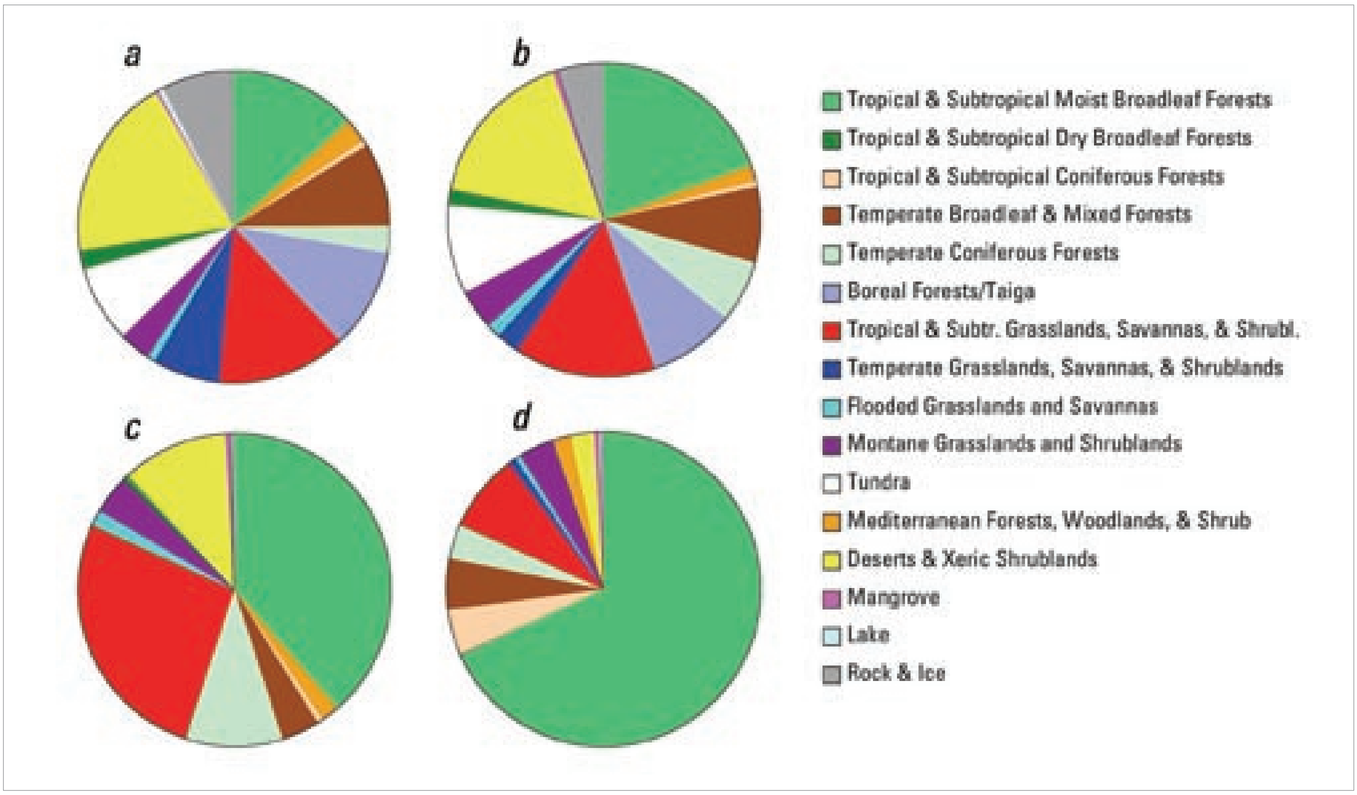

Figure 4.29 Distribution per biome of: (*a*) total land area; (*b*) global protected area; (*c*) area of urgent protected sites; and (*d*) area of urgent unprotected sites (biomes after Olson *et al.* 2001). Overall, tropical forests are the planet's most urgent conservation priorities for the consolidation and, principally, the expansion of the global network of protected areas.

Coniferous Forests corresponds mainly to the large sites in western United States, and the area of *Deserts & Xeric Shrublands* corresponds to large sites in southwestern United States and northern Venezuela. The area occupied by *Tropical and Subtropical Moist Broadleaf Forests* includes some large sites (such as the Tepuis) but is mainly driven by the many much smaller protected sites in regions such as the Andes, Mesoamerica, and Southeast Asia.

Urgent unprotected sites are heavily dominated by *Tropical and Subtropical Moist Broadleaf Forests* (67.9 percent, Figure 4.29d), with *Tropical and Subtropical Coniferous Forests* also appearing as disproportionately much more important than their actual area suggests. Non-tropical biomes correspond to less that 17 percent of the total area recommended as a priority for the expansion of the current network of protected areas.

Insularity

Islands (considered here to be smaller than Australia and Greenland, by which logic New Guinea, Madagascar and Borneo are the largest islands) constitute only 5.2 percent of the total land area of the planet, yet they hold a disproportionately large fraction of the diversity of terrestrial vertebrates: 45 percent of all species analyzed, including 57 percent of the threatened birds, 49 percent of all the mammals, and 39 percent of all the amphibians. They are also areas of extraordinary endemism, with more than half of the species that occur in islands being absent from continental areas: 86 percent of the threatened birds, 42 percent of the mammals, and 51 percent of the amphibians.

The global network of protected areas represents islands in proportion to their area: islands occupy 6.5 percent of the protected land area (Figure 4.30a). This proportion increases only slightly in protected sites highlighted as urgent (7.6 percent, but corresponding to 18.1 percent of the sites selected for birds), mainly because of the dominance of very large continental protected sites in North and South America, and in Africa. However, this picture changes considerably for unprotected urgent sites (Figure 4.30b): 27.6 percent of these are in islands, particularly for mammals (38.3 percent) and threatened birds (33.0 percent). These results underscore the importance of islands for the conservation of vertebrate species, and the need to provide special attention to these in the future expansion of the global network of protected areas.

Topography

Many of the sites highlighted as urgent in the previous discussion are mountainous areas such as the Sierra Madre in Mesoamerica, the Andes, the highlands of Madagascar and Cameroon, the Albertine Rift, the Eastern Arc, the Western Ghats, and the eastern slopes of the Himalayas. These do not correspond to the highest altitudes in the planet, where bare rock and ice make conditions too inhospitable for most living species, but to regions of tropical montane forest (Figure 4.31). The complex topography of these regions promotes high speciation rates (e.g., Fjeldså & Lovett 1997, Moritz *et al.* 2000) which result in high levels of endemism and irreplaceability.

However, the same conditions that make these regions favorable to vertebrate diversity often render them adequate for human settlement (e.g., Fjeldså *et al.* 1999), making them regions of high threat as well.

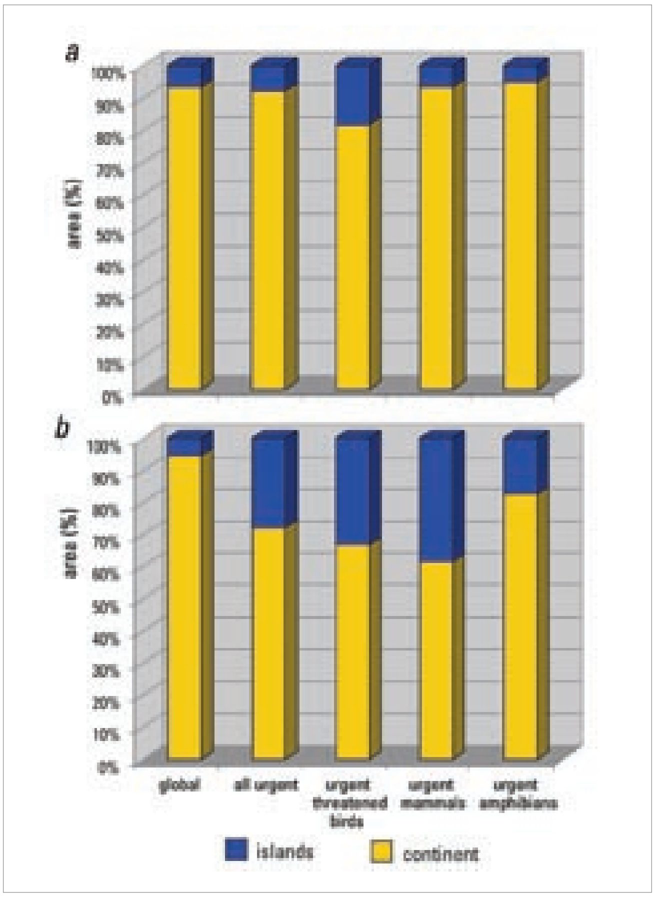

Figure 4.30 Relative proportions of continental and island land area among (*a*) protected and (*b*) unprotected sites: globally, in all urgent sites, and in urgent sites selected for threatened birds, for all mammals and for all amphibians. Both protected and (principally) unprotected sites are biased towards islands, especially for mammals and birds.

Site Species Richness and Regional Endemism

The species richness of individual sites considered in this analysis is influenced by their size, geographic location, insularity and topography. A large fraction of these sites is species-poor: about one third of the unprotected sites have none of the species analyzed here (Figure 4.32a, corresponding mainly to vast frozen areas of Antarctica and Greenland, which in area occupy about one-eight of the land surface).

Protected sites are significantly biased towards sites with higher species richness (Figure 4.32b), although most of these are still relatively poor in species: about one-third of protected sites hold less than 33 species of mammals, amphibians, and threatened birds. In comparison, both protected and (particularly) unprotected urgent sites were mainly selected among those with higher species richness (Figure 4.32a).

As discussed above, urgent sites are also heavily biased towards regions of high local endemism, dominated by species with narrow ranges (Figure 4.33). This is a necessary result because one of the criteria for selecting sites as urgent was irreplaceability.

What Difference Would It Make to Protect the Urgent Sites?

This analysis is the first attempt ever made to establish a global framework to guide decisions for establishing and managing regional and local protected areas. However, the areas considered here for unprotected sites have an average area of 2,650 km^2, larger than the vast majority of the protected areas

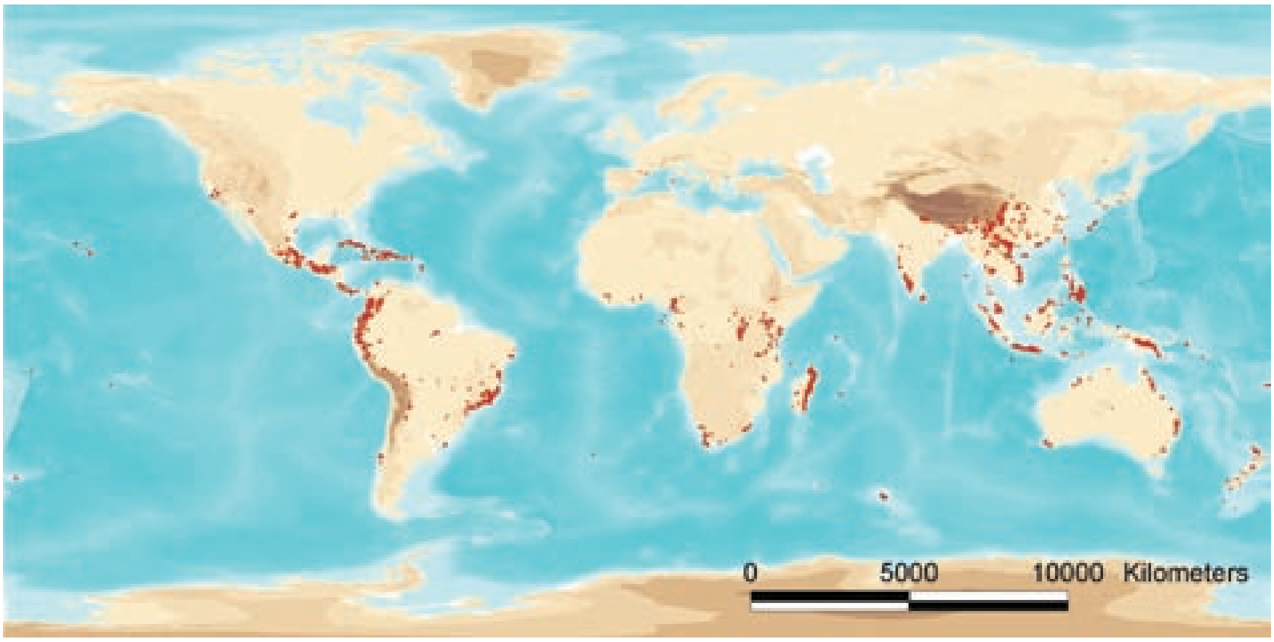

Figure 4.31 Position of urgent unprotected sites in relation to a map of elevation, where darker shades of brown represent higher elevations. Many urgent sites are concentrated on tropical regions of complex topography.

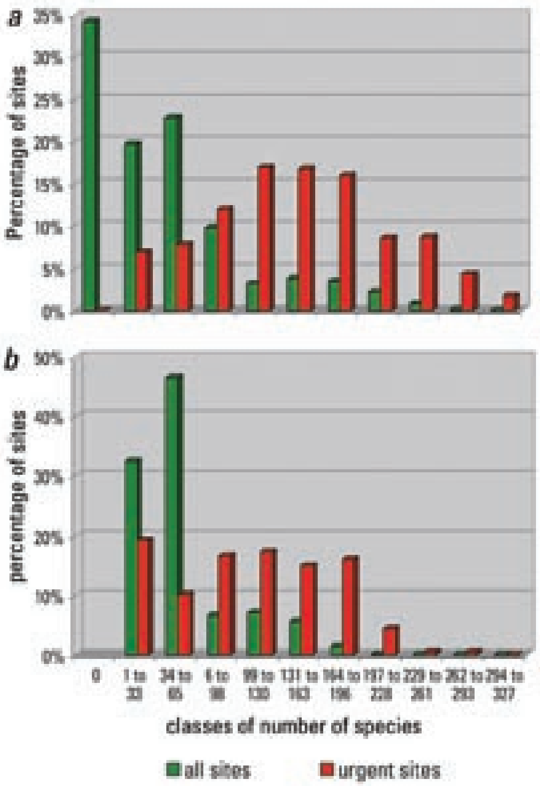

Figure 4.32 Frequency distribution of species richness in (*a*) unprotected sites and (*b*) protected sites, for all sites and for those highlighted as urgent. These values refer to number of sites (of variable size, especially for protected areas), and not to total area. Urgent sites are clearly biased towards those of higher species richness.

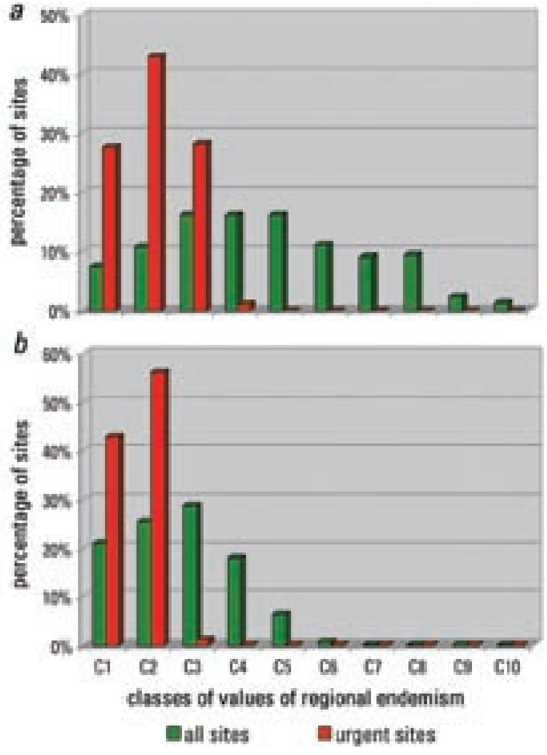

Figure 4.33 Frequency distribution of regional endemism in (*a*) unprotected sites and (*b*) protected sites, both for all sites and for those highlighted as urgent. Regional endemism was calculated for each site as the average range size of those species whose ranges are intercepted by the site. Frequencies are presented for ten equal-sized classes (C1 to C10). These values refer to number of sites (of variable size, especially for protected areas), and not to total area. Urgent sites are clearly biased towards those of higher regional endemism.

of the world (Figure 2.8). They are an artificial partition of the unprotected surface of the planet, created for analytical purposes, with each site usually including a diversity of habitats and land uses, and not corresponding to meaningful units for land management. This means that caution is needed in interpreting the results of global gap analysis in terms of priorities for expanding the global network of protected areas. Given the coarse scale of this analysis, and associated spatial uncertainty, the recommendation is not to create square protected areas following the sites' boundaries. Instead, areas highlighted as urgent should be priorities for finer-scale assessments, to investigate the feasibility and viability of consolidating/expanding the global protected area network while effectively protecting the species in each site that trigger their high values of irreplaceability and threat.

Having this in mind, it is instructive to analyze how the protection of these sites would contribute to changing the current picture of species coverage discussed above.

