Correlations among Extinction Risks Assessed by Different Systems of Threatened Species Categorization

JULIAN J. O'GRADY,* MARK A. BURGMAN,† DAVID A. KEITH,‡ LAWRENCE L. MASTER,§
SANDY J. ANDELMAN,** BARRY W. BROOK,†† GEOFFREY A. HAMMERSON,§ TRACEY REGAN,†
AND RICHARD FRANKHAM*‡‡§§***

*Key Centre for Biodiversity and Bioresources, Department of Biological Science, Macquarie University,
New South Wales 2109, Australia
†School of Botany, University of Melbourne, Parkville, Victoria 3010, Australia
‡NSW National Parks and Wildlife Service, P.O. Box 1967, Hurstville, New South Wales 2220, Australia
§NatureServe, 11 Avenue de Lafayette, 5th Floor, Boston, MA 02111-1736, U.S.A.
**National Center for Ecological Analysis and Synthesis, 735 State Street, Suite 300, Santa Barbara, CA 93101, U.S.A.
††Key Centre for Tropical Wildlife Management, Charles Darwin University, Darwin, Northern Territory 0909, Australia
‡‡Australian Museum, 6 College Street Sydney, New South Wales 2010, Australia
§§Department of Organismic and Evolutionary Biology and Program for Evolutionary Dynamics, Harvard University, One Brattle
Square, Cambridge, MA 02138, U.S.A., email rfrankha@els.mq.edu.au

Abstract: *Many different systems are used to assess levels of threat faced by species. Prominent ones are those used by the World Conservation Union, NatureServe, and the Florida Game and Freshwater Fish Commission (now the Florida Fish and Wildlife Conservation Commission). These systems assign taxa a threat ranking by assessing their demographic and ecological characteristics. These threat rankings support the legislative protection of species and guide the placement of conservation programs in order of priority. It is not known, however, whether these assessment systems rank species in a similar order. To resolve this issue, we assessed 55 mainly vertebrate taxa with widely differing life histories under each of these systems and determined the rank correlations among them. Moderate, significant positive correlations were seen among the threat rankings provided by the three systems (correlations 0.58–0.69). Further, the threat rankings for taxa obtained using these systems were significantly correlated to their rankings based on predicted probability of extinction within 100 years as determined by population viability analysis (correlations 0.28–0.37). The different categorization systems, then, yield related but not identical threat rankings, and these rankings are associated with predicted extinction risk.*

Key Words: endangered species, extinction risk, population viability analysis, threat rankings

Correlaciones entre Riesgos de Extinción Evaluados por Diferentes Sistemas de Categorización de Especies Amenazadas

Resumen: *Se utilizan muchos sistemas diferentes para evaluar los niveles de amenaza que enfrentan las especies. Son prominentes los utilizados por World Conservation Union, NatureServe Heritage y Florida Game and Freshwater Fish Commission (ahora Florida Fish and Wildlife Conservation Commission). Estos sistemas asignan una categoría de amenaza a los taxa mediante la evaluación de sus características demográficas y ecológicas. Estas categorías de amenaza sustentan a la protección legislativa de especies y guían la definición de prioridades en programas de conservación. Sin embargo, se desconoce si estos sistemas de evaluación categorizan a las especies en orden similar. Para resolver este tema, evaluamos 55 taxa, principalmente de*

***Address correspondence to R. Frankham.

Paper submitted March 11, 2003; revised manuscript accepted April 29, 2004.

vertebrados, con historias de vidas muy diferentes con cada uno de estos sistemas y determinamos las correlaciones entre las categorías. Hubo correlaciones positivas moderadas entre las categorías de amenaza proporcionadas por los tres sistemas (correlaciones 0.58-0.69). Más aun, las categorías de amenaza proporcionados por estos sistemas estuvieron correlacionadas significativamente con las categorías definidas con base en la probabilidad de extinción pronosticada en 100 años determinada por análisis de viabilidad poblacional (correlaciones 0.28-0.37). Por lo tanto, los diferentes sistemas de categorización están proporcionando categorías de amenazas relacionadas pero no idénticas, y estas categorías están relacionadas con el riesgo de extinción pronosticado.

Palabras Clave: análisis de viabilidad poblacional, categorías de amenaza, especies en peligro, riesgo de extinción

Introduction

To flag taxa requiring urgent conservation attention, conservation agencies have devised assessment systems that use demographic and ecological parameters to assign each taxon a threat ranking. The most widely recognized system for ranking taxa is the IUCN (World Conservation Union) Red List categorization (IUCN 1994; Baille & Groombridge 1996; IUCN 2000). This system provides a scientific basis for the listing of threatened taxa in red data books and red lists. These listings are intended to highlight taxa at risk of extinction, call attention to factors causing endangerment, support the legislative protection of taxa, and provide input into prioritization of conservation programs (Mace & Lande 1991; Mace 1994; Mace 1995; Baille & Groombridge 1996; Collar 1996; Colyvan et al. 1999). They may also be used to inform reserve selection, constrain development and exploitation, and report on the state of the environment (Possingham et al. 2002). Another widely recognized and influential assessment system is the NatureServe conservation status assessment, formerly referred to as TNC Heritage (Master 1991; Master et al. 2000). This system was originally developed by the Nature Conservancy but has subsequently been modified. It is used by a network of natural heritage programs and conservation data centers throughout the Western Hemisphere. The Florida Game and Freshwater Fish Commission (now the Florida Fish and Wildlife Conservation Commission) system (Millsap et al. 1990) has been a template for several other such systems (e.g., Lunney et al. 1996). We refer to these assessment systems as IUCN, NatureServe, and FG&FFC, respectively.

Table 1. Biological attributes of taxa assessed by the IUCN Red List (IUCN), Florida Game and Freshwater Fish Commission (FG&FFC), and NatureServe categorization systems

Attributes assessed	*IUCN*	*FG&FFC*	*NatureServe*
Distribution (area, etc.)	√	√	√
Distribution trend	√	√	√
Ecological specialization		√	√
Fluctuations in population size or distribution	√		
Number of occurrences (populations)			√
Number of occurrences trend			√
Population concentration	√	√	
Population fragmentation	√		
Population size	√	√	√
Population trend	√	√	√
Probability of extinction	√		
Protection from threat(s)		√	√
Quality of habitat	√		√
Recovery potential		√	
Susceptibility to threat	√		√
Taxonomic significance		√	
Threat magnitude/immediacy			√
General characteristics promoting susceptibility to threat(s) (not assessed in the above categories)		√	√

Although a common goal of all three systems is to provide a threat-based ranking of taxa, each system has a different structure and was derived with somewhat different purposes. Each ranks taxa by assessing different biological attributes (Table 1) and gives different weight to each attribute when determining a taxon's rank. Further, each system employs different protocols to categorize the risk of extinction based on biological attributes of taxa (Millsap et al. 1990; Master 1991; IUCN 2000; Master et al. 2000). The IUCN system ranks taxa according to the highest risk level indicated by any of five criteria. The FG&FFC system ranks taxa by summing points accrued for possession of specified biological characteristics as measured by quantitative and qualitative parameters. The NatureServe system applies a mixture of 12 quantitative and qualitative ranking factors to each taxa but, unlike the other two systems, uses guidelines and adjudicated expert judgment rather than a point- or rule-based scoring system to assign relative extinction risk. The NatureServe approach is influenced by its historical use in helping to select reserve sites, whereas the IUCN system was devised for categorizing taxa for red listing based on perceived risk as assessed using population biology principles (Mace & Lande 1991).

Each system has been used repeatedly to support the listing and legislative protection of endangered taxa (Master 1991; Baille & Groombridge 1996; Lunney et al. 1996;

Alvo & Oldham 2000). It is not known, however, whether using these systems results in a similar priority ranking of taxa across a wide taxonomic range. Repeatable and consistent listings of endangered taxa that reflect extinction risks are vital so that conservation decisions based on these listings are defensible (Rohlf 1991; Keith 1998; Mace & Hudson 1999; Beissinger et al. 2000). Previous work by Burgman et al. (1999) suggests that rank-order correlations among different systems can be very low. The Burgman work, however, was limited to vascular plants of southeastern Australia, a comparatively narrow taxonomic and geographic sample. Alvo and Oldham (2000) compared the IUCN, the Nature Conservancy, and the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) systems in amphibians and reptiles and found positive but incomplete concordance between earlier versions of IUCN and NatureServe Heritage threat rankings.

