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The SAFE index: using a threshold population target to measure relative species threat

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The International Union for Conservation of Nature (IUCN) Red List is arguably the most popular measure of relative species threat, but its threat categories can be ambiguous (eg "Endangered" versus "Vulnerable") and subjective, have weak quantification, and do not convey the threat status of species in relation to a minimum viable population target. We propose a heuristic measure that describes a "species' ability to forestall extinction", or the SAFE index. We compared the abilities of the SAFE index with those of another numerically explicit metric – percentage range loss – to predict IUCN threat categories using binary and ordinal logistic regression. Generalized linear models showed that the SAFE index was a better predictor of IUCN threat categories than was percentage range loss. We therefore advocate use of the SAFE index, possibly in conjunction with IUCN threat categories, because the former indicates the "distance from extinction" of a species, while implicitly incorporating population viability as a variable.

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Conservation biologists have long studied the processes underlying species' extinctions and have sought to devise ways to prevent or mitigate extinctions resulting from human impacts. Recent debates over the likely magnitude of the current extinction crisis have largely focused on the proportion of all species that could disappear during this century (eg Brook *et al.* 2006; Laurance 2007; Bradshaw *et al.* 2009). However, species' extinctions due to anthropogenic factors are just the endpoint conservationists wish to avoid. Today, many species are declining across large swathes of their former geographic ranges, and some species' populations are becoming so seriously diminished in numbers that they are less likely to withstand random catastrophes (Ewens *et al.* 1987) or maintain their original functional roles in ecosystems (Larsen *et al.* 2005) and their evolutionary potential (Franklin and Frankham 1998).

In a nutshell:

- We developed the "species' ability to forestall extinction" (SAFE) index, which incorporates a benchmark population target for long-term species persistence
- This index better predicts the widely used IUCN Red List threat categories than do previous measures such as percentage range loss
- A combined approach – IUCN threat categories together with the SAFE index – is more informative than the IUCN categories alone and provides a good proxy for gauging the relative "safety" of a species from extinction

Earlier terms describing the imperiled status of species that had undergone major declines include the *living dead* (Janzen 1986) and *extinction debt* (Tilman *et al.* 1994), both of which embody the notion of short-term persistence but a long-term consignment to extinction. *Local extinction* or *extirpation* describes the loss of local populations (eg Laurance 1991; Pimm and Askins 1995), but typically has a narrow frame of reference, such as a particular island or habitat fragment. The concept of *ecological extinction* was coined in reference to the reduction of a species to such low abundance that it "no longer interacts significantly with other species" (Estes *et al.* 1989), but determining the critical threshold-abundance values for specific species can be impractical.

The most widely used barometer of a species' threatened status is the International Union for Conservation of Nature (UCN) Red List (www.iucnredlist.org), which classifies species at high risk of global extinction through an explicit, objective, and semi-quantitative framework (IUCN 2010). However, IUCN threat categories such as "Endangered" and "Vulnerable" might not be easily differentiated by the general public, conservation donors, and policy makers without an associated numerical indicator. Furthermore, the IUCN threat categories do not reflect the distance of an extant population of a given species from an arbitrary but risk-averse minimum viable population (MVP) size required for long-term persistence and evolutionary potential (Traill *et al.* 2010).

Some claim that population extinctions (extirpations) are more useful proxies of diminishing biological capital

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than are species extinctions (Ceballos and Ehrlich 2002), especially when it can take a long time for threatened species to be recognized as officially extinct (ie failure to detect the species despite years of searching; McInerny *et al.* 2006). Here, we advocate the use of a more heuristic measure of relative threat that describes a "species' ability to forestall extinction", or the SAFE index:

$$\text{SAFE index} = \log_{10}(N) - \log_{10}(\text{MVP}_t) \qquad \text{(Eq 1)}$$

where N is the species' population estimate throughout the species' known range (ie all populations combined) and MVP_t is an empirically supported threshold MVP target, which is currently set at 5000 individuals according to median demographic and genetic estimates of MPV-size requirements among widely different taxonomic groups (Brook *et al.* 2006; Traill *et al.* 2007, 2010). On precautionary grounds, we suggest using the lower confidence-limit estimates of N and the upper confidence-limit for MVP size, where such estimates exist for the species of interest and are considered statistically robust (Traill *et al.* 2010).

One might argue that a numerically explicit measure of biodiversity loss already exists in the form of percentage range loss, an index used by Ceballos and Ehrlich (2002) to compare historical and present distributions of 173 declining mammal species across six continents. We therefore investigated whether our SAFE index can better predict relative species threat (according to the IUCN Red List) than does percentage range loss.

