A novel approach for global mammal extinction risk reduction

Moreno Di Marco[1], Marcel Cardillo[2], Hugh P. Possingham[3], Kerrie A. Wilson[3], Simon P. Blomberg[3], Luigi Boitani[1], and Carlo Rondinini[1]

[1]Global Mammal Assessment program, Department of Biology and Biotechnologies, Sapienza University of Rome, I-00185 Rome, Italy
[2]Centre for Macroevolution and Macroecology, Research School of Biology, Australian National University, ACT 0200, Canberra, Australia.
[3]School of Biological Sciences, The University of Queensland, St. Lucia, 4072, Queensland, Australia.

Keywords
Benefit metric; extinction risk models; multiple imputation; spatial conservation prioritization; species recovery; terrestrial mammals; threatened species.

Correspondence
Moreno Di Marco, Global Mammal Assessment Program, Department of Biology and Biotechnologies, Sapienza University of Rome, viale dell'Università 32, I-00185 Rome, Italy.
Tel: +39 06 49694218; Fax: +39 06 4958259.
E-mail: moreno.dimarco@uniroma1.it

Received
15 September 2011
Accepted
19 December 2011

Editor
Dr. Amanda Lombard

doi: 10.1111/j.1755-263X.2011.00219.x

Abstract

With one-fourth of the world's mammals threatened with extinction and limited budget to save them, adopting an efficient conservation strategy is crucial. Previous approaches to setting global conservation priorities have assumed all species to have equal conservation value, or have focused on species with high extinction risk, species that may be hard to save. Here, we identify priority species for optimizing the reduction in overall extinction risk of the world's threatened terrestrial mammals. We take a novel approach and focus on species having the greatest recovery opportunity using a new conservation benefit metric: the Extinction risk Reduction Opportunity (ERO). We discover that 65–87% of all threatened and potentially recoverable species are overlooked by existing prioritization approaches. We use the ERO metric to prioritize threatened species, but the potential applications are broader; ERO has the potential to integrate with every strategy that aims to maximize the likelihood of conservation success.

Introduction

Developing global conservation plans for vertebrate species has been a primary focus for conservation scientists in recent years (Brooks *et al.* 2006; Grenyer *et al.* 2006; Hoffmann *et al.* 2010). Mammals are often selected as a model taxon for defining spatial conservation priorities at a global scale (Schipper *et al.* 2008; Rondinini *et al.* 2011b), and recent research efforts have concentrated on defining economically and socially compatible mammal conservation strategies (Carwardine *et al.* 2008). Simultaneously, but independently, biologists have been investigating the predictability of extinction risk from biological traits and phylogeny, mammals again often being the model taxon (Cardillo *et al.* 2005, 2008; Davidson *et al.* 2009; Fritz *et al.* 2009). We combine information on species' current and intrinsic extinction risk to define a new conservation metric, the *Extinction risk Reduction Opportunity* (hereafter: ERO; see details in "Methods"), that detects threatened species with a high biological potential for recovery. This metric builds upon the concept of "latent extinction risk," which identifies species with the greatest potential for future decline, based on the negative discrepancy between current threat status and the extinction risk predicted from biological traits (Cardillo *et al.* 2006). The ERO approach, on the other hand, uses current and intrinsic threat status to identify threatened species with the greatest potential for recovery from an imminent risk of extinction. It focuses on species that are likely to be easiest to save, thereby maximizing the cost efficiency of conservation projects.

Our analyses focus on threatened terrestrial mammals, representing one-fourth of all nonextinct, data-sufficient terrestrial mammal species. We use information reported in the Red List of Threatened Species from the International Union for the Conservation of Nature (IUCN) as a source for species current risk of extinction. We model species' intrinsic extinction risk following an established approach by Cardillo *et al.* (2008; see details in Appendix S1). We use a recently released database of mammals' life history traits (PanTHERIA; Jones *et al.* 2009) as a source for our extinction risk models; we use Multiple Imputation (MI, Rubin 1987; see also Fisher *et al.* 2003) to impute the missing values in the database's fields (see details in Appendix S1). With the use of MI in our extinction risk models, we avoid many of the problems related to the presence of missing data encountered in previous studies (Cardillo *et al.* 2005, 2006, 2008) so that our models are likely to be more stable and robust. We use a recently updated source of mammals' phylogeny (Bininda-Emonds *et al.* 2007) to correct for phylogenetical nonindependence in our models.

