Pinpointing and preventing imminent extinctions

Taylor H. Ricketts\textsuperscript{a,b}, Eric Dinerstein\textsuperscript{a}, Tim Boucher\textsuperscript{a}, Thomas M. Brooks\textsuperscript{d}, Stuart H. M. Butchart\textsuperscript{a}, Michael Hoffmann\textsuperscript{d}, John F. Lamoreux\textsuperscript{i}, John Morrison\textsuperscript{a}, Mike Parr\textsuperscript{g}, John D. Pilgrim\textsuperscript{d}, Ana S. L. Rodrigues\textsuperscript{d}, Wes Sechrest\textsuperscript{h}, George E. Wallace\textsuperscript{a}, Ken Berlin\textsuperscript{a}, Jon Biebly\textsuperscript{a}, Neil D. Burgessa, Don R. Church\textsuperscript{d}, Neil Cox\textsuperscript{h}, David Knox\textsuperscript{a}, Colby Loucks\textsuperscript{a}, Gary W. Luck\textsuperscript{b}, Lawrence L. Master\textsuperscript{a}, Robin Moor\textsuperscript{e}, Robin Naidoo\textsuperscript{a}, Robert Ridgely\textsuperscript{g}, George E. Schatz\textsuperscript{n}, Gavin Shire\textsuperscript{g}, Holly Strand\textsuperscript{h}, Wes Wettengel\textsuperscript{a}, and Eric Wikramanayake\textsuperscript{a}

\textsuperscript{a}Conservation Science Program, World Wildlife Fund, Washington, DC 20037; \textsuperscript{b}Global Priorities Group, The Nature Conservancy, Arlington, VA 22203; \textsuperscript{c}Center for Applied Biodiversity Science, Conservation International, Washington, DC 20036; \textsuperscript{d}BirdLife International, Cambridge CB3 0NA, United Kingdom; \textsuperscript{e}Department of Environmental Sciences, University of Virginia, Charlottesville, VA 22904; \textsuperscript{f}American Bird Conservancy, Washington, DC 20009; \textsuperscript{g}Biodiversity Assessment Unit, World Conservation Union’s Species Survival Commission/Conservation International’s Center for Applied Biodiversity Science, Washington, DC 20036; \textsuperscript{h}Skadden, Arps, Slate, Meagher, and Flom, Washington, DC 20005; \textsuperscript{i}Institute of Zoology, Zoological Society of London, Regent’s Park, London NW1 4RY, United Kingdom; \textsuperscript{j}School of Environmental and Information Sciences, The Johnstone Centre, Charles Sturt University, Albury NSW 2640, Australia; \textsuperscript{k}NatureServe, Arlington, VA 22209; \textsuperscript{l}Biology Department, University of South Florida, Tampa, FL 33620; and \textsuperscript{n}Missouri Botanical Garden, St. Louis, MO 63166

Communicated by Paul R. Ehrlich, Stanford University, Stanford, CA, October 18, 2005 (received for review October 7, 2005)

Slowing rates of global biodiversity loss requires preventing species extinction. Here, we pinpoint centers of imminent extinction, where highly threatened species are confined to single sites. Within five globally assessed taxa (i.e., mammals, birds, selected reptiles, amphibians, and conifers), we find 794 such species, three times the number recorded as having gone extinct since 1500. These species occur in 585 sites, concentrated in tropical forests, on islands, and in mountainous areas. Their taxonomic and geographical distribution differs significantly from that of historical extinctions, indicating an expansion of the current extinction episode beyond sensitive species and places toward the planet’s most biodiverse mainland regions. Only one-third of the sites are legally protected, and most are surrounded by intense human development. These sites represent clear opportunities for urgent conservation action to prevent species loss.

Biodiversity | Conservation | Protected Area | Threatened Species

Recent human-induced extinction rates are 100-1,000 times the geological background rate and are predicted to increase another 10-fold (1). In response, 188 countries have committed to slowing global biodiversity loss (2). Over the long term, achieving this ambitious goal requires broadscale, proactive conservation to protect entire ecosystems before their component species become threatened (3). Many species, however, are already so endangered by human activities that they will likely disappear without immediate site-specific action. Preventing these extinctions must be part of any global strategy to reduce biodiversity loss.

