Cost-effective priorities for global mammal conservation

Josie Carwardine*[†‡], Kerrie A. Wilson[†], Gerardo Ceballos[§], Paul R. Ehrlich[¶], Robin Naidoo[‖], Takuya Iwamura[†], Stefan A. Hajkowicz[‡], and Hugh P. Possingham[†]

[†]The Ecology Centre, University of Queensland, QLD 4072, Australia; [§]Instituto de Ecologia, Universidad Nacional Autónoma de México, Mexico D.F. 04510, Mexico; [¶]Department of Biological Sciences, Stanford University, Palo Alto, CA 94305-5020; [‖]Conservation Science Program, World Wildlife Fund, Washington, DC 20037; and [‡]Commonwealth Scientific and Industrial Research Organisation Sustainable Ecosystems, St. Lucia, QLD 4067, Australia

Edited by Partha Sarathi Dasgupta, University of Cambridge, Cambridge, United Kingdom, and approved May 21, 2008 (received for review July 31, 2007)

Global biodiversity priority setting underpins the strategic allocation of conservation funds. In identifying the first comprehensive set of global priority areas for mammals, Ceballos *et al.* [Ceballos G, Ehrlich PR, Soberón J, Salazar I, Fay JP (2005) *Science* 309:603–607] found much potential for conflict between conservation and agricultural human activity. This is not surprising because, like other global priority-setting approaches, they set priorities without socioeconomic objectives. Here we present a priority-setting framework that seeks to minimize the conflicts and opportunity costs of meeting conservation goals. We use it to derive a new set of priority areas for investment in mammal conservation based on (*i*) agricultural opportunity cost and biodiversity importance, (*ii*) current levels of international funding, and (*iii*) degree of threat. Our approach achieves the same biodiversity outcomes as Ceballos *et al.*'s while reducing the opportunity costs and conflicts with agricultural human activity by up to 50%. We uncover shortfalls in the allocation of conservation funds in many threatened priority areas, highlighting a global conservation challenge.

biodiversity | conservation planning | investment | socioeconomics

Global analyses for entire taxonomic groups have recently used new datasets to identify interesting biogeographic patterns (1–3) but do not identify priority areas for conservation investment, with one notable exception. Ceballos *et al.* (4) present the first global prioritization assessment that aims to represent an entire taxon: mammals. They use a traditional conservation planning approach, which identifies a minimum set of areas capable of representing all targeted biodiversity (5–8). Ceballos *et al.*'s priority set represents 10% of the range of 4795 mammal species and covers 11% of the earth's surface (using a planning cell size of 10,000 km^2). A *post hoc* assessment of their priority set highlights three important outcomes: (i) a large proportion of their priority cells overlap with important areas for crop production, (ii) there is a positive correlation between species richness and human population density within their priority set, and (iii) most centers of endemism for mammals occur in developing nations, where conservation capacity and funds are often limited (9–11). Ceballos *et al.*'s findings highlight a key challenge to the global conservation community: Where should we invest limited conservation funds to protect biodiversity while minimizing conflicts and socioeconomic costs?

Setting aside land for conservation invariably incurs socioeconomic costs: e.g., the opportunity costs of forgone production, social conflicts with alternative land uses, and the financial costs of land purchase and land management (12, 13). Cost minimization objectives are often implicit in conservation: historically biological reserves have been placed on unproductive land and/or in places that provide other environmental (e.g., ecosystem services like erosion control) or socioeconomic benefits (e.g., ecotourism) (14). More recent analytical approaches such as biodiversity hotspots and systematic conservation assessments have attempted to minimize cost by using area as a cost surrogate (4–6, 8). However, analyses that seek to minimize the total area required to meet conservation goals are likely to assign high priority to areas with conflicting human activities (such as agriculture and human settlements), because species richness and intensive land uses tend to correlate spatially (15–17). By not explicitly seeking to avoid such conflicts, Ceballos *et al.* miss an opportunity to provide a practical and cost-effective set of priorities.