We test the performance of our approach in terms of priority species definition and compare it to existing and previously proposed mammal conservation strategies. We evaluate how Critically Endangered (CR) species in the Red List (those having an extremely high risk of extinction; IUCN 2001; IUCN 2010), Alliance for Zero Extinction (AZE) species (those confined within "centers of imminent extinction"; Ricketts *et al.* 2005; AZE 2010) and Evolutionarily Distinct and Globally Endangered (EDGE) species (Collen *et al.* 2011) perform in terms of ERO value. We then use habitat suitability models from the Global Mammal Assessment (GMA) program (Rondinini *et al.* 2011a) to run a global spatial prioritization analysis to define the top 5% of areas for the conservation of the top-ranked ERO species. We compare our results to those found with an analysis oriented toward the detection of top priority areas for an equal number of CR species. We show that existing conservation strategies for mammals are not efficiently addressing species' extinction risk reduction. We finally define taxonomic and spatial priorities for minimizing the risk of extinction in threatened terrestrial mammal species.

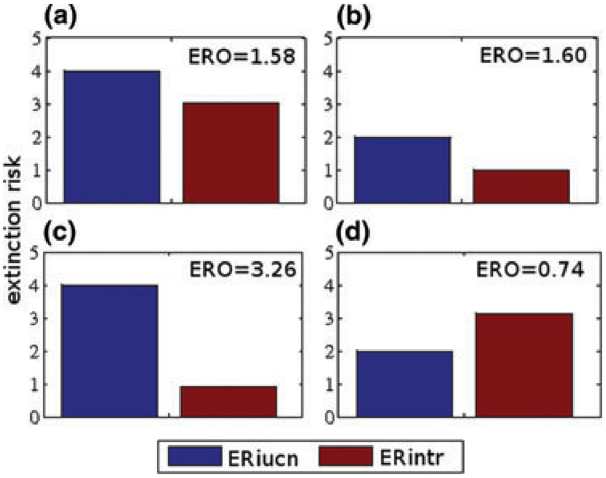

Figure 1 The ERO (Extinction risk Reduction Opportunity) components. The graph shows the current (ER_{IUCN}) and intrinsic (ER_{INTR}) extinction risk of four example species and their associated ERO values (derived from (1) in "Methods"; see Table S2 for a complete species' list). (a) The Aders' Duiker (*Cephalophus adersi*) has both a high ER_{IUCN} and a high ER_{INTR} values, resulting in a medium ERO value. (b) The Clouded Leopard (*Neofelis nebulosa*), has a both a low ER_{IUCN} and a low ER_{INTR} values, resulting in a medium ERO value. (c) The Black-spotted Cuscus (*Spilocuscus rufoniger*) has a high ER_{IUCN} value and a low ER_{INTR} value, resulting a high ERO value. (d) The Andaman Spiny Shrew (*Crocidura hispida*) has a low ER_{IUCN} value and a high ER_{INTR} value, resulting a low ERO value.

Methods

Data sources

Our analysis was focused on threatened species according to IUCN Red List (IUCN 2010), which represent 21.2% of terrestrial nonextinct mammals. As a source for mammal phylogeny, we used a recently updated version (Fritz *et al.* 2009) of the Bininda-Emonds *et al.* (2007)'s supertree. We excluded 163 species from our analysis (14% of the total threatened mammals) due to a lack of phylogenetic information in the updated supertree. We analyzed the freely available PanTHERIA database (Jones *et al.* 2009), recently used to compare global pattern of functional and phylogenetic diversity (Safi *et al.* 2011), to derive the species' biological traits that potentially correlated with extinction risk. We compiled the missing data fields of PanTHERIA using an MI procedure (Rubin 1987) applicable to phylogenetically structured data sets (Fisher *et al.* 2003; Fisher & Blomberg 2011; see details in Appendix S1). We used species' current and (statistically) predicted extinction risk as a currency for assigning a conservation value to each species defining a new conservation metric. The ERO metric accounts for (1) the total possible reduction in species extinction risk, that depends on species' current threat status and (2) the opportunity of having such a reduction, which is related to species' intrinsic risk of extinction. The ERO metric is defined as

$$\mathrm{ERO} = (\mathrm{ER}_{\mathrm{IUCN}} \times (5 - \mathrm{ER}_{\mathrm{INTR}}))/5, \qquad (1)$$

where ER_{IUCN} is the current extinction risk based on the species' IUCN category (IUCN 2010) and ER_{INTR} is the species' intrinsic extinction risk (see example in Figure 1). For each species, ER_{IUCN} was defined by converting the species' IUCN category into a ranked index from 0 to 5 (Purvis *et al.* 2000; Cardillo *et al.* 2005), whereas ER_{INTR} was the fitted value from the extinction risk models (in a 0–5 scale for consistency; see details in Appendix S1). In defining the ERO metric, we assumed that the higher the current extinction risk for a species, the faster we should act to preserve that species, given that the higher the intrinsic extinction risk for a species the smaller is our probability of reducing its current extinction risk. Habitat suitability models from GMA (Rondinini *et al.* 2011a) were finally used as a measure of habitat quality for the species included in the prioritization analysis (see later). The total suitable habitat (in km^2) within each Planning Unit (PU) in the analysis represented the PU absolute value for the species.

