Use and Misuse of the IUCN Red List Criteria in Projecting Climate Change Impacts on Biodiversity

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Abstract

Recent attempts at projecting climate change impacts on biodiversity have used the IUCN Red List Criteria to obtain estimates of extinction rates based on projected range shifts. In these studies, the Criteria are often misapplied, potentially introducing substantial bias and uncertainty. These misapplications include arbitrary changes to temporal and spatial scales; confusion of the spatial variables; and assume a linear relationship between abundance and range area. Using the IUCN Red List Criteria to identify which species are threatened by climate change presents special problems and uncertainties, especially for shorter-lived species. Responses of most species to future climate change are not understood well enough to estimate extinction risks based solely on climate change scenarios and projections of shifts and/or reductions in range areas. One way to further such understanding would be to analyze the interactions among habitat shifts, landscape structure and demography for a number of species, using a combination of models. Evaluating the patterns in the results might allow the development of guidelines for assigning species to threat categories, based on a combination of life history parameters, characteristics of the landscapes in which they live, and projected range changes.

Introduction

Recently observed responses by many species to climate change (Hughes 2000, Parmesan and Yohe 2003, Root *et al.* 2003) have led to efforts to quantify the impact of future climate change on biodiversity. One measure of the impact is a predicted increase in species' extinction rates. A common approach to investigating this involves bioclimatic modeling, which projects future distributions of species under the assumption that the current climatic constraints that define a species' distribution reflect its environmental preferences, and will, therefore, be retained under climate change (thus, often resulting in shifts in species' ranges

towards poles or higher elevations). There are several problems and uncertainties with this approach (Pearson & Dawson 2003, Buckley & Roughgarden 2004, Hampe 2004, Thuiller *et al.* 2004, Araujo *et al.* 2005), which are widely acknowledged. In this paper, we focus on a different problematic aspect of this approach: that of linking the results of bioclimatic models (shifts and reductions in species' ranges) to extinction rates, using an approach loosely based on the IUCN Red List Criteria (IUCN 2001), as has been carried out in a number of recent publications (Thomas *et al.* 2004, Bomhard *et al.* 2005, Shoo *et al.* 2005a, Thuiller *et al.* 2005).

The *IUCN Red List of Threatened Species* (IUCN 2004) is widely regarded as the most authoritative list of globally threatened species (Lamoreux *et al.* 2003, Rodrigues *et al.* 2006). The IUCN Red List Criteria allocate species to categories of extinction risk using simple quantitative rules based on population sizes and population decline rates, and range areas and range declines (Table 1). The Criteria recognize that there are major differences between species, and the circumstances leading to their extinction risk, and therefore, specify closely how the data from species should be used in order to compare each case with the specified quantitative thresholds (IUCN 2001, S&PS 2005).

All recent studies we have reviewed that use the IUCN Red List Criteria to attempt to quantify likely extinctions from climate change have misapplied the Criteria, even if some have explicitly acknowledged that this is the case. Although we do not doubt the central conclusions of these studies that climate change will result in significantly increased extinction rates, these misapplications could nevertheless introduce substantial bias and uncertainty to projections of climate change impacts on biodiversity. We first discuss the misapplication of the Criteria and the biases this introduces. Secondly, we discuss the particular problems and uncertainties associated with applying the IUCN Red List Criteria to species threatened by climate change, and propose some broad approaches for how these can be overcome.

Common Mistakes in Using the Red List Criteria

The main misuses of the criteria involve quantitative estimates of extinction risk, temporal and spatial scales, spatial resolution, and assumptions about species-area relationships.

Quantitative estimates of extinction risk

Four of the IUCN Red List Criteria (A-D) are based on the size and rate of decline of the population and/or geographical range, while the fifth (Criterion E) is based on quantitative models of extinction risk such as Population Viability Analyses (Table 1). Thus, only Criterion E includes quantitative thresholds for the risk of extinction. Because other criteria do not include such thresholds, the risk-based thresholds of Criterion E should not be used to infer an extinction risk for species assessed as threatened under any of the criteria A to D (S&PS 2005). The reasons for this are that, given the variation among species, it is not possible to validate the equivalence of the thresholds in different criteria, and the factors built into an evaluation under E, or under A-D may not be incorporated in the alternative criterion.