Ceballos *et al.* are not alone: with a single exception (ref. 18: an analysis undertaken at the resolution of whole countries that omitted several biodiverse countries because of lack of economic data), global prioritization assessments are undertaken without accounting for socioeconomic objectives. They rely on patterns of species richness, endemism, threat, and/or degree of underrepresentation in existing protected areas networks (19–23). This is despite the substantial gains in efficiency demonstrated by the few studies at smaller scales that explicitly seek to minimize the cost of biodiversity conservation (13, 24–27).

The identification of priority areas for biodiversity conservation at a global scale is essential for informing the strategic allocation of globally fungible resources, i.e., funds that are available for spending outside their country or region of origin (23). They provide a global-scale context by indicating the overall contribution of a region to protecting a particular species, taxa, or major habitat type (4, 23). There is substantial scope for improving the cost-effectiveness of global biodiversity priorities, and the allocation of global conservation funds, by explicitly integrating biological and socioeconomic objectives. In particular, the consideration of objectives for agricultural production is pertinent: this widespread activity approximates land value in many places (12), is a great threat to biodiversity (4), and is critically demanded by societies throughout the world (17).

We present an integrated biological and socioeconomic approach for identifying biodiversity priority areas, and we redefine the mammal priorities set by Ceballos *et al.* We aim to (i) identify priority areas (hereafter termed cells, see *Materials and Methods*) that represent 10% of the geographic range of all mammal species while minimizing conflict with cropped areas, (ii) identify priority cells that achieve the same conservation goals but that minimize the financial loss of agricultural opportunities (both cropping and grazing, see *Materials and Methods*), (iii) evaluate the spatial allocation of current funding from international conservation agencies, and (iv) identify immediate priorities for conservation as those cells that are most important

Author contributions: J.C., K.A.W., G.C., P.R.E., S.A.H., and H.P.P. designed research; J.C. and T.I. performed research; J.C., K.A.W., G.C., R.N., and T.I. analyzed data; and J.C., K.A.W., G.C., P.R.E., R.N., T.I., S.A.H., and H.P.P. wrote the paper.

The authors declare no conflict of interest.

*To whom correspondence should be addressed. E-mail: j.carwardine@uq.edu.au.

This article is a PNAS Direct Submission.

Freely available online through the PNAS open access option.

This article contains supporting information online at www.pnas.org/cgi/content/full/0707157105/DCSupplemental.

Table 1. The area required and costs associated with representing a target of 10% of the geographic range of each mammal species with and without socioeconomic objectives

Study extent	Socioeconomic objective	Area required to meet targets	Cost of meeting targets
All	None	18.4 Mha	2.2 Mha cropped land (12% of total priority area is subject to cropping)
	Minimize area cropped in priority set	18.8 Mha (increase of 2%)	1.1 Mha cropped land (6% of total priority area is subject to cropping)
Potential conservation habitat	None	17.84 Mha	1.5 times minimum opportunity cost
	Minimize opportunity cost of the priority set	18.21 Mha (increase of 2%)	Minimum opportunity cost

Areas of intensive use are excluded when employing the opportunity cost layer as it represents the cost of forgone production in areas of land that are not under intensive use (hereafter ''potential conservation habitat''). Hence scenarios with differing study area extents are not comparable.

for cost-effective mammal conservation, underfunded, and subject to the greatest threat of habitat loss.

Our framework applies cost-effectiveness analysis, an economic evaluation method that can be used to identify the least cost way of reaching conservation targets (28, 29). Like Ceballos *et al.*, we focus on mammals—the only taxon with a complete fine-resolution dataset and a focal taxon of international conservation agencies. Our priorities are cost-effective in terms of minimizing the opportunity costs of agricultural production, but the approach is applicable to a range of market and, given the application of suitable valuation methods, nonmarket socioeconomic costs. Information required for a full cost-effectiveness analysis—comprehensive biological benefits (e.g., other taxa, ecosystems), conservation management costs, social costs and benefits, opportunity costs of forestry, tourism, and urban development—is not available globally at the equivalent resolution of the biodiversity dataset. Many of these are nonmarket costs that cannot be quantified financially but may be considered at more localized scales during implementation (12).