Prioritization analysis

We considered a global grid of square PUs with a 10-km resolution and used Zonation (Moilanen *et al.* 2005; Moilanen 2007) for ranking the PUs according to their species content. We have excluded Antarctica from our analysis as only marine mammals live there. For each species, the geographic range and the amount of suitable habitat (from GMA models) within each relevant PU were considered. The Zonation algorithm produces "*a hierarchical prioritization of the conservation value of the landscape*." It assigns each cell to a landscape fraction based on its priority level; the top 10% of selected cells are part of the top 20%, the top 20% of selected cells are part of the top 30%, and so on (Moilanen & Kujala 2008). We assigned a representation target for each species based on their distribution range dimension, following Rodrigues *et al.* (2004). The target was 10% of the distribution range for species with a range dimension bigger than 250,000 km^2 and 100% of the distribution range for species with a range dimension smaller than 1,000 km^2; for all intermediate-range species, we adopted a log-interpolated value between 10% and 100%. We used the ERO values together with the species representation targets to formulate a generalized benefit function (Moilanen & Kujala 2008) and then used it to run a spatial prioritization analysis to find the top 5% terrestrial area for preserving the top-ranked species according to ERO (see Appendix S2 for details on benefit function formulation). We then repeated the analysis on Red List's CR species (IUCN 2001, 2010) assuming an equal initial conservation value among them, in order to verify the spatial difference occurring with the use of the ERO metric versus the classical Red List categories approach in conservation priorities setting. Both analyses were run on the same number of species, calculated as the number of CR species for which an ERO value was available ($n = 139$, $n \approx 75\%$ of terrestrial CR mammal species; IUCN 2010). We overlapped the final priority area maps to species' fine-scale (300 m) distribution maps (Rondinini *et al.* 2011a), in order to check the representation level of the taxa within the selected cells and the performance of the selection algorithm at the analysis's resolution level (10 km). We then investigated the current protection status of the resulting priority areas in relation to the existing protected areas system. We selected protected areas in IUCN categories I–IV from the World Database of Protected Areas (WDPA 2010). All missing-shape sites were included as a buffer area centered in the WDPA point coordinates, having the same area as declared in the database. We also calculated the level of spatial overlap between our priority areas and the Earth's biodiversity hotspots (Mittermeier *et al.* 2005).

Results

Through the imputation of missing data, we statistically approximated the completion of PanTHERIA database (Jones *et al.* 2009); the rate of missing information for parameter estimation (i.e., the variation in results across the imputed data set that reflects the statistical uncertainty due to missing data; Rubin 1987) appeared to be small (i.e., equal or smaller than 1%) in all orders, with only a few exceptions for some of the intercept parameters (see Table S1 for extinction risk models and Table S2 for a complete list of species and associated ERO values). Species prioritized using EDGE, AZE, and CR measures had a significantly smaller ERO value with respect to a corresponding number of top-rank ERO species (Table 1). Even if EDGE metric was not a good predictor of the potential ERO value for threatened mammals, it performed better than a random choice of species in terms of median ERO. On the other hand, the AZE's species selection procedure resulted in an underrepresentation of the potential ERO value for mammals when compared to randomly selected species sets (Table 1). Unsurprisingly, the use of ERO instead of latent extinction risk (Cardillo *et al.* 2006) gave very different results in term of threatened species ranking (we considered the absolute difference among the percentage ranks of each species according to the two metrics); within threatened species, there was an average difference of 49.57% (se = 0.92%) in the ranking of species according to the two metrics. The average change in rank for a species when using ERO metric instead of Red List categories was 24.70% (se = 0.71%).