Table 1. Generalized linear model (GLM) and generalized linear mixed-effect model (GLMM) sets used to examine the relationship between the probability (Pr) of a species being threatened for 95 mammal species and predictors

Model	*k*	*–LL*	*ΔAIC$_c$*	*wAIC$_c$*	*%DE*
GLM					
Pr(*threat*) ~ *SAFE index*	2	–22.89	0.00	1.00	59.0
Pr(*threat*) ~ *% range loss*	2	–46.37	46.96	0.00	16.8
Pr(*threat*) ~ *1*	1	–55.75	63.65	0.00	0.00
GLMM					
Pr(*threat*) ~ *SAFE index* + (1/*ORDER*)	3	–22.89	0.00	1.00	56.4
Pr(threat) ~ % range loss + (1/*ORDER*)	3	–45.94	46.11	0.00	12.4
Pr(*threat*) ~ *1* + (1/*ORDER*)	2	–52.46	57.02	0.00	0.00

Notes: Only single-term models were considered to test the relative ability of the SAFE index versus percentage range loss in predicting extinction threat (threat). The analytical theme represented by each model (SAFE index, % range loss, the intercept-only model, and mammalian order (ORDER) *as a* random effect), and the information-theoretic ranking of models investigating the predictors of mammal IUCN threat categories according to Akaike's information criterion corrected for small sample size (AIC$_c$) are shown. *k* = number of parameters, *–LL* = maximum log-likelihood, ΔAIC$_c$ = difference in AIC$_c$ for each model from the most parsimonious model, wAIC$_c$ = AIC$_c$ weight, and %DE = percent deviance explained in the response variable by the model under consideration. Two data points were removed for the GLMM because there was only one representative species in its respective mammalian order: riverine rabbit (*Bunolagus monticularis*) and Asian elephant (*Elephas maximus*).

We constructed binary and ordinal logistic regressions to determine which of the two metrics, the SAFE index or percentage range loss, better predicts the IUCN threat categories of mammal species for which extant population sizes were available (95 of 173 species from Ceballos and Ehrlich 2002) on the Red List website (IUCN 2010). We extracted percentage-range-loss data (current range area/original range area) from Ceballos and Ehrlich (2002). Our binary responses consisted of "threatened" and "near/not threatened" after pooling four ("Extinct", "Critically Endangered", "Endangered", and "Vulnerable") and two ("Near Threatened" and "Least Concern") IUCN threat categories, respectively. Our ordinal responses consisted of six IUCN threat categories, ranked according to their indicative risk levels (ie "Extinct" to "Least Concern"). In the binary logistic regression, we fitted generalized linear models (GLMs) using the R package 2.10.1 (R Development Core Team 2010), assigning to candidate models (Table 1) a binomial distribution and logit link function. To control for phylogenetic relatedness, we also fitted generalized linear mixed-effect models (GLMMs) to the data using mammalian order (ORDER; Table 1) as a random effect (Bradshaw and Brook 2010). For the ordinal logistic regression analysis, we used the *polr* function (implemented in the MASS library of the R package), which fits a proportional-odds logistic regression model to an ordinal factor response. We calculated the relative likelihoods and weights of models using Akaike's information criterion (AIC) corrected for small sample sizes (Burnham and Anderson 2002). We compared relative statistical evidence among models using the information–theoretic evidence ratio (ER), which is the AIC$_c$ weight of one model divided by another. The ER is a concept akin to Bayesian odds ratios (McCarthy 2007) and is preferable to a classic null-hypothesis significance test because the likelihood of the alternative model is explicitly evaluated (Bradshaw and Brook 2010). For each model, we also calculated the percentage deviance explained (%DE) as a measure of goodness-of-fit, and compared each model's %DE to determine the proportion of variance in the response that was attributable to each predictor.

We provide SAFE indices for 95 mammal species in WebTable 1. Using an MVP target of 5000 individuals on a logarithmic scale (Traill *et al.* 2010), we calculate that an extinct species would have a SAFE index of –3.7 (ie assuming "extinction" equates to $N = 1$ because $\log_{10}[0]$ is unresolvable; Figure 1). Such a non-linear scale is particularly beneficial for the management of species with low population sizes, because slight population fluctuations will result in acute changes in SAFE indices that can help trigger urgent conservation interventions. Negative SAFE indices indicate that a species is below the threshold MVP target of 5000 individuals (eg if $N = 4000$, then SAFE index = –0.1), whereas positive SAFE indices indicate the species is above that threshold (eg if $N = 6000$, then SAFE index = 0.08).