Results and Discussion

By explicitly seeking to minimize the conflict with cropped areas we are able to halve the cropped area that overlaps with priority cells (Table 1) (12% of the priority cells selected by Ceballos *et al.* are affected by cropping; we reduce this to 6% or 1.1 million ha). Similarly, we achieve the same targets for mammal species representation with a reduction in agricultural opportunity costs of ~35% compared to when opportunity costs are ignored. In both cases these efficiency gains incur only a slight increase in the total area of our priority cells (2%, Table 1), because our targets are area based and held constant.

All continents contain some cells that are required for the representation of our mammal species targets regardless of the socioeconomic objective; the highest proportions occur in Asia, Africa, and North America. Where there are multiple options, we find that accounting for socioeconomic objectives ensures the priority cells selected represent our targets for the least cost. The cells required to meet our mammal targets vary in their relative irreplaceability, or selection frequency, values (see Fig. 1 *a* and *b*). The total irreplaceable area increases (from 1.18 to 1.64 million km^2) when socioeconomic objectives are included, because the solutions consistently favor relatively cheap cells. The greatest proportional changes in irreplaceable area occur in Asia followed by Europe and South America, indicating that there are relatively fewer cost-effective options for meeting targets in these continents. Overall, countries with the greatest amount of irreplaceable area are Indonesia, Mexico, and Papua New Guinea: these and other irreplaceable areas shown in Fig. 1*b* represent potentially important areas for the cost-effective investment in mammal conservation. See supporting information (SI) Table S1 published at www.pnas.org for details of continent- and country-level results.

Spending in each country by international conservation agencies is not significantly related to our cost-effective globally irreplaceable areas for mammals ($R^2 = 0.005$, $P = 0.31$). Spending is better explained by the number of political endemic mammals (species restricted to a single country) ($R^2 = 0.202$, $P \ll 0.05$) and is related to, but not well explained by, mammal species richness ($R^2 = 0.064$, $P \ll 0.05$). These results indicate that spending patterns are largely driven by other objectives, which could include the conservation of other taxa, the preservation of wilderness areas, and sociopolitical goals such as poverty alleviation. Nevertheless, countries that are underfunded relative to their importance for cost-effective mammal conservation are priorities for further spending.

The United States received significantly more funds in 2005 than its relative importance for mammal conservation would recommend (Fig. 2). This may in part be explained by the preferences of some investors to protect local conservation assets, and concerns about the security of funds placed into less politically stable countries. Slightly overfunded countries include China, Croatia, and Zimbabwe, but because of the gross overspending in the United States relative to its importance for mammal conservation, most countries are relatively underfunded: particularly Madagascar, Papua New Guinea, Brazil, Indonesia, Cuba, India, Dominica, Colombia, and the Philippines. All of these countries overlap to some extent with the World Wildlife Fund's (WWF) Global 200 ecoregions (20) and most intercept with Conservation International's hotspots (21) and the crisis ecoregions identified collaboratively by the WWF and The Nature Conservancy (22), suggesting that spending is less than equitable within the global priority areas identified by conservation organizations. Spending patterns of international conservation agencies may have changed since 2005, possibly in response to increasing demand for more accountable spending regimes (30, 31), and we were unable to account for spending by Conservation International, but our findings support previous studies (11, 32) in suggesting that many developing countries are underfunded relative to their biodiversity importance and potential for cost-effective conservation. It is likely that increasing the fungibility of resources to improve spending equitability will be a useful first step in addressing this global biodiversity challenge.