Mammals' CR species have on average a higher intrinsic extinction risk than Endangered species (EN; IUCN 2001), and EN species have a higher intrinsic extinction risk than Vulnerable species (VU; IUCN 2001); there is, however, large overlap among the categories (Figure 2). This was reflected in an almost complete overlap of the ERO probability density function for EN and CR species, which also had a similar median value (Wilcoxon rank sum test, $P = 0.67$). Conversely, VU species had a

Table 1 Comparison of the ERO values of priority species detected according to existing conservation schemes

	IUCN CR	AZE	EDGE	IUCN threatened
Species pool median(95% range)	1.79(0.77–3.10)	1.63(0.53–2.62)	1.91(1.02–2.88)	1.60(0.93–2.68)
Top ERO ranked median(95% range)	2.35(2.09–3.11)	2.41(2.12–3.11)	2.57(2.32–3.15)	[b]
WRS test	$P << 0.01$	$P << 0.01$	$P << 0.01$	[b]
Random test	[a]	0%	97.88%	[b]
Species sets difference	65.24%	87.4%	75%	[b]
n[c]	139	126	80	964

Comparison of ERO values among top ERO ranked species and species detected using other conservation metrics (species pool), using the same species sample dimension (*n*). Species pools came from: CR species (IUCN CR; IUCN 2010), AZE species (AZE 2010), and top ranked EDGE species (Collen *et al.* 2011) (see text for details). IUCN threatened species were included as a general reference.

WRS test = Wilcoxon rank sum test for significance of difference in ERO values among top ERO ranked species and selected species pool; Random test = percentage of cases (out of 10,000 comparisons) where median ERO values of selected species pool resulted bigger than that of an equally sized random species sample (stratified by Red List categories composition of species pool); Species sets difference = percentage of taxa in the species pool not included in the corresponding top ERO ranked species set.

[a] Species pool exactly corresponds to an equally sized stratified sample.

[b] Species pool coincides with top ERO ranked species sample.

[c] Species without a defined ERO value (due to a lack of phylogenetic information) have been excluded from this analysis (see "Methods" and Appendix S1 for details).

significantly smaller median value (Wilcoxon rank sum test, $P << 0.01$ for CR vs. VU and EN vs. VU). Due to their high intrinsic extinction risk value, CR species show the biggest overall loss in conservation value when using the ERO metric instead of IUCN category (Figure 2c) and this also influenced our prioritization analysis.

An average 59.8% (sd = 36.9%) of the species' range was included within the priority area for top-ranked ERO species, and 40 of 139 species (28.8%) were underrepresented with respect to their target (mean proportion of covered representation target = 45.6%, sd = 36.5%). Only 2 of 139 top-rank ERO species (1.4%) were

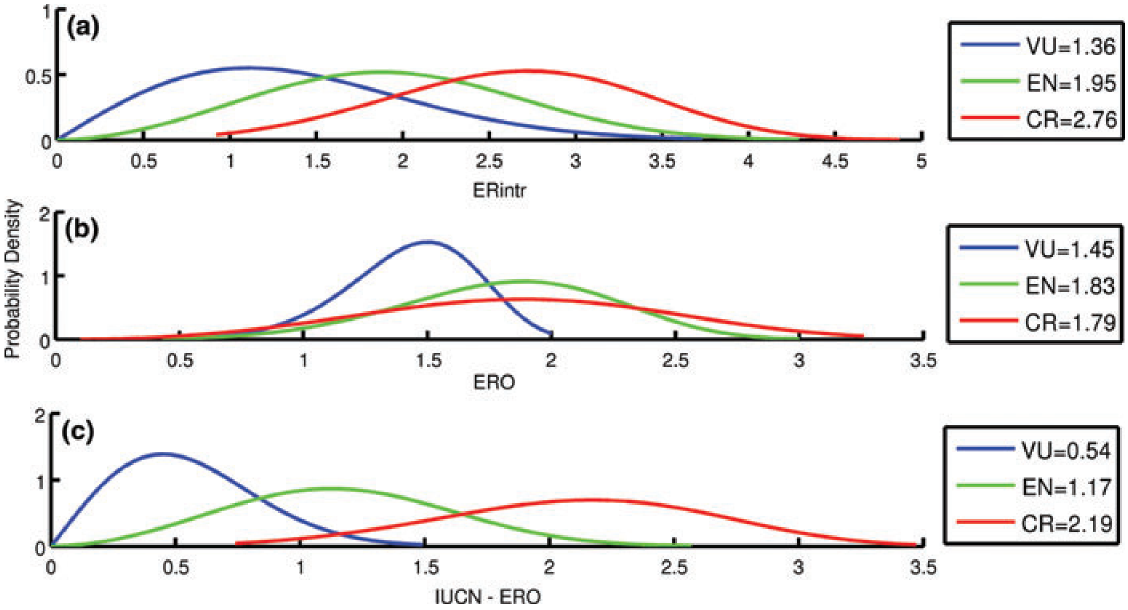

Figure 2 Approximated probability density functions for extinction risk descriptors. Weibull distributions were fitted to the data, data are sorted by Red List categories (IUCN 2001). (a) ERintr = intrinsic Extinction Risk; (b) ERO = Extinction risk Reduction Opportunity; (c) IUCN – ERO = "IUCN minus ERO," representing the difference in species value when adopting the ERO metric instead of Red List categories. In each graph, the median value of the metric for each Red List category is reported in the legend.