We carried out a broad comparative assessment to determine whether the systems employed by the IUCN, NatureServe, and FG&FFC produce a similar priority ranking of taxa. We applied these protocols to a set of 55 mainly vertebrate taxa with varied life histories. We calculated rank correlations among the risks allocated to the taxa by each of the categorization systems. Even when there is close agreement among the systems on species ranks, these may not accurately reflect the rank order of taxa based on extinction risk. We used population viability analyses (PVA) to predict extinction probabilities over a fixed time frame (Brook et al. 2000, 2002; McCarthy et al. 2003) and computed rank correlations among these and risks assessed by each of the three categorization systems.

Methods

Assessment of the Taxa

We used the methods, parameters, and protocols prescribed by the categorization literature to assess the taxa. Because the IUCN Red List categorization system has recently been revised, we used both the established 1994 and the newer 2000 versions of this system. Because the results they produced were identical, only one is reported. Each of the systems we assayed can be used to rank taxonomic units below the species level (Millsap et al. 1990; Master 1991; Master et al. 2000; Gärdenfors et al. 2001). Consequently, we used a mixture of species, subspecies, metapopulations, and populations (all being closed systems [i.e., $\ll 1$ immigrant/emigrant per year]) and assessed all as if they were species. We assessed each taxon for the years when the most comprehensive data set was available (Appendix). As a result, the categorizations assigned to taxa in this study do not necessarily represent each taxon's current listing by each system.

Data for all taxa were collected and prepared for categorizations by J.J.O., thus avoiding effects resulting from assessor differences. For categorization systems that required all parameters to be entered, the best or most probable estimate was used. For systems allowing missing data, a blank was entered when there were no adequate data. Taxa that did not satisfy these requirements were excluded. Categorizations for IUCN and FG&FFC were done using software prepared specifically for this study by T.R. and D.A.K., based on the respective protocols. Algorithms programmed into a spreadsheet organized parameter estimates, matched them to the relevant protocol, and assigned risk categories for each species for each of the protocols. The protocols were implemented as described in the relevant literature (Millsap et al. 1990; IUCN 2000). This was done to ensure that implementation would be consistent across all species. The protocols for the NatureServe system were implemented manually by G.A.H. and L.L.M., who are experts in this categorization system.

Taxa

We applied these protocols to 55 taxa: 18 birds, 32 mammals, 2 reptiles, 1 fish, 1 mollusc, and 1 plant. Details of the taxa and major data sources are given in the Appendix. The taxa had diverse life histories and came from a wide geographic range (Europe, Asia, Africa, North and South America, and Australia). The selection of taxa was largely restricted to mammals and birds because data were relatively available. No other selection filter was applied (i.e., the taxa were the first found for which sufficient published data enabled their assessment).

Population Viability Analysis Modeling

We used PVA to predict the extinction risk of the taxa. PVA gives a noisy but unbiased estimate of extinction risk when applied over many well-studied taxa of mammals and birds (Brook et al. 2000). A similar conclusion was reached in a simulation study (McCarthy et al. 2003). PVA estimates for a suite of taxa, then, should correlate imperfectly but positively with the results of the ranking protocols. Although PVA can be used as part of the IUCN system under criterion E, criterion E rarely determines the assessment (Gärdenfors 2000; O'Grady 2002), and data on endangered species are frequently too scarce for their extinction risk to be estimated by PVA (Mace & Hudson 1999; Matsuda et al. 2000). A PVA may also be imperfectly correlated with the ranking from the NatureServe and FG&FFS protocols because these do not claim to and were not explicitly designed to match extinction likelihood levels. We used well-studied species with higher-than-average amounts of data and for NatureServe the best assessors available, both of which should yield higher correlations with PVA across all protocols.

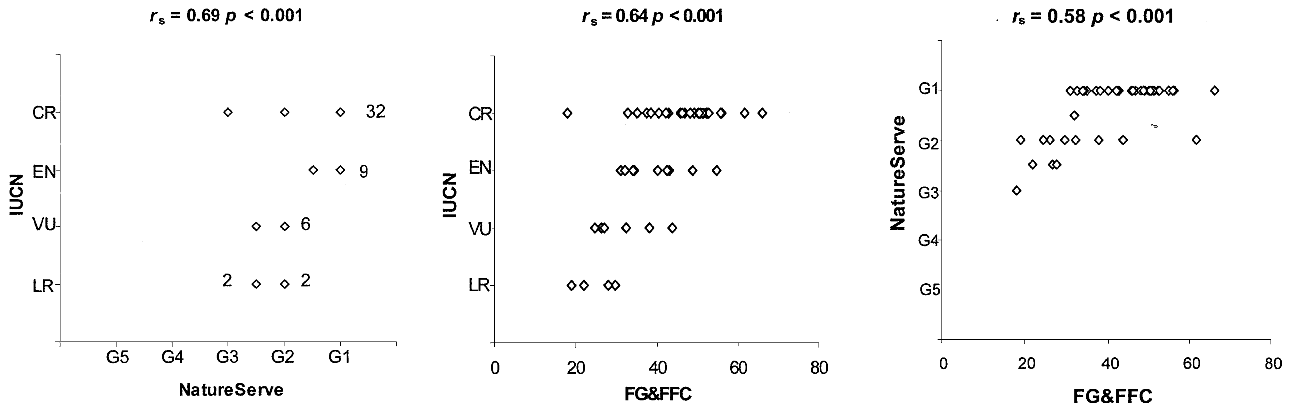

Figure 1. Relationships among the assessments of 55 taxa done using the World Conservation Union (IUCN), NatureServe, and Florida Game and Freshwater Fish Commission (FG&FFC) categorization systems. Actual assessment values are used for FG&FFC, whereas IUCN categories critically endangered (CE), endangered (EN), vulnerable (VU), and lower risk (LR), and the NatureServe categories critically imperiled (G1), imperiled (G2), vulnerable (G3), apparently secure (G4), and demonstrably secure (G5) are designated. Numerals on the left panel refer to the number of points lying on top of each other. Rank correlations between the categorization systems are also reported.

Wherever possible, we obtained the probability of a taxon's extinction from a published PVA. We drew eight of the PVA models from the study by Brook et al. (2000). Where these studies provided various probabilities of extinction in response to various scenarios modeled, we used the probability of extinction generated by the model that the authors deemed most realistic. No published PVA was found for 11 taxa, so using methods described by Brook et al. (2000), we created a PVA model for each of these from the life-history data published for each (Appendix). We assessed probabilities of extinction in 100 years because this corresponds to the time frame for the IUCN vulnerable category that lies at the boundary of threatened and lower risk categories. Of the 55 models, 38 were done with Vortex (Miller & Lacy 1999); 9 were done with count-based models (also known as *r* models; Morris & Doak 2002); 3 were custom written (by the authors of the papers); and 4 were done with RAMAS Metapop (Akçakaya 1996), as specified in the Appendix. Fifty-two taxa were modeled as single populations and three as metapopulations.

Statistical Analyses

We measured correlations of the threat rankings provided by the different assessment systems with Spearman's rank correlation coefficient (r_S), corrected for ties (Sheskin 1997). We also computed rank correlations among each assessment system's ranking and probabilities of extinction in 100 years. Where range ranks were given in the NatureServe system, we used the midpoint of the range in computing the correlations. We carried out one-tailed tests because correlations were expected to be positive. We carried out statistical analyses in MINITAB (version 12).

Results

The threat categories assigned to each of the taxa by each assessment system are provided in the Appendix, along with the predicted probabilities of extinction in 100 years.