Our framework identifies global biodiversity priorities by integrating data on cost-effective irreplaceability, relative underfunding, and threat of habitat loss, or vulnerability (Fig. 3). Funds can be directed toward cells that occur in the top quartile of all three measures, or vulnerability and relative underfunding can be used as a tiebreaker between equally irreplaceable cells. Some cells with lower irreplaceability values will require investment to ensure targets are met for species that occur outside irreplaceable cells. As with all traditional systematic conservation assessments, our approach is a static solution to an inherently dynamic problem. As areas of highest priority receive funds, the relative priority of the remaining cells will alter (30), as will the likelihood of habitat loss (34, 35) and indexes of relative underfunding. At present our ability to undertake a fine-resolution dynamic assessment of conservation priorities at

SUSTAINABILITY SCIENCE

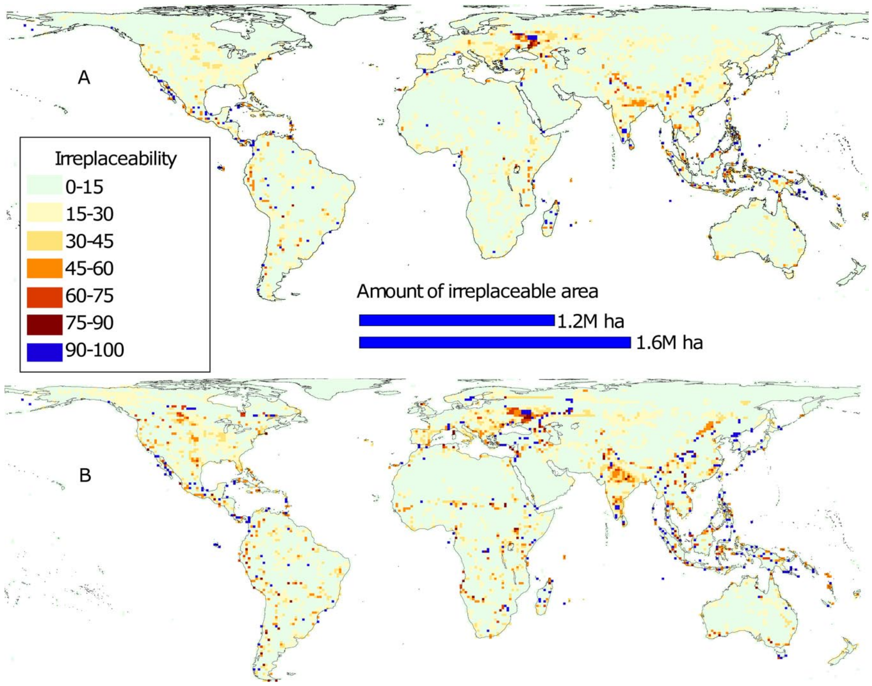

Fig. 1. The irreplaceability, or relative priority, of cells for representing 10% of the range of each species of mammal in potential conservation habitat (*a*) with no socioeconomic objectives and (*b*) while minimizing the agricultural opportunity costs. When socioeconomic objectives are included, relatively cheaper cells are selected more often, creating a greater number of irreplaceable cells. Priorities are driven away from areas with high potential for agricultural production.

a global scale is limited computationally and by data availability: for example, we lack the spatially explicit time series dataset or estimated probability of future habitat loss necessary for a dynamic evaluation (36). These gaps in data and tools represent future conservation research priorities.