Among the species of primary conservation concern are those that are both highly threatened and restricted to single locations. The sites containing such species represent the extremes of two widely accepted principles for prioritizing conservation action: threat (i.e., the likelihood that the biodiversity in that site will be lost) and irreplaceability (i.e., the degree to which options for conservation are lost without the site) (4). With small populations, extreme vulnerability to habitat destruction, and limited options for conservation, these species face imminent extinction in the absence of appropriate conservation action. Furthermore, immediate requirements for their conservation are relatively straightforward; although a variety of conservation activities may eventually be needed, the obvious immediate goal is to conserve habitat in their single remaining sites.

To locate such species, we examine five major taxa for which global data are available (i.e., mammals, birds, selected reptiles, amphibians, and conifers) and identify sites that (i) contain at least one highly threatened species, (ii) represent essentially the sole area of occurrence for the species, and (iii) permit management as a discrete unit. (Hereafter, we refer to places that meet these criteria as “sites” and to species that trigger them as “trigger species.”) Using the resulting data set, we examine the taxonomic and geographic distributions of trigger species and sites, and we compare them with the distributions of historical extinctions to examine shifts in extinction risk over time. We also determine protection status of current sites, assess levels of surrounding human activity, and estimate the costs required to adequately conserve them. These analyses are intended to complement and inform ongoing efforts to conserve global biodiversity (5–10) by identifying sites where urgent conservation action can help to prevent species extinctions.

Methods

We applied three criteria to identify sites. First, a site must contain at least one endangered or critically endangered species, as listed on the 2004 World Conservation Union (IUCN) Red List of Threatened Species (www.iucnredlist.org). A site cannot be designated on the basis of unlisted or unevaluated species, data deficient species, or vulnerable species. A site may be designated as the only suitable reintroduction site for a species assessed as extinct in the wild; only two sites were triggered by this criterion. We adopted the taxonomy followed by the IUCN Red List at the species level and did not identify sites for subspecies or subpopulations.

Second, a site must (i) be the sole area where an endangered or critically endangered species occurs, (ii) contain the overwhelmingly significant (more than ∼95% of the global population) known resident population of the species, or (iii) contain the overwhelmingly significant known population for one life-history segment (e.g., breeding or nonbreeding) of the species. Less than 10% of all sites were triggered by (ii), and only 15 sites (2 for migratory birds and 13 for breeding seabirds) were triggered by (iii).

Third, a site must have a definable boundary, within which habitats, biological communities, or management issues share more in common with each other than they do with those in adjacent areas (e.g., a single lake, mountaintop, or forest fragment). The boundary of the area was defined to correspond to the most practical conservation unit, including considerations of contiguous habitat, management units, and the potential for significant gene flow among populations. There was no explicit size criterion for sites, but median size of sites for which size

Conflict of interest statement: No conflicts declared.

Freely available online through the PNAS open access option.

Abbreviation: IUCN, World Conservation Union.

To whom correspondence should be addressed. E-mail: taylor.ricketts@wwfus.org.

© 2005 by The National Academy of Sciences of the USA
information was available was 12,060 hectares. Although this site definition is not fully objective and repeatable, it balances scientific objectivity with management practicality and follows the methodology applied in studies in refs. 9–11.

Data on species’ threat were taken from the 2004 IUCN Red List of Threatened Species (www.iucnredlist.org). To reduce geographic biases, we limited our analyses to taxa that have been globally assessed by the IUCN Red List. Cycads, the only other globally assessed taxon, will likely be incorporated into the data set next year. For reptiles, only three clades have been globally assessed (i.e., order Testudines, order Crocodylia, and family Iguanidae), representing ∼4% of all reptile species (www.reptile-database.org). We do not claim these clades to be representative of overall patterns of reptile diversity and threat; we included them simply in an effort to use all available suitable information. However, pooled species richness of these three clades is significantly correlated with overall richness of reptiles (www.worldwildlife.org/wildfinder), both among biogeographic realms (Pearson’s correlation coefficient; r = 0.79, P = 0.035) and among terrestrial ecoregions (r = 0.64, P < 0.0001) (12, 13).

Distribution data for critically endangered and endangered species were gathered from primary literature, data compilations (main sources include www.iucnredlist.org, www.globalamphibians.org, and refs. 14–17), and consultations with experts (specific sources available upon request). Because data quality and resolution varied widely among species, each species was evaluated individually by one or more authors against the second and third criteria, and then reviewed by at least one regional expert. (see Supporting Text, which is published as supporting information on the PNAS web site, for discussion of data uncertainty).

To assess protection status of each site, we initially used a geographic information system to assign sites to terrestrial ecoregions, biomes, biogeographic realms, islands, and mountainous areas. We defined ecoregions, biomes, and realms following Olson et al. (13) and mountainous areas following the Millennium Ecosystem Assessment (19). We defined islands as landmasses smaller than Greenland and used ESRI vector map data (20) to identify them.