Temporal scale

The most common mistake involves the time periods over which decline rates and extinction risks are to be calculated.   The IUCN Red List Criteria assess population declines over a period of 10 years or 3 generations (whichever is longer) up to a maximum of 100 years into

the future (IUCN 2001). Several studies arbitrarily change this time scale. For example, Thomas *et al*. (2004) use time scales of 50 years (for CR and EN) and 100 years (for VU) to assess declines in future ranges of species, stating that the original timescales "are not suited to evaluate the consequences of slow-acting but persistent threats". Similarly, Shoo *et al*. (2005a) use a time scale of 100 years to assign species to extinction risk categories based on projected declines in population size. Thuiller *et al*. (2005) use an arbitrary time scale of 80 years to assess declines in future ranges of species (they also incorrectly state that the IUCN Red List Criteria use a 20-year time scale). Bomhard *et al*. (2005) do take generation time into account, but they use three different time scales for three subcriteria (60 years for A2 20 years for A3, and 80 years for A4), whereas all subcriteria require the same time scale (if not more than 100 years).

It is misleading and incorrect to use these arbitrary time frames, especially when the generation times of the species being assessed vary. For example, Thuiller *et al*. (2005) study 1,350 European plants, and assume that they all have the same generation time. Generation times for such a large collection of species would vary considerably; the time periods for estimating declines under the IUCN criteria would range from 10 years for very short-lived plants to 100 years for long-lived trees (or even longer under Criteria A2 and A4). The bias introduced by these arbitrary time frames depends on the generation time of the species involved, and its size and direction cannot be estimated without this information. In the Thomas *et al* study, the animal species considered have relatively short generation times on average, so the overall effect of increasing the timescale is likely to have exaggerated estimates of extinction risk.

Although the issue of "slow-acting but persistent threats" is an important one (discussed below), the *ad-hoc* decision to arbitrarily change time scales while keeping the same decline thresholds as in the IUCN Criteria cannot be justified, even if they are changed in a way to produce conservative results. The time scales and decline thresholds in the IUCN Criteria were set against a common standard to provide broad consistency between Criteria and to allow comparisons across taxonomic groups (IUCN 2001). When time scales are changed and the thresholds are kept the same, the resulting set of rules loses this consistency, and cannot then be referred to as the IUCN Red List Criteria.

Spatial scale
The IUCN Red List is explicitly a global assessment of projected extinction risk for species. Applying the IUCN Red List Criteria at sub-global scales requires special considerations (IUCN 2003). When climate change impacts on species are assessed at a continental or smaller spatial scale, the projections for many species often exclude part of the species' range. Models based only on part of a species' range cannot be used to assess global risk for that species, as they do not take into account the dynamics across the entirety of a species' range. For example, the analysis by Thuiller *et al*. (2005) is restricted to data from western Europe. For some species, this may include all or most of the range, but most species are likely to have ranges that extend into eastern Europe, western Asia, and northern Africa. Ignoring this factor is likely to increase estimates of extinction risk.

Spatial measures and resolution
IUCN Red List Criterion B refers to two spatial measures related to the distribution of the species: Extent of Occurrence (EOO) and Area of Occupancy (AOO). These measures are defined in a specific way (and at a specific resolution for AOO) in order to provide a

consistent standard, based on the thresholds set for the threat categories. Broadly, EOO is the range (e.g. a minimum convex polygon encompassing all sites of present occurrence) and AOO is the area within EOO that is occupied by the species (IUCN 2001).

Thomas *et al*. (2004) compared the size of the projected future distribution area against the IUCN's thresholds for AOO (see Table 1). However, the area that they model is not AOO as defined in the IUCN Criteria. It may actually be closer to EOO, for which the thresholds are much higher (Table 1). In general, the modeled distributions must be processed to estimate EOO and/or AOO, as defined by the IUCN Red List Criteria and related guidelines, before the thresholds specified under Criterion B can be applied to the sizes of these predicted areas. Otherwise, as in the case of arbitrary changes to temporal scales, it results in inconsistencies. In the case of Thomas *et al*. (2004), the results are likely to have been conservative (underestimating potentially threatened species, because the thresholds for EOO are higher than those for AOO), which the authors acknowledge.