In terms of total area occupied, the difference would be small: the current network (as defined in Chapter 2) occupies 10.8 percent of the Earth's land surface. Adding all the urgent unprotected sites (Figure 4.24) would increase this area to 13.4 percent. However, these extra 2.6 percent of the Earth's surface would make a very significant difference to the coverage of the species analyzed (Figure 4.34), in particular for threatened species (Figure 4.35). These areas would reduce the number of absolute gaps (species with current 0 percent coverage) by more than two-thirds, from 1,652 to 543 species. Perhaps more meaningfully, such a scenario would change the current situation, in which only nine percent of the threatened

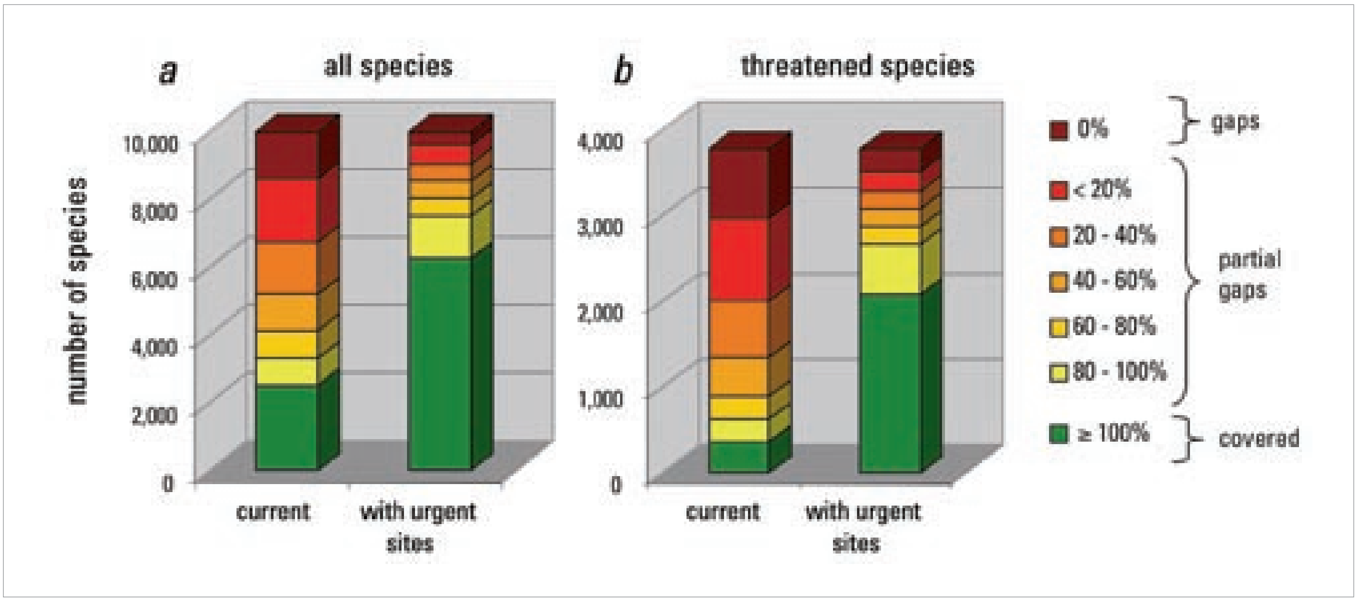

Figure 4.34 Comparison between current species coverage and coverage expected if urgent unprotected sites became protected, in terms of the representation of: (*a*) all species of mammals and amphibians; (*b*) threatened species of birds, mammals and amphibians. Coverage is assessed in terms of the percentage of the species' representation target that is covered by protected areas. Adding urgent unprotected sites to the global network would markedly improve the coverage of species, particularly the threatened ones.

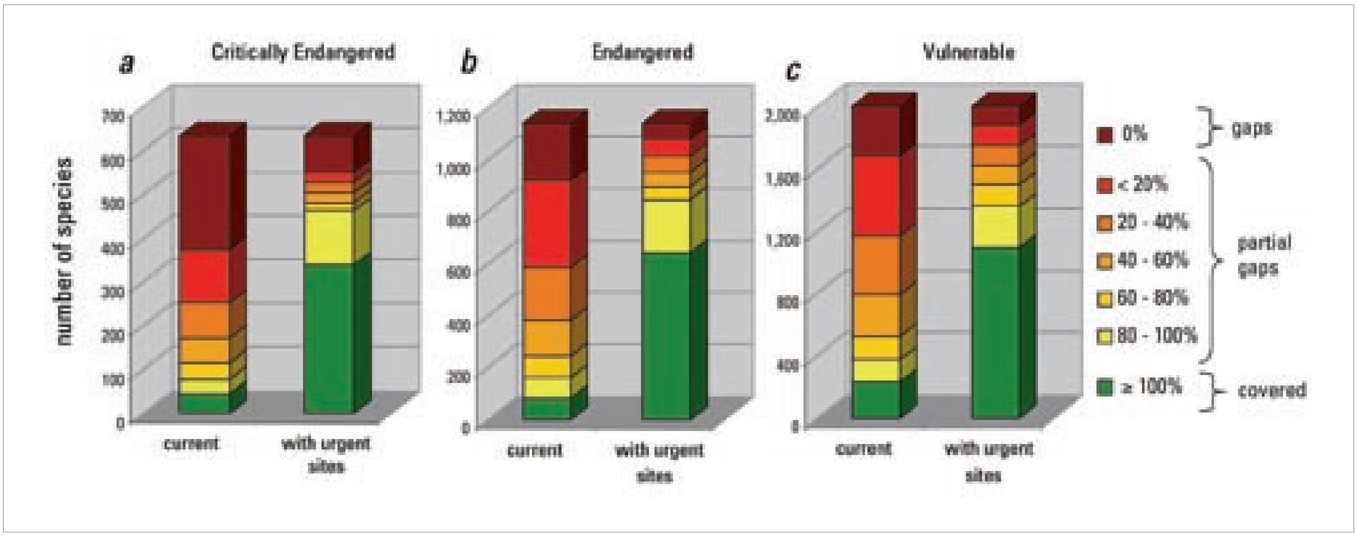

Figure 4.35 Comparison between current species coverage and coverage expected if urgent unprotected sites became protected, in terms of the representation of: (*a*) Critically Endangered, (*b*) Endangered, and (*c*) Vulnerable species. Coverage is assessed in terms of the percentage of the species' representation target that is covered by protected areas. Adding urgent unprotected sites to the global network would markedly improve the coverage of threatened species, particularly those of higher extinction risk.

species meet their targets, to a situation in which 55 percent would.

This said, it is also obvious from Figure 4.34 and Figure 4.35 that protecting these sites would not be sufficient to fill the representation gaps for all species. That is, these sites need to be seen as *priorities* for the expansion of a global network that covers vertebrate species comprehensively, but cannot be interpreted as all that it takes to finish the job (a prioritization, not triage). Conversely, that a given site has not been highlighted as urgent does not mean that it should not be considered for further protection.

Indeed, given that the criteria used for identifying urgent sites were strict in selecting only the very top sites for both irreplaceability and threat, many important areas have not been considered urgent, including many highly irreplaceable ones, in some cases holding species which are still true gaps in the global network of protected areas. Some examples of these sites can be readily found by comparing the maps of irreplaceability in each taxon with the final map of urgency (i.e., compare *a* and *c* in Figure 4.7, Figure 4.11, and Figure 4.17). For example, both the Horn of Africa and the Angola Scarp were highlighted for threatened birds and mammals in both Scenario A and the maps of irreplaceability of Scenario B. They are not been considered among the most urgent sites because the threat levels in this region (as measured in this analysis) were moderate compared to other equally irreplaceable areas. However, they correspond to areas of endemism with virtually no protected area coverage and will necessarily be a part of a truly representative global network. Even if at a global scale such regions are not considered the first priority for action, they should nevertheless be considered as such in national and regional assessments, given the global irreplaceability.

Broader Implications for Conservation Planning

Both Scenario A and B clearly demonstrate the inadequacy of conservation targets based on the percentage of area allocated to protected areas. Indeed, neither the number of gap species per country/administrative territory (throughout referred to as 'countries', $n = 243$) nor the number of unprotected sites of high (>0.9) irreplaceability are related to the percentage of area already protected ($r^2 < 0.001$, $p > 0.5$).

Total species richness is a good predictor ($r^2 = 0.50$ and $r^2 = 0.62$, respectively; $p < 0.0001$), but both the number of gap species per country and the number of sites of high irreplaceability are best explained by the number of endemic species ($r^2 = 0.64$ and $r^2 = 0.87$, respectively; $p < 0.0001$; Figure 4.36).

Multiple linear regressions combining the number of endemic species with the percentage of protected area as predictor variables do not perform significantly better in predicting the number of gap species or the number of unprotected sites of high irreplaceability than simple regressions based on the number of endemic species alone (*F* test, $p > 0.5$).

These results are not an artifact of variable country size. Indeed, although number of endemic species, number of gap species, and number of sites of high irreplaceability are all significantly associated with country area ($p < 0.05$), each of these relationships has much less predictive power (respectively: $r^2 = 0.02$, $r^2 = 0.05$, $r^2 = 0.02$) than either the association between the number of endemics and number of gap species or number of unprotected sites of high irreplaceability.

These results support previous assertions that no single conservation target based on percentage of area protected (10 percent or otherwise) is adequate. Instead, those countries with high levels of species richness and endemism require larger percentages of their territory protected (Soulé & Sanjayan 1998, Rodrigues & Gaston 2001). Conversely, the percentage of area already protected is a very poor indication of the additional conservation needs in each country, and should not be used to make decisions on how to allocate conservation investment among countries. Instead, these should be based on assessments which explicitly incorporate biological data such as levels of endemism.

THE GLOBAL GAP ANALYSIS IN THE CONTEXT OF OTHER GLOBAL PRIORITIZATION SYSTEMS

The global gap analysis is certainly not the first global assessment of priorities for conservation action. Previous studies, mainly lead by international nongovernmental organizations, include those of Centres of Plant Diversity (WWF & IUCN 1994-1997), Endemic Bird Areas (Stattersfield *et al.* 1998), Global 200 ecoregions (Olson & Dinerstein 1998), and biodiversity hotspots (Myers *et al.* 2000b). In addition to these assessments of intrinsically global nature, other systems are in place at the regional level in which consistent criteria are used to identify areas of particular importance which, together, are becoming part of a global network of priority areas. These include, for example, Ramsar sites (http://www.ramsar.org/) World Heritage sites (http://whc.unesco.org) and Important Bird Areas (Fishpool & Evans 2001).

All of these approaches have in common the premise that conservation resources are scarce and should be allocated strategically. However, they diverge from each other and from this global gap analysis in the criteria applied for prioritization, and in the biodiversity features targeted. It is therefore unsurprising that there are differences among their recommended conservation priorities, as well as many similarities (Fonseca *et al.* 2000).

While the similarities reinforce the importance of particular regions as global priorities, the differences should not be seen as a drawback (Fonseca 2003). Given that there is no single measure of biodiversity, but rather a continuum from genes to species to ecosystems to the entire biosphere (Gaston 1996), these should be seen as complementary approaches towards the tremendous task of preserving the world's biodiversity wealth. This is only possible by building from, and creating synergies between, the particular strengths of each approach in addressing particular taxa, regions, spatial scales, or biological, social and economic aspects of conservation action.

The contribution of this global gap analysis towards this bigger picture comes from two characteristics that distinguish it from previous assessments at the global scale:

- It is based on relatively detailed geographical data on the distribution of thousands of species, covering three classes of vertebrates.
- It explicitly accounts for the existing global protected area network in defining priorities for future action that are complementary to existing conservation efforts.

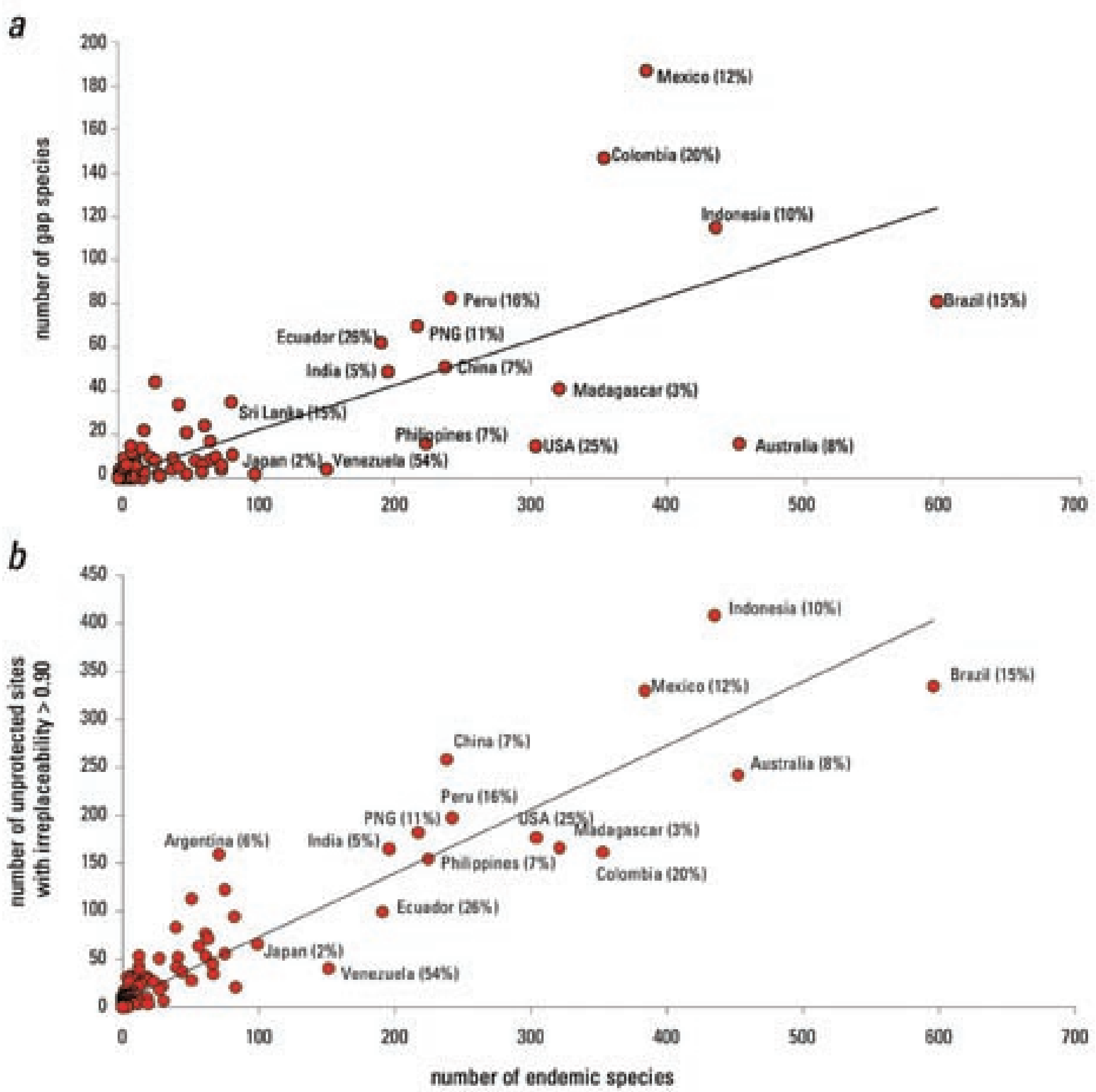

Figure 4.36 Relationship between the number of endemic species and: (*a*) the number of gap species per country/administrative territory according to Scenario A; and (*b*) the number of unprotected sites with irreplaceability above 0.90 according to Scenario B. The percentage of protected area for each country (in parentheses) was calculated using the protected areas considered as such for the purposes of this study, and may differ from official statistics. High numbers of gap species occur in countries with high levels of endemism, not necessarily those with smaller percentage of protected area.

Nevertheless, it is useful to analyze how the results of the global gap analysis compare to those of previous assessments, because this provides valuable insights into the strengths as well as the limitations of this analysis. Below, we concentrate these comparisons on those assessments for which global maps exist.

Ramsar Wetlands of International Importance

Ramsar wetlands of international importance were selected because they contain representative, rare, or unique wetland types and/or because they are of international importance for conserving biological diversity, particularly for waterfowl and fish (http://www.ramsar.org/).

Ramsar sites are proposed on a voluntary basis by each of the 136 Contracting Parties to the Ramsar Convention on Wetlands (Ramsar, Iran, 1971). This explains the concentration of Ramsar wetlands in Europe (Figure 4.37), where many countries have adhered enthusiastically to the principles and implementation of the convention by designating most sites that would qualify for Ramsar status. Implementation in other regions has been less comprehensive (e.g., Perez-Arteaga *et al.* 2002).

