Biological Conservation 89 (1999) 245–249

BIOLOGICAL CONSERVATION

The treatment of uncertainty and the structure of the IUCN threatened species categories

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Received 14 October 1998; received in revised form 10 December 1998; accepted 10 December 1998

Abstract

The classification of species with respect to their conservation status using the IUCN criteria is an important process in many countries, providing a guide for setting conservation priorities. Recent advances have resulted in several approaches to dealing with uncertainty in data used to classify species. These methods demand an unambiguous and transparent logical structure for the criteria. We suggest some changes to the ways in which the criteria are represented that correct an unnecessary inconsistency and which may serve to avoid important errors when uncertainty in the data is considered explicitly.

Keywords: Conservation status; Endangered; IUCN criteria; Threat; Extinct; Uncertainty

1. Introduction

The IUCN Red List criteria (IUCN, 1994, 1996) have become one of the most important decision tools in conservation biology. The criteria apply a set of decision rules to classify species into categories of conservation status. The classification scheme has achieved universal acceptance and has been applied to species from across the taxonomic spectrum. The data resulting from a classification exercise provide the benchmark for environmental reporting at national and international scales. One of the issues to be dealt with in future developments of these rules is to explicitly accommodate uncertainty in population and distribution parameters. In this paper, we review the logical construction of the rules and suggest some modifications that will permit the explicit treatment of uncertainty in the process of the classification of conservation status.

According to the definitions of the categories 'critically endangered', 'endangered' and 'vulnerable' given in the IUCN *Red Data Book* (IUCN, 1996, pp. Intro 19–21), a critically endangered species or subspecies is also both endangered and vulnerable. Similarly, an endangered species or subspecies is also vulnerable. An examination of the various criteria and subcriteria in Table 1 of IUCN (1996, p. Intro 21) reveals that in all subcriteria, satisfaction of the critically endangered criteria is a sufficient condition for satisfaction of the corresponding endangered and vulnerable criteria. Subcriterion C1 states that for a species or subspecies to be critically endangered it must be experiencing a population decline rate of 25% in 3 years or one generation. The corresponding endangered and vulnerable rates are 20% in 5 years or two generations and 10% in 10 years or three generations. To conform with the logical structure of the other rules, and with the description of subcriterion C1 in Annex 2 of IUCN (1996, p. Annex 8–10) and IUCN (1994), it should read "rapid decline rate *at least*...". With this minor correction, all criteria and subcriteria admit the implication:

$$\text{Critically Endangered} \Rightarrow \text{Endangered} \Rightarrow \text{Vulnerable} \quad (1)$$

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0006-3207/99/$ - see front matter
PII: S0006-3207(99)00013-0

Table 1
Degrees of belief in the past rate of decline of populations of *Gentiana wingecarribiensis* (D. Keith, pers. comm.)

IUCN threshold	Degree of belief
> 80%	0.20
50–80%	0.35
20–50%	0.25
0–20%	0.20

For example, consider the case of the Giant Sea Bass (*Stereolepis gigas*) outlined in (IUCN, 1996, pp. Intro 19–20). This species is listed as critically endangered because its population decline rate is at least 80% in 10 years or three generations. Clearly this implies that its population decline is *at least* 50% in 10 years or three generations—the condition required for classification as endangered. Similarly, *S. gigas* is also vulnerable.

2. The logical structure of the IUCN classification

Isaac and Mace (1998) outlined workshop deliberations regarding the reformulation of the IUCN criteria. In these discussions, it is apparent that the structure embodied in Fig. 1 (which comes from IUCN 1996, p. Intro 18) is an important representation of the intended logical relationships among the categories. For example, the workshop noted that the category of 'conservation dependent' does not fit naturally or logically into the dendrogram of categories (i.e. Fig. 1). Likewise, it was generally agreed that the category 'least concern' should be separated out from 'near threatened' and 'conservation dependent' on the dendrogram.

The logical structure of the verbal description of the rules outlined above contradicts Fig. 1 in which the three categories 'critically endangered', 'endangered' and 'vulnerable' are taken to be mutually exclusive. While this anomaly may not be serious in itself, it has ramifications for the interpretation of the categories when the data contributing to the classification of a species are uncertain. Specifically, Implication 1 is in direct conflict with Fig. 1 (this assumes the standard reading of tree diagrams, where branches at a given level partition the level above). That is, according to Fig. 1, a particular threatened species or subspecies must belong to one and only one of these categories. But we have already seen that *S. gigas* belongs to all three categories.

