ELSEVIER
Biological Conservation □ (□□□□) □–□
BIOLOGICAL CONSERVATION
www.elsevier.com/locate/biocon

Setting priorities for conservation: the influence of uncertainty on species rankings of Indiana mammals

Shannon M. Knapp*, Robin E. Russell, Robert K. Swihart

Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907-1159, USA

Received 21 December 2001; received in revised form 15 June 2002; accepted 15 August 2002

Abstract

Systems for ranking species can aid governmental agencies and other groups in determining conservation priorities. However, current systems rarely account for the effects that uncertainty, i.e. incomplete knowledge of a species or biological variability within a species, may have on determining a species' rank. We tested whether three methods of incorporating uncertainty into a ranking system produced changes in conservation priorities. Our analysis focused on 55 species of mammals native to Indiana, USA. Uncertainty was incorporated into a ranking system by permitting survey respondents to assign probabilities to each category of a question. The ranks between species priority scores for methods with and without uncertainty were highly correlated. All methods gave results comparable to the qualitative ranking system currently in use. However, some species of conservation concern received substantially different ranks across methods. We recommend using a variety of scoring methods to produce a robust assessment of a species' conservation status.

Keywords: Ranking system; Uncertainty; Indiana mammals; Conservation priority; Threatened and endangered species

---

1. Introduction

Conservation programs rarely receive funding sufficient to address more than the most urgent concerns. Not surprisingly, methods for prioritizing potential target species in terms of their conservation status (i.e. degree of threat, *sensu* Todd and Burgman, 1998) are integral components of the conservation planning process (IUCN, 1994; Mace, 1994). Qualitative methods for categorizing species according to risk (e.g. US Fish and Wildlife Service, 1983, Fitter and Fitter, 1987) are appealing because they are simpler and less reliant on difficult-to-gather data. However, such methods suffer from a nearly complete reliance on expert opinion and difficulty in assigning species to distinct categories of risk (Mace and Lande, 1991). Quantitative methods for prioritizing species range from simple indexes depending on a few relatively easily measured variables (e.g. Freitag and Van Jaarsveld, 1997; Cofré and Marquet, 1999) to fairly sophisticated systems of assigning points for various biological, life history, and management variables (e.g. Millsap et al., 1990). Adoption of quantitative methods has been hampered by lack of data (Ceballos and Navarro, 1991; Mace, 1994), but their objectivity and repeatability are desirable attributes not found in qualitative methods (Todd and Burgman, 1998).

None of the methods referenced earlier consider uncertainty of information when prioritizing species, even though uncertainty has been acknowledged as an issue that needs to be addressed (IUCN, 1994; Mapstone, 1995). Uncertainty may take many forms, including sampling variation, inherent stochasticity in time or space, missing or incomplete information, subjective judgment, and the use of inexact terminology (Morgan and Henrion, 1990; Akçakaya et al., 2000; Regan et al., 2000). Consideration of uncertainty acknowledges that a range of possible outcomes may exist, rather than a single outcome. Recently, several authors have considered methods for incorporating uncertainty into systems for setting conservation priorities. Todd and Burgman (1998) suggested the use of fuzzy sets as a means of incorporating uncertainty from expert opinion together with probabilistic variation into point-scoring systems. Burgman et al. (1999a) demonstrated the use of probabilistic rule sets, thereby permitting

---

* Corresponding author. Tel.: +1-765-494-3599.
E-mail address: knappsm@purdue.edu (S.M. Knapp).

0006-3207/02/$ - see front matter © 2002 Published by Elsevier Science Ltd.
PII: S0006-3207(02)00278-1

the confidence interval for each parameter to be considered explicitly when setting conservation priorities. For The World Conservation Union (IUCN) criteria, Regan et al. (2000) proposed using fuzzy boundaries when faced with inexact terminology for conservation categories and ranking criteria, and Akçakaya et al. (2000) proposed an alternative method for incorporating uncertainty when assigning species to categories. Incorporation of uncertainty intuitively should provide a substantial advance over methods based on point estimates. Illustrative examples based on hypothetical species (Todd and Burgman, 1998) or selected case studies (Burgman et al., 1999a, Akçakaya et al., 2000) have demonstrated methods for incorporating uncertainty into prioritization schemes. These examples also demonstrated how consideration of uncertainty can change assessment of a species' conservation status. However, a systematic appraisal of the effects of uncertainty requires a comparison of species rankings, for an array of species, from a scoring system with and without uncertainty. Burgman et al. (1999b) recently reported on such a comparison for threatened Australian plant species. They concluded that the choice of the way in which uncertainty is treated may have substantial effects on the subsequent assessment of risk. Here we examine the generality of their conclusion by applying the point-scoring system of Millsap et al. (1990) to mammals of Indiana, USA. We focused on Indiana mammals because the state lacked a systematic appraisal method. Moreover, a comparative assessment of methods was facilitated by the relatively low number of mammal species in Indiana and by the willingness of specialists there to assist in the rating process. Point estimates were compared with three methods for incorporating uncertainty (Todd and Burgman, 1998; Burgman et al., 1999a). Our objective was to determine whether changes in risk assessment occurred as a consequence of incorporating uncertainty into species conservation priorities.

2. Methods

2.1. Survey

We developed a survey based primarily on the categorical point-scoring method developed by Millsap et al. (1990) for Florida fish and wildlife species. Cut-off points for categories were adjusted where needed for appropriateness for Indiana mammals (e.g. young per adult female per year ranging from <1 to >3 versus <1 to >100). A total of 18 questions regarding the biology and basic population parameters of each species were used in the final analysis (Appendix). Surveys were sent to members of the Indiana Department of Natural Resources (IDNR) Technical Advisory Committee on Mammals and additional specialists suggested by IDNR personnel. Surveys were completed independently by 3–7 reviewers for each species. Three reviewers completed surveys for all 55 mammal species.