Nevertheless, the overall poor overlap between tropical Ramsar sites and areas identified as urgent by the global gap analysis (Figure 4.37, Table 4.3) is most likely a result of a major difference in emphasis between these two assessments:

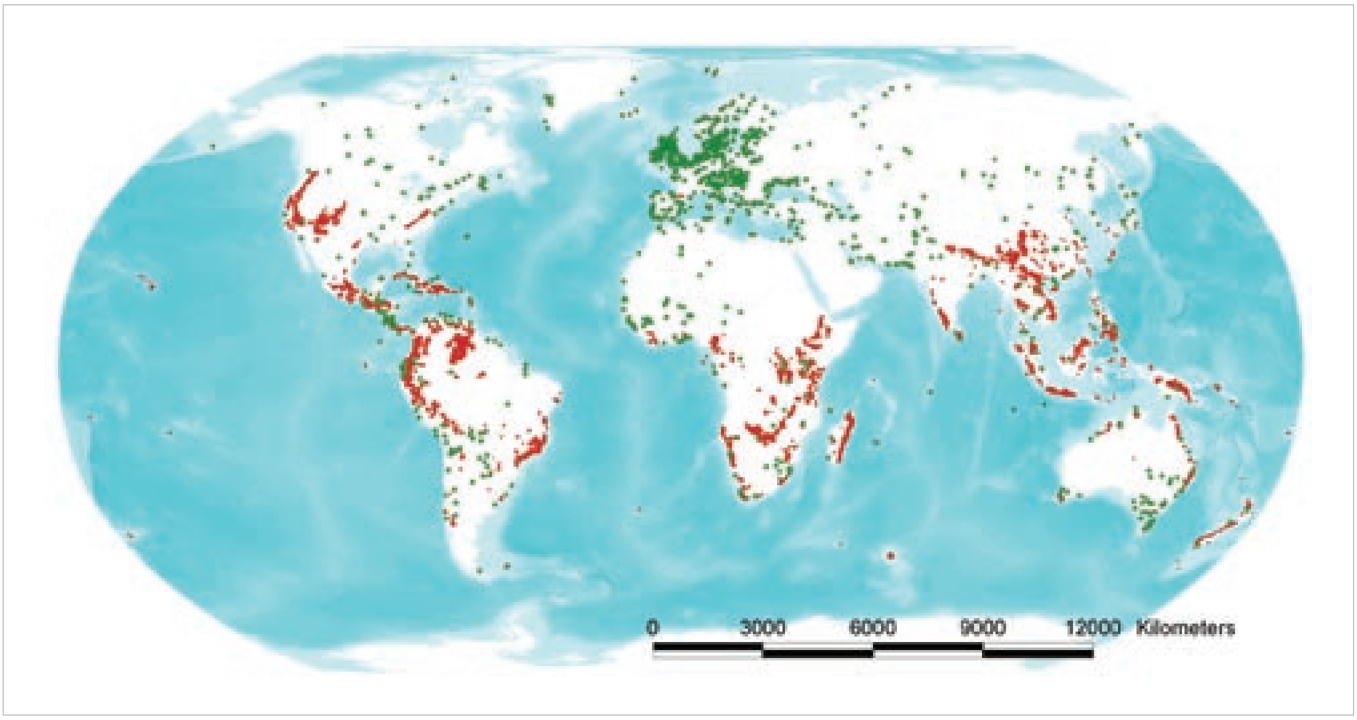

Figure 4.37 Overlap between Ramsar wetlands of international importance (in green) and the urgent protected and unprotected sites highlighted by the global gap analysis (in red).

Table 4.3 Overlap between areas identified under other global prioritization systems and urgent areas identified by the global gap analysis. We calculated the percentage of urgent protected and unprotected sites that are overlapped by each of the global prioritization system, both in terms of percentage of sites and in terms of percentage of total urgent area that those sites correspond to. The percentage of overlap, *O* is the proportional overlap between sites, varying from zero (no common sites) to 100 (maximum possible overlap); *CI* is the 95% confidence interval obtained from deriving this overlap at random 1,000 times.

	urgent protected sites covered		urgent unprotected sites covered	
	% sites	% area	% sites	% area
Ramsar sites	3	13	2	2
World Heritage sites	12	53	-	-
Megadiversity countries	55	65	70	71
Biodiversity hotspots	77	37	73	74
Endemic Bird Areas	87	73	82	82
Global 200 ecoregions	92	98	91	91

Ramsar's emphasis is on wetlands, while the global gap analysis concentrates on terrestrial ecosystems. Also, Ramsar sites are triggered by large concentrations of migratory waterbirds, which are very poorly addressed by the present assessment.

Countries designating Ramsar sites are responsible for implementing conservation measures, hence it is natural that more overlap is found between protected than unprotected urgent sites (Table 4.3).

World Heritage List (Natural Criteria)

The Convention Concerning the Protection of the World Cultural and Natural Heritage (the World Heritage Convention, http://whc.unesco.org/) was adopted by the General Conference of UNESCO in 1972, and has been signed by more than 170 countries. The Convention encourages countries to ensure the protection of their own natural and cultural heritage as well as to nominate sites within their national territory for inclusion on the World Heritage (WH) List. Currently, there are 754 sites inscribed on the WH List Criteria.

To assess the relationship between WH sites and the results of the global gap analysis, we considered only sites designated for natural properties, under criteria ii, iii and/or iv (i.e., excluding those classified only for their palaeontological value, criterion i). To qualify under each of these criteria, sites should:

- Criterion ii: Be outstanding examples representing significant ongoing ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals.

- Criterion iii: Contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance.

- Criterion iv: Contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.

Given that for sites to be included (and retained) on the WH List, countries must provide evidence of adequate protection and management, all of these sites correspond to protected areas. Hence, the comparison made here is only in relation to urgent protected sites.

Twelve percent of the urgent protected sites coincide with WH sites, covering 53 percent of the total area of urgent protected sites (Table 4.3, Figure 4.38; given that many protected sites are a combination of protected areas, this is larger than

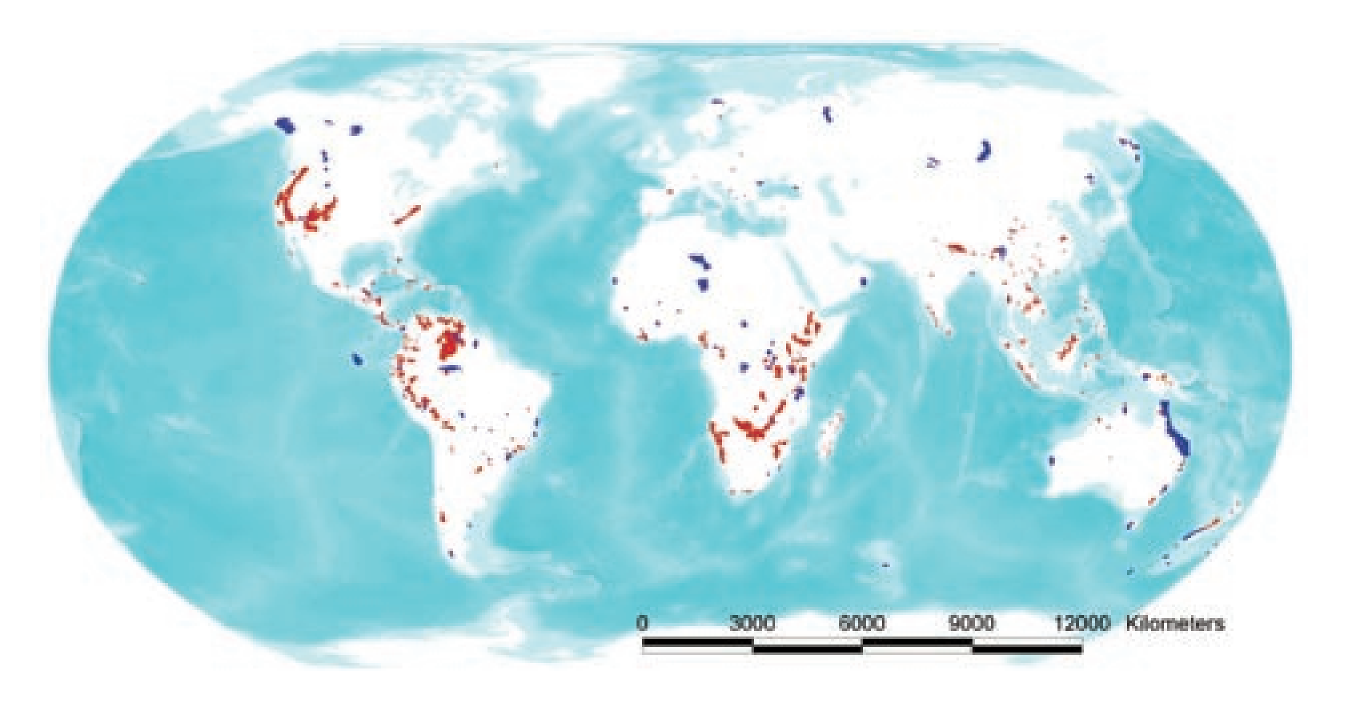

Figure 4.38 Overlap between World Heritage sites classified under criteria ii, iii and iv (in blue) and the urgent protected and unprotected sites highlighted by the global gap analysis (in red).

Table 4.4 Correspondence between World Heritage sites and urgent protected sites highlighted by the global gap analysis. Total numbers of sites are not exactly as in the official list because transboundary sites were mapped separately for each country.

	Number of WH sites	Number (%) of WH sites that are urgent
Criteria ii, iii, iv	178	59 (34%)
Criteria ii, iv	151	54 (36%)
Criterion iv	108	45 (42%)

the area effectively overlapped between World Heritage sites and urgent sites). Coincident sites are located mainly in tropical regions.

Perhaps more revealing is the proportion of WH sites identified as urgent, particularly when considering sites classified under criteria more directly related to this global gap analysis (Table 4.4). More than a third of the WH sites classified for criteria ii, iii, and iv are highlighted as urgent. This fraction increases to 36 percent when excluding sites classified for their aesthetic beauty (i.e., including only criteria ii and iv), and becomes 42 percent when considering only those sites classified for their natural habitats (criterion iv). This coincidence is particularly interesting, given that WH sites are designated for their "outstanding universal value", which, at least for criterion iv, could be measured by their global irreplaceability.

Another interesting pattern is that nearly half of the sites in the WH in Danger List (9 out of 20 sites classified under criteria ii, iii and iv) are highlighted as urgent in this global gap analysis. The WH in Danger List include those sites for the conservation of which major operations are necessary and for which assistance has been requested under this Convention.

Megadiversity Countries

The concept of megadiversity countries was coined by Mittermeier (1988) and developed by Conservation International (Mittermeier *et al.* 1997) to highlight 17 countries that hold particularly large numbers of plant and vertebrate species as endemics, namely Australia, Brazil, China, Colombia, Democratic Republic of Congo, Ecuador, India, Indonesia, Madagascar, Malaysia, Mexico, Papua New Guinea, Peru, Philippines, South Africa, United States, and Venezuela.

The majority of the protected sites highlighted as urgent, and even more of the urgent unprotected sites, overlap with megadiversity countries (Figure 4.39, Table 4.3). Conversely, all megadiversity countries include both protected and unprotected urgent sites.

The main differences between the results are likely due to the different spatial units considered. In Mittermeier *et al.* (1997) the unit is the country, which naturally favors large nations (mainly tropical ones) with high absolute numbers of species. The units considered in the global gap analysis (protected and unprotected sites) are much smaller, hence priority regions are defined on a finer scale. This allows small countries to stand out that have relatively low total numbers of species but high proportions of endemics (e.g., Sri Lanka, Panama, Cuba). In addition, sites of high urgency are not evenly spread within each megadiversity country (particularly for the largest, such as Australia, Brazil, China, and the United States) and instead concentrate in regions of high endemism within these countries.

Nevertheless, given that most decisions relevant for biodiversity conservation take place on a national scale (Hunter & Hutchinson 1994), there are clear advantages in an approach which uses countries as a the unit of analysis. The megadiversity countries analysis has inspired most of the countries it highlights to sign the Cancun Declaration of Like-Minded Megadiversity Countries, establishing a common agenda for sustainable development and cooperation (http://www.megadiverse.com/).

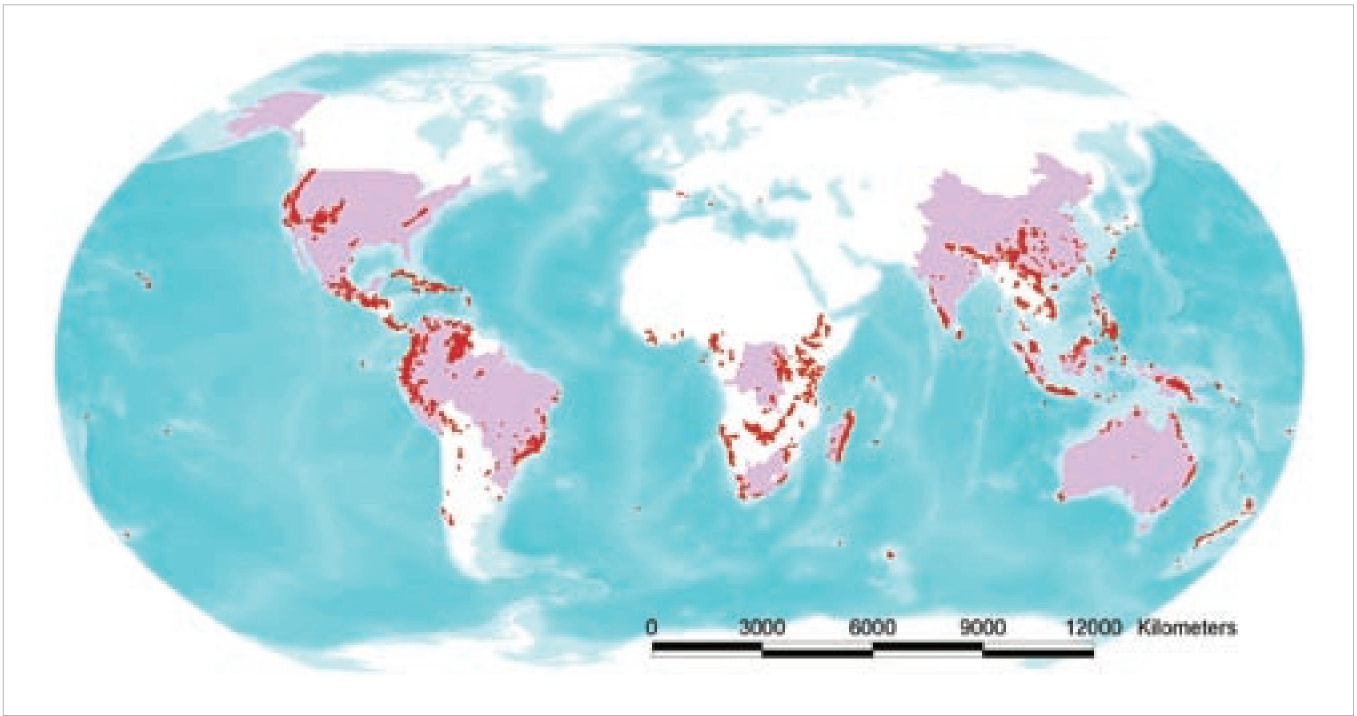

Figure 4.39 Overlap between the megadiversity countries (in purple) and the urgent protected and unprotected sites highlighted by the global gap analysis (in red).

Biodiversity Hotspots

The concept of biodiversity hotspots was proposed by Norman Myers (Myers 1988, 1990) to designate areas with exceptional levels of endemism and of threat. Based on this concept, Conservation International proposed 25 global biodiversity hotspots (Mittermeier *et al.* 1998, 1999, Myers *et al.* 2000b) defined as areas of the planet that hold as endemics at least 1,500 plant species (0.5 percent of global plant species) and have lost at least 70 percent of their natural habitat.

Given that both the biodiversity hotspot and global gap analysis approaches are based on the same premise – that high priority should be given to areas of high irreplaceability (endemism) and high threat – the overlap between the results of these two approaches is not a coincidence (Figure 4.40, Table 4.3). There are, however, three important exceptions to this overall pattern.

First, while 77 percent of the urgent protected sites are included in hotspots, these correspond to only 37 percent of the total urgent protected area. This is explained by the fact that hotspots do not overlap most of the largest protected sites highlighted as urgent, including many in Africa, the United States, and Amazonia. This is not unexpected. As discussed above, these protected sites are being triggered as urgent because of their large size (that increases the absolute numbers of threatened species, as well as the proportion of the ranges of individual species inside the protected site, hence irreplaceability). For the purposes of the global gap analysis, these correspond to truly important areas in the current global protected area network. However, these are regions of the planet quite well protected against habitat loss, and that therefore do not justify hotspot status.

Second, there are four hotspots for which there is little coverage by urgent areas: the Mediterranean Basin, Southwest Australia, Caucasus and Cerrado. All of these can be explained by differences in the taxonomic scope of the two assessments (plants in the biodiversity hotspots, vertebrates in the global gap analysis), as all of these hotspots are areas of high plant endemism but relatively low endemism of birds, mammals, and amphibians. This underscores that the global gap analysis is unlikely to address the conservation needs of non-analyzed taxa. This said, the hotspots of the California Floristic Province, Central Chile, the Cape Fynbos, and the Succulent Karoo all nevertheless appear as urgent priorities in this analysis, although none have particularly high vertebrate endemism relative to their plant endemism.

Third, there are concentrations of unprotected urgent sites that are not biodiversity hotspots. The main ones are: the Albertine Rift, the Kenyan Highlands and the Ethiopian Highlands, in Africa; Southeastern China and Taiwan, in Asia; and the Queensland Wet Tropics, and Papua New Guinea in Australasia region. The simplest explanation for these would be taxonomic bias, and that is indeed the case with the Kenyan Highlands, which is triggered mainly by mammalian endemism (Figure 4.11a). However, all of the other areas also hold exceptional levels of plant endemism. Papua New Guinea is an interesting case: this area has more than 1,500 endemic plant species but instead of being considered a hotspot it is a high biodiversity wilderness area (Mittermeier *et al.* 2003) because of low levels of habitat destruction. All other regions mentioned above face high threats and may indeed be recognized as biodiversity hotspots under the criteria of Myers *et al.* (2000b) as knowledge on their flora improves (Brooks *et al.* 2002). Perhaps the most striking example is the Albertine Rift, one of the top priorities for vertebrate conservation in Africa (Brooks *et al.* 2001) but with an extremely poorly known flora (Plumptre *et al.* 2003).