To evaluate human pressures surrounding sites, we used a geographic information system to create buffers of 50-km radius around each site, with overlapping buffers merged to avoid double counting. We then calculated the mean human population density (www.ornl.gov/gist) and human footprint (21) within the merged buffer area (data resolution: 30 arc seconds; water bodies excluded) and compared them with the mean outside of buffers, both for the world’s terrestrial surface (excluding Antarctica) and within the 338 terrestrial ecoregions (13) that contain sites.

Finally, to calculate potential annual management costs for sites, we used models developed by Balmford et al. (22) based on the ratio of gross national product (GNP) to country area, purchasing power parity (PPP), and site area. Data for country area, GNP, and PPP were taken from the World Bank (23).

Reliable information on site area was available for only 208 of the 508 sites in developing countries, so we limited our analyses to these sites. Even for areas that are currently protected, funding is generally lower than that required to meet conservation goals (22). We therefore assumed unmet costs by using percentage estimates from Bruner et al. (24) (developing countries) and James et al. (25) (developed countries). Some sites are only partially covered by protected areas; for cost calculations, we conservatively treated these as unprotected sites.

Results and Discussion
Our criteria yield 794 trigger species, distributed among 595 sites, that are likely to become extinct unless immediate and direct
action is taken (Fig. 1; Table 2, which is published as supporting information on the PNAS web site). Since 1500, 245 extinctions have been recorded in these major taxonomic groups (www.iucnredlist.org); we therefore risk losing three times as many species as are known to have become extinct since 1500 and are mapped according to their last recorded location. Regardless of management status, all sites are small and, therefore, highly susceptible to human activities in the surrounding landscape. In circular buffers of 50-km radius surrounding each site, mean human population density (www.ornl.gov/gist) is 127 people/km² (range: 0–3,262), about three times the global mean of 45 people/km² and about twice the mean of 68 people/km² within ecoregions (13) containing sites. Similarly, mean human footprint, an aggregate index of human land use, population, and infrastructure (21), is 25.5

Broader shifts in geography are also evident. For example, 21% of extinct species were found in the Neotropics (the world’s richest biogeographic realm; ref. 29); this proportion has now more than doubled to 50% of trigger species (Fig. 1; G-test: G² = 972.7, P < 0.0001). Accompanying this geographic expansion is a taxonomic shift: 53% of historically recorded extinctions were birds (occurring largely on islands), whereas 51% of trigger species are amphibians (28) (occurring largely in mainland mountainous areas; Table 1; G-test: G² = 753.0, P < 0.0001). The more complete record of historical avian extinctions biases this result, but the pattern is almost certainly true because amphibians cannot disperse easily over seawater and historically did not occur on many oceanic islands.

Table 1. Distribution of species facing imminent extinction (i.e., trigger species) and historically extinct species among taxa and islands, mountains, and low mainland areas

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Islands*</th>
<th>Mountains†</th>
<th>Low mainland‡</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trigger</td>
<td>Extinct</td>
<td>Trigger</td>
<td>Extinct</td>
</tr>
<tr>
<td>Mammals</td>
<td>80</td>
<td>49</td>
<td>35</td>
<td>5</td>
</tr>
<tr>
<td>Birds</td>
<td>128</td>
<td>121</td>
<td>51</td>
<td>1</td>
</tr>
<tr>
<td>Reptiles‡</td>
<td>7</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Amphibians</td>
<td>88</td>
<td>19</td>
<td>268</td>
<td>11</td>
</tr>
<tr>
<td>Conifers</td>
<td>9</td>
<td>0</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>312</td>
<td>197</td>
<td>366</td>
<td>17</td>
</tr>
</tbody>
</table>

Trigger species meet the criteria necessary to trigger sites for this analysis (see Methods). Historically extinct species are known to have become extinct since 1500 (www.iucnredlist.org) and are mapped according to their last recorded location.

†Islands are defined as landmasses smaller than Greenland (New Guinea being the largest island) and include mountainous sections of islands.
‡Mountains exclude mountainous sections of islands and are defined on the mainland by using classification from the Millennium Ecosystem Assessment (19).
§Low mainland regions are neither on islands nor in mountainous regions of continental mainlands.