For each question, reviewers were asked to estimate the probability that a species fell into a category. For 3 questions (Nos. 16–18, Appendix), reviewers were asked to estimate the relative frequency with which the species fell into each category. The questions used to rank species were based on parameters taken from the species' entire distribution (e.g. global population size). We also included several questions designed to gauge the conservation status of the species in Indiana, because state agencies may wish to prioritize species based on conservation criteria within the jurisdiction of their agency in addition to global criteria. If a parameter was estimated for both the state- and global-scales, we reduced the points for each category by half so that the contribution of the parameter to the final score would be similar to that of Millsap et al. (1990).

Reviewers were asked to rate their level of knowledge for each species; each of the five possible levels was assigned a weight (Table 1). We calculated the average probability, weighted by the reviewers' level of expertise, for each category. The reviewer-weighted average was then used to calculate each of the scores. We used three of the four Action Variables from Millsap et al. (1990) to gauge reviewer perceptions about the level of knowledge available for each species (Appendix). These were not incorporated into the conservation scores used to rank each species.

2.2. Methods for computing conservation scores

We incorporated uncertainty by computing a score for each species using a weighted average (WA), a probabilistic rule set (P90), and fuzzy sets (FS). These were compared to an equivalent system (PS) that did not incorporate uncertainty. The PS score was calculated by summing across all biological questions the point value assigned to the category with the highest probability. This is analogous to a situation where reviewers are asked to come to a consensus on each category for a species (e.g. Millsap et al., 1990; Kirkland and Krim, 1990). Weighting by expertise reflects the increased influence that those with more experience with a species or taxon might have over a group. Although the mean or median category might seem a reasonable option, we elected to use the category with the highest probability because we felt that this most closely reflected what an individual or group would select when required to select only one category. Scores for action variables also were calculated using the point system.

For the P90 score, we followed the suggestion of Burgman et al. (1999a) and used the highest-valued category containing the 90th percentile for each question. Using confidence limits may provide a better

Table 1
Levels of reviewer expertise and associated weights

Level	Description	Weight (points)
Average	General knowledge only; have never engaged in research or management activities for the species or any other species in its family	1
Fair	General knowledge combined with 1–3 years of research or management for the target species or a species within the same family	1.25
Good	Specialized knowledge derived from 3 to 5 years of research or management activities for the target species or congeneric species	1.5
Very Good	Specialized knowledge derived from > 5 years of research or management activities for the target species; acknowledged as one of the top 3–4 experts in the state on this species	1.75
Excellent	Specialized knowledge derived from > 10 years of research or management activities for the target species; acknowledged as one of the top 3–4 experts in the midwest on this species	2

means of ensuring that threatened species are not overlooked (Burgman et al., 1999a).

We followed the methods outlined by Todd and Burgman (1998) to calculate the FS score. We multiplied the probability of each category to get the overall probability of that combination of categories (algebraic product method, Todd and Burgman, 1998). This was done for all possible combinations of categories. We also calculated the score associated with each combination of categories. Several different combinations of categories might yield the same total score, so we summed the probabilities of all combinations with the same total score to get the total probability for that score. We then selected the score with the highest probability as our FS score (Todd and Burgman, 1998).

Because there were nearly 5×10^{11} possible combinations of categories using all 18 questions, the following modifications had to be made. We used a subset of 14 questions to calculate the fuzzy set score (Appendix). The four deleted questions each concerned global population parameters (e.g. global population size) and had corresponding questions for state-level population parameters. Eliminating four questions reduced the number of possible combinations to 6.8×10^{8} and allowed all possible combinations for a species to be calculated using a C program in approximately 10 minutes using a 266 MHz TM processor. Where global-level questions were excluded, the points for the paired state-level questions were doubled to maintain the contribution of that parameter to the overall score. We compared FS scores to an equivalent point system based on the same set of 14 questions and point-weightings, because the fuzzy set scores were based on only 14 questions and differences in the questions used can contribute to difference in ranks and standardized scores.

Scores for WA were calculated from the product of the estimated probability associated with each category and the score for the category,

$$\sum_{i=1}^{18}\sum_{j=1}^{7}X_{ij}P_{ij},$$

i = question number, j = response category, X = point value for category, P = probability.

2.3. Calculating variance

We calculated a probability distribution of all possible scores for each species, using the product of all possible combinations of categories. Due to the large number of combinations and the prohibitive computing time, the same 14 questions and points that were used to calculate the fuzzy set scores were used to calculate the distribution of scores. The fuzzy set score is equivalent to the mode of this distribution. Because only a subset of questions was used, the estimate of variance was considered an index of the total variance in scores for the species. Variance for each species was calculated by

$$\sum_{i=0}^{99}P_i\left(i-\bar{i}\right)^2,$$

where the possible scores i range from 0 to the maximum score of 99, $\bar{i}$ is the mean score, and P_i is the probability associated with score i for a particular species.

2.4. Statistical analysis

From the raw scores for each system, we calculated the ranks and standardized z-scores for each species. In cases where scores were tied between two or more species, the median rank was used. Larger raw scores and z-scores are associated with smaller ranks, indicating a greater conservation priority.

We measured the disparity between the methods of computing scores in two ways. We examined the number of positions each species moved in the ranking using the absolute value of the difference between ranks in each uncertainty system and the point system. We also correlated the ranks and z-scores of species between each uncertainty system and the equivalent point system.