These results reinforce the hypothesis that areas identified as priorities for vertebrates constitute priorities also for other more diverse groups (here, plants), even if the reverse is not always the case (as for the hotspots in Mediterranean-type ecosystems).

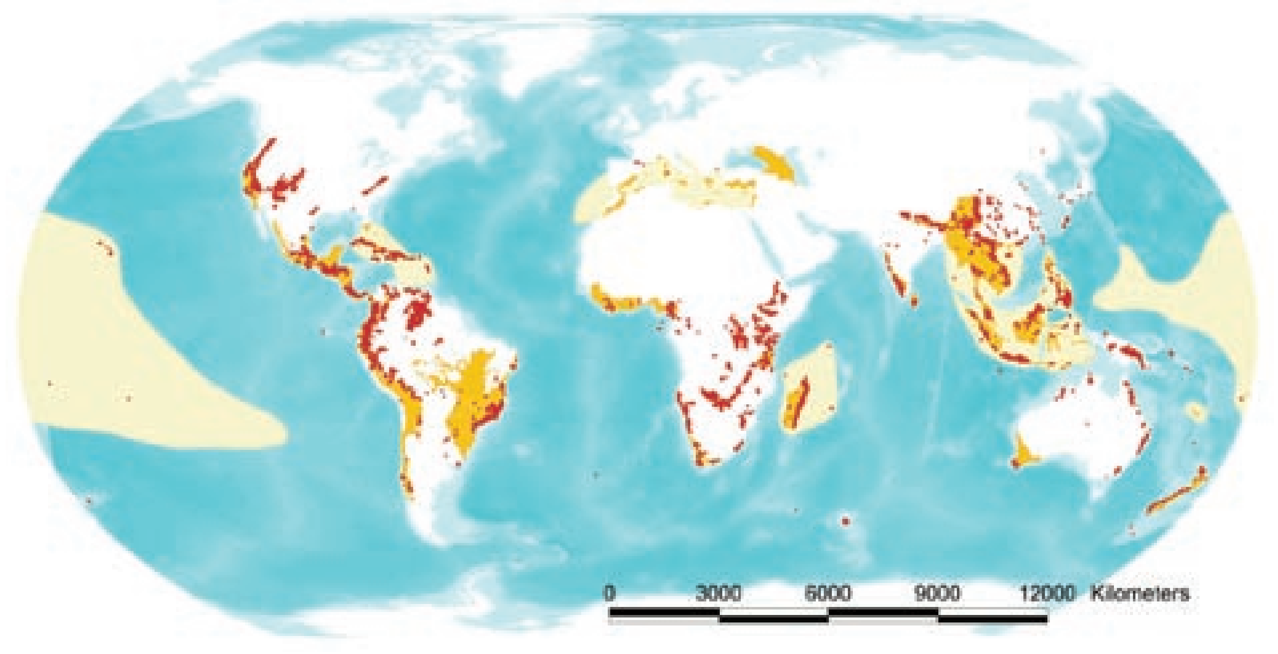

Figure 4.40 Overlap between the biodiversity hotspots (in orange, with yellow marking the outer boundary in some of the hotspots) and the urgent protected and unprotected sites highlighted by the global gap analysis (red).

Endemic Bird Areas

Endemic Bird Areas (EBAs) are 218 regions of the world noticeable for their levels of bird endemism. First proposed by the International Council for Bird Preservation (ICBP 1992) and developed following the organization's change to become BirdLife International (Stattersfield *et al.* 1998), they correspond to regions where two or more restricted-range bird species (those with historical breeding ranges smaller than 50,000 km^2) completely or partially overlap.

EBAs were classified under three levels of priority for conservation action according to a combination of biological importance and level of threat. Hence, Critical EBAs (76) are those of highest priority, followed by Urgent (62) and High priorities (80).

Although highly variable in size (from less than 1km^2 to 550,000 km^2) and on average about twice as large as the sites considered here, the EBA analysis and the gap analysis operate on the same (regional) scale. Furthermore, endemism is a main criterion for prioritization in both. Hence, it is not surprising that there is a high level of correspondence between the two approaches: not only are 82 percent of the urgent sites inside EBAs (Figure 4.41, Table 4.3), 70 percent of the EBAs are also touched by an urgent protected or unprotected site.

If the comparison is restricted to EBAs of higher priority, the match becomes more noticeable: 78 percent of the Critical and Urgent EBAs, and 79 percent of the Critical EBAs are overlapped by urgent sites.

Given that EBAs are defined by birds, it is also not surprising that EBAs closely match the irreplaceability maps of protected (Figure 4.5a) and, particularly, unprotected sites (Figure 4.7a) for threatened birds. That the match is not more exact is probably a consequence of differences in the two sets of species used in each of these two approaches: approximately 2,600 restricted-range species in the EBAs and 1180 threatened species in the gap analysis (about 75 percent of threatened species being also restricted-range).

Global 200 Ecoregions

The Global 200 ecoregions, proposed by WWF-US (Olson & Dinerstein 1998), are outstanding examples of each major habitat type, including freshwater and marine systems as well as terrestrial habitats, selected to represent every continent and every ocean basin. The spatial unit in this approach is the ecoregion: large areas of relatively uniform climate that harbor a characteristic set of species and ecological communities.

Nearly all protected and unprotected urgent sites highlighted in the global gap analysis are included in the Global 200 (Figure 4.42, Table 4.3). The reverse pattern is not found (many of the Global 200 ecoregions hold no urgent sites), and this is natural, given that the Global 200 occupy an area seven times larger than the urgent sites highlighted in the global gap analysis.

The main differences in the results of these two assessments are explained by their different objectives. The global gap analysis is driven by a combination of irreplaceability and threat, which therefore does not highlight ecoregions of low endemism (such as the boreal forest) or low threat (such as many deserts). The Global 200 aim first at covering each major habitat type, and only then selects the most representative ecoregion within each of these habitat types. Nevertheless, there is a high degree of overlap between the tropical Global 200 ecoregions and the urgent areas highlighted in the global gap analysis.

Other Priority Assessments

As mentioned above, several other global assessments of conservation priority have been proposed, but have not been mapped worldwide to date and so are not analyzed directly in comparison to the results of this global gap analysis.

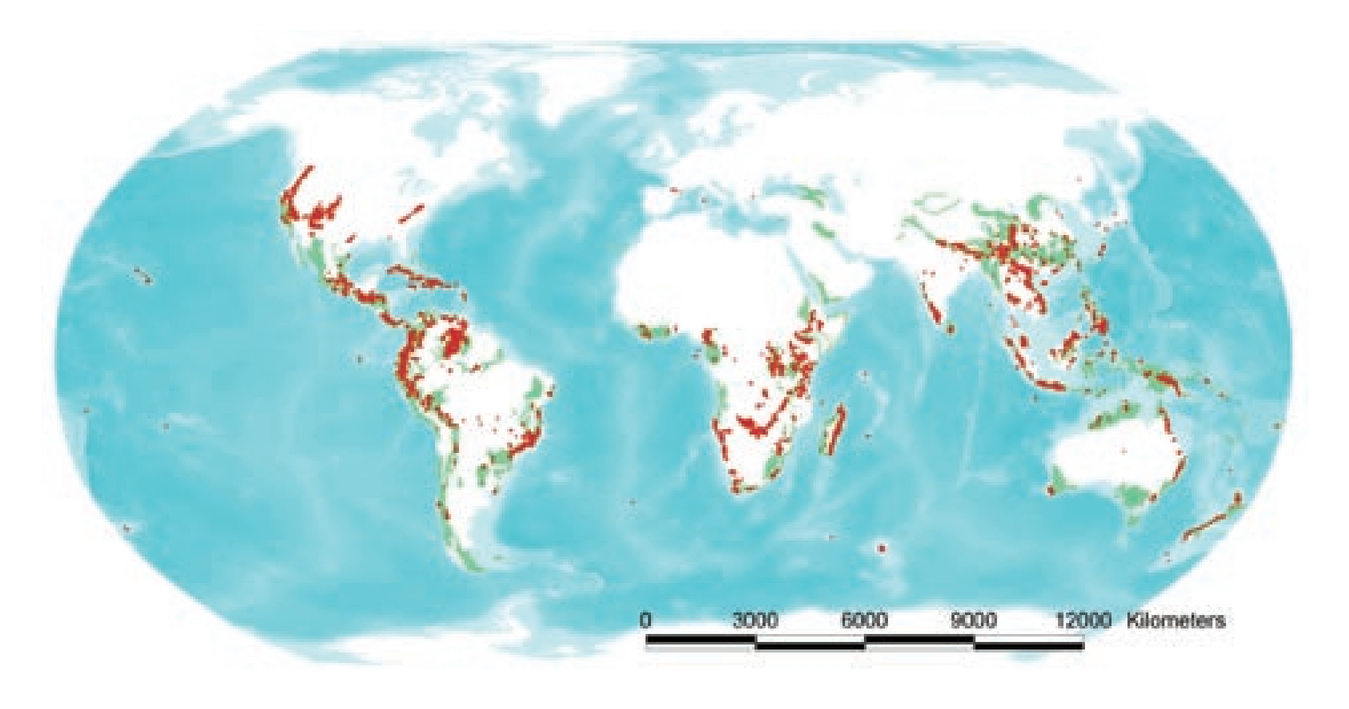

Figure 4.41 Overlap between the Endemic Bird Areas (in green) and the urgent protected and unprotected sites highlighted by the global gap analysis (in red).

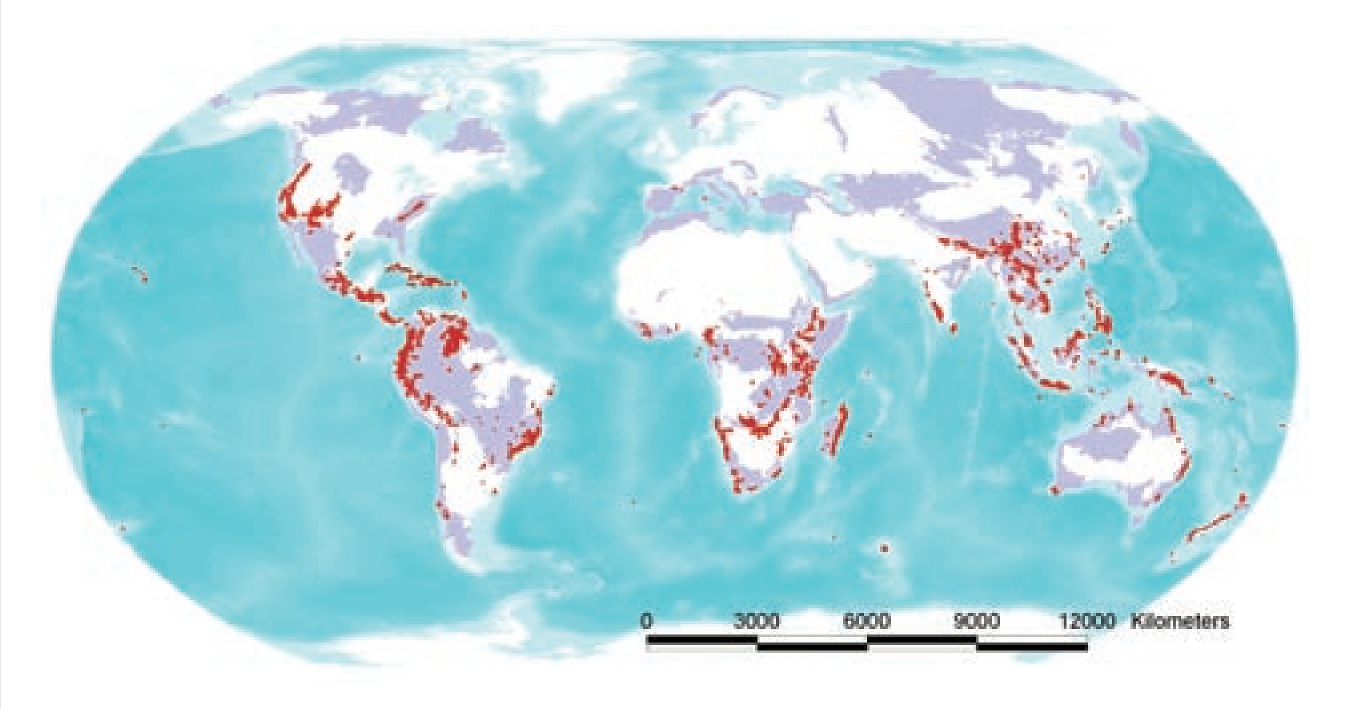

Figure 4.42 Overlap between the Global 200 ecoregions (in purple) and the urgent protected and unprotected sites highlighted by the global gap analysis (in red).

The Important Bird Areas (IBA) program of the BirdLife International partnership identifies site scale priorities for threatened, restricted-range, biome-restricted and congregatory birds on a country-by-country basis (Fishpool *et al.* 1998). While this program has published results for many countries and regions, notably Africa (Fishpool & Evans 2001) and Europe (Heath *et al.* 2000), the analysis is not yet complete globally, and so comparisons with the global gap analysis are not yet possible. While it is highly likely that almost all protected sites and regions identified as urgent by this global gap analysis will also be IBAs, even for non-avian species (Brooks *et al.* 2001), the converse will not be true - IBAs cover many more sites than are discussed here.

The Important Bird Area concept is currently being expanded to incorporate other taxa, and so identify 'key biodiversity areas.' Another, more recent initiative, which will again compare directly to this global gap analysis is the work of the Alliance for Zero Extinction, a multi-institutional partnership seeking to identify and conserve all sites holding the sole population of a Critically Endangered or Endangered species. The alliance has not yet published its results but, given their strict criteria for inclusion, a tight overlap with the results of the gap analysis is likely.

One site-scale analysis that may not correspond so closely to our results is that of Centres of Plant Diversity (WWF & IUCN 1994-1997). This identified sites worldwide known to hold many species or many endemic species. While many, maybe most, of the areas and regions identified in our analysis will probably also be centres of plant diversity (cf. overlap with biodiversity hotspots, above), the latter include a number of areas - especially in Mediterranean-type biomes - of enormous importance for plants but less so for terrestrial vertebrates.

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CHAPTER 5

Final Conclusions


Cheri Sugal

Sovi Basin, Vitu Levu, Fiji. Oceanic islands worldwide emerge as urgent priorities for the establishment of protected areas.

This is the first global analysis of the extent of conservation action, assessed as the establishment of protected areas. It is thus the first analysis of priority regions towards filling the remaining gaps in the global network of protected areas. The fundamental message emerging from the analysis is that, while the global terrestrial coverage of protected areas is now approaching 10 percent, it is still far from complete. This is the case even for the representation of the best-known and more charismatic of all species. Even under the extremely 'optimistic' Scenario A, we show that more than 1,000 species of birds, mammals, and amphibians are not represented in any way in even one protected area. Threatened species are proportionally more poorly represented, particularly those with higher levels of threat. We therefore see these results as a call for the establishment of new protected areas, particularly in those regions that would contribute most to the global system. The highest priorities for establishment of such protected areas are those regions that are not only the most irreplaceable, but also face the greatest threat – those mapped as urgent in Figure 4.24.

The vast majority of these regions are in low-income countries in the tropics – those that can least afford the costs and, particularly, the opportunity costs of establishing and enforcing protected areas (James *et al.* 1999). This is the case even if the long term local benefits of protected areas are factored in (Balmford *et al.* 2003), because much of the benefit of the establishment of protected areas will be realized at a global scale (Kremen *et al.* 2000). Thus, our recommendation for the rapid establishment of protected areas in urgent regions comes hand-in-hand with a recommendation that the costs of this conservation are largely borne by the global community, as represented by multi- and bi-lateral institutions, foundations, and private corporations and individuals (Balmford & Whitten 2003).

Several geographic specificities of the results from this global gap analysis bear reiterating. Tropical forest habitats – especially moist, but also dry – appear as an exceptional priority, both absolutely and relative to their area, particularly when combined with topographical complexity. The outstanding urgency of increased conservation investment in small tropical island territories is also emphasized by our results: many of them are characterized by both exceptional irreplaceability and exceptional threat.

For most tropical regions, we found a coincidence of both urgency for establishing new protected areas and urgency for consolidating the existing ones. Needless to say, in areas of the planet where such regions have disproportionately little protected area coverage to date – Asia is the most obvious example – the need for accelerated protected area establishment is all the more urgent. Conversely, in priority regions where many protected areas already exist – as in much of Latin America and Africa – investment to improve existing management and to ensure active protection is an important priority.

Overall, these results support those of existing studies in emphasizing the global importance of the endemic-rich tropics (Mittermeier *et al.* 1997, Olson & Dinerstein 1998, Stattersfield *et al.* 1998, Myers *et al.* 2000b, Mittermeier *et al.* 2003), while increasing spatial resolution and taxonomic breadth.