Clearly either the definitions of the categories must be changed to conform with Fig. 1, or Fig. 1 must be changed to conform with the definitions summarised in Table 1 of IUCN (1996, p. Intro 21). The former option would involve specifying upper and lower bounds for the relevant criteria for the endangered and vulnerable categories so that all three categories are mutually exclusive. It is the latter option, however, that we advocate and which appears to be the intent of the IUCN criteria, based on their description in Annex 2 of IUCN (1996, p. Annex 8–10) and IUCN (1994).

3. The effects of rule structure on uncertain estimates

It is well known that the data available for threatened species classifications is often very poor. A great deal of current research is devoted to developing methods to incorporate and quantify the uncertainty in the data

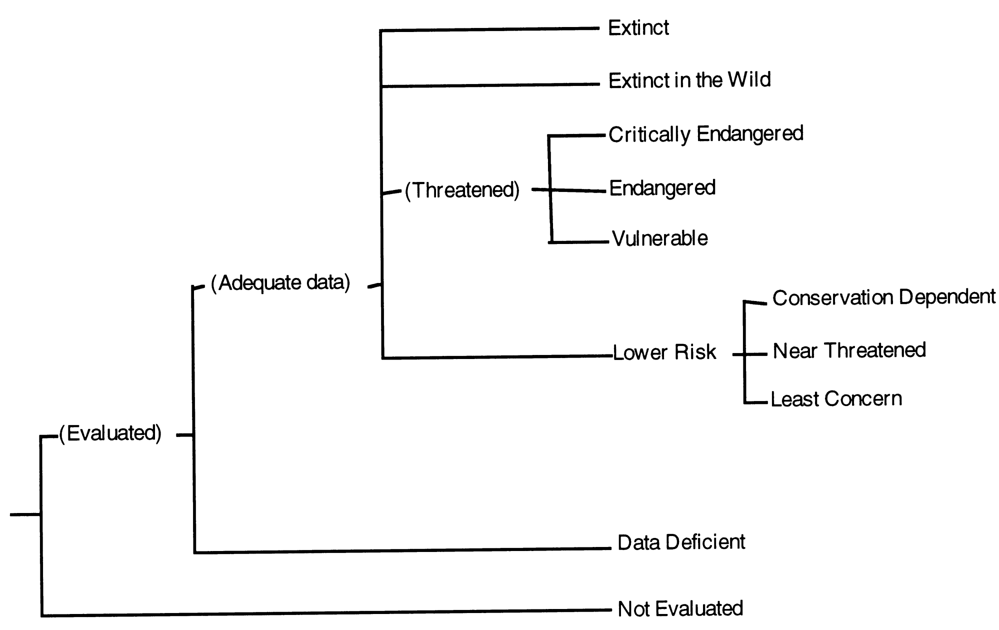

Fig. 1. Structure of the categories for conservation status according to IUCN (1996).

(see Akçakaya et al., in press, for instance) or at least to make the categories in question less sensitive to misclassifications resulting from poor data (see Regan et al., in press). This leads to our reason for favouring criteria that satisfy Implication 1. We illustrated this by way of an example.

One approach to modelling uncertainty in data is to appeal to *degrees of belief*. These take values between zero and one for any given proposition, and measure an individual's confidence in the truth of the proposition in question (Skyrms, 1966; Horwich, 1982). A degree of belief of 1 is reserved for (complete) certainty of the truth of the proposition, while 0 is reserved for certainty that the proposition in question is false. Typically, however, our degrees of belief lie in the (open) interval (0,1). Assume that if we have a degree of belief above a certain figure (0.5, say) then we will treat the proposition in question as true. Now suppose that we wish to classify some species *S* according to the IUCN criteria. Also suppose that we have a degree of belief of 0.4 that *S* has a population size of less than 50 mature individuals and we have a degree of belief of 0.4 that *S* has a population size of between 50 and 250 mature individuals. We would thus have a degree of belief of 0.8 that *S*'s population size is *less than* 250. Thus, according to IUCN criterion D, we could classify *S* as endangered. This is surely the right result. Note also that this result depends crucially upon having the "less than 250 mature individuals" condition in the endangered clause of criterion D. If this clause were modified in the way required to bring the criteria into line with Fig. 1 (so that the clause reads, in part, "less than 250 and greater than 50"), we would not have a degree of belief above 0.4 that the species belongs to *any* of the three categories. We would therefore not be able to classify *S* as threatened at all.