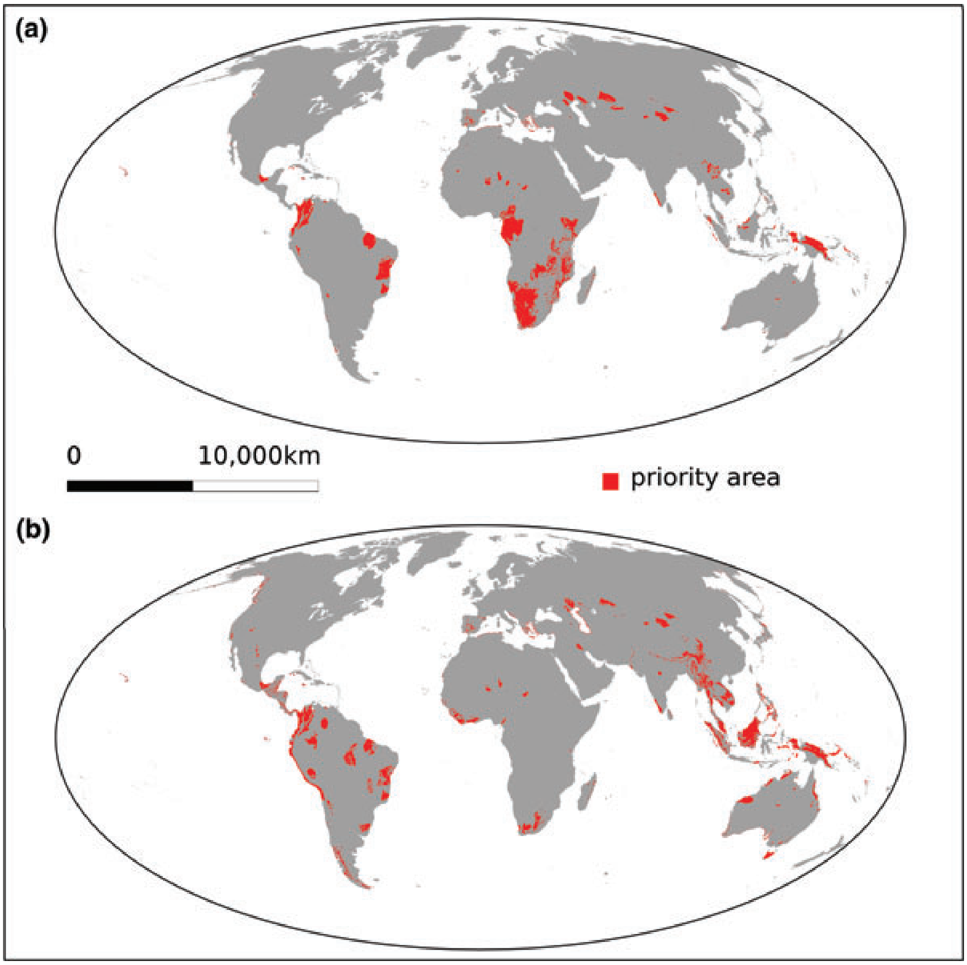

Figure 3 Top priority areas detected for conserving threatened species. Priority areas include the highest ranked 5% of cells. (a) Priority areas for CR species (IUCN 2010); (b) priority areas for top-rank ERO species. Scale-bar and colors are the same in both maps, cell size is 100 km^2 (Antarctica was excluded from analysis).

excluded from the top 5% ERO priority area (both them were part of the top 10% area). The priority area selected for CR species conservation, included on average a bigger portion of CR species range (mean proportion of included range was 87.4%, sd = 20.9%) and 51 of 139 CR species (36.7%) were underrepresented with respect to their target (mean proportion of covered target = 74.8%, sd = 23.2%). We discovered that our approach, focusing on opportunity rather than likely loss, significantly alters spatial conservation priorities for mammals. Priority areas detected according to CR species distribution overlaps only partially with ERO priority sites (Figure 3; see also example in Figure S1 for a detailed interpretation), with 61.85% of the area being selected only under one or the other criterion. Only 7.04% of the ERO priority areas fall into the current protected area network (WDPA 2010), even though half of them (48.02%) have already been included into the earth's biodiversity hotspots (Mittermeier *et al.* 2005).