The geographic heterogeneity of these results also demonstrates the limitations of area-based conservation targets, such as the 10 percent target suggested at the IVth World Parks Congress. Not only is 10 percent clearly far too low as a global target (Soulé & Sanjayan 1998), but – in order to conserve biodiversity effectively – targets for the establishment of protected areas must be based on biodiversity, which is only very poorly reflected by area (Rodrigues & Gaston 2001). The compilation of very large new biodiversity datasets and development of powerful analytical techniques, both facilitated by the rapid development of computing and information technology over the last decade, are starting to make this possible (Levitt 2002).

Nevertheless, the data available at a global scale are still coarse, and assessments such as this global gap analysis merely provide the first cut towards a global framework, from which detailed regional and local analyses form the key. Hence, this assessment cannot replace on the ground efforts facilitated by expert knowledge. These can incorporate much more detailed information on the conservation needs of each species and the adequacy of particular areas, while bringing socioeconomic considerations into the conservation planning equation (e.g., Pressey 1998, Cowling *et al.* 2003). The areas highlighted as urgent in this global gap analysis should be priorities for such assessments.

However, in building a truly comprehensive protected area network, these assessments need to take place in every region and every nation. We reiterate that the global gap analysis is an assessment for establishing global *priorities* – not a triage method for deciding in which regions conservation planning should be abandoned. The irreplaceability maps for each taxa (Figure 4.7a, Figure 4.11a, Figure 4.17a) clearly demonstrate that, even for the coverage of just these vertebrate species, just focusing on the regions highlighted as urgent is not enough to construct a representative system. Building the global network of protected areas can only happen by embedding regional/national strategies in a global vision.

The premise in this global gap analysis is that the analyzed species of mammals, amphibians, and threatened birds are conservation targets in their own right. This assessment does not claim to address biodiversity wholesale. Nevertheless, general congruence between the results obtained for each of the taxa analyzed, as well as between the overall results of this analysis and those obtained by other global assessments, suggest that those areas identified as urgent priorities by this global gap analysis are also likely to be high priorities for other terrestrial taxa (Howard *et al.* 1998). However they are most certainly not *sufficient* to adequately cover the conservation needs of these other taxa, particularly those with higher levels of endemism and diversity, such as plants and invertebrates (Rodrigues & Gaston 2001). This is supported by the finding that the area highlighted for birds and mammals (Figure 4.7c, Figure 4.11c) was much less than the area highlighted for amphibians (Figure 17c), and that not all biodiversity hotspots selected for plants were well covered by the results of this global gap analysis (Figure 4.40). Hence, future assessments of other taxa should be made as soon as data become available.

One segment of biodiversity that is clearly not covered well by this analysis is the aquatic realm, and we applaud efforts to plan the expansion of the protected area system in the world's freshwaters and oceans (Roberts *et al.* 2002). The marine network of protected areas is even less comprehensive than the terrestrial one (Roberts 2003) and freshwater ecosystems are some of the most threatened and neglected (Abell 2002).

Further, we should re-emphasize that the results of this global gap analysis are about representation of species, not addressing the issues of persistence and viability. Clearly, the mere establishment of a protected area may mean little without commensurate investment in management and enforcement (Brandon *et al.* 1998), and our results highlight protected areas in which it is pressing to ensure that such investment is taking place. In addition, edge effects on protected areas (Gascon *et al.* 2000) and limited dispersal between them (Tewksbury *et al.* 2002) will often mean that such areas cannot be viable without simultaneous efforts to ameliorate pressures across the broader landscape (Rosenzweig 2003). With the emerging threat from global climate change, these efforts are even more critical. Other threats to biodiversity, such as invasive species (particularly on small islands) and disease, require conservation measures that go well beyond habitat protection. All this said, while clearly not sufficient alone to conserve biodiversity in perpetuity, protecting habitat *per se* is an essential first step without which no long-term conservation will succeed (Lens *et al.* 2002). Establishing protected areas is one of the major ways of achieving this goal, but conservation planners in each region need to make use of a broader set of tools for ensuring the persistence of their share of global biodiversity.

Overall, we view the results of this initial global gap analysis with tempered optimism. Sizeable areas of the planet, particularly in North America and in Europe, are well ahead, at least for the representation of terrestrial vertebrate species, although even in these regions the task is far from finished (e.g., Scott *et al.* 2001b). In the megadiverse tropics, massive efforts to establish protected areas over the last few decades have contributed substantially to the conservation of global biodiversity. Nevertheless, if the world's nations are to conserve their living biodiversity heritage, a greatly increased and strategically placed investment in establishing new protected areas must be made as soon as possible.

REFERENCES CITED

Abbitt, R.J.F., Scott, J.M., & Wilcove, D.S. 2000. The geography of vulnerability: Incorporating species geography and human development patterns into conservation planning. *Biological Conservation* 96: 169-175.

Abell, R. 2002. Conservation biology for the biodiversity crisis: A freshwater follow-up. *Conservation Biology* 16: 1435-1437.

Alcover, J.A., Sans, A., & Palmer, M. 1998. The extent of extinctions of mammals on islands. *Journal of Biogeography* 25: 913-918.

Alford, R.A. & Richards, S.J. 1999. Global amphibian declines: A problem in applied ecology. *Annual Review of Ecology and Systematics* 30: 133-165.

Amiet, J-L. 1983. Un essai de cartographie des anoures du Cameroun. *Alytes* 2: 124-146.

Armenteras, D., Gast, F., & Villareal, H. 2003. Andean forest fragmentation and the representativeness of protected natural areas in the eastern Andes, Colombia. *Biological Conservation* 113: 245-256.

Atkinson, P., Peet, N., & Alexander, J. 1991. The status and conservation of the endemic bird species of São Tomé and Príncipe, West Africa. *Bird Conservation International* 1: 255-282.

Aveling, C., Fay, J.M., Ham, R., Langrand, O., Sugal, C., White, L., Hart, J.A., Pilgrim, J., & Mittermeier, R.A. 2002. The Congo forests of Central Africa. In: Mittermeier, R.A., Mittermeier, C.G., Robles Gil, P., Pilgrim, J.D., Fonseca, G.A.B., Brooks, T.M., & Konstant, W.R. (Eds.), *Wilderness: Earth's Last Wild Places.* pp.108-133 Mexico City: CEMEX.

B

Baillie, J. & Groombridge, B. (Eds.). 1996. *IUCN Red List of Threatened Animals.* Gland [Switzerland]: IUCN.

Bakarr, M.I., Fonseca, G.A.B., Mittermeier, R., Rylands, A.B., & Walker Painemilla, K. 2001. (Eds.). *Hunting and Bushmeat Utilization in the African Rain Forest: Perspectives Towards a Blueprint for Conservation Action.* Advances in Applied Biodiversity Science 2. Washington DC: Conservation International.

Baker, W.L. 1992. The Landscape Ecology of Large Disturbances in the Design and Management of Nature-Reserves. *Landscape Ecology* 7: 181-194.

Balmford, A. 1996. Extinction filters and current resilience: The significance of past selection pressures for conservation biology. *Trends in Ecology & Evolution* 11: 193-196.

Balmford, A. & Whitten, T. 2003. Who should pay for tropical conservation, and how could the costs be met? *Oryx* 37: 238-250.

Balmford, A., Mace, G.M., & Leader-Williams, N. 1996. Designing the ark: Setting priorities for captive breeding. *Conservation Biology* 10: 719-727.

Balmford, A., Moore, J.L., Brooks, T., Burgess, N., Hansen, L.A., Williams, P., & Rahbek, C. 2001. Conservation conflicts across Africa. *Science* 291: 2616-2619.

Balmford, A., Bruner, A., Cooper, P., Costanza, R., Farber, S., Green, R.E., Jenkins, M., Jefferiss, P., Jessamy, V., Madden, J., Munro, K., Myers, N., Naeem, S., Paavola, J., Rayment, M., Rosendo, S., Roughgarden, J., Trumper, K., & Turner, R.K. 2002. Economic reasons for conserving wild nature. *Science* 297: 950-953.

Balmford, A., Gaston, K.J., Blyth, S., James, A., & Kapos, V. 2003. Global variation in terrestrial conservation costs, conservation benefits, and unmet conservation needs. *Proceedings of the National Academy of Sciences* 100: 1046–1050.

Balvanera, P., Daily, G.C., Ehrlich, P.R., Ricketts, T.H., Bailey, S-A., Kark, S., Kremen, C., & Pereira, H. 2001. Conserving biodiversity and ecosystem services. *Science* 291: 2047.

Barnes, K.N. 1998. *The Important Bird Areas of Southern Africa.* Johannesburg: BirdLife South Africa.

Beattie, A. & Ehrlich, P.R. 2001. *Wild Solutions: How Biodiversity Is Money in the Bank.* New Haven [CT]: Yale University Press.

Bedward, M., Pressey, R.L., & Keith, D.A. 1992. A new approach for selecting fully representative reserve networks - Addressing efficiency, reserve design and land suitability with an iterative analysis. *Biological Conservation* 62: 115-125.

Bell, B.D. 1996. Aspects of the ecological management of New Zealand frogs: Conservation status, location, identification, examination, and survey techniques. *Ecological Management* 4: 91-111.

Bencke, G.A. & Maurício, G.N. 2002. *Important Bird Area Program in Brazil. Phase 1: Data Compilation and Analysis of Available Information for the Atlantic Forest Region.* Porto Alegre [Brazil]: BirdLife International Brasil Programme.

Bennett, E.L., Nyaoi, A.J., & Sompud, J. 2000. Saving Borneo's bacon: The sustainability of hunting in Sarawak and Sabah. In: Robinson, J.G. & Bennett, E.L. (Eds.), *Hunting for Sustainability in Tropical Forests.* pp.305-324. New York: Columbia University Press.

Berger, L., Speare, R., Daszak, P., Green, D.E., Cunningham, A.A., Goggin, C.L., Slocombe, R., Ragan, M.A., Hyatt, A.D., McDonald, K.R., Hines, H.B., Lips, K.R., Marantelli, G., & Parkes, H. 1998. Chytridiomycosis causes amphibian mortality associated with population declines in the rain forests of Australia and Central America. *Proceedings of the National Academy of Sciences* 95: 9031-9036.

Biju, S.D. 2001. A synopsis to the frog fauna of the Western Ghats, India. *Occasional Publication of ISCB* 1: 1-24.

BirdLife International. 2000. *Threatened Birds of the World*. Barcelona and Cambridge: Lynx Edicions and BirdLife International.

Blackburn, L., Nanjappa, P., & Lannoo, M.J. 2001. *An Atlas of the Distribution of U.S. Amphibians.* Muncie [Indiana]: Ball State University.

Blackburn, T.M. & Gaston, K.J. 1996. Spatial patterns of species richness in birds in the New World. *Ecography* 19: 369-376.

Blaustein, A.R., Romansic, J.M., Kiesecker, J.M., & Hatch, A.C. 2003. Ultraviolet radiation, toxic chemicals and amphibian population declines. *Diversity & Distributions* 9: 123-140.

Boitani, L., Corsi, F., De Biase, A., Carranza, I.D.I., Ravagli, M., Reggiani, G., Sinibaldi, I., & Trapanese, P. 1999. *A Databank for the Conservation and Management of the African Mammals.* Rome: Istituto di Ecologia Applicata.

Bonaccorso, F.J. 1998. *Bats of Papua New Guinea*. Washington DC: Conservation International.

Borkin, L.J. 1999. Distribution of Amphibians in North Africa, Europe, Western Asia, and the Former Soviet Union. In: Duellman, W.E. (Ed.), *Patterns and Distributions of Amphibians: A Global Perspective.* pp.329-420. Baltimore: Johns Hopkins University Press.

Brandon, K., Redford, K.H., Sanderson, S.E. (Eds.). 1998. *Parks in Peril - People, Politics, and Protected Areas.* Washington DC: Island Press for The Nature Conservancy.

Brito, D. & Figueiredo, M.S.L. 2003. Minimum viable population and conservation status of the Atlantic Forest spiny rat *Trinomys eliasi. Biological Conservation* 113: 153-158.

Brooke, M. de L. 1995. The modern avifauna of the Pitcairn Islands. *Biological Journal of the Linnean Society* 56: 199-212.

Brooks, T. 2000. Extinct species. In: BirdLife International. (Eds.), *Threatened Birds of the World*. pp.701-708. Barcelona and Cambridge: Lynx Edicions and BirdLife International.

Brooks, T.M., Pimm, S.L., & Collar, N.J. 1997. Deforestation predicts the number of threatened birds in insular Southeast Asia. *Conservation Biology* 11: 382-394.

Brooks, T.M., Pimm, S.L., Kapos, V., & Ravilious, C. 1999. Threat from deforestation to montane and lowland birds and mammals in insular South-east Asia. *Journal of Animal Ecology* 68: 1061-1078.

Brooks, T., Balmford, A., Burgess, N., Fjeldså, J., Hansen, L.A., Moore, J., Rahbek, C., & Williams, P. 2001. Toward a blueprint for conservation in Africa. *BioScience* 51: 613-624.

Brooks, T.M., Mittermeier, R.A., Mittermeier, C.G., Fonseca, G.A.B., Rylands, A.B., Konstant, W.R., Flick, P., Pilgrim, J., Oldfield, S., Magin, G., & Hilton-Taylor, C. 2002. Habitat loss and extinction in the hotspots of biodiversity. *Conservation Biology* 16: 909-923.

Brown, J.H. 1984. On the relationship between abundance and distribution of species. *The American Naturalist* 124: 255-279.

Brown, J.H., Mehlman, D.W., & Stevens, G.C. 1995. Spatial variation in abundance. *Ecology* 76: 2028-2043.

Bruner, A.G., Gullison, R.E., Rice, R.E., & Fonseca, G.A.B. 2001. Effectiveness of parks in protecting tropical biodiversity. *Science* 291: 125-128.

Burbidge, A.A. & Manly, B.F.J. 2002. Mammal extinctions on Australian islands: Causes and conservation implications. *Journal of Biogeography* 29: 465-473.

Bury R.B. 1988. Habitat relationships and ecological importance of amphibians and reptiles. In: Raedeke, K.J. (Ed.), *Streamside Management: Riparian Wildlife and Forestry Interactions.* pp.61-76. Seattle: Institute of Forest Resources, University of Washington.

Butchart, S.H.M., Brooks, T.M., Davies, C.W.N., Dharmaputra, G., Dutson, G.C.L., Lowen, J.C., & Sahu, A. 1996. Conservation status of the birds of Flores and Sumbawa, Indonesia. *Bird Conservation International* 6: 335-370.

C

Caicco, S.L., Scott, J.M., Butterfield, B., & Csuti, B. 1995. A gap analysis of the management status of the vegetation of Idaho (USA). *Conservation Biology* 9: 498-511.

Campbell, J.A. 1999. Distribution patterns of amphibians in the West Indies. In: Duellman, W.E. (Ed.), *Patterns and Distributions of Amphibians: A Global Perspective.* pp.111-210. Baltimore: Johns Hopkins University Press.

Carret, J.C. 2003. *Environnement et Pauvreté: Le Cas des Aires Protégées de Madagascar.* Unpublished Presentation. Appui Partenarial de la Banque mondiale au Programme Environnement (PE) 3 de la République de Madagascar. Antananarivo: World Bank.

Castro Parga, I., Moreno Saiz, J.C., Humphries, C.J., & Williams. P.H. 1996. Strengthening the natural and national park system of Iberia to conserve vascular plants. *Botanical Journal of the Linnean Society* 121: 189-205.

Ceballos, G. & Brown, J.H. 1995. Global patterns of mammalian diversity, endemism, and endangerment. *Conservation Biology* 9: 559-568.

Chapin, F.S., Zavaleta, E.S., Eviner, V.T., Naylor, R.L., Vitousek, P.M., Reynolds, H.L., Hooper, D.U., Lavorel, S., Sala, O.E., Hobbie, S.E., Mack, M.C., & Diaz, S. 2000. Consequences of changing biodiversity. *Nature* 405: 234-242.

Chomitz, K.M. & Gray, D.A. 1996. Roads, land use, and deforestation: A spatial model applied to Belize. *World Bank Economic Review* 10: 487-512.

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

Clark, F.S. & Slusher, R.B. 2000. Using spatial analysis to drive reserve design: A case study of a national wildlife refuge in Indiana and Illinois (USA). *Landscape Ecology* 15: 75-84.

Clout, M.N. & Craig, J.L. 1995. The conservation of critically endangered flightless birds in New Zealand. *Ibis* 137(Supplement): 181-190.

Coe, M.J. & Foster, J.B. 1972. The mammals of the northern slopes of Mount Kenya. *Journal of the East African Natural History Society* 131: 1-18.

Cogger, H.G. 1992. *Reptiles and Amphibians of Australia.* Sydney [Australia]: Reed New Holland.

Collar, N.J. 2003. Beyond value: Biodiversity and the freedom of the mind. *Global Ecology and Biogeography* 12: 265-269.

Collar, N.J., Andreev, A.V., Chan, S., Crosby, M.J., Subramanya, S., & Tobias, J.A. 2001. *Threatened Birds of Asia: The BirdLife International Red Data Book.* Cambridge [UK]: BirdLife International.