Conclusions

We highlight fine-resolution global priority areas for cost-effective mammal conservation and show the funding redistribution necessary to improve spending equitability in priority areas, particularly in developing countries. While our global priority areas for mammals will not equitably represent other taxa, recent analyses suggest that the choice of taxon group is less important than socioeconomic factors in driving optimal funding schedules (37). We acknowledge, however, that a comprehensive set of conservation priority areas should be informed by multiple taxonomic groups, ecological processes and evolutionary data, implementation costs, and a measure of opportunity cost across more than one dominant sector. We are not the first to call for improved data to aid this cause (3, 13). As more comprehensive information becomes available we can

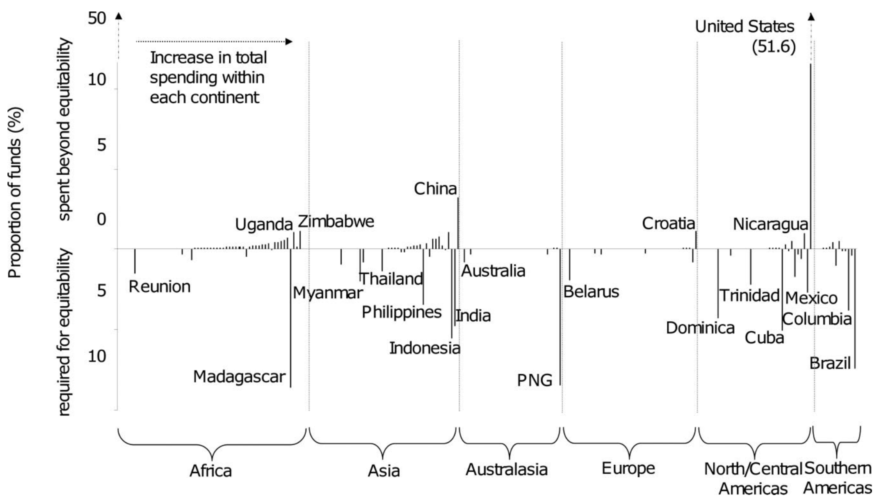

Fig. 2. Actual spending in each country relative to the proportion of spending required for equitability based on our irreplaceable priorities for cost-effective mammal conservation. Within each continent countries are ordered from left to right in increasing amounts of total spending, which is independent of the size of the residuals. Residuals of ~0 were present for most countries, indicating that both spending and irreplaceable area are zero or close to zero or that the proportions of each are comparable. For example, Morocco received 0.37% of funds in 2005, and if funds were distributed equitably on the basis of the cost of investing in irreplaceable areas in Morocco, it would have received 0.42%. Morocco is therefore slightly underfunded with a residual of −0.04. Large negative residuals represent countries that received a major shortfall in funds given the area that is irreplaceable for mammal conservation—hence these countries represent potential priorities for future spending.

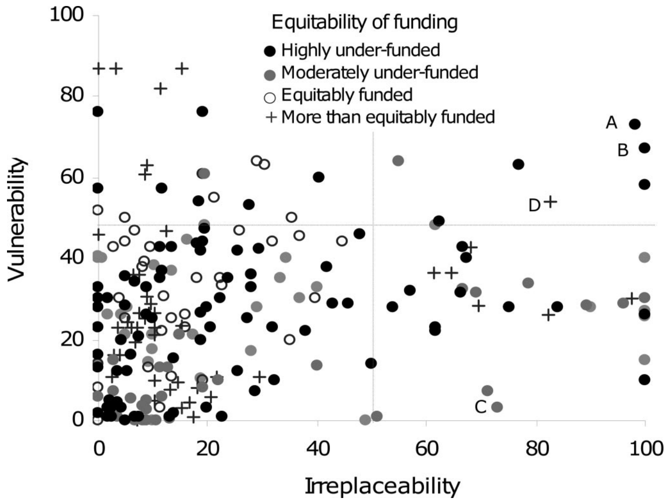

Fig. 3. The irreplaceability, vulnerability, and relative equitability in funding for a random selection of 250 cells. This framework can be used to prioritize further investment: cell (a) is a high priority as it is highly irreplaceable and vulnerable and occurs in an underfunded country (Indonesia); (b) is a high priority, a totally irreplaceable and vulnerable cell that occurs in Brazil, which is also an underfunded country; (c) is moderately irreplaceable, not vulnerable by our measure, and exists in moderately underfunded Bolivia (hence may represent a less immediate priority for further spending); and (d) in the United States might be lower priority for additional funding despite its moderately high irreplaceability and vulnerability, but would be an ideal place to direct funding that is unable to be allocated outside the United States.

address more complex biological and socioeconomic objectives and find increasingly cost-effective solutions.