Correlations among Systems in Threat Rankings

Correlations among the ranking of the taxa by each system were all positive but far from completely concordant (Fig. 1). The strength of correlations among threat rankings yielded by the IUCN, NatureServe, and FG&FFC systems were moderate ($r_S = 0.58$–0.69) and significant (all $p < 0.001$). The correlations were almost identical when similar populations of the same taxa were pooled (*Cervuce eldi hainanus*, *Gorilla gorilla beringei*, *Ovis aries*, and *Panthera tigris sumatrae*), and the significance was unchanged. The correlations were similar when restricted to mammals and birds.

An alternative means for describing the concordance is to ask how often the highest threat ranking for a species according to one system is also the highest according to another. Of 34 taxa in the IUCN critically endangered category, 32 fell into the highest NatureServe category G1 (critically imperiled), whereas only one fell into G2 (imperiled) and one into G3 (vulnerable). Notably, the latter case was the contentious southern bluefin tuna (*Thunnus maccoyii*). It was also ranked the least threatened by the FG&FFC system. Of the 41 taxa in the NatureServe G1 category, 32 were categorized as critically endangered and 9 as endangered in the IUCN system. Of the 20 highest risk taxa ranked under FG&FFC, 19 were listed as critically

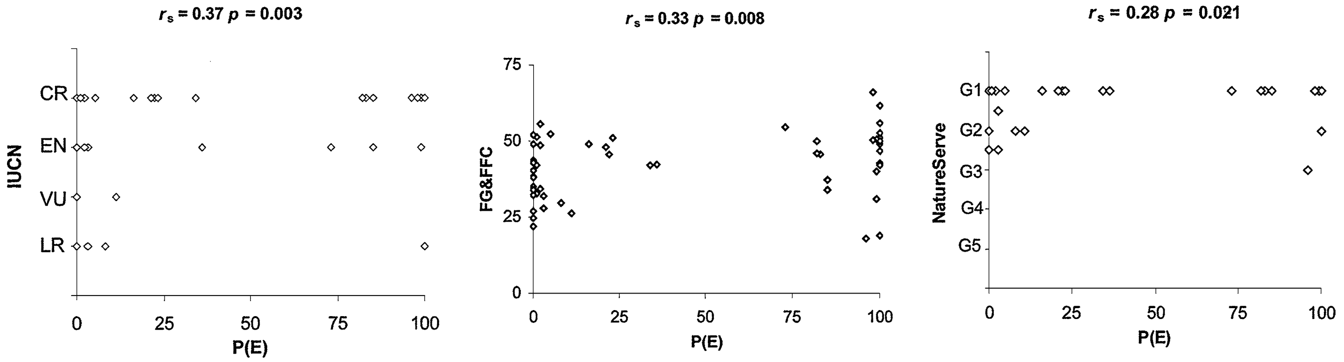

Figure 2. Relationships among the assessments of 55 taxa done using the World Conservation Union (IUCN), Florida Game and Freshwater Fish Commission (FG&FFC), and NatureServe categorization systems with predicted probability of extinction in 100 years estimated by population viability analysis (probability of extinction [P(E)]). Rank correlations are also reported.

endangered and 1 as endangered under IUCN, whereas all were categorized as G1 under the NatureServe system.

Correlations of Categorizations with Projected Extinction Risks

Correlations among the assessment systems and probabilities of extinction were weakly positive (Fig. 2). Rankings between these assessment systems and PVA were all significant (p ranging from 0.003 to 0.021). The correlations, however, were all weaker than those between the priority rankings for the different assessment systems, with r_S ranging between 0.28 and 0.37.

The rank correlations of the categorizations with probabilities of extinction from PVA were recalculated for mammals and birds only (this excluded five taxa) because we had larger samples for these taxa and because the protocols might perform differently for other taxa. The correlations were similar to those for the full data set: 0.32 with IUCN ($p = 0.011$), 0.33 with NatureServe ($p = 0.010$), and 0.33 with FG&FFC ($p = 0.011$).

Discussion

Our study revealed two major findings. First, the assessment systems of IUCN, NatureServe, and FG&FFC gave positively correlated rankings of taxa. Second, threat rankings from all the systems were positively correlated with predicted extinction risks from PVA but to a lesser degree than they were correlated with each other.

The taxa identified as belonging to the highest risk category generally ranked in the highest or next highest risk categories or ranks for the other systems. The most discordant ranking was for the southern bluefin tuna (*T. maccoyii*). It was categorized as critically endangered by the IUCN system but only as G3 (vulnerable) by NatureServe, and it was ranked the least threatened by the FG&FFC system. This case is contentious (see Matsuda et al. 1998; Matsuda et al. 2000). The southern bluefin tuna has a very large population size that has declined rapidly. The rate of population decline was sufficient to lead to it being placed in the highest risk category in IUCN, but was insufficient for it to be placed in high risk categories in the other two systems, even though all three systems use population decline in their categorizations.

The threat rankings from the three systems were positively correlated despite their use of different ranking protocols. This is an important result. The correlations based on this data set ($r_S \sim 0.58$–0.69) compare very favorably with those based on a set of vascular plants ($r_S \sim 0.04$–0.59; Burgman et al. 1999). In particular, there was much greater concordance between IUCN and FG&FFC for our animal data ($r_S = 0.64$) than for the plant taxa ($r_S = 0.13$) in the Burgman et al. (1999) study. This appears to be a real difference, rather than an artifact of missing data, because both studies were done on well-studied taxa and there were few missing data. The weaker concordance for plants is probably a result of the systems being designed initially for animals. The FG&FFC system was designed specifically for animals, although most of the criteria are nonetheless applicable to plants. The IUCN system also originated from more of an animal focus (Mace & Lande 1991), but it is applicable to both animals and plants (Keith 1998). Individual differences among assessors could also account for the difference in the two studies.

The other published comparison of categorization systems is by Alvo and Oldham (2000). They compared the IUCN, TNC Heritage, and COSEWIC systems for 93 native and introduced amphibian and reptile species in Canada. Species that were ranked as high risk by TNC Heritage were always ranked as of concern under IUCN, whereas species ranked as low risk by TNC Heritage were always ranked as least concern under IUCN. Overall, the concordance seems to be somewhat less than what we found, but the assessments were done using earlier versions of the systems we compared.

Threat categorizations for the three systems were related to predicted extinction risk. These correlations, however, were weaker than those found among the categorization systems themselves. The most likely reasons for the differences in correlation are the precision with which the most important variables that determine extinction risk were incorporated into the protocols and the exclusion from PVA of variables with poor predictive ability. In a study of 16 parameters used in these categorization systems over 45 taxa, O'Grady et al. (2004) found that the best predictors of extinction risk were current population size and rate of change in population size. Other variables had significant predictive ability when interaction terms were entered but had lesser explanatory power. The use of different types of PVA models may also have contributed to the low correlations among categorizations and predicted extinction risks. The predictive abilities of RAMAS Metapop and Vortex, however, are comparable (Brook et al. 2000). Further, simple count-based PVA models (*r* models), based solely on initial population size and variation in population size, have similar predictive abilities to full PVA models (Brook 1999). Differences among operators in building PVA models are likely to have contributed to the low correlations. The low correlation of NatureServe categorizations with predicted extinction risk may have resulted partly from the lack of data in the two lowest risk categories.

Differences among rankings from the PVAs and the categorization systems derive, at least in part, from the wide confidence intervals around PVA estimates, especially over time frames of 100 years. Correlations substantially less than 1 should be expected, even if the ranking protocols were exactly correct. The PVAs and the assessments we conducted used the same data and were interpreted mostly by the same individual. In other circumstances, when different people and different information bases are involved, the strength of the correlations is likely to be lower.

Data scarcity is a major problem in categorizing species. For example, Lunney et al. (1996) reported that only 6% of species in New South Wales had adequate data for assessment under the FG&FFC procedures of Millsap et al. (1990). Data scarcity also challenged the assessment of the well-studied taxa we assayed, even in the IUCN system, which assesses fewer parameters than the other systems. This situation was acute where long-term trends in population size and range were assayed. For example, even the best references for the southern sea otter (*Enhydra lutris nereis;* Appendix) had data gaps such that there were uncertainties about the census size during the 1800s and whether population size declined or grew prior to 1900 (desirable for the NatureServe system).