Conant, R. & Collins, J.T. 1998. *Peterson Field Guide to Reptiles and Amphibians of Eastern and Central North America.* 3rd Ed. New York: Houghton Mifflin Company.

Cowling, R.M. & Pressey, R.L. 2003. Introduction to systematic conservation planning in the Cape Floristic Region. *Biological Conservation* 112: 1-13.

Cowling, R.M., Richardson, D.M., & Pierce, S.M. 1997. *The Vegetation of Southern Africa.* Cambridge [UK]: Cambridge University Press.

Cowling, R.M., Pressey, R.L., Lombard, A.T., Desmet, P.G., & Ellis, A.G. 1999. From representation to persistence: Requirements for a sustainable system of conservation areas in the species-rich Mediterranean-climate desert of southern Africa. *Diversity and Distributions* 5: 51-71.

Croxall, J.P. 1991. *Seabird Status and Conservation: A Supplement.* ICBP Tech. Pub. No. 11. Cambridge [UK]: International Council for Bird Preservation.

D

Davis, F.W., Stoms, D.M., & Anderman, S. 1999. Systematic reserve selection in the USA: An example from the Columbia Plateau ecoregion. *Parks* 9: 31-42.

Davison, G.W.H. 1992. *Birds of Mount Kinabalu, Borneo.* Kota Kinabalu [Subah, Malaysia]: Natural History Publications (Borneo) and Koktas Sabah.

Defler, T.R., Rodríguez-M., J.V., & Hernández-Camacho, J.I. 2003. Conservation priorities for Colombian primates. *Primate Conservation* 19: 10-18.

Deininger, K. & Minten, B. 1997. *Determinants of Forest Cover and the Economics of Protection: An Application to Mexico.* Washington DC: World Bank.

Denton, J.S., Hitchings, S.P., Beebee, T.J.C., & Gent, A. 1997. A recovery program for the natterjack toad (*Bufo calamita*) in Britain. *Conservation Biology* 11: 1329-1338.

Di Giacomo, A.S., Fraga, R.M., Krapovickas, S.F., & Casañas, H. 2001. *Pampas Argentinas: Important Bird Areas in Temperate and Subtropical Grasslands from Argentina.* Informe de Aves Argentinas/AOP. Project 074-01. Buenos Aires: BirdLife / Vogelbescherming Nederland.

Diamond, J.M. 1975. The island dilemma: Lessons of modern biogeographic studies for the design of nature reserves. *Biological Conservation* 7: 129-146.

Diamond, J.M. 1991. A new species of rail from the Solomon Islands and convergent evolution of insular flightlessness. *Auk* 108: 461-470.

Dinerstein, E. & Wikramanayake, E.D. 1993. Beyond hotspots - How to prioritize investments to conserve biodiversity in the Indo-Pacific region. *Conservation Biology* 7: 53-65.

Dobson, A.P., Rodriguez, J.P., Roberts, W.M., & Wilcove, D.S. 1997. Geographic distribution of endangered species in the United States. *Science* 275: 550-553.

Doughty, C., Day, N., & Plant, A. 1999. *Birds of the Solomons, Vanuatu & New Caledonia.* London: Christopher Helm.

Dourojeanni, M.J. 1999. *The Future of the Latin American Natural Forests.* Environmental Division Working Paper. Washington DC: (IADB) Inter-American Development Bank.

Driver, A., Desmet, P., Rouget, M., Cowling, R., & Maze, K. 2003. *Succulent Karoo Ecosystem Plan: Biodiversity Component Technical Report.* Cape Conservation Unit, Report No CCU 1/03. Cape Town: Botanical Society of South Africa

Drost, C.A. & Fellers, G.M. 1996. Collapse of a regional frog fauna in the Yosemite area of the California Sierra Nevada, USA. *Conservation Biology* 10: 414-425.

Duellman, W.E. 1999a. Global distribution of amphibians: Patterns, conservation, and future challenges. In: Duellman, W.E. (Ed.), *Patterns and Distributions of Amphibians: A Global Perspective.* pp.1- 30. Baltimore: Johns Hopkins University Press.

Duellman, W.E. 1999b. Distribution patterns of amphibians in South America. In: Duellman, W.E. (Ed.), *Patterns and Distributions of Amphibians: A Global Perspective.* pp.255-328. Baltimore: Johns Hopkins University Press.

Duellman, W.E., & Sweet, S.S. 1999. Distribution patterns of amphibians in the Nearctic region of North America. In: Duellman, W.E. (Ed.), *Patterns and Distributions of Amphibians: A Global Perspective.* pp.255-328. Baltimore: Johns Hopkins University Press.

E

East, R. 1999. *African Antelope Database 1998.* Occasional Paper of the IUCN Species Survival Commission No. 21. Gland [Switzerland]: IUCN Species Survival Commission Antelope Specialist Group.

Ebenhard, T. 1988. Introduced birds and mammals and their ecological effects. *Swedish Wildlife Research* 13: 1-107.

Efron, B. 1982. *The Jackknife, the Bootstrap, and Other Resampling Plans.* Philadelphia: Society of Industrial and Applied Mathematics.

Ehrlich, P.R. 1992. Population biology of Checkerspot Butterflies and the preservation of global biodiversity. *Oikos* 63: 6-12.

Eisentraut, M. 1973. Die Wirbeltierfauna von Fernando Poo und Westkamerun. *Bonner Zoologische Monographien* 3: 1-428.

Emmons, L.H. & Feer, F. 1990. *Neotropical Rainforest Mammals*. Chicago: University of Chicago Press.

Emslie, R. & Brooks, M. 1999. *African Rhino – Status Survey and Conservation Action Plan.* Gland [Switzerland]: IUCN/SSC African Rhino Specialist Group.

(EPA) Environment Protection Authority and (MEDAC) Ministry of Economic Development and Cooperation. 1997. *The Conservation Strategy of Ethiopia. The Resource Base, its Utilization, and Planning for Sustainability.* Volume I. Addis Ababa: EPA and MEDAC.

(ESRI) Environmental Systems Research Institute. 2000. *ArcView GIS 3.2a.* New York: Environmental Systems Research Institute, Inc.

F

Fa, J.E., Yuste, J.E.G., & Castelo, R. 2000. Bushmeat markets on Bioko Island as a measure of hunting pressure. *Conservation Biology* 14: 1602-1613.

Fearnside, P.M. & Ferraz, J. 1995. A conservation gap analysis of Brazil Amazonian vegetation. *Conservation Biology* 9: 1134-1147.

Fei, L., Ye, C-Y., & Liu, M-Y. 1999 *Atlas of Amphibians of China.* Zhengzhou: Henan Science and Technology Press.

Ferrier, S., Pressey, R.L., & Barrett, T.W. 2000. A new predictor of the irreplaceability of areas for achieving a conservation goal, its application to real-world planning, and a research agenda for further refinement. *Biological Conservation* 93: 303-325.

Fishpool, L.D.C. & Evans, M.I. (Eds.). 2001. *Important Bird Areas in Africa and Associated Islands: Priority Sites for Conservation.* Newbury and Cambridge: Pisces Publications and BirdLife International.

Fishpool, L.D.C., Heath, M.F., Waliczy, Z., Wege, D.C., & Crosby, M.J. 1998. Important Bird Areas – Criteria for selecting sites of global conservation significance. In: Adams, N.J. & Slotow, R.H. (Eds.), Proceedings of the 22nd International Ornithological Congress, Durban. *Ostrich* 69: 428. Johannesburg: BirdLife South Africa.

Fjeldså, J. & Krabbe, N. 1990. *Birds of the High Andes.* Copenhagen: Zoological Museum of the University of Copenhagen.

Fjeldså, J. & Lovett, J.C. 1997. Geographical patterns of old and young species in African forest biota: The significance of specific montane areas as evolutionary centres. *Biodiversity and Conservation* 6: 325-346.

Fjeldså, J., Lambin, E., & Mertens, B. 1999. Correlation between endemism and local ecoclimatic stability documented by comparing Andean bird distributions and remotely sensed land surface data. *Ecography* 22: 63-78.

Flannery, T. 1995. *Mammals of New Guinea.* Sydney: Reed New Holland.

Flores, O. 1993. Herpetofauna of Mexico: Distribution and endemism. In: Ramammoorthy, T.P., Bye, R., Lot, A., & Fa, J. (Eds.), *The Biological Diversity of México: Origins and Distribution.* pp.235-238. Oxford: Oxford University Press.

Fonseca, G.A.B. 1985. The vanishing Brazilian Atlantic Forest. *Biological Conservation* 34: 17-34.

Fonseca, G.A.B. 2003. Conservation science and NGOs. *Conservation Biology* 17: 345-347.

Fonseca, G.A.B., Balmford, A., Bibby, C., Boitani, L., Corsi, F., Brooks, T., Gascon, C., Olivieri, S., Mittermeier, R.A., Burgess, N., Dinerstein, E., Olson, D., Hannah, L., Lovett, J., Moyer, D., Rahbek, C., Stuart, S., & Williams, P. 2000. Following Africa's lead in setting priorities. *Nature* 405: 393-394.

Frost, D.R. 2002. Amphibian Species of the World: an online reference. V2.21 (15 July 2002). Online. Available: http://research.amnh.org/herpetology/amphibia/index.html. July 23, 2003.

G

Galindo-Leal, C. 2003. *Of Two Worlds: The Frogs, Toads, and Salamanders of the Yucatán Peninsula, Mexico.* Saint Paul: Pangaea.

Ganzhorn, J.U., Lowry, P.P., Schatz, G.E., & Sommer, S. 2001. The biodiversity of Madagascar: One of the world's hottest hotspots on its way out. *Oryx* 35: 346-348.

García-Gonzales, R., Herrer, J., & Hidalgo, R. 1985. Estimacíon puntal de diversos parametros poblacionales y distributivos del sarrio en el Pirineo occidental. *Pirineos* 125: 53-63.

Gasc, J.P., Cabela, A., Crnobrnja-Isailovic, J., Dolmen, D., Grossenbacher, K., Haffner, P., Lescure, J., Martens, H., Martínez Rica, J.P., Maurin, H., Oliveira, M.E., Sofianidou, T.S., Veith, M., & Zuiderwijk, A. 1997. *Atlas of Amphibians and Reptiles in Europe.* Paris: SPN / IEGB / MNHN.

Gascon, C., Williamson, G.B., & Fonseca, G.A.B. 2000. Receding forest edges and vanishing reserves. *Science* 288: 1356-1358.

Gaston, K.J. 1994. *Rarity.* London: Chapman & Hall.

Gaston, K.J. 1996. *Biodiversity-A Biology of Numbers and Difference.* Oxford: Blackwell Science.

Gaston, K.J., Williams, P.H., Eggleton, P., & Humphries, C.J. 1995. Large-scale patterns of biodiversity - Spatial variation in family richness. *Proceedings of the Royal Society of London Series B-Biological Sciences* 260: 149-154.

Gaston, K.J., Blackburn, T.M., & Lawton, J.H. 1997. Interspecific abundance range size relationships: An appraisal of mechanisms. *Journal of Animal Ecology* 66: 579-601.

Glaw, F. & Vences, M. 1994. *A Fieldguide to the Amphibians and Reptiles of Madagascar.* 2nd Ed. Bonn: Zoologisches Forschungsinstitut und Museum Alexander Koenig.

Gochfeld, M. & Burger, J. 1996. Family Sternidae (Terns). In: del Hoyo, J., Elliot, A., & Sargatal, J. (Eds.), *Handbook of the Birds of the World. Vol. 3. Hoatzin to Auks*. pp.624-667. Barcelona: Lynx Edicions.

Gurd, D.B., Nudds, T.D., & Rivard, D.H. 2001. Conservation of mammals in eastern North American wildlife reserves: How small is too small? *Conservation Biology* 15: 1355-1363.

H

Hannah, L., Midgley, G.F., Lovejoy, T., Bond, W.J., Bush, M., Lovett, J.C., Scott, D., & Woodward, F.I. 2002. Conservation of biodiversity in a changing climate. *Conservation Biology* 16: 264-268.

Hanski, I. 1982. Dynamics of regional distribution: The core and satellite species hypothesis. *Oikos* 38: 210-221.

Harrison, D.L. & Bates, P.J.J. 1991. *The Mammals of Arabia.* 2nd Ed. England: Harrison Zoological Museum.

Harrison, J.A., Allan, D.G., Underhill, L.G., Herremans, M., Tree, A.J., Parker, V., & Brown, C.J. (Eds.) 1997. *The Atlas of Southern African Birds.* Johannesburg: BirdLife South Africa.

Hawkins, F., Andriamasimanana, R., Seing, S., & Rabeony, Z. 2000. The sad story of Alaotra Grebe *Tachybaptus rufolavatus. Bulletin of the African Bird Club* 7: 115-117.

Heath, M.F., Evans, M.I., Hoccom, D.G., Payne, A.J., & Peet, N.B. (Eds.). 2000. *Important Bird Areas of Europe: Priority Sites for Conservation.* Cambridge: BirdLife International.

Hedges, S.B. 1993 Global amphibian declines – A perspective from the Caribbean. *Biodiversity and Conservation* 2: 290-303

Hedges, S.B. 1999. Distribution patterns of amphibians in the West Indies. In: Duellman, W.E. (Ed.), *Patterns and Distributions of Amphibians: A Global Perspective.* pp.211-354. Baltimore: Johns Hopkins University Press.

Hengeveld, R. 1990. *Dynamic Biogeography.* Cambridge: Cambridge University Press.

Hernández-Baños, B.E., Peterson, A.T., Navarro-Sigüenza, A.G., & Escalante-Pliego, P. 1995. Bird faunas of the humid montane forests of Mesoamerica: Biogeographic patterns and conservation priorities. *Bird Conservation International* 5: 251-277.

Hilton-Taylor, C. 2000. *2000 IUCN Red List of Threatened Species.* Gland [Switzerland]: The IUCN Species Survival Commission.

Holdaway, R.N. 1994. *Chatham Islands Ornithology: A Tribute to Sir Charles A. Fleming.* Wellington [New Zealand]: Ornithological Society of New Zealand.

Howard, P.C., Viskanic, P., Davenport, T.R.B., Kigenyi, F.W., Baltzer, M., Dickinson, C.J., Lwanga, J.S., Matthews, R.A., & Balmford, A. 1998. Complementarity and the use of indicator groups for reserve selection in Uganda. *Nature* 394: 472 - 475.

Howell, K.M. 1993. Herpetofauna of the eastern African forests. In: Lovett, J.C. & Wasser, S.K. (Eds.), *Biogeography and Ecology of the Rain Forests of Eastern Africa.* pp.173-201 Cambridge: Cambridge University Press.

Hughes, J.B., Daily, G.C., & Ehrlich, P.R. 1997. Population diversity: Its extent and extinction. *Science* 278: 689-692.

Hulme, P.E. 2003. Biological invasions: Winning the science battles but losing the conservation war? *Oryx* 37: 178-193.

Hunter, M.L. & Hutchinson, A. 1994. The Virtues and Shortcomings of Parochialism - Conserving Species That Are Locally Rare, but Globally Common. *Conservation Biology* 8: 1163-1165.

I

(ICBP) International Council for Bird Preservation. 1992. *Putting Biodiversity on the Map: Priority Areas for Global Conservation.* Cambridge [UK]: International Council for Bird Preservation.

Imberti, S. & Barnett, J.M. 1999. El piden austral *Rallus antarcticus* redescubierto en Chile. *Boletín Chileno de Ornitología* 6: 44-45.

Inger, R.F. 1999. Distribution of amphibians in Southern Asia and adjacent islands. In: Duellman, W.E. (Ed.). 1999. *Patterns and Distributions of Amphibians: A Global Perspective*. pp. 211-354. Baltimore: Johns Hopkins University Press.

(IPCC) Intergovernmental Panel on Climate Change. 2002. *Climate Change and Biodiversity*. Online. Available: http://www.ipcc.ch/pub/tpbiodiv.pdf. August 4 2003.

Itô, Y., Miyagi, K., & Ota, H. 2000. Imminent extinction crisis among the endemic species of the forests of Yanbaru, Okinawa, Japan. *Oryx* 34: 305-316.

(IUCN) The World Conservation Union. 1992. *Protected Areas of the World: A Review of National Systems. Volume 3: Afrotropical.* Gland [Switzerland]: IUCN.

(IUCN) The World Conservation Union. 1994a. *Guidelines for Protected Area Management Categories*. Gland [Switzerland] and Cambridge [UK]: CNPPA with the assistance of WCMC, IUCN.

(IUCN) The World Conservation Union. 1994b. *IUCN Red List Categories*. Gland [Switzerland]: IUCN Species Survival Commission.

(IUCN) The World Conservation Union. 1998. *1997 United Nations List of Protected Areas.* Prepared by UNEP-WCMC and WCPA. Gland [Switzerland] and Cambridge [UK]: IUCN. Online. Available: http://www.unep-wcmc.org/protected_areas/data/un_econtents.htm. May 30 2003.

(IUCN) The World Conservation Union. 2001. *IUCN Red List Categories and Criteria: Version 3.1.* Gland [Switzerland] and Cambridge [UK]: IUCN Species Survival Commission.