Estimates of the rate of population decline of the threatened Australian herb *Gentiana wingecarribiensis* serve to illustrate the point. A judgement was made concerning the rate of decline in the number of individuals over the last 10 years (IUCN criterion A) (Table 1).

To classify *G. wingecarribiensis* according to the IUCN criteria, we need to interpret Table 1 in an unambiguous fashion that is consistent with the IUCN rule set. We have a degree of belief of 0.2 that the species has experienced a rate of decline of at least 80% and we also have a degree of belief of 0.35 that it has experienced a rate of decline of between 50 and 80%. We would thus have a degree of belief of 0.55 that the rate of decline was at least 50%. According to IUCN criterion A, then, we could classify *G. wingecarribiensis* as endangered. Like the previous hypothetical example, this result depends upon having the "at least 50%" condition in the endangered clause of criterion A (i.e. we require the categories to satisfy Implication 1) because none of the degrees of belief is greater than 0.5. Without the "at least 50%" condition, so that Implication 1 is satisfied, *G. wingecarribiensis* would fail to be classified in any of the 'threatened' categories.

In this last case, the classification of *G. wingecarribiensis* as endangered could have been made by appealing simply to the highest degree of belief (or to a point estimate that ignored uncertainty). In this case our highest degree of belief was 0.35 and this was for the population-decline category of 50–80%. We would thus get the same result by this method (without the "at least 50%" condition in criterion A) as with the cumulative degrees of belief method. It is clear that this will not always be the case though. If the degrees of belief for the rate of decline of the population for *G. wingecarribiensis* were as in Table 2 instead, appeal to the highest degree of belief or the corresponding point estimate would result in the classification 'vulnerable' *not* 'endangered'. Yet surely the latter is the correct classification, since we have a degree of belief above 0.5 that the population decline rate is at least 50%.

This perspective on the IUCN criteria provides a means for interpreting the categories in the presence of uncertainty. When a species is classified, one may use empirical measures of population size or range, or subjective estimates of these same parameters. In either case, the degree of belief is represented by the proportion of the statistical distribution of the parameter estimate that falls within some interval. For instance, the beliefs in Table 1 for *G. wingecarribiensis* may be represented by a distribution (Fig. 2). One may have poor quality data but be quite sure that the species is correctly classified (Isaac and Mace, 1998). In the case of Fig. 2, we can be reasonably certain that the species is at least vulnerable because 80% of the distribution lies above the vulnerable threshold of a 20% decline. Alternatively, one may wish to accept the species as other than critically endangered only if it is more than 90% certain that the species is not critically endangered (Burgman et al., 1998). Such formulations are only possible if both the representation of the structural relationships among the categories and the rules, may be unambiguously interpreted to give nested subsets, rather than as mutually exclusive sets.

It is clear from the actual and hypothetical examples presented above that there are two ways in which misclassifications may occur. The first is when uncertainty

Table 2
Hypothetical degrees of belief in the past rate of decline of populations of *Gentiana wingecarribiensis*

IUCN threshold	Degree of belief
> 80%	0.20
50–80%	0.35
20–50%	0.4
0–20%	0.05

is ignored, as in the last, hypothetical case (Table 2). The second is when, in the presence of uncertainty, the threatened categories fail to satisfy Implication 1, as in the case of *G. wingecarribiensis* (Table 1) and in the case of the hypothetical species *S*. It is thus important that the IUCN classifications be equipped for the incorporation of estimates of uncertainties.

4. An alternative representation of the structure

We suggest that Fig. 1 should be modified to respect the definitions of the three categories—'critically endangered', 'endangered' and 'vulnerable'—set out in Table 1 of IUCN (1996, p. Intro 21). In particular, the logical structure of the sets should conform with Implication 1. The resulting 'threatened' branch of the tree in Fig. 1 would be as in Fig. 3. This structure is perhaps best represented by a Venn diagram, as in Fig. 4.