Species were classified as either listed or non-listed, based on prior qualitative assessment of conservation status: listed species were defined as those that are state or federally endangered or state species of special concern (Table 2). There are no federally threatened mammals in Indiana and the state of Indiana has no ‘‘threatened’’ classification. We used *t*-tests to determine whether the variance in scores differed between listed and non-listed species.

Residuals of the regressions between each uncertainty method and the equivalent point system were examined for the effect of current conservation status (listed versus non-listed species) using a *t*-test and for the effect of taxonomic Order using an ANOVA. Due to sampling size constraints, only orders Insectivora, Chiroptera, Rodentia, and Carnivora were compared.

To summarize information contained in the four scoring methods, we conducted a principal components analysis. A frequency distribution of scores from the first principal component (PC1) was created to identify potential ‘‘cut off’’ points for species of high conservation priority. We correlated PC1 with the scores for Action Variables to determine whether a trend existed between conservation priority and knowledge about a species. We also plotted PC1 against the scores for Action Variables to identify potential research priorities among species.

2.5. Quantifying uncertainty

To determine whether the scores from Action Variables were linked to levels of uncertainty, we computed correlation coefficients between Action Variables and the index of variance in scores calculated from the probability distribution. Variance in the response to a particular question for a particular species may be due to biological uncertainty, to disagreement between reviewers (each of whom might be highly confident about his response), or to a combination of these factors. In an attempt to partition this variance, we correlated species’ scores for a pair of related variables: a biological variable (No. 7: Geographic range in Indiana) and an Action Variable (No. 1: Knowledge of distribution in Indiana; see Appendix). We predicted that if knowledge of distribution was rated as high for a given reviewer, then the response for geographic range in Indiana should have a low variance for that reviewer. We calculated a score for biological variable No. 7 and action variable No. 1 using WA. We then calculated the variance of biological variable No. 7,

$$\sum_{i=1}^{10} P_i\left(i-\bar{i}\right)$$

where the possible scores i range from 0 to the maximum score of 10. We correlated the scores for each of the two variables using all reviewers and again using only the three reviewers that completed surveys for all 55 Indiana mammal species to determine if some reviewers may have been more consistent than others.

3. Results

3.1. Species ranks

All 55 species of mammals native to Indiana were ranked in descending order of conservation priority for each of the five methods of computing scores (Table 2). The chiropterans *Myotis austroriparius* and *Corynorhinus rafinesquii* were ranked or tied for first and second position, respectively, by all methods. Also ranking in the top 10 with all methods were two other bat species, *Myotis grisescens* and *Nycticeius humeralis*, two rodents, *Neotoma magister* and *Spermophilus franklinii*, and a reintroduced carnivore, *Lontra canadensis*. All of these species were listed as endangered either federally or at the state level, except *Corynorhinus rafinesquii*, which is a species of special concern in Indiana (Table 2). The federally endangered chiropteran, *Myotis sodalis*, ranked in the top 10 with WA and P90. A lagomorph listed as state-endangered in Indiana, *Sylvilagus aquaticus*, ranked in the top 10 for all methods except P90. An insectivore of special concern in Indiana, *Condylura cristata*, ranked in the top 10 for all methods except WA and P90 (Table 2). The only notable departure from the listed conservation status of species was a rodent, *Reithrodontomys megalotis*, which ranked among the bottom 10 species for all methods despite being regarded as a species of special concern in Indiana (Table 2).

3.2. Concordance between methods

Correlations based on ranks and standardized *z*-scores between PS (uncertainty not incorporated) and WA, P90, and FS (uncertainty incorporated) ranged from 0.873 to 0.971 (Table 3). The lowest correlations and highest average change in position occurred in P90. The smallest changes in rank occurred when comparing PS and WA, although changes were comparable for FS (Table 3). The correlations between standardized *z*-scores ($r = 0.989$) and ranks ($r = 0.993$) were highly significant for the two PS methods (14 and 18 questions), indicating a close correspondence. The mean change in rank was 1.3.

Analysis of variance on residuals derived from regressions between scores for methods with and without uncertainty indicated that changes in relative conservation status of mammalian Orders generally were minimal. However, carnivores exhibited an increase in average conservation priority when WA was used

Table 2
Ranks for 55 species of Indiana mammals using PS (18 questions and 14 questions), WA, P90, and FS, and 90% Confidence Interval for scores from the computed distribution