(IUCN) The World Conservation Union. 2002. *2002 IUCN Red List of Threatened Species.* Gland [Switzerland] and Cambridge [UK]: IUCN. Online. Available: http://www.redlist.org. 30 May 2002.

J

Jablonski, D. 1995. *Extinctions in the fossil record.* In: Lawton, J.H. & May, R.M. (Eds.), *Extinction Rates.* pp.25-44. Oxford: Oxford University Press.

Jacobs, M.J. & Schloeder, C.A. 2001. *Impacts of Conflict on Biodiversity and Protected Areas in Ethiopia.* Washington DC: Biodiversity Support Program.

James, A.N., Gaston, K.J., & Balmford, A. 1999. Balancing the Earth's accounts. *Nature* 401: 323-324.

Janzen, D. 1983a. *Costa Rican Natural History.* Chicago: Chicago University Press.

Janzen, D.H. 1983b. No park is an island: Increase in interference from outside as park size decreases. *Oikos* 41: 402-410.

Jarvi, S.I., Atkinson, C.T., & Fleischer, R.C. 2001. Immunogenetics and resistance to avian malaria in Hawaiian Honeycreepers (Drepanidinae). *Studies in Avian Biology* 22: 254-263.

Jennings, M.D. 2000. Gap analysis: Concepts, methods, and recent results. *Landscape Ecology* 15: 5-20.

Jha, C.S., Dutt, C.B.S., & Bawa, K.S. 2000. Deforestation and land use changes in Western Ghats, India. *Current Science* 79: 231-238.

K

Kats, L.B. & Ferrer, R.P. 2003. Alien predators and amphibian declines: Review of two decades of science and the transition to conservation. *Diversity & Distributions* 9: 99-110.

Kiesecker, J.M., Blaustein, A.R., & Belden, L.K. 2001. Complex causes of amphibian population declines. *Nature* 410: 681-684.

Kiester, A.R., Scott, J.M., Csuti, B., Noss, R.F., Butterfield, B., Sahr, K., & White, D. 1996. Conservation prioritization using GAP data. *Conservation Biology* 10: 1332-1342.

Kingdon, J. 1989. *Island Africa.* Princeton: Princeton University Press.

Kirkpatrick, J.B. 1983. An iterative method for establishing priorities for the selection of nature reserves - An example from Tasmania. *Biological Conservation* 25: 127-134.

Kirwan, G.M., Martins, R.P., Morton, K.M., & Showler, D.A. 1996. The status of birds in Socotra and Abd Al-Kuri and the records of the OSME survey in spring 1993. *Sandgrouse* 17: 83-101.

Kremen, C., Niles, J.O., Dalton, M.G., Daily, G.C., Ehrlich, P.R., Fay, J.P., Grewal, D., & Guillery, R.P. 2000. Economic incentives for rain forest conservation across scales. *Science* 288: 1828-1832.

L

Lambert, D. & Moritz, C. 1995. Biological conservation in New Zealand. *Pacific Conservation Biology* 2: 1-123.

Lambert, F.R. & Collar, N.J. 2002. The future for Sundaic lowland forest birds: Long-term effects of commercial logging and fragmentation. *Forktail* 18: 127-146.

Laurance, W.F. & Bierregaard, R.O., Jr. (Eds.). 1997. *Tropical Forest Remnants: Ecology, Management, and Conservation of Fragmented Communities.* Chicago: University of Chicago Press.

Laurent, A., Prévot, N., & Mallet, B. 2001. Original data in ecology, behaviour, status, historic and present distribution of the Beira *Dorcatragus megalotis* (Bovide: Antilopinae) in the Republic of Djibouti and adjacent territories of Somalia and Ethiopia. *Mammalia* 66(1): 1-16.

Lawton, J.H. 1993. Range, population abundance and conservation. *Trends in Ecology & Evolution* 8: 409-413.

Lekagul, B. & McNeely, J.A. 1988. *Mammals of Thailand.* 2nd Ed. Bangkok: Sahakarnbhat.

Lens, L., Van Dongen, S., Norris, K., Githiru, M., & Matthysen, E. 2002. Avian persistence in fragmented rainforest. *Science* 298: 1236-1238.

Levitt, J.N. 2002. *Conservation in the Internet Age.* Washington DC: Island Press.

Lombard, A.T., Hilton-Taylor, C., Rebelo, A.G., Pressey, R.L., & Cowling, R.M. 1999. Reserve selection in the Succulent Karoo, South Africa: Coping with high compositional turnover. *Plant Ecology* 142: 35-55.

Long, A.J. 1994. Restricted-range and threatened bird species in tropical montane cloud forests. In: Hamilton, L.S., Juvik, J.O., & Scatena, F.N. (Eds.), *Tropical Montane Cloud Forests.* pp.47-65. Honolulu: East-West Center.

Lutz, W., Sanderson, W., & Scherbov, S. 2001. The end of world population growth. *Nature* 412: 543-545.

M

Macdonald, D.W. 2001. *The New Encyclopedia of Mammals*. Oxford: Oxford University Press.

Mack, A.L. & Alonso, L.E. (Eds.). 2000. *A Biological Assessment of the Wapoga River Area of Northwestern Irian Jaya, Indonesia*. Washington DC: Conservation International.

MacPhee, R.D.E. & Flemming, C. 1999. *Requiem Æternam*: The last five hundred years of mammalian species extinctions. In: MacPhee, R.D.E. (Ed.), *Extinctions in Near Time: Causes, Contexts, and Consequences*. pp.333-371. New York: Plenum Press.

Malcom, J.R. 1997. Biodiversity of small mammals in Amazonian forest fragments. In: Laurance, W.F. & Bierregaard, Jr., R.O. (Eds.), *Tropical Forest Remnants: Ecology, Management and Conservation of Fragmented Communities*. pp.207-221 Chicago: University of Chicago Press.

Malkmus, R., Manthey, U., Vogel, G., Hoffmann, P., & Kosuch, J. 2002. *Amphibians and Reptiles of Mount Kinabalu (North Borneo).* Ruggell [Germany]: A.R.G. Gantner Verlag Kommanditgesellschaft.

Mallari, N.A.D., Tabaranza, B.R., Jr., & Crosby, M.J. 2001. *Key Conservation Sites in the Philippines*. Makati City [Philippines]: Bookmark.

Mandaville, J.P. 1986. Plant life in the Rub' al-Khali (the Empty Quarter), south-central Arabia. *Proceedings of the Royal Society of Edinburgh* 89B: 147-157.

Margules, C.R. & Pressey, R.L. 2000. Systematic conservation planning. *Nature* 405: 243-253.

Mast, R.B., Rodríguez M., J.V., Mittermeier, R.A., Sobrevilla, C., Carrisoza, S., Ponce del Prado, C., Chicchón, A., Zurita S., S.P., Stotz, D.F., Morales R., M., Mittermeier, C.G., McEnany, A. & Norton, L.S. 1999. Tropical Andes. In: Mittermeier, R.A., Meyers, N., Robles Gil, P., & Mittermeier, C.G. (Eds.), *Hotspots - Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions*. pp.68-83. Mexico City: CEMEX/Conservation International.

Mayr, E. & Phelps, W.H. 1967. The origin of the bird fauna of the southern Venezuelan highlands. *Bulletin of the American Museum of Natural History* 136: 269-328.

McKinney, M.L. 2001. Role of human population size in raising bird and mammal threat among nations. *Animal Conservation* 4: 45-57.

Meegaskumbura, M., Bossuyt, F., Pethiyagoda, R., Manamendra-Arachchi, K., Bahir, M., Milinkovitch, M.C., & Schneider, C.J. 2002. Sri Lanka: An amphibian hot spot. *Science* 298: 379.

Mehlman, D.W. 1997. Change in avian abundance across the geographic range in response to environmental change. *Ecological Applications* 7: 614-624.

Meine, C.D. & Archibald, G.W. 1996. *The Cranes: Status Survey and Conservation Action Plan.* Gland [Switzerland]: IUCN.

Mitchell-Jones, A.J., Amori, G., Bogdanowicz, W., Krystufek, B., Reijnders, P.J.H., Spitzenberger, F., Stubbe, M., Thissen, J.B.M., Vohralik, V., & Zima, J. 1999. *The Atlas of European Mammals*. London: Poyser Natural History.

Mittermeier, R.A. 1988. Primate diversity and the tropical forest: Case studies from Brazil and Madagascar and the importance of megadiversity countries. In: Wilson, E.O. (Ed.), *Biodiversity.* pp.145-154. Washington DC: National Academy Press.

Mittermeier, R.A., Robles-Gil, P., & Mittermeier, C.G. 1997. *Megadiversity: Earth's Biologically Wealthiest Nations*. Mexico City: CEMEX.

Mittermeier, R.A., Myers, N., Thomsen, J.B., da Fonseca, G.A.B., & Olivieri, S. 1998. Biodiversity hotspots and major tropical wilderness areas: Approaches to setting conservation priorities. *Conservation Biology* 12: 516-520.

Mittermeier, R.A., Meyers, N., Robles Gil, P., & Mittermeier, C.G. 1999. *Hotspots-Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions*. Mexico City: CEMEX/Conservation International.

Mittermeier, R.A., Mittermeier, C.G., Brooks, T.M., Pilgrim, J.D., Konstant, W.R., Fonseca, G.A.B. da, & Kormos, C. 2003. Wilderness and biodiversity conservation. *Proceedings of the National Academy of Sciences*: in press.

Moore, F.R., Gauthreaux, S.A., Jr., Kerlinger, P., & Simons, T.R. 1995. Habitat requirements during migration: Important link in conservation. In: Martin, T.E. & Finch, D.M. (Eds.), *Ecology and Management of Neotropical Migrant Birds*. pp.121-144. Oxford: Oxford University Press.

Moors, P.J. 1985. *Conservation of Island Birds*. ICBP Tech. Pub. No. 3. Cambridge [UK]: International Council for Bird Preservation.

Moritz, C., Patton, J.L., Schneider, C.J., & Smith, T.B. 2000. Diversification of rainforest faunas: An integrated molecular approach. *Annual Review of Ecology and Systematics* 31: 533-563.

Muchoney, D., El Baz, F., & Kristensen, P. 2002. The Sahara/Sahel. In: Mittermeier, R.A., Mittermeier, C.G., Robles Gil, P., Pilgrim, J.D., Fonseca, G.A.B. da, Brooks, T.M., & Konstant, W.R. (Eds.), *Wilderness*. pp. 374-383. Mexico City: CEMEX.

Musters, C.J.M., de Graaf, H.J., & ter Keurs, W.J. 2000. Can protected areas be expanded in Africa? *Science* 287: 1759-1760.

Myers, J.H., Simberloff, D., Kuris, A.M. & Carey, J.R. 2000a Eradication revisited: dealing with exotic species. *Trends in Ecology & Evolution* 15: 316-320.

Myers, N. 1988. Threatened biotas: 'Hotspots' in tropical forests. *Environmentalist* 8: 187-208.

Myers, N. 1990. The biodiversity challenge: Expanded hotspot analysis. *Environmentalist* 10: 243-255.

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

N

Nantel, P., Bouchard, A., Brouillet, L., & Hay, S. 1998. Selection of areas for protecting rare plants with integration of land use conflicts: A case study for the west coast of Newfoundland, Canada. *Biological Conservation* 84: 223-234.

Nelson, W.B., Ferreira, C.A.C., da Silva, M.F., & Kawasaki, M.L. 1990. Endemism centres, refugia and botanical collection density in Brazilian Amazonia. *Nature* 345: 714-716.

Newmark, W.D. 1987. A land-bridge island perspective on mammalian extinctions in western North American Parks. *Nature* 325: 430-432.

Newmark, W.D. 1996. Insularization of Tanzanian Parks and the Local Extinction of Large Mammals. *Conservation Biology* 10: 1549-1556.

Nicholls, A.O., Viljoen, P.C., Knight, M.H. & van Jaarsveld, A.S. 1996. Evaluating population persistence of censused and unmanaged herbivore populations from the Kruger National Park, South Africa. *Biological Conservation* 76: 57-67.

Nowak, R.M. 1999. *Walker's Mammals of the World.* 6th Ed. Baltimore: Johns Hopkins University Press.

(NSW-NPWS) New South Wales National Parks and Wildlife Service. 2001. *C-Plan: Conservation Planning Software.* User Manual for C-Plan Version 3.06. Armidale [Australia]: New South Wales National Parks and Wildlife Service.

Nussbaum, R.A., Brodie, E.D., Jr., & Storm, R.M. 1983. *Amphibians and Reptiles of the Pacific Northwest.* Moscow [Idaho]: University of Idaho Press.

O

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

Olson, D.M., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D., Powell, G.V.N., Underwood, E.C., D'Amico, J.A., Strand, H.E., Morrison, J.C., Loucks, C.J., Allnutt, T.F., Lamoreux, J.F., Ricketts, T.H., Itoua, I., Wettengel, W.W., Kura, Y., Hedao, P., & Kassem, K. 2001. Terrestrial ecoregions of the world: A new map of life on earth. *BioScience* 51: 933-938.

P

Parker, T.A., III & Goerck, J.M. 1997. The importance of national parks and biological reserves to bird conservation in the Atlantic Forest region of Brazil. *Ornithological Monographs* 48: 527-541.

Parmesan, C. & Yohe, G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421: 37-42.

Patterson, B.D. 1996. The 'species alias' problem. *Nature* 380(6575): 589-589

Patterson, B.D. 2001. Fathoming tropical biodiversity: The continuing discovery of Neotropical mammals. *Diversity and Distributions* 7: 191-196.

Patterson, B.D., Ceballos, G. Sechrest, W., Tognelli, M.F., Brooks, T., Luna, L., Ortega, P., Salazar, I., & Young, B.E. 2003 *Digital Distribution Maps of the Mammals of the Western Hemisphere – Version 1.0.* Arlington [Virginia]: NatureServe.

Peres, C.A. & Lake, I.R. 2003. Extent of non-timber resource extraction in tropical forests: Accessibility to game vertebrates by hunters in the Amazon Basin. *Conservation Biology* 17: 521-535.

Perez-Arteaga, A., Gaston, K.J., & Kershaw, M. 2002. Undesignated sites in Mexico qualifying as wetlands of international importance. *Biological Conservation* 107: 47-57.

Peterson, A.T., Flores-Villela, O.A., Leon-Paniagua, L.S., Llorente-Bousquets, J.E., Luis-Martínez, M.A., Navarro-Siguënza, A.G., Torres-Chavez, M.G., & Vargas-Fernández, J.I. 1993. Conservation priorities in Mexico: Moving up in the world. *Biodiversity Letters* 1: 33-38.

Peterson, A.T., Ball, L.G., & Brady, K.W. 2000. Distribution of the birds of the Philippines: Biogeography and conservation priorities. *Bird Conservation International* 20: 149-167.

Pimm, S.L., Russell, G.J., Gittleman, J.L., & Brooks, T.M. 1995. The future of biodiversity. *Science* 269: 347-350.

Plumptre, A.J., Behangana, M., Davenport, R., Kahindo, C., Kityo, R., Ndomba, E., Nkuutu, D., Owiunji, I., Ssegawa, P., & Eilu, G. 2003. The biodiversity of the Albertine Rift. *Albertine Rift Technical Reports* No. 3.

Poulsen, M.K., Cahyadin, Y., & Lambert, F.R. 1998. *Evaluation of the Proposed Lalobata and Ake Tajawe National Park in the Context of Biodiversity Conservation Priorities on Halmahera.* Bogor [Indonesia]: PHPA/BirdLife International – Indonesia Programme.

Pounds, J.A. & Crump, M.L. 1994. Amphibian declines and climate disturbance - The case of the Golden Toad and the Harlequin Frog. *Conservation Biology* 8: 72-85.

Pounds, J.A., Fogden, M.P.L., Savage, J.M., & Gorman, G.C. 1997. Tests of null models for amphibian declines on a tropical mountain. *Conservation Biology* 11: 1307-1322.

Pounds, J.A., Fogden, M.P.L., & Campbell, J.H. 1999. Biological response to climate change on a tropical mountain. *Nature* 398: 611-615.

Powell, G.V.N., Barborak, J., & Rodriguez, S.M. 2000. Assessing representativeness of protected natural areas in Costa Rica for conserving biodiversity: A preliminary gap analysis. *Biological Conservation* 93: 35-41.

Poynton, J.C. 1999. Distribution of Amphibians in Sub-Saharan Africa, Madagascar, and Seychelles. In: Duellman, W.E. (Ed.), *Patterns and Distributions of Amphibians*: A Global Perspective. pp.445-482. Baltimore: Johns Hopkins University Press.

Pratt, H.D., Bruner, P.L., & Berrett, D.G. 1987. *The Birds of Hawaii and the Tropical Pacific.* Princeton: Princeton University Press.

Pressey, R.L. 1994. Ad hoc reservations - Forward or backward steps in developing representative reserve systems. *Conservation Biology* 8: 662-668.

Pressey, R.L. 1998. Algorithms, politics, and timber: An example of the role of science in a public, political negotiation process over new conservation areas in production forests. In: Wills, R.T. & Hobbs, R.J. (Eds.), *Ecology for Everyone: Communicating Ecology to Scientists, the Public, and Politicians.* pp.73-87. Sydney: Surrey Beatty & Sons.