Similar reasoning leads to the conclusion that if a species or subspecies is extinct then it is extinct in the wild. This too conflicts with Fig. 1 where 'extinct' and 'extinct in the wild' are treated as mutually exclusive categories. The 'extinct' branch of the tree in Fig. 1 should thus be as in Fig. 5. Again, this is best represented by a Venn diagram, as in Fig. 6.

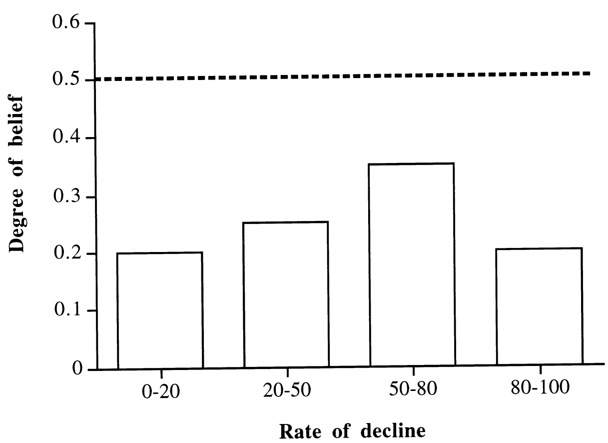

Fig. 2. Degrees of belief in the rate of decline of *Gentiana wingecarribiensis* over the last 10 years (D. Keith, pers. comm). The broken line represents the threshold for a belief to be treated as true.

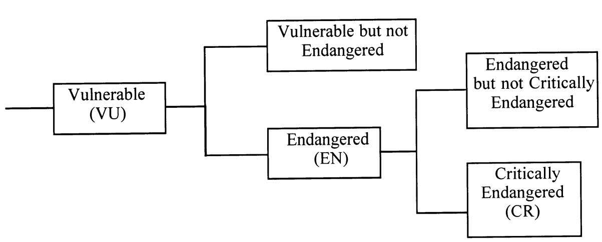

Fig. 3. Revised structure of IUCN categories for the 'threatened' categories.

It is not possible to represent all of the features of the rule set by a dendrogram like that shown in Fig. 1. For example, the usual reading of a tree diagram (Fig. 1) is that any species (or subspecies) can be a member of only one set. However, clearly species may be both extinct in the wild and conservation dependent (Isaac and Mace, 1998). Likewise, a species may be both critically endangered and extinct in the wild.

We summarise the classification decision procedure in flow-chart form in Fig. 7. In this figure the categories 'vulnerable', 'endangered', and 'critically endangered', for instance, are not represented as mutually exclusive. Nor are the two extinct categories represented as mutually exclusive. While it is true that on any single run through the program, a species will be classified in one and only one category, this does not imply that the

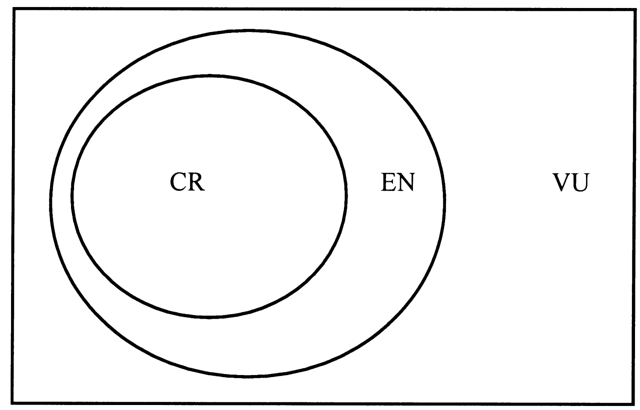

Fig. 4. Venn diagram of IUCN categories for the 'threatened' categories.

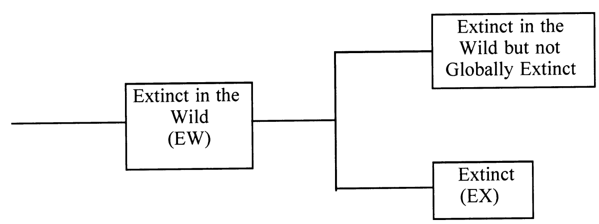

Fig. 5. Revised structure of IUCN categories for the 'extinct' categories.