How can data scarcity be overcome when using these assessment systems? The IUCN and NatureServe systems recognize this difficulty (IUCN 1994; Master 1991; Master et al. 2000), and in such situations their flexibility is an advantage, allowing the assessor scope to declare a taxon threatened by a factor where quantitative data are unavailable. NatureServe's system also uses range ranks (e.g., G2G3), where the range spans the degree of uncertainty. NatureServe's approach requires, however, that assessors be skilled in using the system to avoid subjectivity and to promote repeatability of sequential assessments. Statistical techniques may also be used to reduce subjectivity. For example, we used nonlinear regression across the data gap for the southern sea otter to decide whether population size was increasing or declining during the last 200 years. Frequently it is necessary to use data carrying a degree of uncertainty (as a result of, for example, natural variation or measurement error) and to accept the range of assessment that will stem from this uncertainty. The RAMAS red list software indicates the sensitivity of the rankings under the IUCN system to the degree of uncertainty in the data (Akçakaya et al. 2000).

The correlation of risk ranking among the categorization systems, and among the rankings and extinction risks from PVA, are insufficient to prevent disagreements over the "true" conservation status of taxa. Political conflicts have arisen where different methods to determine a species' conservation status gave different answers (Baille & Groombridge 1996; Mace & Hudson 1999), especially for the status of economically important fish species such as the southern bluefin tuna (Matsuda et al. 1998; Matsuda et al. 2000). Such disagreements can erode confidence in conservation decisions and in the agencies responsible for those decisions (Mrosovsky 1997). Many of the differences among the categorization systems may be justified because each system seeks to emphasize particular attributes and processes in response to the political and ecological settings in which they were created.

Acknowledgments

We thank C. Drill for technical assistance, A. Maynard and D. O'Meally for assistance in preparing the figures, and three anonymous reviewers for comments on the manuscript. An Australian Postgraduate Research Award provided financial support for J.J.O. This is publication number 376 of the Key Centre for Biodiversity and Bioresources.

Literature Cited

Akçakaya, H. R. 1996. RAMAS Metapop: viability analysis for stage-structured metapopulations. Version 2.0. Applied Biomathematics, Setauket, New York.

Akçakaya, H. R., S. Ferson, M. A. Burgman, D. A. Keith, G. M. Mace, and C. R. Todd. 2000. Making consistent IUCN classifications under uncertainty. Conservation Biology **14:**1001–1013.

Akçakaya, H. R., M. A. McCarthy, and J. L. Pearce. 1995. Linking landscape data with population viability analysis: management options for the helmeted honeyeater, *Lichenostomus melanops cassidix*. Biological Conservation **73:**169–176.

Alvo, R., and M. J. Oldham. 2000. A review of the status of Canada's amphibian and reptile species: a comparison of three ranking systems. Canadian Field-Naturalist **114:**520–540.

Ashraf, N. V. K., R. Chellam, S. Molur, D. Sharma, and S. Walker. 1995. Population and habitat viability assessment P.H.V.A. workshops for Asiatic lion, *Panthera leo persica*. Conservation Breeding Specialist Group, Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Baille, J., and B. Groombridge. 1996. The IUCN red list of threatened animals. World Conservation Union, Gland, Switzerland.

Ballou, J. D., R. C. Lacy, D. Kleiman, A. Rylands, and S. Ellis. 1998. Leontopithecus II, final report, the second population and habitat viability assessment for Lion tamarins *Leontopithecus*). Conservation Breeding Specialist Group, Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Beier, P. 1993. Determining minimum habitat areas and habitat corridors for cougars. Conservation Biology **7:**94–108.

Beissinger, S. R., J. M. Reed, J. M. Wunderle Jr., S. K. Robinson, and D. M. Finch. 2000. Report of the AOU Conservation Committee on the Partners in Flight species prioritization plan. Auk **117:**549–561.

Binkley, C. S., and R. S. Miller. 1983. Population characteristics of the whooping crane, *Grus americana*. Canadian Journal of Zoology **61:**2768–2776.

Bonaccorso, F., P. Clark, P. Miller, and O. Byers. 1998. Conservation assessment and management plan for the tree kangaroos of Papua New Guinea and population and habitat viability assessment for Matschie's tree kangaroo. Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Brook, B. W. 1999. Evaluating population viability analysis. Ph.D. thesis. Macquarie University, Sydney.

Brook, B. W., M. A. Burgman, H. R. Akçakaya, J. J. O'Grady, and R. Frankham. 2002. Critiques of PVA ask the wrong questions: throwing the heuristic baby out with the numerical bathwater. Conservation Biology **16:**262–263.

Brook, B. W., and J. Kikkawa. 1998. Examining threats faced by island birds: a PVA on the Capricorn silvereye using long-term data. Journal of Applied Ecology **35:**491–503.

Brook, B. W., J. R. Cannon, R. C. Lacy, C. Mirande, and R. Frankham. 1998. A comparison of the population viability analysis packages GAPPS, INMAT, RAMAS and VORTEX for the whooping crane (*Grus americana*). Animal Conservation **2:**23–31.

Brook, B. W., L. Lim, R. Harden, and R. Frankham. 1997*a*. Does population viability analysis software predict the behaviour of real populations? A retrospective study on the Lord Howe Island woodhen *Tricholimnas sylvestris* (Sclater). Biological Conservation **82:** 119–128.

Brook, B. W., L. Lim, R. Harden, and R. Frankham. 1997*b*. How secure is the Lord Howe island woodhen? A population viability analysis using VORTEX. Pacific Conservation Biology **3:**125–133.

Brook, B. W., J. J. O'Grady, A. P. Chapman, M. A. Burgman, H. R. Akçakaya, and R. Frankham. 2000. Predictive accuracy of population viability analysis in conservation biology. Nature **404:**385–387.

Burgman, M. A., D. A. Keith, and T. V. Walshe. 1999. Uncertainty in comparative risk analysis for threatened Australian plant species. Risk Analysis **19:**585–598.

Clutton-Brock, T. H., I. R. Stevenson, P. Marrow, A. D. MacColl, A. I. Houston, and J. M. McNamara. 1996. Population fluctuations, reproductive costs and life-history tactics in female Soay sheep. Journal of Animal Ecology **65:**675–689.

Clutton-Brock, T. H., O. F. Price, S. D. Albon, and P. A. Jewell. 1991. Persistent instability and population regulation in Soay sheep. Journal of Animal Ecology **60:**593–608.

Clutton-Brock, T. H., O. F. Price, S. D. Albon, and P. A. Jewell. 1992. Early growth and population fluctuations in Soay sheep. Journal of Animal Ecology **61:**381–396.

Coimbra-Filho, A. F., and R. A. Mittermeier. 1977. Conservation of the Brazilian lion tamarins *Leontopithecus rosalia*. Pages 59–94 in P. Rainier and G. H. Bourne, editors. Primate conservation. Academic Press, New York.

Collar, N. J. 1996. The reasons for red data books. Oryx **30:**121–130.

Colyvan, M., M. A. Burgman, C. R. Todd, H. R. Akçakaya, and C. Boek. 1999. The treatment of uncertainty and the structure of the IUCN threatened species categories. Biological Conservation **89:**249–249.

Cooch, E. G., and F. Cooke. 1991. Demographic changes in a snow goose population: biological and management implications. Pages 168–189 in C. M. Perrins, J. D. Lebreton, and G. I. M. Hirons, editors. Bird population studies. Relevance to conservation and management. Oxford University Press, Oxford, United Kingdom.

Crossman, D. G., C. N. Johnson, and A. B. Horsup. 1994. Trends in the population of the northern hairy-nosed wombat *Lasiorhinus krefftii* in Epping Forest National Park, central Queensland. Pacific Conservation Biology **1:**141–149.

Degnan, S. M. 1993. Genetic variability and population differentiation inferred from DNA fingerprinting in silvereyes (Aves: Zosteropidae). Evolution **47:**1105–1117.

De Leon, J., N. Lawas, R. Escalada, P. Ong, R. Callo, S. Hedges, J. Ballou, D. Armstrong, and U. S. Seal. 1996. Tamaraw (*Bubalus mindorensis*) population and habitat viability assessment. Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Disney, H. J. de S. 1974*a*. Woodhen. Australian Natural History **18:** 70–73.