Species	PS 18 ranks	PS 14 ranks	WA ranks	P90 ranks	FS ranks	90% CI scores
*Myotis austroriparius**	1	1	1	1.5	1	64–84
Corynorhinus rafinesquii[a]	2	2	2	1.5	2	48–76
*Neotoma magister**	3	3	5	10	6	45–62
*Myotis grisescens***	4	5.5	4	5	3	46–64
*Sylvilagus aquaticus**	5	5.5	7	13	4.5	42–62
*Nycticeius humeralis**	6	5.5	8	7	8	36–60
*Spermophilus franklinii**	7	5.5	6	3	7	42–64
*Lontra canadensis**	8	8	3	4	4.5	46–68
Lasionycteris noctivagans	9.5	10	14	14.5	13	32–55
Condylura cristata[a]	9.5	9	11	11.5	10	37–57
*Myotis sodalis***	11	14	9	8	13	34–56
Mustela nivalis[a]	12	13	12	9	11	33–63
Myotis keenii	13	15	13	14.5	15	32–50
*Lynx rufus**	14.5	11	10	6	9	39–60
Geomys bursarius[a]	14.5	12	18	22.5	13	34–48
Castor canadensis	16	18	16	25	19	31–41
Urocyon cinereoargenteus	17	16	20	32	24	24–33
Pipistrellus subflavus	19	22	17	20	17	28–47
Lasiurus cinereus	19	18	21	21	19	26–46
Myotis lucifugus	19	22	19	24	21.5	28–41
Sorex hoyi[a]	21	18	23	17	21.5	25–44
Glaucomys volans	22	24	25	31	26.5	22–37
Sorex fumeus[a]	23	20	26	29	23	24–39
*Taxidea taxus**	24	22	15	11.5	16	29–48
Lasiurus borealis	25.5	26	30	39.5	26.5	19–35
Marmota monax	25.5	26	22	18	26.5	20–42
Vulpes vulpes	27	26	24	41	19	28–42
Eptesicus fuscus	28	28.5	33	22.5	34.5	17–35
Canis latrans	29	28.5	27	37.5	34.5	22–37
Sciurus carolinensis	30.5	32.5	31	30	30	20–35
Mustela vison	30.5	32.5	28	33	26.5	21–34
Spermophilus tridecemlineatus	32	30.5	29	16	30	18–39
Sorex longirostris	33	30.5	37	26	30	18–37
Cryptotis parva	34	34	35	19	37.5	16–37
Mephitis mephitis	35	35	32	28	36	19–36
Microtus ochrogaster	36	39	46	51	44	13–22
Ondatra zibethicus	38	39	42	45	44	14–26
Tamiasciurus hudsonicus	38	36	38	34	32.5	19–35
Odocoileus virginianus	38	39	36	35	44	17–39
Mustela frenata	40	39	34	27	32.5	20–34
Sorex cinereus	41	39	43	39.5	39	14–32
Microtus pinetorum	42	43	39	36	37.5	15–32
Sylvilagus floridanus	43	43	52	54	52.5	9–17
Blarina brevicauda	44	45	51	47	51	9–25
Scalopus aquaticus	45	46.5	45	43.5	46.5	12–27
Procyon lotor	46	46.5	41	50	42	15–26
Tamias striatus	48	49	48	48	48	11–23
Sciurus niger	48	49	40	37.5	40.5	20–35
Zapus hudsonius	48	49	50	43.5	49.5	10–25
Didelphis virginiana	51	51.5	47	46	49.5	13–27
Synaptomys cooperi	51	51.5	49	49	46.5	10–26
Reithrodontomys megalotis[a]	51	43	44	42	40.5	18–33
Microtus pennsylvanicus	53	53	53	53	54	6–15
Peromyscus maniculatus	54	54	54	52	52.5	5–20
Peromyscus leucopus	55	55	55	55	55	4–15

See text for an explanation of scoring systems. ** Indicates species recognized as endangered at both federal and state levels. *Indicates species recognized as endangered only at the state level.

[a] Indicates species of special concern in Indiana, a less critical status than endangered.

Table 3
Measures of concordance between conservation scores for 55 species of Indiana mammals using a scoring method that did not incorporate uncertainty (PS) and methods incorporating uncertainty

Statistic	Concordance with PS		
	18 Questions		14 Questions
	WA	P90	FS
Correlation *z*-scores	0.969	0.873	0.968
Correlation, ranks	0.971	0.892	0.971
Mean change	2.8	53.8	2.9
Median change	2	5	2.5
Modal change	0	4	1
Minimum change	0	0	0
Maximum change	10	16	9.5

Point-based scoring systems were derived from Milisap et al. (1990) and consisted of either 18 questions or 14 questions. Scoring methods incorporating uncertainty included a weighted average (WA), a probabilistic rule set based on the 90th percentile (P90), and fuzzy sets (FS). See the text for details regarding scoring systems. Concordance was measured as the correlation between standardized *z*-scores computed for each scoring method, and also as the correlation between conservation rankings. The absolute value of the change in species rank between scoring methods that did and did not incorporate uncertainty was computed, and mean, median, and modal changes are reported, as well as the minimum and maximum change observed across all species.

($F = 6.24$, df = 3, $P < 0.001$). Listed species ranks were not significantly different between any two methods. As expected, ranks were significantly lower and *z*-scores were significantly higher for listed species than non-listed species for all methods ($t > 6.1$, df = 53, $P < 0.0001$ for all comparisons), indicating a greater conservation priority for listed species.

As expected, given the high level of correlation between each of the scoring methods, all four variables exhibited large loadings on the first principal component. We interpreted PC1, which accounted for 95.4% of the variation in the four methods, as a combined conservation score. Thirteen of the fifteen largest PC1 scores were for listed species. Two unlisted bat species, *Myotis keenii* and *Lasionycteris noctivagans*, had PC1 scores comparable to many listed species (Fig. 1). Four species of special concern (*Sorex hoyi, Sorex fumeus, Geomys bursarius,* and *Reithrodontomys megalotis*) had PC1 scores less than 0.5, suggesting overestimation of their conservation status using the qualitative system.

The plot of Action Variable scores versus PC1 scores illustrates the relationship between the amount of information known about a species and the species conservation priority (Fig. 1). In particular, species located in quadrant I exhibit biological attributes which render them susceptible to extinction and for which little information exists. Five non-listed species, all chiropterans, and eight listed species are located in quadrant I. All species located completely within quadrant III, reflecting low conservation priority and adequate biological information, are non-listed. *Reithrodontomys megalotis*, a species of special concern, is located in quadrant II indicating a low conservation priority but a lack of information regarding the species. There was no correlation between PC1 and the Action Variable Score ($r = 0.025$, $P > 0.50$).