Pressey, R.L. 1999. Applications of irreplaceability analysis to planning and management problems. *Parks* 9: 42-52.

Pressey, R.L. & Cowling, R.M. 2001. Reserve selection algorithms and the real world. *Conservation Biology* 15: 275-277.

Pressey, R.L. & Taffs, K.H. 2001. Scheduling conservation action in production landscapes: Priority areas in western New South Wales defined by irreplaceability and vulnerability to vegetation loss. *Biological Conservation* 100: 355-376.

Pressey, R.L., Humphries, C.J., Margules, C.R., Vanewright, R.I., & Williams, P.H. 1993. Beyond opportunism - Key principles for systematic reserve selection. *Trends in Ecology & Evolution* 8: 124-128.

Pressey, R.L., Johnson, I.R. & Wilson, P.D. 1994. Shades of Irreplaceability - Towards a Measure of the Contribution of Sites to a Reservation Goal. *Biodiversity and Conservation* 3: 242-262.

Pressey, R.L., Ferrier, S., Hager, T.C., Woods, C.A., Tully, S.L., & Weinman, K.M. 1996. How well protected are the forests of northeastern New South Wales? - Analyses of forest environments in relation to formal protection measures, land tenure, and vulnerability to clearing. *Forest Ecology and Management* 85: 311-333.

Project ZICOMA. 1999. *Les Zones d'Importance pour la Conservation des Oiseaux à Madagascar.* Antananarivo [Madagascar]: Project ZICOMA.

Purvis, A., Gittleman, J.L., Cowlishaw, G., & Mace, G.M. 2000. Predicting extinction risk in declining species. *Proceedings of the Royal Society of London Series B-Biological Sciences* 267: 1947-1952.

R

Rebelo, A.G. & Siegfried, W.R. 1992. Where should nature-reserves be located in the Cape Floristic Region, South Africa - Models for the spatial configuration of a reserve network aimed at maximizing the protection of floral diversity. *Conservation Biology* 6: 243-252.

Redford, K.H. 1992. The empty forest. *Bioscience* 42: 412-422.

Renjifo, L.M., Servat, G.P., Goerck, J.M., Loiselle, B.A., & Blake, J.G. 1997. Patterns of species composition and endemism in the northern Neotropics: A case for conservation of montane avifaunas. *Ornithological Monographs* 48: 577-594.

Reyers, B., Fairbanks, D.H.K., Jaarsveld, A.S.V., & Thompson, M. 2001. Priority areas for the conservation of South African vegetation: A coarse-filter approach. *Diversity & Distributions* 7: 79-95.

Richardson, K.S. & Funk, V.A. 1999. An approach to designing a systematic protected area system in Guyana. *Parks* 9: 7-16.

Riley, J. 1997. The birds of Sangihe and Talaud, North Sulawesi. *Kukila* 9: 3-36.

Rivard, D.H., Poitevin, J., Plasse, D., Carleton, M., & Currie, D.J. 2000. Changing species richness and composition in Canadian national parks. *Conservation Biology* 14: 1099-1109.

Roberts, C.M. 2003. Our shifting perspectives on the oceans. *Oryx* 37: 166-177.

Roberts, C.M., McClean, C.J., Veron, J.E.N., Hawkins, J.P., Allen, G.R., McAllister, D.E., Mittermeier, C.G., Schueller, F.W., Spalding, M., Wells, F., Vynne, C., & Werner, T.B. 2002. Marine biodiversity hotspots and conservation priorities for tropical reefs. *Science* 295: 1280-1284.

Robertson, A., Simmons, R.E., Jarvis, A.M., & Brown, C.J. 1995. Can bird atlas data be used to estimate population size? A case study using Namibian endemics. *Biological Conservation* 71: 87-95.

Rodrigues, A.S.L. & Gaston, K.J. 2001. How large do reserve networks need to be? *Ecology Letters* 4: 602-609.

Rodrigues, A.S.L., Gregory, R.D., & Gaston, K.J. 2000. Robustness of reserve selection procedures under temporal species turnover. *Proceedings of the Royal Society of London Series B-Biological Sciences* 267: 49-55.

Rosenzweig, M.L. 2003. Reconciliation ecology and the future of species diversity. *Oryx* 37: 194-205.

Roy, M.S., Torres-Mura, J.C., Hertel, F., Lemus, M., & Sponer, R. 1999. Conservation of the Juan Fernandez Firecrown and its island habitat. *Oryx* 33: 223-232.

Rubenstein, D.R., Chamberlain, C.P., R. Holmes, T., Ayres, M.P., Waldbauer, J.R., Graves, G.R. & Tuross, N.C. 2002. Linking breeding and wintering ranges of a migratory songbird using stable isotopes. *Science* 295: 1062-1065.

Rylands, A.B. & Pinto, L.P. de S. 1998. *Conservação da Biodiversidade Na Amazônia Brasileira: Uma Análise do Sistema de Unidades de Conservação.* Cadernos FBDS, No. 1. Rio de Janeiro: Fundação Brasileira para o Desenvolvimento Sustentável (FBDS).

Rylands, A.B., Schneider, H., Langguth, A., Mittermeier, R.A., Groves, C.P., & Rodríguez-Luna, E. 2000. An assessment of the diversity of New World primates. *Neotropical Primates* 8: 61-93.

S

Salathé, T. 1991. *Conserving Migratory Birds*. ICBP Tech. Pub. No. 12. Cambridge: International Council for Bird Preservation.

Sánchez-Azofeifa, G.A., Daily, G.C., Pfaff, A.S.P., & Busch, C. 2003. Integrity and isolation of Costa Rica's national parks and biological reserves: Examining the dynamics of land-cover change. *Biological Conservation* 109: 123-135.

Sanderson, E.W., Jaiteh, M., Levy, M.A., Redford, K.H., Wannebo, A.V., & Woolmer, G. 2002a. The human footprint and the last of the wild. *Bioscience* 52: 891-904.

Sanderson, E.W., Redford, K.H., Vedder, A., Coppolillo, P.B., & Ward, S.E. 2002b. A conceptual model for conservation planning based on landscape species requirements. *Landscape and Urban Planning* 58: 41-56.

Schiøtz, A. 1999. *Treefrogs of Africa*. Germany: Chimaira.

Scott, J.M., Mountainspring, S., Ramsey, F.L., & Kepler, C.B. 1986. Forest bird communities of the Hawaiian Islands: Their dynamics, ecology, and conservation. *Studies in Avian Biology* 9: 1-431.

Scott, J.M., Davis, F., Csuti, B., Noss, R., Butterfield, B., Groves, C., Anderson, H., Caicco, S., Derchia, F., Edwards, T.C., Ulliman, J., & Wright, R.G. 1993. Gap analysis - A geographic approach to protection of biological diversity. *Wildlife Monographs* 123: 1-41.

Scott, J.M., Conant, S., & van Riper III, C. 2001a. Evolution, ecology, conservation, and management of Hawaiian birds: A vanishing avifauna. *Studies in Avian Biology* 22: 1-428.

Scott, J.M., Davis, F.W., McGhie, R.G., Wright, R.G., Groves, C., & Estes, J. 2001b. Nature reserves: Do they capture the full range of America's biological diversity? *Ecological Applications* 11: 999-1007.

Shackleton, D.M. (Ed.). 1997. *Wild Sheep and Goats and their Relatives: Status Survey and Conservation Action Plan for Caprinae*. Gland [Switzerland]: IUCN.

Sierra, R., Campos, F., & Chamberlin, J. 2002. Assessing biodiversity conservation priorities: Ecosystem risk and representativeness in continental Ecuador. *Landscape and Urban Planning* 59: 95-110.

Sillero-Zubiri, C., Hoffmann, M., & Macdonald, D.W. (Eds.). (In press). *Canids: Foxes, Wolves, Jackals and Dogs. Status Survey and Conservation Action Plan*. Gland [Switzerland] and Cambridge [UK]: SSC Canid Specialist Group, IUCN.

Sinclair, A.R.E., Mduma, S.A.R., & Arcese, P. 2002. Protected areas as biodiversity benchmarks for human impact: Agriculture and the Serengeti avifauna. *Proceedings of the Royal Society of London Series B-Biological Sciences* 269: 2401-2405.

Skinner, J.D. & Smithers, R.H.N. 1990. *The Mammals of the Southern African Subregion.* 2nd ed. Pretoria: University of Pretoria.

Smith, G. & Gillett, H. 2002. *European Forests and Protected Areas: Gap Analysis*. pp. 27. Cambridge [UK]: UNEP-WCMP, WWF.

Soulé, M.E. (Ed.). 1987. *Viable Populations for Conservation*. Cambridge: Cambridge University Press.

Soulé, M.E. & Sanjayan, M.A. 1998. Conservation targets: Do they help? *Science* 279: 2060-2061.

Stattersfield, A.J., Crosby, M.J., Long, A.J., & Wege, D.C. 1998. *Endemic Bird Areas of the World - Priorities for Biodiversity Conservation.* Cambridge: BirdLife International.

Stebbins, R.C. 2003. *Peterson Field Guide to Reptiles and Amphibians of Western North America.* 3rd Ed. New York: Houghton Mifflin Company.

Stephens, P.A., d'Sa, C.A., Sillero-Zubiri, C., & Leader-Williams, N. 2001. Impact of livestock and settlement on the large mammalian wildlife of Bale Mountains National Park, southern Ethiopia. *Biological Conservation* 100: 307-322.

Strittholt, J.R. & Boerner, R.E.J. 1995. Applying biodiversity gap analysis in a regional nature reserve design for the Edge of Appalachia, Ohio (USA). *Conservation Biology* 9: 1492-1505.

Stuart, B. 1999. Amphibians and reptiles. In: Duckworth, J.W., Salter, R.E., & Khounboline, K. (Eds.). 1999. *Wildlife in Lao PDR. 1999 Status Report.* pp. 43-67. Vientiane, Lao PDR: IUCN.

Stuart, S.N. 1986. *Conservation of Cameroon Montane Forests.* Cambridge: International Council for Bird Preservation.

Stuart, S.N. & Johnsingh, A.J.T. 2003. South Asian Ungulates. In: Mittermeier, R.A., Mittermeier, C.G., Robles Gil, P., Brooks, T.M., Hoffmann, M., Fonseca, G. & Konstant, B. (Eds.), *Wildlife Spectacles*. In press. Mexico: CEMEX.

Swash, A. & Still, R. 2000. *Birds, Mammals and Reptiles of the Galapagos Islands: An Identification Guide.* Robertsbridge [UK]: Pica Press.

T

Terborgh, J. & Winter, B. 1983. A method for siting parks and reserves with special reference to Colombia and Ecuador. *Biological Conservation* 27: 45-58.

Terborgh, J., Lopez, L., Nuñez, P., Rao, M., Shahabuddin, G., Orihuela, G., Riveros, M., Ascanio, R., Adler, G.H., Lambert, T.D., & Balbas, L. 2001 Ecological meltdown in predator-free forest fragments. *Science* 294: 1923-1926.

Tewksbury, J.J., Levey, D.J., Haddad, N.M., Sargent, S., Orrock, J.L., Weldon, A., Danielson, B.J., Brinkerhoff, J., Damschen, E.I., & Townsend, P. 2002. Corridors affect plants, animals, and their interactions in fragmented landscapes. *PNAS* 99: 12923-12926.

Thomas, R. 2000. Longlining: A major threat to the world's seabirds. *World Birdwatch* 22: 10-13.

Trauth, S.E., Wilhide, J.D., & Daniel, P. 1992. Status of the Ozark hellbender, Cryptobranchus bishopi (Urodela: Crypotbranchidae), in the Spring River, Fulton County, Arkansas. *Proceedings of the Arkansas Academy of Science* 46: 83-86.

Turner, I.M. & Corlett, R.T. 1996. The conservation value of small isolated fragments of lowland tropical rain forest. *Trends in Ecology and Evolution* 11: 330-333.

Tyler, M.J. (Ed.). 1997. *The Action Plan for Australian Frogs*. Canberra: Wildlife Australia Endangered Species Program.

Tyler, M.J. 1999. Distribution patterns of amphibians in the Australo-Papuan region. In: Duellman, W.E. (Ed.), *Patterns and Distributions of Amphibians: A Global Perspective*. pp.541-563. Baltimore: Johns Hopkins University Press.

U

(UN) United Nations. 2001. *World Population Monitoring 2001 - Population, Environment and Development*. New York: United Nations Population Division.

(UNEP) United Nations Environment Programme. 2002. *African Environment Outlook: Integrated Environmental Assessment Reporting*. United Nations Environment Programme.

V

van Schaik, C.P., Terborgh, J., & Dugelby, B. 1997. The silent crisis: the state of rainforest nature preserves. In: Kramer, R., van Schaik C., & Johnson, J. (Eds.). 1997. *Last Stand: Protected Areas and the Defense of Tropical Biodiversity*. pp. 64-89. Oxford UK: Oxford University Press.

Vargas-T, N. & Solano, C. 1996. Evaluación del estado de dos poblaciones de *Saguinus leucopus* para determinar areas potenciales de conservación en un sector del Valle del Magdalena medio, Colombia. *Neotropical Primates* 4: 13-15.

Vernon, C.J. 1999. Biogeography, endemism, and diversity of animals in the Karoo. In: Dean, W.R.J. & Milton, S.J. (Eds.). 1999. *The Karoo: Ecological Patterns and Processes*. pp. 57-86. Cambridge [UK]: Cambridge University Press.

Vitousek, P.M., Mooney, H.A., Lubchenco, J., & Melillo. J.M. 1997. Human domination of earth's ecosystems. *Science* 277: 494-499.

W

Wickramagamage, P. 1998 Large-scale deforestation for plantation agriculture in the hill country of Sri Lanka and its impacts. *Hydrological Processes* 12, 2015-2028.

Williams, P.H. 1996. *WORLDMAP 4 WINDOWS: Software and help document 4.1*. Distributed privately, London & http: //www.nhm.ac.uk/science/projects/worldmap.

Williams, P., Gibbons, D., Margules, C., Rebelo, A., Humphries, C., & Pressey, R. 1996. A comparison of richness hotspots, rarity hotspots, and complementary areas for conserving diversity of British birds. *Conservation Biology* 10: 155-174.

Wilson, D.E. & Reeder, D.M. 1993. *Mammal Species of the World: A Taxonomic and Geographic Reference*. 2nd ed. Washington DC: Smithsonian Institution Press.

Woodroffe, R. & Ginsberg, J.R. 1998. Edge Effects and the Extinction of Populations Inside Protected Areas. *Science* 280: 2126-2128.

Woodroffe, R. & Ginsberg, J.R. 2000. Ranging behaviour and vulnerability to extinction in carnivores. In: Gosling, L.M. & Sutherland, W.J. (Eds.), *Behaviour and Conservation*. pp.125-140. Cambridge: Cambridge University Press.

Woodruff, D.S. 2001. Declines of biomes and biotas and the future of evolution. *Proceedings of the National Academy of Sciences* 98: 5471-5476.

Woods, C.A. & Sergile, F.E. 2001. *Biogeography of the West Indies: Patterns and Perspectives*. Boca Raton [FL]: CRC Press.

Woods, R.W. & Woods, A. 1997. *Atlas of Breeding Birds of the Falkland Islands*. Oswestry, UK: Anthony Nelson.

(WRI) World Resources Institute. 2000. *World Resources 2000-2001*. pp. 389. Washington DC: World Resources Institute.

Wright, R.G., & Scott, J.M. 1996. Evaluating the ecological suitability of lands for parks and protected areas using Gap Analysis databases. In: Wright, R.G. (Ed.). *National Parks and Protected Areas: Their Role in Environmental Protection*. pp.121-131. Cambridge [MA]: Blackwell Science.

(WWF & IUCN) World Wildlife Fund for Nature & The World Conservation Union. 1994-1997. *Centres of Plant Diversity: A Guide and Strategy for Their Conservation. 3 Volumes*. Cambridge, UK: IUCN Publications Unit for WWF (World Wide Fund for Nature) and IUCN (The World Conservation Union).

Y

Yalden, D.W. & Largen, M.J. 1992. The endemic mammals of Ethiopia. *Mammal Review* 22: 115-150.

Young, B.E., Lips, K.R., Reaser, J.K., Ibanez, R., Salas, A.W., Cedeno, J.R., Coloma, L.A., Ron, S., La Marca, E., Meyer, J.R., Munoz, A., Bolanos, F., Chaves, G., & Romo, D. 2001. Population declines and priorities for amphibian conservation in Latin America. *Conservation Biology* 15: 1213-1223.

Young, S.S. & Wang, C.Y. 2001. Land-cover change analysis of China using global-scale Pathfinder AVHRR Landcover (PAL) data, 1982-92. *International Journal of Remote Sensing* 22: 1457-1477.

Z

Zacharias, V.J. & Gaston, A.J. 1999. The recent distribution of endemic, disjunct and globally uncommon birds in the forests of Kerala State, southwest India. *Bird Conservation International* 9: 191-225.

Zhao, E-M. and Adler, K. 1993. *Herpetology of China*. Oxford [Ohio]: Society for the Study of Amphibians and Reptiles and Chinese Society for the Study of Amphibians.