Disney, H. J. de S. 1974*b*. Survey of the woodhen. Pages 73–76 in H. F. Recher and S. S. Clark, editors. Environmental survey of Lord Howe Island. Department of Environmental Studies, Australian Museum, Sydney.

Dufty, A. C. 1994. Habitat and spatial requirements of the eastern barred bandicoot (*Perameles gunnii*) at Hamilton, Victoria. Wildlife Research **21:**459–472.

Eberhardt, L. L., B. M. Blanchard, and R. R. Knight. 1994. Population trend of the Yellowstone grizzly bear as estimated from reproductive and survival rates. Canadian Journal of Zoology **72:**360–363.

Eberhardt, L. L., R. R. Knight, and B. M. Blanchard. 1986. Monitoring grizzly bear population trends. Journal of Wildlife Management **50:** 613–618.

Eguchi, K. 1993. Temporal changes in food resources, parental feeding and breeding success of Heron Island silvereyes, *Zosterops lateralis chlorocephala*. Ecological Research **8:**319–327.

Estes, J. A. 1981. The case of the sea otter. Pages 167–180 in P. A. Jewell and S. Holt, editors. Problems in management of locally abundant wild mammals. Academic Press, New York.

Gaines, E. P., and M. R. Ryan. 1988. Piping plover habitat use and reproductive success in North Dakota. Journal of Wildlife Management **52:**266–273.

Gaona, P., P. Ferreras, and M. Delibes. 1998. Dynamics and viability of a metapopulation of the endangered Iberian lynx (*Lynx pardinus*). Ecological Monographs **68:**349–370.

Gärdenfors, U. 2000. Population viability analysis in the classification of threatened species: problems and potentials. Ecological Bulletins **48:**181–190.

Gärdenfors, U., C. Hilton-Taylor, G. M. Mace, and J. P. Rodríguez. 2001. The application of IUCN Red List criteria at regional levels. Conservation Biology **15:**1206–1212.

Grenfell, B. T., K. Wilson, B. F. Finkenstadt, T. N. Coulson, S. Murray, S. D. Albon, J. M. Pemberton, T. H. Clutton-Brock, and M. J. Crawley. 1998. Noise and determinism in synchronized sheep dynamics. Nature **394:**674–677.

Gutiérrez, R. J., and J. Pritchard. 1990. Distribution, density, and age structure of spotted owls on two southern California habitat islands. Condor **92:**491–495.

Haig, S. M. 1992. Piping plover. Pages 1–18 in A. Poole, P. Stettenheim, and F. Gill, editors. The birds of North America. The American Ornithologists' Union, Washington, D.C.

Haig, S. M., and L. W. Oring. 1988. Genetic differentiation of piping plovers across North America. Auk **105:**260–267.

Harcourt, A. H. 1981. Can Uganda's gorillas survive? A survey of the Bwindi Forest Reserve. Biological Conservation **19:**269–282.

Harris, M. P. 1974. A complete census of the flightless cormorant (*Nannopterum harrisi*). Biological Conservation **6:**188–191.

Harris, M. P., and S. Wanless. 1991. Population studies and conservation of puffins, *Fratercula arctica*. Pages 230–248 in C. M. Perrins, J. D. Lebreton, and G. I. M. Hirons, editors. Bird population studies. Relevance to conservation and management. Oxford University Press, Oxford, United Kingdom.

Hoyle, S. D., A. B. Horsup, C. N. Johnson, D. G. Crossman, and H. McCallum. 1995. Live trapping of the hairy-nosed wombat *Lasiorhinus krefftii*: population size estimates and effects on individuals. Wildlife Research **22:**741–755.

IUCN (World Conservation Union). 1994. IUCN red list categories. Species Survival Commission, World Conservation Union, Gland, Switzerland.

IUCN (World Conservation Union). 2000. The 2000 IUCN red list of threatened species. Species Survival Commission, World Conservation Union, Gland, Switzerland.

Jewell, P. A., C. Milner, and J. M. Boyd. 1974. Island survivors: the ecology of the Soay sheep of St Kilda. The Athlone Press of the University of London.

Kaiya, Z., S. Ellis, M. Leatherwood, M. Bruford, and U. S. Seal. 1994. Baiji (*Lipotes vexillifer*) population and habitat viability assessment. Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Keith, D. A. 1998. An evaluation and modification of World Conservation Union red list criteria for classification of extinction risk in vascular plants. Conservation Biology **12:**1076–1090.

Kierulff, M. C. M., and P. P. de Oliveira. 1996. Re-assessing the status and conservation of the golden lion tamarin *Leontopithecus rosalia* in the wild. Dodo **32:**98–115.

Kjos, C. O., O. Byers, P. Miller, J. Borovansky, and U. S. Seal. 1998. Population and habitat viability assessment (PHVA) for the winged mapleleaf mussel (*Quadrula fragosa*). Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Knight, R. R., and L. L. Eberhardt. 1985. Population dynamics of Yellowstone grizzly bears. Ecology **66:**323–334.

Komdeur, J. 1996. Breeding of the Seychelles magpie robin *Copsychus sechellarum* and implications for its conservation. Ibis **138:** 485–491.

Lacy, R. C., and T. W. Clark. 1990. Population viability assessment of the eastern barred bandicoot in Victoria. Pages 131–145 in T. W. Clark and J. H. Seebeck, editors. Management and conservation of small populations. Chicago Zoological Society, Brookfield, Illinois.

Lacy, R. C., N. R. Flesness, and U. S. Seal. 1989. Puerto Rican parrot (*Amazona vittata*) population viability analysis. Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

La Haye, W. S., R. J. Gutiérrez, and H. R. Akçakaya. 1994. Spotted owl metapopulation dynamics in southern California. Journal of Animal Ecology **63:**775–785.

Lunney, D., A. Curtin, D. Ayers, H. G. Cogger, and C. R. Dickman. 1996. An ecological approach to identifying the endangered fauna of New South Wales. Pacific Conservation Biology **2:**212–231.

Mace, G. M. 1994. An investigation into the methods for categorizing the conservation status of species. Pages 293–312 in P. J. Edwards, R. M. May, and N. R. Webb, editors. Large-scale ecology and conservation biology. Blackwell, Oxford, United Kingdom.

Mace, G. M. 1995. Classification of threatened species and its role in conservation planning. Pages 197–213 in J. H. Lawton and R. M. May, editors. Extinction rates. Oxford University Press, Oxford, United Kingdom.

Mace, G. M., and E. J. Hudson. 1999. Attitudes toward sustainability and extinction. Conservation Biology **13:**242–246.

Mace, G. M., and R. Lande. 1991. Assessing extinction threats: towards a reevaluation of IUCN threatened species categories. Conservation Biology **5:**148–157.

Madsen, T., and R. Shine. 1996. Lifetime reproductive success in adders (*Vipera berus*). Journal of Animal Ecology **63:**561–568.

Madsen, T., B. Stille, and R. Shine. 1996. Inbreeding depression in an isolated population of adders *Vipera berus*. Biological Conservation **75:**113–118.

Manansang, J., S. Hedges, D. Siswomartono, P. Miller, and U. S. Seal. 1996*a*. Anoa species (*Bubalus quarlesi* & *Bubalus depressicornis*) population and habitat viability assessment workshop report. Conservation Breeding Specialist Group, Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Manansang, J., A. Macdonald, D. Siswomartono, P. Miller, and U. S. Seal. 1996*b*. Babirusa (*Babyrousa babyrussa*) population and habitat viability assessment. Conservation Breeding Specialist Group, Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Marmontel, M., S. R. Humphrey, and T. J. O'Shea. 1997. Population viability analysis of the Florida manatee (*Trichechus manatus latirostris*), 1976–1991. Conservation Biology **11:**467–481.

Maschinski, J., R. Frye, and S. Rutman. 1997. Demography and population viability of an endangered plant species before and after protection from trampling. Conservation Biology **11:**990–999.

Master, L. L. 1991. Assessing threat and setting priorities for conservation. Conservation Biology **5:**559–563.