31), whereas 87 (15%) are partially included in a protected area, and the protection status of 48 (8%) sites is unknown. Regardless of management status, all sites are small and, therefore, highly susceptible to human activities in the surrounding landscape. In circular buffers of 50-km radius surrounding each site, mean human population density (www.ornl.gov/gist) is 127 people/km² (range: 0–3,262), about three times the global mean of 45 people/km² and about twice the mean of 68 people/km² within ecoregions (13) containing sites. Similarly, mean human footprint, an aggregate index of human land use, population, and infrastructure (21), is 25.5
to be complemented with control of invasive species or disease, management, or protected area enforcement and to monitor avoidance of these impending extinctions will be to safeguard their sites opportunities for conservation. Clearly, the primary response to (www.iucnredlist.org). The 794 trigger species represent similar assistance from the industrialized world will be needed to pay for countries (Table 4, which is published as supporting information for all of them. 

Although the species we identify here require immediate attention and may often prove difficult to conserve, their recovery is within reach. Indeed, several species that would have met all three of our criteria in the past are now recovering due to successful conservation and are no longer eligible. These species include Rodrigues Fody (Foudia flavicans), Seychelles Warbler (Acrocephalus sechellensis), Seychelles Magpie-Robin (Copyschus sechellarum), and Black Robin (Petroica traversi) (www.iucnredlist.org). The 794 trigger species represent similar opportunities for conservation. Clearly, the primary response to avoid these impending extinctions will be to safeguard their sites through land purchase, conservation easements, community management, or protected area enforcement and to monitor their condition over time. In some cases, such measures will need to be complemented with control of invasive species or disease, translocation, or ex situ breeding or cultivation. Over the longer term, climate change may increasingly threaten trigger species, including those on isolated mountains or low-lying islands (32) (Table 1). However, although other interventions may be necessary at certain sites, protection of existing habitat is essential for all of them.

The vast majority of sites (508 of 595) are in developing countries (Table 4, which is published as supporting information on the PNAS web site) (23), and in many cases, substantial assistance from the industrialized world will be needed to pay for their conservation. After published estimates (22, 24), we calculate that annual management costs per site in developing countries will likely span four orders of magnitude, from $470 to $3,500,000 (median $220,000). Annual costs for each of three sites in Ecuador, for example, average $36,000 (managed by Fundacion Jocotoco; R.R., unpublished data). One-time acquisition costs for unprotected sites can be many times their management costs (25) but may often be much lower because protection may be achieved through redesignation of public lands to higher levels of protection or better enforcement of existing designations (24).

The species identified here are only a fraction of those at risk of extinction from intensifying human activities. Available data limited our analyses to five taxonomic groups, and more trigger species (particularly freshwater species, terrestrial invertebrates, and plants) will be identified as knowledge improves. Even within the analyzed taxa, species not confined to a single site can be equally threatened and in need of conservation actions (e.g., wide-ranging but fast-declining species, such as Asian Gyps vultures; ref. 33). Furthermore, a global conservation strategy must also consider broader biodiverse regions, population diversity, ecological processes, and ecosystem services to human communities (3, 5–8, 34, 35) (Supporting Text). Nonetheless, the sites we identify are a critical subset of global conservation priorities, complementing other efforts by focusing on relatively small scales and short time horizons: They are known places where extinctions are imminent unless immediate conservation action is taken.

We thank M. Bakarr, L. Bennun, L. Cayet, J. Chanson, R. Chipley, L. Fishpool, G. Fonseca, C. Hilton-Taylor, J. Hoekstra, R. Hudson, M. Hunter, R. Livensmore, P. McGowan, J. Miller, R. Mittermeier, B. Phillips, C. Pollock, K. Redford, R. Riordan, J. Robinson, A. Shenkin, M. Sneyr, E. Sterling, S. Stuart, C. Sugal, B. Swift, J. Tzem, C. Wilson, B. Young, Giorgio’s, all members of the Alliance for Zero Extinction, and >100 additional colleagues for data, site reviews, ideas, and valuable input throughout the project. We are also grateful to the many dedicated people who volunteer their time and effort to develop IUCN Red List assessments, without which these analyses would simply not be possible. G. Mace, G. Orians, K. Redford, and D. Wilcove much improved the manuscript with their comments. Finally, we acknowledge the many supporters of this collaborative effort and the data collection on which it depends, including Beneficia Foundation, BirdLife International’s Founder Patrons and Rare Bird Club, Critical Ecosystem Partnership Fund, Disney Foundation, Regina Bauer Frankenberg Foundation, Ben Hammett, John D. and Catherine T. MacArthur Foundation, MAVA Foundation, Gordon and Betty Moore Foundation, Moore Family Foundation, George Meyer, National Science Foundation Grants DEB-0130273 and INT-0322375, and the U.S. Department of State.