Incorporating socioeconomic objectives must become the international norm for supporting cost-effective spending on biodiversity conservation. The benefits of improved efficiency are essential at a time when international conservation agencies are subject to demands for more accountable spending regimes (31). Implementation of conservation action on the ground will require a range of politically and culturally sensitive approaches applied at local scales within priority areas, including sustainable development and capacity building in many areas (10, 38). The reconciliation of global-scale priorities with the implementation of conservation actions at a local scale represents an additional challenge—one that will require the efforts of governments, nongovernment organizations, conservation planners and practitioners, indigenous people, and private landowners (38, 39).

Materials and Methods

We use the conservation planning software MARXAN (v1.8.2) (40), which solves an optimization problem of representing target amounts of biodiversity at a minimal cost. Ceballos *et al.* used MARXAN to minimize the number of cells selected to represent 10% of the range of each mammal species. We retain 10% representation targets, but explicitly seek to achieve these targets while first minimizing the total fractional crop area of the cells selected (41) and then minimizing agricultural opportunity cost: the potential forgone economic returns from agricultural production (cropping and grazing) (42).

The potential economic returns from agricultural production are estimated at a 5′ resolution by the maximum of the potential crop and livestock yields per unit area based on land capability, multiplied by the producer price (42). We assume that land already under intensive use (cropping and built-up areas) is incompatible with conservation. Hence we scale the opportunity cost and species distributions to the area of nonintensive use or ''potential conservation habitat'' of each cell, estimated by subtracting the fractional cropped area and the fractional built-up area (41) from the total cell area. The final cost of each cell therefore represents the maximum potential agricultural profits from the nonintensively used land (grazed land was considered nonintensive) in the cell, regardless of whether this potential is realized. We keep original species representation targets; two species are unable to meet these targets when areas of intensive use are excluded.

To gain insight into the flexibility of cost-effective ways to meet our targets we generate 250 solutions in MARXAN for each of our three scenarios: no socioeconomic objectives, minimize area cropped, and minimize agricultural opportunity cost. We calculate the relative priority, or irreplaceability, of each cell by the frequency of solutions in which it is selected. Irreplaceable cells in each scenario are those selected in all 250 solutions. We use the most cost-effective of the 250 runs to evaluate the cost of representing 10% of each mammal's range, first in terms of area cropped and then in terms of total opportunity cost of forgone agricultural production.

We compare spending patterns in each country by major five international conservation agencies, the World Bank, the Global Environmental Facility, The Nature Conservancy, the Wildlife Conservation Society, and the World Conservation Union (30), to each country's tally of (i) irreplaceable areas for cost-effective mammal conservation, (ii) mammal species richness, and (iii) number of political endemics. We determine the proportion of funds that would be allocated to each country if spending of international funds was based equitably on our mammal priorities. (Our assessment could account for in-country spending, if such data were available globally). We divide the opportunity cost of acting in all globally irreplaceable areas within each country by the summed opportunity cost of conserving all irreplaceable sites in all countries and subtract this proportion from the proportion of funds actually invested in each country in 2005. Thus we quantify the proportion of funds requiring redistribution to or from a country to create equitable spending. We do not adjust spending in each country by Purchasing Power Parity because this would bias our priorities to poorer countries where the costs of production are cheaper (and hence opportunity costs of protection less). This adjustment was not warranted because we do not account for broader societal costs.

We estimate the relative degree of threat of habitat loss to each cell using a global human footprint dataset (43) that depicts human influence on a scale of 0–100.