Master, L. L., B. A. Stein, L. S. Kutner, and G. A. Hammerson. 2000. Vanishing assets: conservation status of U.S. species. Pages 93–118 in B. A. Stein, L. S. Kutner, and J. S. Adams, editors. Precious heritage: the status of biodiversity in the United States. Oxford University Press, New York.

Matsuda, H., Y. Takenaka, T. Yahara, and Y. Uozumi. 1998. Extinction risk assessment of declining wild populations: the case of the southern bluefin tuna. Researches on Population Ecology **40:**271–278.

Matsuda, H., T. Yahara, and Y. Kaneko. 2000. Extinction risk assessment of threatened species. Population Ecology **42:**3–4.

Mattson, D.J., and M. M. Reid. 1991. Conservation of the Yellowstone grizzly bear. Conservation Biology **5:**364–372.

McCarthy, M. A., S. J. Andelman, and H. P. Possingham. 2003. Reliability of relative predictions in population viability analysis. Conservation Biology **17:**982–989.

McCarthy, M. A., D. C. Franklin, and M. A. Burgman. 1994. The importance of demographic uncertainty: an example from the helmeted honeyeater *Lichenostomus melanops cassidix*. Biological Conservation **67:**135–142.

Menkhorst, P., and D. Middleton. 1991. The helmeted honeyeater recovery plan 1989–1993. Department of Conservation and Environment, Melbourne, Victoria, Australia.

Miller, B., and K. J. Mullette. 1985. Rehabilitation of an endangered Australian bird: the Lord Howe Island woodhen *Tricholimnas sylvestris* (Sclater). Biological Conservation **34:**55–95.

Miller, P. S., and R. C. Lacy. 1999. VORTEX: a stochastic simulation of the extinction process. Version 8. User's manual. Conservation Breeding Specialist Group, Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Miller, R. S., D. B. Botkin, and R. Mendelssohn. 1974. The whooping crane population of North America. Biological Conservation **6:** 106–111.

Millsap, B. A., J. A. Gore, D. E. Runde, and S. I. Cerulean. 1990. Setting priorities for the conservation of fish and wildlife species in Florida. Wildlife Monographs **111:**1–57.

Minta, S. C., T. W. Clark, and P. Goldstraw. 1990. Population estimates and characteristics of the eastern barred bandicoot in Victoria, with recommendations for population modeling. Pages 47–75 in T. W. Clark and J. H. Seebeck, editors. Management and conservation of small populations. Chicago Zoological Society, Brookfield, Illinois.

Mirande, C., et al. 1997. Computer simulations of possible futures for two flocks of whooping cranes. Proceedings of the Seventh North American Crane Workshop **7:**181–200.

Morris, W. F., and D. F. Doak. 2002. Quantitative conservation biology:

theory and practice of population viability analysis. Sinauer Associates, Sunderland, Massachusetts.

Mrosovsky, N. 1997. IUCN's credibility critically endangered. Nature **389:**436.

Murphy, E. C., and K. R. Whitten. 1976. Dall sheep demography in McKinley Park and a reevaluation of Murie's data. Journal of Wildlife Management **40:**597–609.

Nolet, B. A., and J. M. Baveco. 1996. Development and viability of a translocated beaver *Castor fiber* population in the Netherlands. Biological Conservation **75:**125–137.

Noon, B. R., and K. S. McKelvey. 1996. Management of the spotted owl: a case history in conservation biology. Annual Review of Ecology and Systematics **27:**135–162.

O'Grady, J. J. 2002. Evaluating the accuracy of species assessment systems using population viability analysis. Ph.D. thesis. Macquarie University, Sydney.

O'Grady, J. J., D. H. Reed, B. W. Brook, and R. Frankham. 2004. What are the best correlates of predicted extinction risk? Biological Conservation **118:**513–520.

Palomares, F., A. Rodríguez, R. Laffite, and M. Delibes. 1991. The status and distribution of the Iberian lynx *Felis pardina* (Temminck) in Coto Doñana area, SW Spain. Biological Conservation **57:**159–169.

Peterson, R. O., and R. E. Page. 1988. The rise and fall of Isle Royale wolves, 1975–1986. Journal of Mammalogy **69:**89–99.

Peterson, R. O., R. E. Page, and K. M. Dodge. 1970. Wolves, moose, and the allometry of population cycles. Science **224:**1350–1352.

Peterson, R. O., N. J. Thomas, J. M. Thurber, J. A. Vucetich, and T. A. Waite. 1998. Population limitation and the wolves of Isle Royale. Journal of Mammalogy **79:**828–841.

Plissner, J. H., and S. M. Haig. 2000. Viability of piping plover *Charadrius melodus* metapopulations. Biological Conservation **92:**163–173.

Possingham, H. P., S. J. Andelman, M. A. Burgman, R. A. Medellin, L. L. Masters and D. A. Keith. 2002. Limits to the use of threatened species lists. Trends in Ecology & Evolution **17:**503–507.

Powell, A. N. 1991. Great Lakes piping plovers: recovery or extirpation? Endangered Species Update **8:**1–4.

Ralls, K., D. P. Demaster, and J. A. Estes. 1996. Developing a criterion for delisting the southern sea otter under the U.S. endangered species act. Conservation Biology **10:**1528–1537.

Reed, J. M., C. S. Elphick, and L. W. Oring. 1998. Life-history and viability analysis of the endangered Hawaiian stilt. Biological Conservation **84:**35–45.

Reidman, M.L., J. A. Estes, N. M. Staedler, A. A. Giles, and D. R. Carlson. 1994. Breeding patterns and reproductive success of California sea otters. Journal of Wildlife Management **58:**391–399.

Rodríguez, A., and M. Delibes. 1992. Current range and status of the Iberian lynx *Felis pardina* Temminck 1824, in Spain. Biological Conservation **61:**189–196.

Rohlf, D. J. 1991. Six reasons why the Endangered Species Act doesn't work–and what to do about it. Conservation Biology **5:**273–282.

Ryan, M. R., B. G. Root, and P. M. Mayer. 1993. Status of piping plovers in the Great Plains of North America: a demographic simulation model. Conservation Biology **7:**581–585.

Rylands, A., K. Strier, R. Mittermier, J. Borovansky, and U. S. Seal. 1998. Population and habitat viability assessment (PHVA) for the Muriqui (*Brachyteles arachnoides*). Conservation Breeding Specialist Group, Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Seal, U. S. 1990. Bali starling (*Leucopsar rothschildi*) viability analysis and species survival plan workshop report. Conservation Breeding Specialist Group, Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Seal, U. S. 1992*a*. Aruba Island rattlesnake (*Crotalus durissus unicolor*) population and habitat viability assessment. Conservation Breeding Specialist Group, Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Seal, U. S. 1992*b*. Kirtland's warbler (*Dendroica kirtlandii*) population and habitat viability assessment workshop report. Conservation Breeding Specialist Group, Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Seal, U. S. 1994. Attwater's prairie chicken (*Tympanuchus cupido attwateri*) population and habitat viability assessment. Conservation Breeding Specialist Group, Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Seal, U. S., and M. W. Bruford. 1991. Pink pigeon conservation viability assessment workshop. Conservation Breeding Specialist Group, Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Seal, U. S., and T. Foose. 1989. Javan rhinoceros (*Rhinoceros sondaicus*) population viability analysis. Conservation Breeding Specialist Group, Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Seal, U. S., P. Garland, D. Butler, A. Grant, and C. O'Donnell. 1991. Population viability analysis for Kea (*Nestor notabilis*) and Kaka (*Nestor meridionalis*). Conservation Breeding Specialist Group, Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Seebeck, J. H., A. F. Bennett, and A. C. Dufty. 1990. Status, distribution and biogeography of the eastern barred bandicoot, *Perameles gunnii*, in Victoria. Pages 21–32 in T. W. Clark and J. H. Seebeck, editors. Management and conservation of small populations. Chicago Zoological Society, Chicago.

Sheskin, D. J. 1997. Handbook of parametric and nonparametric statistical procedures. CRC Press, Boca Raton, Florida.