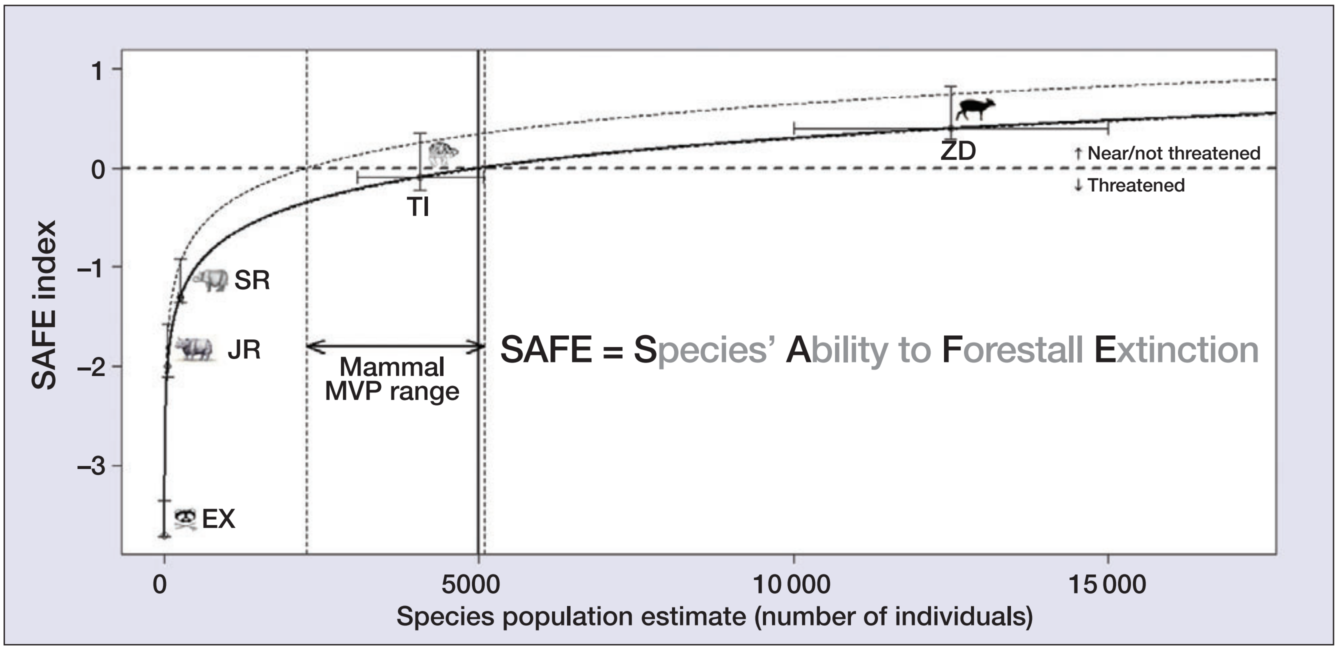


Figure 1. *Plots of SAFE indices against species population estimates with: (1) an empirically supported threshold minimum viable population (MVP) target (solid line and curve; 5000 individuals according to Traill* et al. *2010); and (2) lower and upper 95% confidence limits of mammal-specific MVP thresholds (dashed lines and curves; 2261 and 5095 individuals, respectively, according to Traill* et al. *2007). An extinct species (EX), the Javan rhinoceros (JR;* Rhinoceros sondaicus*), Sumatran rhinoceros (SR;* Dicerorhinus sumatrensis*), tiger (TI;* Panthera tigris*), and zebra duiker (ZD;* Cephalophus zebra*) are highlighted (with vertical and horizontal confidence intervals) to illustrate their decreasing relative threat and increasing potential for long-term persistence (from left to right).*