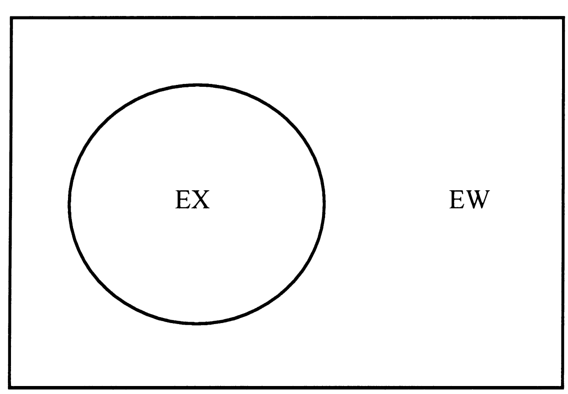

Fig. 6. Venn diagram of IUCN categories for the 'extinct' categories.

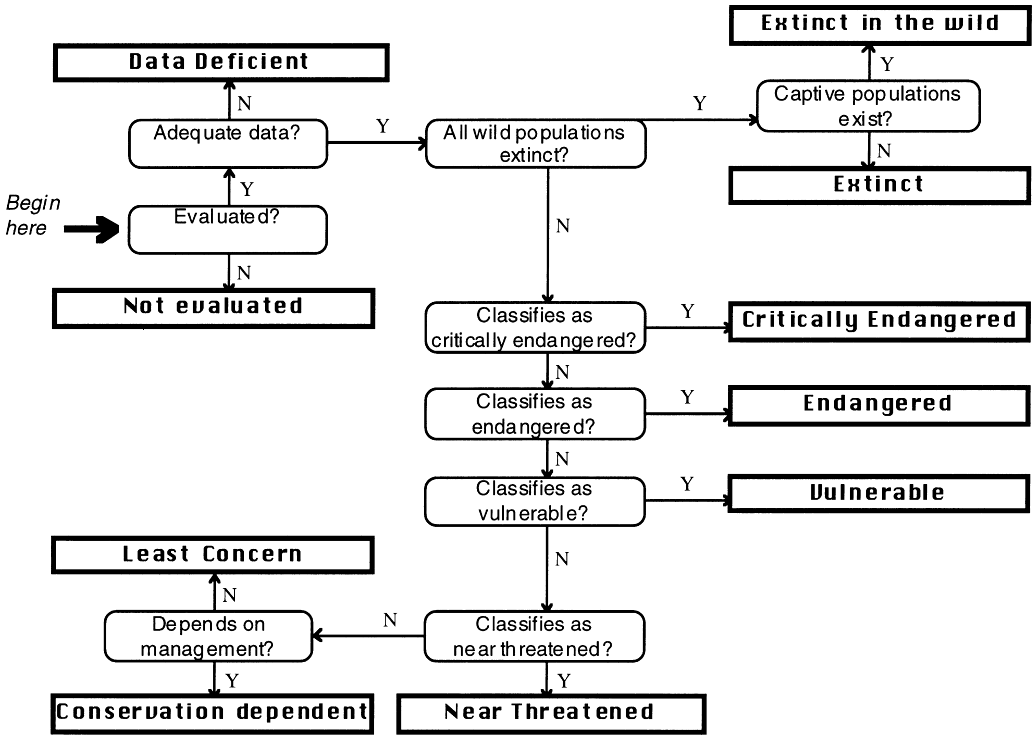

Fig. 7. Flow chart of the IUCN classification decision procedure.

categories themselves are mutually exclusive. This figure does not address issues about the structure of the categories one way or another—it is purely a decision tree. For example, if we answer "No" to the question "Captive populations exist?", we get the classification 'extinct' but we know that if a species is extinct, it is also extinct in the wild. However, we want any species that *can* be classified as 'extinct' to be classified as 'extinct' even though it is also 'extinct in the wild'. Thus we think of Fig. 7 as a program for making the required classifications—not as *defining* the categories. Seen in this light, Fig. 7 faithfully represents the structure and the intent of the IUCN rules and does so in a way that allows membership of more than one set. Thus, it anticipates future developments in which uncertainty may be dealt with explicitly by the IUCN protocols.

The problems we have identified revolve around Fig. 1, the representation of the rule-set structure developed by the IUCN (1996, p. Intro 18). This figure is misleading since it does not accurately capture the structure of the IUCN categories. We believe that it is important to represent the structure of these categories accurately because this structure readily accommodates various approaches to dealing with uncertainty in data.

Acknowledgements

We are indebted to David Keith, Georgina Mace, Helen Regan and the referees of *Biological Conservation* for their help and comments.

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