Discussion

ERO and latent extinction risk (Cardillo *et al.* 2006) describe different (almost opposite) aspects of species' extinction risk. Although latent risk identifies species with a potentially high future risk of decline despite being currently nonthreatened (a proactive approach that aims to anticipate future species declines), ERO identifies species that are facing an imminent risk of decline and have the biological potential for recovery (a reactive approach to potentially solvable problems). Detecting species with a high ERO value thus allows conservation planners to optimize the short-term efforts for minimizing species declines. Our results suggest that more conservation emphasis should be placed on areas that are important for extinction risk reduction, especially (but not exclusively) in South America and Southeast Asia, where the biggest proportion of top-ranked ERO species is found (Figures 3 and S1). Currently, these areas are largely unprotected, and only partially included in biodiversity hotspots; this is undesirable, considering the limited expenditure in biodiversity conservation and the rate of ongoing biodiversity loss (Butchart *et al.* 2010).

Species with a high extinction risk deserve immediate conservation attention, but not all threatened species have the same intrinsic extinction risk value, hence the same opportunity of being recovered (Table S2). For example, both Saiga Antelope (*Saiga tatarica*) and Javan Rhinoceros (*Rhinoceros sondaicus*) are CR species in the Red List (IUCN 2010); by calculating an intrinsic extinction risk of 1.12 for the former and 4.34 for the latter, the ERO approach suggests that investing in conservation of Saiga (ERO = 3.1) will provide a greater contribution to reducing overall mammal extinction risk compared to Javan Rhinoceros (ERO = 0.53). We did not account for information on conservation investment for threatened species, which is a factor affecting species recovery (i.e., spending more conservation money on Javan Rhinoceros might increase its chances of recovery, despite its low ERO value). The ERO metric does not preclude the possibility of greater investment in lower ranked species; it simply provides a way of ranking threatened species while accounting for their recovery potential.

We recognize that there may be considerable uncertainty involved in ranking one species over another for three main reasons: (1) species considered to have an equal threat status (i.e., the same Red List category) do not necessarily have the same current probability of extinction; (2) some species are Data-Deficient and cannot be assigned to a threat status category; and (3) extinction risk models vary in their predictive power among clades. None of these points affect the overall advantages of the ERO framework if compared to previous approaches; shifts in species ranking are possible in response to both future conservation status changes and updated life history information.

It has been stressed in the past that spending money on the most threatened species is not an efficient way of allocating limited conservation funds (Possingham *et al.* 2002). Our results support this idea, showing that CR species have on average a higher intrinsic extinction risk than EN or VU species. In this study, we have used ERO to rank threatened species under the IUCN Red List, but the basic principle of prioritizing the most easily recoverable threatened species could be extended beyond this by combining ERO with other prioritization schemes. For example, AZE (Ricketts *et al.* 2005) focuses on species restricted to small and isolated sites (and generally having a small ERO value). ERO values could provide a way of ranking AZE species by accounting for their recovery potential. Other recent approaches to conservation prioritization incorporate phylogenetic information in the definition of species conservation value (Redding & Mooers 2006; Isaac *et al.* 2007; Collen *et al.* 2011), yet without detecting the most biologically profitable opportunities for conservation. Incorporating ERO into metrics such as EDGE (Isaac *et al.* 2007; Collen *et al.* 2011) could allow fine tuning of phylogenetically based conservation priorities. Moreover, using ERO will provide recommendation that are clearly interpretable in conservation terms, as desirable in order to augment the relevance of comparative studies of extinction risk to conservation practice (Cardillo & Meijaard 2012).

In our analyses, we explored a portion of the extinction risk reduction problem with a new emphasis on recovery opportunity, but we did not consider all the factors affecting species recovery. In particular, we did not account for specific conservation actions in our prioritization analysis (Wilson *et al.* 2011), and we did not consider conservation costs related to the actions (i.e., what is the cost of preserving one or more viable Saiga populations in the next *n* years?). We do not claim that our metric will provide the final solution to the global conservation prioritization problem, yet it will add a necessary (and currently disregarded) piece of information. Economic and social factors must be considered when defining a conservation strategy and we believe that ERO would be a valid component of a comprehensive prioritization framework that takes these factors into account, as suitable data become available.