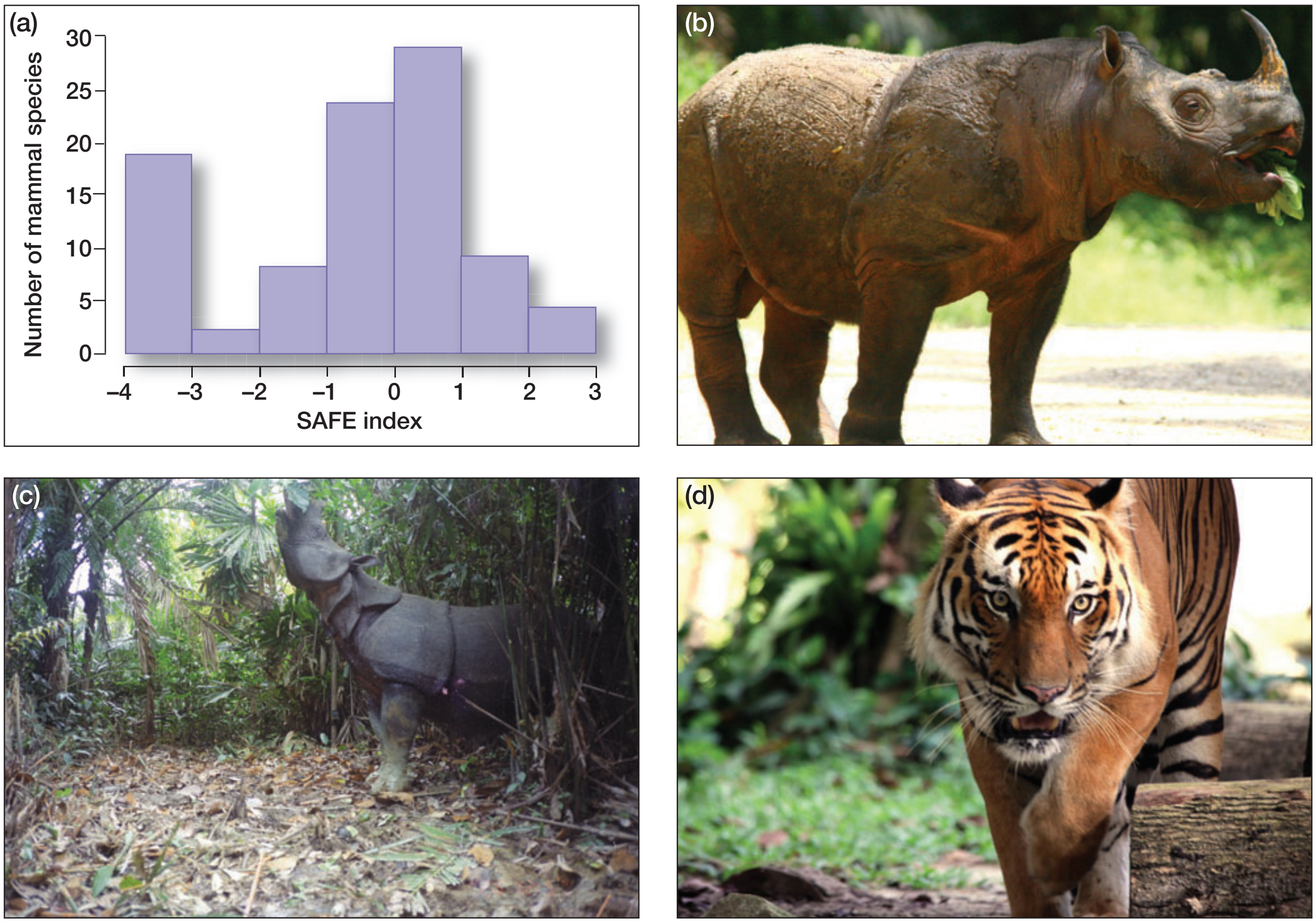
If taxon-specific SAFE indices incorporating population and MVP-size uncertainties are desired, then species abundance estimates (*N*) can be substituted with lower and upper confidence-limit estimates (eg 1996 and 2447 for Grevy's zebra [*Equus grevyi*], respectively; WebTable 1), whereas the generalized threshold MVP target (MVP_t) of 5000 individuals can also be replaced by the lower and upper 95% confidence limits of taxon-specific MVP thresholds (eg 2261 and 5095 for mammals, respectively; Traill *et al.* 2007). To incorporate these differences, we provide three additional variants of the SAFE index, to represent a greater range of uncertainty (WebTable 1); as before, we fitted both GLMs and GLMMs to these indices, to determine their relative capacity to predict Red List threat categories for mammals.

Binary logistic regression revealed that our SAFE index is a better predictor of mammal IUCN threat categories than is percentage range loss (ie the former had higher model weights and described ~59% of the deviance, as compared with only ~17% for the latter; Table 1). Despite including *ORDER* as a random effect, GLMM results were similar: model weights were identical and the %DE shifted only slightly (Table 1). The model with our SAFE index also had far higher bias-corrected support relative to the model, with only percentage range loss (ER = 1.58×10^{10} times providing as much support). Similarly, ordinal logistic regression showed that the SAFE index was a better predictor of relative species threat than percentage range loss; the former had a higher model weight (0.97 versus 0.03) and explained a higher percentage of deviance in the probability of being threatened (6% versus 4%; %DE values here are lower than those in the binomial models because the variance is spread over more IUCN threat categories in the ordinal regression). GLMs and GLMMs showed that the three uncertainty variants of the SAFE index were still far better predictors of mammal threat status than was percentage range loss, but still did not outperform (in terms of %DE) the original SAFE index based on an MVP value of 5000 individuals (WebTable 2).

Conclusions

The SAFE index is attractive for at least three reasons. First, it has a far superior ability to predict IUCN threat categories, as compared with the percentage range loss of a species (Table 1). Second, it does not rely on the difficult-to-obtain demographic data needed to construct detailed population viability analyses necessary for predicting extinction risk. Finally, it leverages some recent meta-analyses on the MVP size estimates for well-studied groups (Traill *et al.* 2007).

On the basis of numeric, meta-analytic, and genetic evidence, MVP estimates (standardized to a time scale of 40 generations and 99% persistence probability) show marked consistency among taxa whose populations range around 5000 adult individuals (Traill *et al.* 2007, 2010). Whether practitioners choose this standard MVP value and a simple median population-size estimate for target species, or instead elect to use more conservative values,



WWF-Malaysia/SK Lee

PHKA/WWF-Indonesia/N Foead

Malaysian Conservation Alliance for Tigers/L A Shepherd

Figure 2. *(a) Histogram of SAFE indices across the 95 mammal species in our analysis, indicating ~21% close to extinction (ie SAFE indices < –2) and ~ 58% at "tipping points" (ie SAFE indices between 1 and –1). Practitioners of conservation triage may want to prioritize resources on (b) the Sumatran rhinoceros (*Dicerorhinus sumatrensis*) instead of (c) the Javan rhinoceros (*Rhinoceros sondaicus*) (–1.36 versus –2.10, respectively). Alternatively, donors with limited resources may want to channel their conservation efforts toward (d) the tiger (*Panthera tigris*), a species at the "tipping point", with a SAFE index of –0.21.*

will be dictated by their acceptance of the inherent uncertainties. Regardless, the SAFE index provides a more meaningful and fine-grained interpretation of the relative threat of species extinction than do the IUCN threat categories alone. The IUCN has yet to base its threat categories on predictions from population viability analyses because of inadequate data or models for most listed species (Traill *et al.* 2010).