3.3. Variance calculations

The index of variation in scores was significantly greater for listed species than for non-listed species ($t = 4.12$, df = 53, $P = 0.001$). The correlation between variance and the Action Variable score was 0.403 ($P < 0.01$). The correlation between the knowledge of geographic distribution question (Action Variable No. 1) and the variance in Biological Variable No. 7 regarding geographic distribution was 0.32 using all reviewers ($P < 0.001$) and 0.28 ($P < 0.05$), 0.41 ($P < 0.005$), and 0.36 ($P < 0.01$) for the three reviewers who completed all 55 surveys.

4. Discussion

Overall, there was a high concordance between the conservation rankings generated by methods incorporating uncertainty and the equivalent method without uncertainty. In a general sense, ranking methods based on point-estimate scores appear to adequately represent a species' conservation status in Indiana. However, methods incorporating uncertainty can provide useful information and merit additional consideration. We discuss four possible explanations for the results we obtained, and explain our reasons for supporting the use of multiple scoring methods when assessing species conservation priorities.

First, and most importantly, it is impossible to determine which method of incorporating uncertainty is "best" or even whether incorporating uncertainty increases the accuracy of a ranking system. Without an independent measure of the "true" ranking of species, we were only able to compare results between different methods and with the qualitative methods currently being used in Indiana. Nonetheless, using a variety of scoring methods should result in a more robust assessment of a species' conservation status, because each method differs in how extinction risk is quantified. Numerous techniques are possible for combining results derived from different scoring methods, including cluster analysis or principal components analysis (Fig. 1).

Second, the high correlations we found between ranks generated using methods with and without uncertainty reflect the similarity between ranks for all 55 mammal species in Indiana. Large differences in ranks between methods would cause great concern regarding the reliability and applicability of the scoring methods. However, few species demonstrated substantial shifts

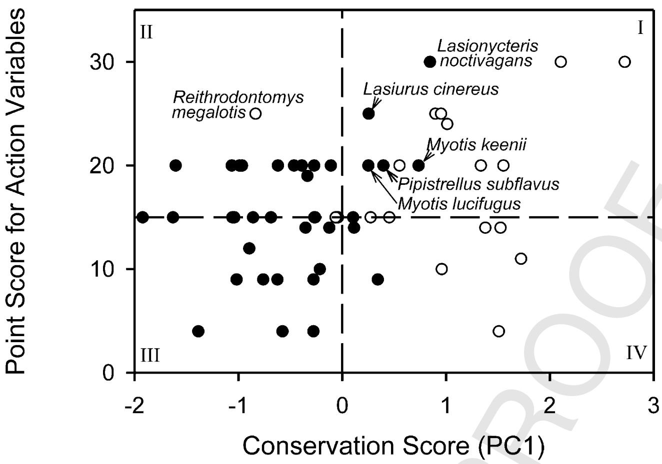

Fig. 1. Plot of the point score for Action Variables (Appendix) versus a composite conservation score derived from principal components analysis. Principal component scores were computed from our point-scoring, fuzzy set, probabilistic rule set, and weighted average methods. Scores from the first principal component explained 95.4% of the total variation in scores. The first principal component represents an average conservation score for each species and is plotted on the abscissa. Larger scores indicate greater conservation concern. Greater scores for action variables indicate less knowledge of a species' biology. Open circles designate state-listed species of Indiana mammals. Quadrant cut points were based on the origin for PC1 and the median score for Action Variables. Conservation scores, which are based on Biological Variables, were much greater for listed than for non-listed species ($t = 6.74$, 25 df, $P < 0.0001$). Scores for Action Variables did not differ between listed and non-listed species ($t = 1.71$, 25 df, $P = 0.12$).

between methods. For example, *Lynx rufus*, a state endangered species, had a rank of 14.5 under PS and increased to a rank of 6 under P90. *Taxidea taxus*, also a state endangered species, ranked 24th under PS and increased to a rank of 11.5 under P90. Alternatively, the state endangered *Sylvilagus aquaticus* ranked fifth under PS but dropped to 13th under P90, and the state endangered *Neotoma magister* ranked third under PS but dropped to 10th under P90.

Taxonomic groups above the level of species also may differ systematically in their rankings between methods. For instance, carnivores in Indiana were a greater conservation priority on average under WA than under PS. Using a variety of ranking methods may help to identify vulnerable species or groups of species that might otherwise be undetected.

Third, states with a greater number of endemic or endangered species than Indiana could yield greater differences between methods than we detected. Indiana includes only two federally listed species and no endemic species. In addition, if a broader array of taxa in the state had been ranked (e.g. plants, fungi, invertebrates, vertebrates), uncertainty likely would have had a greater impact on conservation rankings. For example, little is known about many species of invertebrates (relative to most mammals and birds). Presumably, their ranks would change more than birds or mammals between a method that incorporates uncertainty and one that does not.

Finally, our point-estimate-based systems used several questions (14 or 18), and these questions were not independent. For example, two questions (Nos. 17 and 18, Appendix) addressed a species' intrinsic population growth rate, and, therefore, its potential to recover from population crashes. In addition, several questions were focused on population and range sizes and trends. Inclusion of several related questions might account for some of the variation attributable to uncertainty. Overestimates for some questions might be negated by underestimates for other, related questions, so that with a large number of questions, effects of uncertainty for individual questions may balance out in the final score used to rank the species. Uncertainty may have greater effects on systems based on very few questions (e.g. Cofré and Marquet, 1999). Using multiple, independent reviewers for each species and taking a point estimate from the average score of each reviewer may also have served to incorporate some of the effects of uncertainty by averaging out differences.