Future risk projections for species (Visconti *et al.* 2011) could also be integrated into the analyses, in order to take into account species' potential for recovery under different extinction risk scenarios, or to account for predicted changes in the primary threatening processes (e.g., climate change). Even though different conservation metrics are designed to address different conservation objectives, ERO has the potential to integrate with every metric that aims to maximize the likelihood of conservation success. Several conservation programs such as the IUCN's "Save Our Species" program (www.sospecies.org) and the "Mohamed bin Zayed" species conservation fund (www.mbzspeciesconservation.org), orient their call to the conservation of a particular group of species or areas; these programs may benefit of a metric such as ERO to evaluate the expected efficacy of several proposed research projects in terms of potential extinction risk reduction. Moreover, conservation agencies such as IUCN, Wildlife Conservation Society (www.wcs.org), and Conservation International (www.conservation.org) may explicitly include status recovery as a requirement for the definition of a global conservation strategy. Future research should focus on the definition of a combined (and comprehensive) species' conservation metric that accounts for ERO value. Defining a combined metric could directly affect the adoption of a joint conservation strategy that could in turn raise the chance of having a more cooperative effort among several existing conservation agencies.

Acknowledgments

We are grateful to M. Cabeza, R.J. Smith, S.N. Stuart, the editor and 3 anonymous reviewers for their comments on a previous version of the manuscript; B. Collen for providing data; D.B. Segan for providing useful tips on the prioritization analysis. We thank A. Tschirley for providing a text revision in an earlier version of the manuscript; D. Baisero, F. Chiozza, and P. Visconti for several stimulating discussions.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1: Statistical Modeling and Multiple Imputation

Appendix S2: Formulation of the generalized benefit function used for the prioritization analysis

Table S1: Minimum adequate models of intrinsic extinction risk for terrestrial mammal orders

Table S2: List of terrestrial mammal species used for analysis and their extinction risk values (as defined in the text)

Figure S1: Difference in priority area definition in southeast Asia and northern Australia, according to (a) IUCN's critically endangered (CR) species distribution or (b) top-ranked ERO species distribution.

References

Alliance for Zero Extinction. (2010) AZE 2010 update. Available from: http://www.zeroextinction.org. Accessed 1 May 2011.

Bininda-Emonds, O.R.P., Cardillo M., Jones K.E. *et al.* (2007) The delayed rise of present-day mammals. *Nature* **446,** 507–512.

Brooks, T., Mittermeier R., da Fonseca G.A.B. *et al.* (2006) Global biodiversity conservation priorities. *Science* **313,** 58–61.

Butchart, S.H.M., Walpole M., Collen B. *et al.* (2010) Global biodiversity: indicators of recent declines. *Science* **328,** 1164–1168.

Cardillo, M., Mace G.M., Gittleman J.L., Jones K.E., Bielby J., Purvis A. (2008) The predictability of extinction: biological and external correlates of decline in mammals. *Proc R Soc B* **275,** 1441–1448.

Cardillo, M., Mace G.M., Gittleman J.L., Purvis A. (2006) Latent extinction risk and the future battlegrounds of mammal conservation. *Proc Natl Acad Sci USA* **103,** 4157–4161.

Cardillo, M., Mace G.M., Jones K.E. *et al.* (2005) Multiple causes of high extinction risk in large mammal species. *Science* **309,** 1239–1241.

Cardillo, M., Meijaard E. (2012) Are comparative studies of extinction risk useful for conservation? *Trends Ecol Evol*, doi:10.1016/j.tree.2011.09.013.

Carwardine, J., Wilson K.A., Ceballos G. *et al.* (2008) Cost-effective priorities for global mammal conservation. *Proc Natl Acad Sci USA* **105,** 11446–11450.

Collen, B., Turvey S.T., Waterman C. *et al.* (2011) Investing in evolutionary history: implementing a phylogenetic approach for mammal conservation. *Philos T R Soc B* **366,** 2611–2622.

Davidson, A.D., Hamilton M.J., Boyer A.G., Brown J.H., Ceballos G. (2009) Multiple ecological pathways to extinction in mammals. *Proc Natl Acad Sci USA* **106,** 10702–10705.

Fisher, D.O., Blomberg S.P. (2011) Correlates of rediscovery and the detectability of extinction in mammals. *Proc R Soc B* **278,** 1090–1097.

Fisher, D.O., Blomberg, S.P., Owens I.P.F. (2003) Extrinsic versus intrinsic factors in the decline and extinction of Australian marsupials. *Proc R Soc B* **270,** 1801–1808.