We believe that the SAFE index could serve as a quantitative measure of relative threat status that can be more readily understood by the general public, donors, and policy makers, who may not appreciate the need to consider population viability in conservation and who do not understand the IUCN categorical classifications. For example, the Asian elephant (*Elephas maximus*) has a SAFE index of 0.92 (*N* = 41 410), whereas the index for tigers (*Panthera tigris*) is –0.21 (*N* = 3062). Although both species are classified as "Endangered" according to IUCN (2010), the latter arguably warrants more urgent conservation attention (see Clements *et al.* 2010). However, this does not necessarily mean we should reduce efforts to protect endangered species with positive SAFE indices, such as the Asian elephant, because other threats such as population fragmentation and poaching may be higher for certain species.

More than half (58%) of all mammal species in our analyses appear to be at vulnerability thresholds, or "tipping points", with SAFE indices between 1 and –1 (Figure 2). Donors with limited resources might wish to focus on such species; the tiger, for instance, has a SAFE index of –0.21 (Figures 1 and 2). Roughly one-quarter of the species in our analysis are very close to extinction, with SAFE indices below –2 (Figure 2). Under such desperate circumstances, those considering conservation triage (Walker 1992) might elect to channel resources toward species such as the Sumatran rhinoceros (*Dicerorhinus sumatrensis*) rather than the precarious Javan rhinoceros (*Rhinoceros sondaicus*); these species have SAFE indices of –1.36 and –2.10, respectively (Figures 1 and 2).

When communicating the danger of extinction, the threat status of an imperiled species becomes much more apparent through the use of the SAFE index in conjunction with IUCN Red List categories. For this reason, we advocate including the SAFE index in future Red List classifications. However, the use of a standard MVP target for all species will always be controversial and such general principles have their limitations when population context (eg connectivity, degree of habitat fragmentation, source–sink dynamics, and disease susceptibility) can overwhelm extinction risk arising from stochastic disturbances. Empirically based alternatives to a standard MVP might exist and could work equally well under the same "distance" principle embodied in the SAFE index – our key point is that species should be assigned a continuous and quantifiable index of "distance from extinction".

Ultimately, the SAFE index serves as a scientifically defensible rule of thumb when complete demographic data are unavailable for a species, as is usually the case. As our empirical data show, threatened species with deceptively large populations – including those with thousands of individuals – can still have a high probability of eventually succumbing to global extinction. We should therefore avoid complacency and heed the best evidence available while attempting to avoid the permanent loss of these species.

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WebTable 1. Ninety-five mammal species with their associated lower/upper-bound population estimates (IUCN 2010), IUCN threat categories (LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered; CE = Critically Endangered; EX = Extinct; IUCN 2010), percentage range loss (Ceballos and Ehrlich 2002), and the SAFE index calculated through the general formula: $\log_{10}(N) - \log_{10}(\mathrm{MVP}_t)$, where N = lower-bound population estimate and MVP_t = threshold MVP target currently set at 5000 individuals according to Traill *et al*. (2007). Three other variants of the SAFE index are provided, to represent a range of uncertainty based on the lower and upper 95% confidence limits of mammal-specific MVP thresholds (2261 and 5095, respectively; Traill *et al*. 2007): (1) SAFE (low) = $\log_{10}$(lower population estimate bound) – $\log_{10}$(5095); (2) SAFE (upp) = $\log_{10}$(upper population estimate bound) – $\log_{10}$(2261); and (3) SAFE (med) = median of SAFE (low) and SAFE (upp).