The ranks presented here are dependent on the system of questions used. The questions used, although reasonable, are not exhaustive. Likewise, the weighting of questions, cut-off points for categories, points assigned to categories, and weights assigned to a reviewer's level of expertise are reasonable but arbitrary. Different sets of questions or different methods of quantification could produce different results (Burgman et al., 1999b). Action Variables also could have a significant impact on rankings if incorporated into the scores. We ranked species on purely biological attributes that would affect the risk of extinction and the potential for population recovery. Including factors that assessed how much is known about a species would have lowered the ranks of many endangered species. Species with the most known about their biology or the most intensive monitoring tend to fall at opposite ends of the spectrum—the very plentiful game or commercially harvested species (e.g. *Odocoileus virginianus*) and the very rare (e.g. *Gymnogypsus californianus*). Keeping knowledge variables separate would allow agencies to specifically target research towards species that have greater conservation priority but about which little is known (e.g. Fig. 1, quadrant I).

4.1. Implications for conservation of Indiana mammals

Reithrodontomys megalotis ranked near the bottom of the list for all scoring methods (ranks ranged from 40.5 to 51), suggesting that it be removed from the state's list of Species of Special Concern. However, the plot of Action Variables versus principal component scores (Fig. 1) indicates that additional information regarding this species may be appropriate. The location of *Reithrodontomys megalotis* in quadrant II suggests that although its conservation priority is relatively low, little is known about the species' biology. *Reithrodontomys megalotis* is a relatively recent immigrant to northwest Indiana, where it initially occupied a restricted range of sites. Few studies have been done on the species in the state, but it has expanded its range steadily to the south and east since its arrival in the 1960s (Mumford and Whitaker, 1982, unpublished data).

Chiropterans as a group consistently ranked as high conservation priorities. The 12 chiropteran species in Indiana constituted 5 of the 10 species of greatest concern under PS, WA, P90, and 4 of the top 10 species under FS. Two chiropteran species in particular stood out as good candidates for additional research or protection: *Lasionycteris noctivagans* and *Myotis keeni* are not state or federally listed, but they ranked from 9.5 to 14.5 and 13 to 15, respectively, and were very close in rank to the federally endangered *Myotis sodalis* under all methods. Moreover, the plot of Action Variable score versus PC1 indicates that these two species, along with the other three species of non-listed chiropterans located in quadrant I, should be considered for listing and prioritized for future study (Fig. 1).

Based partly on the analysis conducted here, the Mammal Technical Advisory Committee to the Indiana Department of Natural Resources has recommended adding the species of bats mentioned in the preceding paragraph to the state's list of Species of Special Concern and removing *Reithrodontomys megalotis* from the list.

4.2. Recommendations

We believe there are benefits to incorporating uncertainty into ranking systems. When used in conjunction with traditional ranking systems based on point estimates of parameters, uncertainty-based systems can highlight species that may otherwise be overlooked.

Of the three methods of incorporating uncertainty that we tested, WA seemed to provide the best balance between straightforward calculation and incorporating the full probability distribution. FS becomes prohibitively time consuming to calculate when too many questions and categories are used in the ranking system, making it impractical in some instances. An additional problem with FS can occur if the distribution of scores for a particular species is bimodal, because a score at one extreme may be selected when the probability is only minutely different from the secondary mode at the other extreme. P90 is simple to calculate and is intended to err toward a conservative assessment of a species' conservation status. However, as much information about the probability distribution of scores is lost with P90 as with PS, because it simply supplants one point estimate (the mean or mode of a population parameter) with another (the 90th percentile of the population parameter).

Ultimately, incorporating uncertainty into ranking systems is a poor substitute for improved knowledge. Additional funding and research is needed to diminish the uncertainty we have about the basic biology and natural history of species and to monitor their populations more accurately. By increasing knowledge about species' biology, the influence of uncertainty on conservation rankings can be reduced.

Uncited reference

Keith, 1998; Lunney et al., 1996

Acknowledgements

For their participation in the conservation survey, we thank Todd Atwood, Tom Gehring, Jacob Goheen, Ralph Kirkpatrick, James Mitchell, Harmon Weeks, Jr., Rod Williams, and especially Scott Johnson and John Whitaker, Jr. Helpful comments on the manuscript were provided by Todd Atwood, Scott Johnson, Katie Smith, John Whitaker, Jr., Brian Millsap, and one anonymous reviewer. This is Purdue Agricultural Research Programs manuscript number 16660.

Appendix

Questions, categories, and points for Biological and Action Variables. Two point systems were used: (1) the full set of 18 Biological Variables was used for the PS, P90, and WA scores; (2) a set of 14 questions was used to calculate FS score, the score variance index, and a 14-question PS score.