Fritz, S.A., Bininda-Emonds O.R.P., Purvis A. (2009) Geographical variation in predictors of mammalian extinction risk: big is bad, but only in the tropics. *Ecol Lett* **12,** 538–549.

Grenyer, R., Orme C.D.L., Jackson S.F. *et al.* (2006) Global distribution and conservation of rare and threatened vertebrates. *Nature* **444,** 93–96.

Hoffmann, M., Hilton-Taylor C., Angulo A. *et al.* (2010) The impact of conservation on the status of the world's vertebrates. *Science* **330,** 1503–1509.

Isaac, N.J.B., Turvey S.T., Collen B., Waterman C., Baillie J.E.M. (2007) Mammals on the EDGE: conservation priorities based on threat and phylogeny. *PLoS One* **2,** e296.

IUCN. (2010) IUCN Red List of Threatened Species. Version 2010.3. Available from: www.iucnredlist.org. Accessed 01 May 2011.

IUCN Species Survival Commission. (2001) *IUCN red list categories and criteria, version 3.1*. IUCN Gland, Switzerland and Cambridge, UK.

Jones, K.E., Bielby J., Cardillo M. *et al*. (2009) PanTHERIA: a species-level database of life history, ecology, and geography of extant and recently extinct mammals. *Ecology* **90,** 2648.

Mittermeier, R.A., Gil P.R., Hoffman M. *et al*. (2005) *Hotspots revisited: earth's biologically richest and most endangered terrestrial ecoregions*. CEMEX. University of Chicago Press, USA.

Moilanen, A. (2007) Landscape zonation, benefit functions and target-based planning: unifying reserve selection strategies. *Biol Conserv* **134,** 571–579.

Moilanen, A., Franco A.M.A., Early R.I., Fox R., Wintle B., Thomas C.D. (2005) Prioritizing multiple-use landscapes for conservation: methods for large multi-species planning problems. *Proc R Soc B* **272,** 1885–1891.

Moilanen, A., Kujala H. (2008) Zonation: spatial conservation planning framework and software version 2.0. Available from: http://www.ncbi.nlm.nih.gov. Accessed 01 May 2011.

Possingham, H.P., Andelman S.J., Burgman M.A., Medellìn R.A., Master L.A., Keith D.A. (2002) Limits to the use of threatened species lists. *Trends Ecol Evol* **17,** 503–507.

Purvis, A., Gittleman J.L., Cowlishaw G., Mace G.M. (2000) Predicting extinction risk in declining species. *Proc R Soc B* **267,** 1947–1952.

Redding, D.W., Mooers A.Ø. (2006) Incorporating evolutionary measures into conservation prioritization. *Conserv Biol* **20,** 1670–1678.

Ricketts, T.H., Dinerstein E., Boucher T. *et al*. (2005) Pinpointing and preventing imminent extinctions. *Proc Natl Acad Sci USA* **102,** 18497–18501.

Rodrigues, A.S.L., Akçakaya H.R., Andelman S.J. *et al*. (2004) Global gap analysis: priority regions for expanding the global protected-area network. *Bioscience* **54,** 1092–1100.

Rondinini, C., Di Marco M., Chiozza F. *et al*. (2011a) Global habitat suitability models of terrestrial mammals. *Philos T R Soc B* **366,** 2633–2641.

Rondinini, C., Rodrigues A.S.L., Boitani L. (2011b) The key elements of a comprehensive global mammal conservation strategy. *Philos T R Soc B* **366,** 2591–2597.

Rubin, D.B. (1987) *Multiple imputation for nonresponse in surveys*. Wiley Online Library. Wiley, New York USA.

Safi, K., Cianciaruso M.V., Loyola R. D., Brito D., Armour-Marshall K., Diniz-Filho J.A.F. (2011) Understanding global patterns of mammalian functional and phylogenetic diversity. *Philos T R Soc B* **366,** 2536–2544.

Schipper, J., Chanson J.S., Chiozza F. *et al*. (2008) The status of the world's land and marine mammals: diversity, threat, and knowledge. *Science* **322,** 225–230.

Visconti, P., Pressey R.L., Giorgini D. *et al*. (2011) Future hotspots of terrestrial mammal loss. *Philos T R Soc B* **366,** 2693–2702.

WDPA Consortium. (2010) *World database on protected areas*. IUCN and UNEP-WCMC, Cambridge, UK.

Wilson, K.A., Evans M.C., Di Marco M. *et al*. (2011) Prioritizing conservation investments for mammal species globally. *Philos T R Soc B* **366,** 2670–2680.