Common name	*Scientific name*	*Lower pop estimate*	*Upper pop estimate*	*IUCN threat category*	*% range loss*	*SAFE*	*SAFE (low)*	*SAFE (upp)*	*SAFE (med)*
Addax	*Addax nasomaculatus*	300	300	CE	94.8	–1.22	–1.23	–0.88	–1.06
African wild ass	*Equus africanus*	70	600	CE	97.5	–1.85	–1.86	–0.58	–1.22
African wild dog	*Lycaon pictus*	3000	5500	EN	84.0	–0.22	–0.23	0.39	0.08
Alice springs mouse	*Pseudomys fieldi*	2000	2000	VU	100.0	–0.40	–0.41	–0.05	–0.23
Alpine ibex	*Capra ibex*	30 000	30 000	LC	77.7	0.78	0.77	1.12	0.95
Asian elephant	*Elephas maximus*	41 410	52 345	EN	80.5	0.92	0.91	1.36	1.14
Baird's tapir	*Tapirus bairdii*	5500	5500	EN	67.9	0.04	0.03	0.39	0.21
Banded hare-wallaby	*Lagostrophus fasciatus*	9700	9700	EN	98.9	0.29	0.28	0.63	0.46
Banteng	*Bos javanicus*	5000	8000	EN	87.1	0.00	–0.01	0.55	0.27
Barbary macaque	*Macaca sylvanus*	15 000	15 000	EN	90.5	0.48	0.47	0.63	0.55
Beira	*Dorcatragus megalotis*	7000	7000	VU	22.9	0.15	0.14	0.49	0.32
Big-eared hopping-mouse	*Notomys macrotis*	0	0	EX	100.0	–3.70	–3.71	–3.35	–3.53
Bilby	*Macrotis lagotis*	10 000	10 000	VU	84.6	0.30	0.29	0.65	0.47
Bison	*Bison bison*	15 000	30 000	NT	99.1	0.48	0.47	1.12	0.80
Blackbuck	*Antilope cervicapra*	50 000	50 000	NT	61.9	1.00	0.99	1.34	1.17
Blue buck	*Hippotragus leucophaeus*	0	0	EX	100.0	–3.70	–3.71	–3.35	–3.53
Bongo	*Tragelaphus eurycerus*	28 000	28 000	NT	34.9	0.75	0.74	1.09	0.92
Bridled nailtail wallaby	*Onychogalea fraenata*	1100	1100	EN	98.7	–0.66	–0.67	–0.31	–0.49
Broad-faced potoroo	*Potorous platyops*	0	0	EX	100.0	–3.70	–3.71	–3.35	–3.53
Brown bear	*Ursus arctos*	200 000	200 000	LC	85.3	1.60	1.59	1.95	1.77
Brown hyaena	*Hyaena brunnea*	5000	8000	NT	55.2	0.00	–0.01	0.55	0.27
Central hare-wallaby	*Lagorchestes asomatus*	0	0	EX	100.0	–3.70	–3.71	–3.35	–3.53
Cheetah	*Acinonyx jubatus*	7500	7500	VU	59.6	0.18	0.17	0.52	0.35
Common hippopotamus	*Hippopotamus amphibius*	125 000	148 000	VU	82.8	1.40	1.39	1.82	1.61
Crescent nailtail wallaby	*Onychogalea lunata*	0	0	EX	100.0	–3.70	–3.71	–3.35	–3.53
Cuvier's gazelle	*Gazella cuvieri*	1750	2950	EN	99.3	–0.46	–0.46	0.12	–0.17
Darling Downs hopping-mouse	*Notomys mordax*	0	0	EX	100.0	–3.70	–3.71	–3.35	–3.53
Desert bandicoot	*Perameles eremiana*	0	0	EX	100.0	–3.70	–3.71	–3.35	–3.53
Desert rat-kangaroo	*Caloprymnus campestris*	0	0	EX	100.0	–3.70	–3.71	–3.35	–3.53
Dibatag	*Ammodorcas clarkei*	1500	1500	VU	75.3	–0.52	–0.53	–0.18	–0.36
Dibbler	*Parantechinus apicalis*	500	1000	EN	33.5	–1.00	–1.01	–0.35	–0.68
Eastern hare-wallaby	*Lagorchestes leporides*	0	0	EX	100.0	–3.70	–3.71	–3.35	–3.53
Ethiopian wolf	*Canis simensis*	239	239	EN	95.3	–1.32	–1.33	–0.98	–1.16
European beaver	*Castor fiber*	639 000	639 000	LC	88.4	2.11	2.10	2.45	2.28
European bison	*Bison bonasus*	1800	1800	VU	99.5	–0.44	–0.45	–0.10	–0.28
European mink	*Mustela lutreola*	1500	2000	EN	54.2	–0.52	–0.53	–0.05	–0.29
Gaur	*Bos gaurus*	13 000	30 000	VU	89.1	0.41	0.41	1.12	0.77
Giraffe	*Giraffa camelopardalis*	80 000	80 000	LC	88.7	1.20	1.20	1.55	1.38
Golden bandicoot	*Isoodon auratus*	22 000	22 000	VU	97.1	0.64	0.64	0.99	0.82
Golden lion tamarin	*Leontopithecus rosalia*	1000	1000	EN	99.0	–0.70	–0.71	–0.35	–0.53
Gould's mouse	*Pseudomys gouldii*	0	0	EX	100.0	–3.70	–3.71	–3.35	–3.53
Greater stick-nest rat	*Leporillus conditor*	4000	4000	VU	99.3	–0.10	–0.11	0.25	0.07
Grevy's zebra	*Equus grevyi*	1996	2447	EN	91.8	–0.40	–0.41	0.03	–0.19
Guanaco	*Lama guanicoe*	535 750	589 750	LC	73.6	2.03	2.02	2.42	2.22