Sibley, F. C., R. D. Mallette, J. C. Borneman, and R. S. Dalen. 1969. Californian condor surveys 1968. California Fish and Game **55:** 298–306.

Siniff, D. B., and K. Ralls. 1991. Reproduction, survival and tag loss in Californian sea otters. Marine Mammal Science **7:**211–229.

Smales, I. J., S. A. Craig, C. A. Williams, and R. W. Dunn. 1990. The helmeted honeyeater: decline, conservation, and recent initiatives for recovery. Pages 235–238 in T. W. Clark and J. H. Seebeck, editors. Management and conservation of small populations. Chicago Zoological Society, Brookfield, Illinois.

Smallwood, K. S. 1994. Trends in California mountain lion populations. Southwestern Naturalist **39:**67–72.

Song, Y-L. 1996. Population viability analysis for two isolated populations of Hainan eld's deer. Conservation Biology **5:**1467–1472.

Spencer, D. L., and C. J. Lensink. 1970. The muskox of Nunivak island, Alaska. Journal of Wildlife Management **34:**1–15.

Suchy, W., L. L. McDonald, M. D. Strickland, and S. H. Anderson. 1985. New estimates of minimum viable population size for grizzly bears of the Yellowstone ecosystem. Wildlife Society Bulletin **13:**223–228.

Tilson, R. L., K. Soemarna, W. Ramono, S. Lusli, K. Traylor-Holzer, and U. S. Seal. 1992. Sumatran tiger population and habitat viability analysis workshop. Conservation Breeding Specialist Group, Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Walker, S. 1992. Manipur brow-antlered deer (*Cervus eldi eldi*) locally known as Sangai, population and habitat viability assessment. Conservation Breeding Specialist Group, Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Walkinshaw, L. H. 1993. Kirtland's warbler: the natural history of an endangered species. Cranbrook Institute of Science, Bloomfield Hills, Michigan.

Watson, J., C. Warman, D. Todd, and V. Laboudallon. 1992. The Seychelles magpie robin, *Copsychus sechellarum*: ecology and conservation of an endangered species. Biological Conservation **61:** 93–106.

Wayne, R. K., N. Lehman, D. Girman, P. J. P. Gogan, D. A. Gilbert, K. Hansen, R. O. Peterson, U. S. Seal, A. Eisenhawker, L. D. Mech, and R. J. Krumenaker. 1991. Conservation genetics of the endangered Isle Royale gray wolf. Conservation Biology **5:**41–51.

Werikhe, S., L. Macfie, N. Rosen, and P. Miller. 1997. Can the mountain gorilla survive? Population and habitat viability assessment for

Gorilla gorilla beringei. Conservation Breeding Specialist Group, Species Survival Commission, World Conservation Union, Apple Valley, Minnesota.

Wiegand, T., J. Naves, T. Stephan, and A. Fernandes. 1998. Assessing the risk of extinction for the brown bear (*Ursus arctos*) in the Cordillera Cantabrica, Spain. Ecological Applications **68:**539–570.

Wiemeyer, S. N. J., M. Scott, M. P. Anderson, P. H. Bloom, and C. J. Stafford. 1988. Environmental contaminants in Californian condors. Journal of Wildlife Management **52:**238–247.

Wilbur, S. R. 1980. Estimating the size and trend of the California condor population 1965–1978. California Fish and Game **66:**40–48.

Wilcox, L. 1959. A twenty year banding study of the piping plover. The Auk **76:**129–152.

Wykes, B. J. 1985. The helmeted honeyeater and related honeyeaters of Victorian woodlands. Pages 205–217 in A. Keast, H. F. Recher, H. Ford, and J. Trompp, editors. Birds of eucalypt forests and woodlands. Surrey Beatty and Sons, Chipping Norton, New South Wales.

Appendix. The 55 taxa used in this study (species/subspecies and common name); categorizations by the IUCN Red List (IUCN), the Florida Game and Freshwater Fish Commission (FG&FFC), and the NatureServe systems; the population viability analysis (PVA) models or packages used; the probability of extinction (P[E]) over 100 years determined using PVA; the year in which the taxon was assessed using data up to and including the year specified; the taxonomic level assessed; the taxon location; and major data sources.

Species/subspecies	*Common name*	*IUCN*^{a}	*FG&FFC*^{b}	*Nature-Serve*^{c}	*PVA*^{d}	*P(E) 100 years*	*Year*	*Taxonomic level assessed and modeled and locality*	*Major data source*
Alces alces	moose	VU	26.3	G2	r	11^{c}	1985	population: Isle Royale, Michigan, U.S.A.	Peterson et al. 1970
Amazona vittata	Puerto Rican Parrot	CR	66	G1	V	98	1975	subspecies: Luquillo Forest, Puerto Rico	Lacy et al. 1989
Astragalus cremnophylax	sentry milk-vetch	CR	55.9	G1	r	100^{c}	1990	population, Grand Canyon National Park, Arizona, U.S.A.	Maschinski et al. 1997
Babyrousa babyrussa babyrussa	babirusa	EN	31	G1	V	99	1996	population: Buru Island, Indonesia	Manansang et al. 1996b
Babyrousa babyrussa togeanensis	babirusa	EN	40	G1	V	99	1996	subspecies: Togian Islands, Indonesia	Manansang et al. 1996b
Brachyteles arachnoides	muriqui	CR	40.3	G1	V	0	1998	population: Estação Biológica de Caratinga population, Minas Gerais, Brazil	Rylands et al. 1998
Bubalus depressicornis	lowland anoa	CR	51	G1	V	100	1995	population: Tanjung Amolengu Wildlife Reserve, Sulawesi, Indonesia	Manansang et al. 1996a
Bubalus mindorensis	tamaraw	CR	49	G1	V	16	1996	population: Mount Iglit-Baco National Park, Sumatra, Indonesia	De Leon et al. 1996
Canis lupus	gray wolf	CR	37.3	G1	V	85	1978	population: Isle Royale, Michigan, U.S.A.	Peterson et al. 1970; Peterson & Page 1988; Wayne et al. 1991; Peterson et al. 1998
Castor fiber	beaver	CR	35	G1	C	0	1993	population: Biesbosch National Park, Netherlands	Nolet & Baveco 1996
Cervus eldi eldi	sangai	EN	54.6	G1	V	73	1994	subspecies: Keibul Lamjao National Park, Manipur, India	Walker 1992
Cervuce eldi hainanus	Hainan Eld's deer	CR	51.3	G1	V	1	1986	population 1: Hainan Island, China	Song 1996
Cervuce eldi hainanus	Hainan Eld's deer	CR	51.3	G1	V	1	1986	population 2: Hainan Island, China	Song 1996
Charadrius melodus	Piping Plover	LR	22	G2G3 (G2)	V	0	1996	metapopulation: Great Lakes/Northern Great Plains, U.S.A.	Wilcox 1959 Gaines & Ryan 1988; Haig & Oring 1988; Powell 1991; Haig 1992; Ryan et al. 1993; Plissner & Haig 2000
Chen caerulescens caerulescens	Lesser Snow Goose	LR	19	G2	RM	100^{c}	1987	population: La Pérouse Bay, Northern Manitoba, Canada	Cooch & Cooke 1991
Columba mayeri	Pink Pigeon	CR	49	G1	V	100	1991	species: Mauritius	Seal & Bruford 1991
Copsychus sechellarum	Seychelles Magpie Robin	CR	49	G1	V	100	1981	population: Frégate Island, Seychelles Islands, U.K.	Watson et al. 1992; Komdeur 1996
Crotalus durissus unicolor	Aruba Island rattlesnake	CR	45.7	G1	V	83	1992	subspecies: Aruba Island, Dutch Leeward Islands, Netherlands	Seal 1992a
Dendroica kirtlandii	Kirtland's Warbler	CR	61.6	G1	V	1	1971	species: Michigan, U.S.A.	Seal 1992b; Walkinshaw 1993
Dendrolagus matschiei	Matschie's tree kangaroo	CR	32.7	G2	V	100	1998	population: Huon Peninsula, New Guinea	Bonaccorso et al. 1998
Enhydra lutris nereis	southern sea otter	VU	43.6	G2	r	0^{c}	1994	population: central Californian coastal waters, U.S.A.	Estes 1981; Siniff & Ralls 1991; Reidman et al. 1994; Ralls et al. 1996
Felis concolor	cougar	CR	38.3	G1	C	0	1992	population: Santa Ana Mountain Range, California, U.S.A	Beier 1993; Smallwood 1994
Fratercula arctica	Common Puffin	VU	27	G2G3 (G2)	RM	0^{c}	1982	population: Isle of May, U.K.	Harris & Wanless 1991
Gorilla gorilla beringei	mountain gorilla	CR	52	G1	V	0	1989	population: Virunga Conservation Area, Democratic Republic of Congo/Rwanda/Uganda, Africa	Werikhe et al. 1997
Gorilla gorilla beringei	mountain gorilla	CR	49	G1	V	0	1997	population: Bwindi Inpenetrable Forest National Park, Uganda, Africa	Harcourt 1981; Werikhe et al. 1997
Grus americana	Whooping Crane	CR	45.6	G1	V	22	1968	population: Aransas National Wildlife Refuge, Texas, U.S.A.	Miller et al. 1974; Binkley & Miller 1983; Mirande et al. 1997; Brook et al. 1998
Gymnogyps californianus	California Condor	CR	46.7	G1	r	100^{c}	1980	species: California, U.S.A.	Sibley et al. 1969; Wilbur 1980; Wiemeyer et al. 1988
Himantopus mexicanus knudseni	Hawaiian Stilt	VU	24.7	G2	V	0	1995	subspecies: Hawaiian Islands, U.S.A.	Reed et al. 1998
Lasiorhinus krefftii	northern hairy-nosed wombat	CR	52.3	G1	r	5^{c}	1998	species: Epping Forest, Queensland, Australia	Crossman et al. 1994; Hoyle et al. 1995
Leontopithecus rosalia	golden lion tamarin	CR	55.6	G1	V	2	1998	population: Poço das Antas Biological Reserve, Brazil	Coimbra-Filho & Mittermeier 1977; Kierulff & de Oliveira 1996; Ballou et al. 1998