Biological Variables	Points	
	18	14
1. Global population size: What is the size of the adult population (i.e. abundance) throughout its entire range?		
a. 0–1000	5	–
b. 1001–5000	4	–
c. 1001–10,000	3	–
d. 10,001–50,000	2	–
e. 50,001–100,000	1	–
f. >100,000	0	–
2. Total population size in Indiana: What is the size of the adult population (i.e. abundance) in Indiana?		
a. 0–100	5	10
b. 101–500	4	8
c. 501–3000	3	6
d. 3001–10,000	2	4
e. 10,001–50,000	1	2
f. >50,000	0	0
3. Global population trend: What is the overall trend in population size throughout the species' range over the last 20 years? Include both the natural range of the species and areas it had not historically occupied but to which it was introduced by humans. If population trend is unknown, consider trends in the availability and condition of the species' habitat as indicative of population trend.		
a. Population size known to be decreasing	5	5
b. Trend unknown but population size suspected to be decreasing	4	4
c. Population formerly experienced serious declines but is presently stable or increasing	3	3
d. Population size stable or suspected to be stable or increasing	1	1
e. Population size known to be increasing	0	0
4. Population trend in Indiana: What is the trend in population size in Indiana over the last 20 years?		
a. Population size known to be decreasing	5	5
b. Trend unknown but population size suspected to be decreasing	4	4
c. Population formerly experienced serious declines but is presently stable or increasing	3	3
d. Population size stable or suspected to be stable or increasing	1	1
e. Population size known to be increasing	0	0
5. Local population density: Across the species' range, what is the average local density of individuals in appropriate habitat? Values below are in individuals per km^2 (with the corresponding number of individuals per acre and per square mile in parentheses).		
a. <1/km^2 (<0.004/acre, <2.6/mi^2)	10	10
b. 1–10/km^2 (0.004–0.04/acre, 2.6–26/mi^2)	9	9
c. 10–100/km^2 (0.04–0.40/acre, 26–260/mi^2)	8	8
d. 100–500/km^2 (0.40–2/acre, 260–1,300/mi^2)	5	5
e. 500–1000/km^2 (2–4/acre, 1,300–2,600/mi^2)	2	2
f. 1000–2500/km^2 (4–10/acre, 2600–6500/mi^2)	1	1
g. >2500/km^2 (>10/acre, >6500/mi^2)	0	0
6. Global geographic range size: What is the size over which the species is distributed during the season when its distribution is most restricted (e.g. for a species that breeds over 10,000 km^2 and hibernates over 1000 km^2 farther south, use the area of the wintering range in your response)? For reference, Indiana spans an area of about 94,000 km^2 (23 million acres or 36,300 mi^2).		
a. Less than 1000 km^2 (<386 mi^2)	5	–
b. 1000–5000 km^2 (386–1930 mi^2)	4.5	–
c. 5001–40,000 km^2 (<1931–15,440 mi^2) or up to 2/5 the size of Indiana	3.5	–
d. 40,001–100,000 km^2 (15,441–38,610 mi^2) or about 2/5 the size of Indiana to just slightly larger than Indiana	2	–
e. 100,001–2,000,000 km^2 (38,611–772,000 mi^2) or about the size of Indiana to 1/4 of the area of the continental US	0.5	–
f. $>2,000,000$ km^2 ($<772,000$ mi^2)	0	–
7. Geographic range in Indiana: What is the percentage of the state over which the species is distributed, irrespective of season?		
a. $<10\%$ of Indiana	5	10
b. 10–25%	4	8
c. 26–50%	2.5	6
d. 51–75%	1	2
e. $>75\%$	0	0

(*continued on next page*)

Biological Variables	Points	
	18	14
8. Trend in global range size: What is the percentage change in global area occupied by the species since European settlement?		
a. Area occupied is ⩽10% of area before Europeans	5	–
b. Area occupied is 11–25% of area before Europeans	4	–
c. Area occupied is 26–75% of area before Europeans	2.5	–
d. Area occupied is 76–99% of area before Europeans	1	–
e. Area occupied has remained same or increased since Europeans arrived	0	–
9. Trend in Indiana range size: What is the percentage change in the portion of Indiana occupied by the species since European settlement?		
a. Area of IN occupied is ⩽10% of area before Europeans	5	10
b. Area of IN occupied is 11–25% of area before Europeans	4	8
c. Area of IN occupied is 26–75% of area before Europeans	2.5	6
d. Area of IN occupied is 76–99% of area before Europeans	1	2
e. Area of IN occupied has remained same or has increased since Europeans arrived	0	0
10. Global degree of temporal compression of species' geographic range: To what degree do individuals within populations congregate or aggregate either seasonally (e.g. at hibernacula, breeding sites, migration focal points) or daily (e.g. communal roosts) at specific locations throughout the species' range? A congregation or aggregation as described here implies a regular temporal compression of the distribution of a species that occurs independent of the factors considered in questions 7–10.		
a. Majority congregate at less than 10 locations	5	–
b. Congregations at 10–25 locations	3	–
c. Congregations at >25 locations	1	–
d. Species does not congregate	0	–
11. Degree of temporal compression of species' geographic range in Indiana: To what degree do individuals within populations congregate or aggregate either seasonally (e.g. at hibernacula, breeding sites, migration focal points) or daily (e.g. communal roosts) at specific locations in Indiana?		
a. Majority congregate at less than 10 locations	5	10
b. Congregations at 10–25 locations	3	6
c. Congregations at >25 locations	1	2
d. Species does not congregate	0	0
12. Response to changes in available food: What is the primary way in which local populations of the species respond to decreases in availability of their preferred food type? Consider a "preferred food type" to be a prey species or guild within a taxonomic family (for plants), order (for invertebrates) or class (for vertebrates) that composes the highest portion of the diet at a given time. According to this definition, examples of preferred food types include such categories as fish, mammals, birds, grasshoppers (Orthoptera), beetles (Coleoptera), cattails (Typhaceae), sedges (Cyperaceae), grasses (Poaceae), beech-oak (Fagaceae), walnut-hickory (Juglandaceae), and pines-spruce-hemlock (Pinaceae).		
a. Local population density of species declines; no substantial shift in diet—"specialist"	3.3	3
b. Substantial shift in diet, with little change in local population density of species—"generalist"	0	0
13. Habitat types used in Indiana: How many of the following habitat types are used routinely by the species (i.e. incorporated into home ranges and used for nesting, resting, escape cover, or foraging)? Consider the following 10 habitat types in your deliberations: mature deciduous forest, mid-successional (pole timber) forest, shrub-scrub, savannah, tall-grass prairie, row crops, pasture-hayfields, wooded wetlands (including streams), marshes, urban-residential.		
a. 1 habitat type	10	10
b. 2 habitat types	7	7
c. 3–4 habitat types	5	5
d. 5–6 habitat types	2	2
e. ⩾7 habitat types	0	0
14. Reproductive specialization: What is the primary way in which local populations respond to decreases in availability of preferred breeding sites (e.g. tree or snag species or size class)?		
a. Number of individuals or number of breeding attempts declines, but no substantial shifts to other breeding sites—"specialist"	3.3	3
b. Substantial shifts to alternate breeding sites, with little change in number of individuals—"generalist"	0	0
15. Other specialization: What other ecological or behavioral specializations exist that are not covered in questions 12 and 13 (e.g. strict requirements for hibernacula, narrow ambient temperature limits, or specific resting/roosting structures)?		
a. Highly specialized	3.3	3
b. Moderately specialized	1.7	2
c. Not specialized	0	0