continued

WebTable 1. *– continued*

Common name	*Scientific name*	*Lower pop estimate*	*Upper pop estimate*	*IUCN threat category*	*% range loss*	*SAFE*	*SAFE (low)*	*SAFE (upp)*	*SAFE (med)*
Hartebeest	*Alcelaphus buselaphus*	362 000	362 000	LC	69.7	1.86	1.85	2.20	2.03
Hastings River mouse	*Pseudomys oralis*	10 000	10 000	VU	93.9	0.30	0.29	0.65	0.47
Iberian lynx	*Lynx pardinus*	84	143	CE	97.2	–1.77	–1.78	–1.20	–1.49
Indian rhinoceros	*Rhinoceros unicornis*	2575	2575	VU	95.3	–0.29	–0.30	0.06	–0.12
Javan rhinoceros	*Rhinoceros sondaicus*	40	60	CE	95.9	–2.10	–2.11	–1.58	–1.85
Jentink's duiker	*Cephalophus jentinki*	2000	2000	EN	88.1	–0.40	–0.41	–0.05	–0.23
Kouprey	*Bos sauveli*	50	250	CE	84.6	–2.00	–2.01	–0.96	–1.49
Kowari	*Dasyuroides byrnei*	10 000	10 000	VU	64.3	0.30	0.29	0.65	0.47
Leadbeater's possum	*Gymnobelideus leadbeateri*	2000	2000	EN	74.5	–0.40	–0.41	–0.05	–0.23
Lechwe	*Kobus leche*	98 000	98 000	LC	82.0	1.29	1.28	1.64	1.46
Lesser bilby	*Macrotis leucura*	0	0	EX	100.0	–3.70	–3.71	–3.35	–3.53
Lesser stick-nest rat	*Leporillus apicalis*	0	0	CE*	100.0	–3.70	–3.71	–3.35	–3.53
Lion	*Panthera leo*	16 500	30 000	VU	67.7	0.52	0.51	1.12	0.82
Long-tailed hopping-mouse	*Notomys longicaudatus*	0	0	EX	100.0	–3.70	–3.71	–3.35	–3.53
Mountain nyala	*Tragelaphus buxtoni*	1500	4000	EN	44.0	–0.52	–0.53	0.25	–0.14
Northern hairy-nosed wombat	*Lasiorhinus krefftii*	115	115	CE	95.9	–1.64	–1.65	–1.29	–1.47
Numbat	*Myrmecobius fasciatus*	1000	1000	EN	97.3	–0.70	–0.71	–0.35	–0.53
Okapi	*Okapia johnstoni*	35 000	50 000	NT	68.4	0.85	0.84	1.34	1.09
Pampas deer	*Ozotoceros bezoarticus*	20 000	80 000	NT	22.9	0.60	0.59	1.55	1.07
Philippine spotted deer	*Cervus alfredi*	2500	2500	EN	49.5	–0.30	–0.31	0.04	–0.14
Pig-footed bandicoot	*Chaeropus ecaudatus*	0	0	EX	100.0	–3.70	–3.71	–3.35	–3.53
Pronghorn antelope	*Antilocapra americana*	700 000	700 000	LC	17.9	2.15	2.14	2.49	2.32
Puku	*Kobus vardonii*	130 000	130 000	NT	86.1	1.41	1.41	1.76	1.59
Pygmy hippopotamus	*Hexaprotodon liberiensis*	2000	3000	EN	98.7	–0.40	–0.41	0.12	–0.15
Red-fronted gazelle	*Gazella rufifrons*	25 000	25 000	VU	54.2	0.70	0.69	1.04	0.87
Red-tailed phascogale	*Phascogale calura*	10 000	10 000	NT	99.1	0.30	0.29	0.65	0.47
Riverine rabbit	*Bunolagus monticularis*	500	500	CE	57.5	–1.00	–1.01	–0.66	–0.84
Roan antelope	*Hippotragus equinus*	40 000	76 000	LC	34.4	0.90	0.89	1.53	1.21
Rufous hare-wallaby	*Lagorchestes hirsutus*	4300	6700	VU	99.3	–0.07	–0.07	0.47	0.20
Sable antelope	*Hippotragus niger*	54 000	75 000	LC	50.9	1.03	1.03	1.52	1.28
Scimitar-horned oryx	*Oryx dammah*	4300	6700	EX	97.1	–0.07	–0.07	–0.47	–0.20
Shark Bay mouse	*Pseudomys praeconis*	2000	2000	VU	88.4	–0.40	–0.41	–0.05	–0.23
Short-tailed hopping-mouse	*Notomys amplus*	0	0	EX	100.0	–3.70	–3.71	–3.35	–3.53
Smoky mouse	*Pseudomys fumeus*	2500	2500	VU	90.7	–0.30	–0.31	0.04	–0.14
Soemmerring's gazelle	*Nanger soemmerringii*	6000	6500	VU	94.3	0.08	0.07	0.46	0.27
Spotted hyaena	*Crocuta crocuta*	27 000	47 000	LC	13.6	0.73	0.72	1.32	1.02
Spotted-tailed quoll	*Dasyurus maculatus*	20 000	20 000	NT	15.6	0.60	0.59	0.95	0.77
Springbuck	*Antidorcas marsupialis*	2 000 000	2 500 000	LC	52.8	2.60	2.59	3.04	2.82
Sumatran rhinoceros	*Dicerorhinus sumatrensis*	220	275	CE	92.0	–1.36	–1.36	–0.91	–1.14
Thylacine	*Thylacinus cynocephalus*	0	0	EX	100.0	–3.70	–3.71	–3.35	–3.53
Tiger	*Panthera tigris*	3062	5066	EN	87.5	–0.21	–0.22	0.35	0.07
Toolache wallaby	*Macropus greyi*	0	0	EX	100.0	–3.70	–3.71	–3.35	–3.53
Tsessebe	*Damaliscus lunatus*	300 000	400 000	LC	62.4	1.78	1.77	2.25	2.01
Vicuña	*Vicugna vicugna*	347 273	347 273	LC	83.6	1.84	1.83	2.19	2.01
Western barred bandicoot	*Perameles bougainville*	10 000	10 000	EN	100.0	0.30	0.29	0.65	0.47
Western quoll	*Dasyurus geoffroii*	10 000	10 000	NT	98.5	0.30	0.29	0.65	0.47
White rhino	*Ceratotherium simum*	17 480	17 480	NT	97.0	0.54	0.54	0.89	0.72
White-footed rabbit-rat	*Conilurus albipes*	0	0	EX	100.0	–3.70	–3.71	–3.35	–3.53
Woolly spider monkey	*Brachyteles arachnoides*	1300	1300	EN	89.6	–0.59	–0.59	–0.24	–0.42
Yellow-footed rock-wallaby	*Petrogale xanthopus*	10 000	10 000	NT	24.2	0.30	0.29	0.65	0.47
Zebra duiker	*Cephalophus zebra*	10 000	15 000	VU	59.9	0.30	0.29	0.82	0.56