ACKNOWLEDGMENTS. We are grateful to Ben Halpern, John Fay, Navin Ramankutty, John Foley, the Wildlife Conservation Society, the Center for International Earth Science Information Network, and Columbia University for data provision. We also thank Michael Bode and Hedley Grantham for useful comments and advice. J.C. and S.A.H. were supported by the Commonwealth Scientific and Industrial Research Organisation, K.A.W. and H.P.P. were supported by the Australian Research Council and the Applied Environmental Decision Analysis Commonwealth Environmental Research Facility, G.C. was supported by Universidad Nacional Autónoma de México and Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (Mexico), P.R.E. was supported by the LuEsther T. Mertz Charitable Trust and Peter Bing, and T.I. was supported by the Australian government's Endeavour Awards.

1. Orme CDL, *et al*. (2005) Global hotspots of species richness are not congruent with endemism or threat. *Nature* 436:1016–1019.
2. Lamoreux JF, *et al*. (2006) Global tests of biodiversity concordance and the importance of endemism. *Nature* 440:212–214.
3. Ceballos G, Ehrlich PR (2006) Global mammal distributions, biodiversity hotspots, and conservation. *Proc Natl Acad Sci USA* 103:19374–19379.
4. Ceballos G, Ehrlich PR, Soberón J, Salazar I, Fay JP (2005) Global mammal conservation: What must we manage. *Science* 309:603–607.
5. Margules CR, Pressey RL (2000) Systematic conservation planning. *Nature* 405:243–253.
6. Possingham HP, Wilson KA (2005) in *Principles of Conservation Biology*, eds Groom MJ, Meffe, GK (Sinauer Associates, Sunderland, MA), pp. 509–533.
7. Church R, ReVelle C (1974) The maximal coverage location problem. *Papers Reg Science Assoc* 32:101–118.
8. Kirkpatrick JB (1983) An iterative method for establishing priorities for the selection of nature reserves: an example from Tasmania. *Biol Conserv* 25:127–134.
9. Rodriguez JP, Rodriguez-Clark KM, Oliveira-Miranda MA, Good T, Grajal A (2006) Professional capacity building: the missing agenda in conservation priority setting. *Conserv Biol* 20:1340.
10. Balmford A, Gaston KJ, Blyth S, James A, Kapos V (2003) Global variation in terrestrial conservation costs, conservation benefits, and unmet conservation needs. *Proc Natl Acad Sci USA* 100:1046–1050.
11. Smith RJ, Muirm RDJ, Walpole MJ, Balmford A, Leader-Williams N (2003) Governance and the loss of biodiversity. *Nature* 426:67–70.
12. Naidoo R, Balmford A, Ferraro PJ, Polasky S, Ricketts TH, Rouget M (2006) Integrating costs into conservation planning. *Trends Ecol Evol* 21:681–687.
13. Moore J, Balmford A, Allnut T, Burgess N (2004) Integrating costs into conservation planning across Africa. *Biol Conserv* 117:343–350.
14. Knight AT, Cowling RM (2007) Embracing opportunism in the selection of priority conservation areas. *Conserv Biol* 21:1124–1126.
15. Abbitt RJF, Scott JM, Wilcove DS (2000) The geography of vulnerability: incorporating