continued

Appendix. (continued)

Species/subspecies	Common name	IUCN[a]	FG&FFC[b]	Nature-Serve[c]	PVA[d]	P(E) 100 years	Year	Taxonomic level assessed and modeled and locality	Major data source
Leucopsar rothschildi	Bali Starling	CR	42.7	G1	V	100	1989	species: Bali Barat National Park, Bali, Indonesia	Seal 1990
Lichenostomus melanops cassidix	Helmeted Honeyeater	CR	52.6	G1	r	100	1987	species: Yellingbo, Victoria, Australia	Wykes 1985; Smales et al. 1990; Menkhorst & Middleton 1991; McCarthy et al. 1994; Akçakaya et al. 1995
Lipotes vexillifer	Baiji dolphin	CR	50.6	G1	V	99	1993	species: Yangtze River, China	Kaiya et al. 1994
Lynx pardinus	Iberian lynx	CR	42	G1	V	34	1993	metapopulation: Doñana National Park, Iberian Peninsula, Spain	Palomares et al. 1991; Rodríguez & Delibes 1992; Gaona et al. 1998
Nannopterum harrisi	Flightless Cormorant	LR	29.7	G2	RM	8[e]	1971	species: Galapagos Islands, Ecuador	Harris 1974
Nestor notabilis	Kea	EN	32	G1G2 (G1)	V	3	1997	species: Southern Alps, South Island, New Zealand	Seal et al. 1991
Ovibos moschatus	muskox	VU	38	G2	r	0[e]	1968	population: Nunivak Island, Alaska, U.S.A.	Spencer & Lensink 1970
Ovis aries	Boreray sheep	EN	34.3	G1	V	2	1976	population: Boreray Island, Scotland	Jewell et al. 1974; Clutton-Brock et al. 1991; Clutton-Brock et al. 1992; Clutton-Brock et al. 1996; Grenfell et al. 1998
Ovis aries	Soay sheep	VU	32.3	G2	V	0	1976	population: Hirta Island, Saint Kilda Archipelago, Scotland	Jewell et al. 1974; Clutton-Brock et al. 1991; Clutton-Brock et al. 1992; Clutton-Brock et al. 1996; Grenfell et al. 1998
Ovis dalli	Dall sheep	LR	28	G2G3 (G2)	RM	3[e]	1961	population: Mount McKinley National Park, Alaska, U.S.A.	Murphy & Whitten 1976
Panthera leo persica	Asiatic lion	EN	34	G1	V	0	1990	subspecies: Gir Forest, Gujarat, India	Ashraf et al. 1995
Panthera tigris sumatrae	Sumatran tiger	CR	48	G1	V	21	1992	population: Way Kambas National Park, Sumatra, Indonesia	Tilson et al. 1992
Panthera tigris sumatrae	Sumatran tiger	CR	46	G1	V	82	1992	population: Berbak National Park, Sumatra, Indonesia	Tilson et al. 1992
Perameles gunnii	eastern-barred bandicoot	CR	50	G1	V	100	1989	population: Hamilton, Victoria, Australia	Lacy & Clark 1990; Minta et al. 1990; Seebeck et al. 1990; Dufty 1994
Quadrula fragosa	winged mapleleaf mussel	EN	42.9	G1	V	0	1997	population: St. Croix River, Minnesota & Wisconsin, U.S.A.	Kjos et al. 1998
Rhinoceros sondaicus	Javan rhinoceros	CR	50	G1	V	82	1989	population: Ujung Kulon National Park, Java, Indonesia	Seal & Foose 1989
Strix occidentalis occidentalis	Californian Spotted Owl	EN	42.3	G1	RM	36	1991	metapopulation: Southern California, U.S.A.	Gutiérrez & Pritchard 1990; La Haye et al. 1994; Noon & McKelvey 1996
Thunnus maccoyii	southern bluefin tuna	CR	18	G3	r	96	1994	species: world's southern oceans	Matsuda et al. 1998
Trichechus manatus latirostris	Florida manatee	VU	38	G2	V	0	1991	subspecies: New World Atlantic Ocean	Marmontel et al. 1997
Tricholimnas sylvestris	Lord Howe Island Woodhen	EN	48.6	G1	V	2	1989	species: Lord Howe Island, Australia	Disney 1974a Disney 1974b; Miller & Mullette 1985; Brook et al. 1997a; Brook et al. 1997b
Tympanuchus cupido attwateri	Attwater's Prairie Chicken	CR	42	G1	V	100	1993	subspecies: Texas, U.S.A.	Seal 1994
Ursus arctos	brown bear	CR	51	G1	C	23	1995	population: Western population, Cordillera Cantabrica, Spain	Wiegand et al. 1998
Ursus arctos horribilis	grizzly bear	CR	42	G1	V	1	1978	population: Yellowstone National Park, Wyoming/Idaho/Montana, U.S.A.	Knight & Eberhardt 1985; Suchy et al. 1985; Eberhardt et al. 1986; Mattson & Reid 1991; Eberhardt et al. 1994; Brook et al. 2000
Vipera berus	viper	CR	50.3	G1	r	98[e]	1990	population: Smygehuk, Sweden	Madsen & Shine 1996; Madsen et al. 1996
Zosterops lateralis chlorocephala	Capricorn silvereye	EN	34	G1	V	85	1979	population: Heron Island, Queensland, Australia	Degnan 1993; Eguchi 1993; Brook & Kikkawa 1998

[a] *Threat categories of the IUCN system in decreasing order of threat: CR, critically endangered; EN, endangered; VU, vulnerable; and LR, lower risk.*

[b] *In the systems of the FG&FFC, the higher the point score assigned the more threatened the taxon.*

[c] *Threat categories of the NatureServe system in decreasing order of threat: G1, G2, G3, G4, and G5. Where two categorizations are given, they are range ranks to span the range of uncertainty and the categorization in parentheses is the rounded rank.*

[d] *Type of population viability analysis model used: C, custom written; V, VORTEX (or its precursor);* r, *count-based* r *model; RM, RAMAS Metapop.*

[e] *Taxa for which a new population viability analysis was done for this study.*