Note: *The IUCN still lists this species as CE, even though population estimates are at zero.

WebTable 2. Generalized linear model (GLM) and generalized linear mixed-effect model (GLMM) sets used to examine the relationship between the probability (Pr) of being threatened for 95 mammal species and predictors

Model	*k*	*–LL*	ΔAIC_c	$wAIC_c$	*%DE*
GLM					
Pr(*threat*) ~ *SAFE (low)*	2	–22.89	0.00	1.00	58.9
Pr(*threat*) ~ *% range loss*	2	–46.37	46.94	0.00	16.8
Pr(*threat*) ~ *1*	1	–55.75	63.63	0.00	0.00
Pr(*threat*) ~ *SAFE (upp)*	2	–22.48	0.00	1.00	59.7
Pr(*threat*) ~ *% range loss*	2	–46.37	47.77	0.00	16.8
Pr(*threat*) ~ *1*	1	–55.75	64.46	0.00	0.00
Pr(*threat*) ~ *SAFE (med)*	2	–22.47	0.00	1.00	59.7
Pr(*threat*) ~ *% range loss*	2	–46.37	47.79	0.00	16.8
Pr(*threat*) ~ *1*	1	–55.75	64.48	0.00	0.00
GLMM					
Pr(*threat*) ~ *SAFE (low)* + (*1/ORDER*)	3	–22.89	0.00	1.00	56.4
Pr(*threat*) ~ *% range loss* + (*1/ORDER*)	3	–45.94	46.10	0.00	12.4
Pr(*threat*) ~ *1* + (*1/ORDER*)	2	–52.46	57.0	0.00	0.00
Pr(*threat*) ~ *SAFE (upp)* + (*1/ORDER*)	3	–22.48	0.00	1.00	57.2
Pr(*threat*) ~ *% range loss* + (*1/ORDER*)	3	–45.94	46.92	0.00	12.4
Pr(threat) ~ 1 + (*1/ORDER*)	2	–52.46	57.83	0.00	0.00
Pr(*threat*) ~ *SAFE (med)* + (*1/ORDER*)	3	–22.47	0.00	1.00	57.2
Pr(*threat*) ~ *% range loss* + (*1/ORDER*)	3	–45.94	46.94	0.00	12.4
Pr(*threat*) ~ *1* + (*1/ORDER*)	2	–52.46	57.85	0.00	0.00

Notes: Only single-term models were considered to test the relative ability of three uncertainty variants of the SAFE index versus percentage range loss to predict extinction threat (threat). See WebTable 1 for definitions of SAFE (low), SAFE (upp), and SAFE (med). The analytical theme represented by each model (SAFE, % range loss, the intercept-only model, and mammalian order (ORDER) as a random effect), and the information–theoretic ranking of models investigating the predictors of mammal threat status according to Akaike's information criterion corrected for small sample size (AIC_c) are shown. *k* = number of parameters, *–LL* = maximum log-likelihood, ΔAIC_c = difference in AIC_c for each model from the most parsimonious model, $wAIC_c$ = AIC_c weight, and %DE = percent deviance explained in the response variable by the model under consideration. Two data points were removed for the GLMMs because there was only one representative species in its respective mammalian order: *Bunolagus monticularis* and *Elephas maximus*.

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