(*continued on next page*)

Biological Variables		Points	
		18	14
16.	Breeding system: With what relative frequency does the species use the following breeding systems? For our purposes, polygamy represents breeding and pair-bond formation by an individual of 1 sex with >1 individual of the opposite sex, promiscuity represents indiscriminant breeding between males and females with no pair bind formation, and monogamy represents breeding and pair-bond formation between a single male and female.		
	a. Polygamy	10	10
	b. Promiscuity	0	0
	c. Monogamy	5	5
17.	Young per adult female per year: Considering the entire geographic range, with what relative frequencies do the following categories reflect offspring produced by adult females of the species each year?		
	a. <1 per year	5	5
	b. ⩾1 and <2 per year	4	4
	c. ⩾2 and <4 per year	3	3
	d. ⩾4 and <8 per year	2	2
	e. ⩾8 and <12 per year	1	1
	f. ⩾12 per year	0	0
18.	Age at first parturition—females: Considering the entire geographic range, with what relative frequencies do the following categories reflect the ages at which females of the species give birth for the first time?		
	a. <3 months of age	0	0
	b. ⩽3 and <6 months of age	1	1
	c. ⩽6 months and <1 year of age	2	2
	d. 1 year of age	3	3
	e. >1 but less than 2 years of age	4	4
	f. ⩽2 years of age	5	5

Action Variables (not included in ranking score under any system)		
1.	Knowledge of distribution in Indiana:	
	a. Distribution is extrapolated from a few known locations, or knowledge is limited to general range maps in Indiana	10
	b. Broad range limits or habitat associations are known, but local occurrence cannot be predicted accurately	5
	c. Distribution is well known and occurrence can be accurately predicted throughout Indiana	0
2.	Knowledge of population trend in Indiana:	10
	a. Not currently monitored	6
	b. Monitored locally	4
	c. Statewide monitoring but not with statistical sensitivity	0
	d. Statewide monitoring with statistical sensitivity, or nearly complete census	
3.	Knowledge of limitations for Indiana population of the species:	
	a. Factors affecting population size and distribution are unknown or unsubstantiated	10
	b. Some factors affecting population size or distribution are known	5
	c. Most factors affecting population size and distribution are known	0

References

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

Burgman, M.A., Keith, D.A., Rohlf, F.J., Todd, C.R., 1999a. Probabilistic classification rules for setting conservation priorities. Biological Conservation 89, 227–231.

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

Ceballos, G., Navarro, D., 1991. Diversity and conservation of Mexican mammals. In: Mares, M.A., Schmidly, D.J. (Eds.), Latin American Mammalogy. University of Oklahoma Press, Norman, OK, pp. 167–198.

Cofré, H., Marquet, P.A., 1999. Conservation status, rarity, and geographic priorities for conservation of Chilean mammals: an assessment. Biological Conservation 88, 53–68.

Fitter, R., Fitter, M. (Eds.), 1987. The Road to Extinction. World Conservation Union and United Nations Environmental Programme, Gland, Switzerland.

Freitag, S., Van Jaarsveld, A.S., 1997. Relative occupancy, endemism, taxonomic distinctiveness and vulnerability: prioritizing regional conservation actions. Biodiversity and Conservation 6, 211–232.

IUCN, 1994. International Union for the Conservation of Nature Red List Categories. IUCN Species Survival Commission, Gland, Switzerland.

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.

Kirkland Jr., G.L., Krim, P.M., 1990. Survey of the statuses of the mammals of Pennsylvania. Journal of the Pennsylvania Academy of Science 64, 33–45.

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

Mace, G.M., 1994. Classifying threatened species: means and ends. Philosophical Transactions of The Royal Society of London 344, 91–97.

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

Mapstone, B.D., 1995. Scalable decision rules for environmental impact studies: effect size, Type I, and Type II errors. Ecological Applications 5, 401–410.

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

Morgan, M.G., Henrion, M., 1990. Uncertainty: a Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis. Cambridge University Press, Cambridge.

Regan, H.M., Colyvan, M., Burgman, M.A., 2000. A proposal for fuzzy International Union for the Conservation of Nature (IUCN) categories and criteria. Biological Conservation 92, 101–108.

Todd, C.R., Burgman, M.A., 1998. Assessment of threat and conservation priorities under realistic levels of uncertainty and reliability. Conservation Biology 12, 966–974.

US Fish and Wildlife Service, 1983. Endangered and threatened species listing and recovery priority guidelines. Federal Register 43 (184), 43098–43105.