species geography and human development patterns into conservation planning. *Biol Conserv* 96:169–175.
16. Araújo MB (2003) The coincidence of people and biodiversity in Europe. *Glob Ecol Biogeogr* 12:5–12.
17. McKee JK, Sciulli PW, Fooce CD, Waite TA (2004) Forecasting global biodiversity threats associated with human population growth. *Biol Conserv* 115:161–164.
18. Balmford A, Gaston KJ, Rodrigues ASL, James A (2000) Integrating costs of conservation into international priority setting. *Conserv Biol* 14:1–9.
19. Olson DM, Dinerstein E (1998) The global 200: A representation approach to conserving the Earth's most biologically valuable ecoregions. *Conserv Biol* 12:502–515.
20. Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J (2000) Biodiversity hotspots for conservation priorities. *Nature* 403:853–858.
21. Rodrigues ASL, *et al*. (2004) Effectiveness of the global protected area network in representing species diversity. *Nature* 428:640–643.
22. Hoekstra JM, Boucher TM, Ricketts TH, Roberts C (2005) Confronting a biome crisis: global disparities of habitat loss and protection. *Ecol Lett* 8:23–29.
23. Brooks TM, *et al*. (2006) Global biodiversity conservation priorities. *Science* 313:58–61.
24. Ando A, Camm L, Polasky S, Solow A (1998) Species distributions, land values and efficient conservation. *Science* 279:2126–2128.
25. Polasky S, Camm JD, Garber-Yonts B (2001) Selecting biological reserves cost-effectively: an application to terrestrial vertebrate conservation in Oregon. *Land Econ* 77:68–78.
26. Stewart RR, Possingham HP (2005) Efficiency, costs and trade-offs in marine reserve design. *Environ Model Assess* 10:203–213.
27. Luck GW, Rickets TH, Daily GC, Imhoff M (2004) Alleviating spatial conflict between people and biodiversity. *Proc Natl Acad Sci USA* 101:182–186.
28. Levin H, McEwan PJ (2001) *Cost-Effectiveness Analysis: Methods and Applications* (Sage Publications, Thousand Oaks, CA), 2nd Ed.
29. Cullen R, Hughey KFD, Fairburn G, Moran E (2005) Economic analysis to aid nature conservation decision making. *Oryx* 39:327–324.
30. Halpern BS, *et al*. (2005) Gaps and mismatches between global priorities and spending. *Conserv Biol* 20:56–64.
31. Ferraro PJ, Pattanayak S (2006) Money for nothing? A call for empirical evaluation of biodiversity conservation investments *PLoS Biol.* 4(4):e105.
32. James A, Gaston K, Balmford A (1999) Balancing the earths accounts. *Nature* 401:323–324.
33. Pressey RL, Taffs KH (2001) Scheduling conservation action in production landscapes: priority areas in western New South Wales defined by irreplaceability and vulnerability to vegetation loss. *Biol Conserv* 100:355–376.
34. Costello C, Polasky S (2004) Dynamic reserve site selection. *Resource Energy Econ* 26:157–174.
35. Armsworth PR, Daily GC, Kareiva P, Sanchirico JN (2006) Land market feedbacks can undermine biodiversity conservation. *Proc Natl Acad Sci USA* 103:5403–5408.
36. Wilson KA, McBride M, Bode M, Possingham HP (2006) Prioritizing global conservation efforts. *Nature* 40:337–340.
37. Bode M, *et al*. (2008) Does taxonomic congruence matter to global conservation investment? *Proc Natl Acad Sci USA* 105:6498–6501.
38. Pierce SM, *et al*. (2005) Systematic conservation planning products for land-use planning: interpretation for implementation. *Biol Conserv* 125:441–458.
39. Knight AT, Cowling RM, Campbell BM (2006) Planning for implementation: an operational model for implementing conservation action. *Conserv Biol* 20:408–419.
40. Possingham HP, Ball I, Andelman S (2000) Mathematical methods for identifying representative reserve networks. *Quantitative Methods for Conservation Biology*, eds Ferson S, Burgman M. (Springer, New York), pp 291–305.
41. Ramankutty N, Foley JA (1999) Estimating historical changes in global land cover: Croplands from 1700–1992. *Glob Ecol Biogeogr* 8:381.
42. Naidoo R, Iwamura T (2007) Global-scale mapping of economic benefits from agricultural lands: implications for conservation priorities. *Biol Conserv* 140:40–49.
43. Wildlife Conservation Society (WCS), Center for International Earth Science Information Network (CIESIN) Columbia University (2002) Last of the Wild Project, Version 1, 2002: *Global Human Footprint Dataset* (*Geographic*) Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University.