Spatial resolution is an important issue even when the projected areas are not compared to the Criterion B thresholds. For example, the spatial resolution used by Thuiller *et al*. (2005) (50 x 50 km, projected to 10' grid) may be adequate for making broad projections of biodiversity impacts, but is too coarse for making predictions about specific species, particularly in mountainous areas, because it cannot incorporate the large variation in species' distributions and in microclimate brought about by high topographic relief. The use of a coarser resolution may underestimate threats for such species if smaller scale declines are not projected at the coarser resolution.

Relationship between distribution and population size

Biodiversity impacts simulated in the studies referred to above are often based on (or even limited to) changes in projected range of the species, ignoring other aspects of the species' biology. For example, when Criterion A is used to predict species extinction rates based on changes in range area (as was done by Bomhard *et al*. 2005 and Thuiller *et al*. 2005), a linear relationship between abundance and range area is assumed. In practice, although there is usually a positive and sometimes linear relationship between abundance and area among species, the relationship is rarely linear within individual species, and theory suggests it is unlikely that a species' abundance will decline at the same rate as its range area (Lawton 1993, Rodríguez 2002). However, the assumption is especially problematic in the context of climate change impacts. This is because several additional factors are likely to change (and in many cases exacerbate) the effects of climate change on species viability beyond the effects predicted by range shifts or changes in available habitat area (thus, methods that do not incorporate these factors may underestimate extinction risks). These factors include non-uniform spatial distribution of a species throughout its range (Shoo *et al*. 2005b), interaction of range shifts with fragmentation and land-use (Benning *et al*. 2002), isolation (e.g. Honnay *et al*. 2002), increased frequency of extreme weather events (McLaughlin *et al*. 2002), increased spatial correlation of local temperatures, with an associated increase in spatial correlation of local population dynamics (Post & Forchhammer 2004), diseases (Burrowes *et al*. 2004), and other biotic interactions (Arnott & Ruxton 2002, Frederiksen *et al*. 2004).

Although these factors are often discussed in the literature (including by the authors of the studies we have discussed), bioclimatic models rarely incorporate them. Because these factors involve demographic processes (dispersal, population fluctuations, and trends in vital rates) and the spatial structure of the landscape, they are ignored by assessments that are

based solely on projected range area changes. These factors are incorporated into the IUCN Red List Criteria through the use of variables such as "severely fragmented", "continuing decline", "population reduction", "extreme fluctuations", as well as by explicit calculation of extinction risk in Criterion E. These options are further discussed in the next section.

Red-listing Species Threatened by Climate Change

Although analyses of overall extinction rates resulting from climate change can provide important information about potential impacts on biodiversity, we believe that a more practical use of the IUCN Red List in this context is to identify those species that are or may become threatened by climate change. The IUCN Red List Criteria are used to categorize species according to their risk of extinction, based on information on population size, habitat, range, fragmentation, fluctuations, threats, and trends in population size, habitat and range. In this section, we discuss specific criteria that can be used to red-list species threatened by climate change, and special problems and uncertainties that are associated with the use of these criteria. The following are only a summary of preliminary guidelines on valid approaches; further details are currently being developed.

Population reduction

Criterion A3 is used to list species when there is a population reduction projected or suspected to occur in the future, based on an index of abundance appropriate to the taxon, or a decline in occupied habitat, range or habitat quality. For example, recently the IUCN SSC Polar Bear Specialist Group recommended listing this species as VU under Criterion A3 due to global warming (Wiig 2005). Although this is the most straightforward way to red-list species threatened by climate change, there are two issues to consider. First, this criterion requires a projected reduction in *abundance*. Although this population reduction may be based on a projected decline in occupied habitat, range, or habitat quality, any assumed relationship between abundance and habitat/range must be justified, as discussed above.

Second, for short-lived species, Criterion A has a limited time horizon (3 generations or 10 years, whichever is longer).   Because climate change can affect species in long time horizons (50+ years), three generations will often be too soon for the impacts of climate change to be apparent on these species, even if past greenhouse gas emissions have already determined (and have made inevitable) climate change effects in longer time horizons. In most cases, however, uncertainties and lack of knowledge of environmental trends and demographic characteristics of species make it very unreliable to make predictions of extinction risk over periods longer than 3 generations. In cases where sufficient data exist, and assessors are confident that longer-term predictions are justifiable, Criterion E can be used (see below). In addition, recent studies demonstrate that climate change can affect species viability much faster than implied by range shifts, when it interacts with other factors (Pounds *et al*. 2006). When such factors are incorporated into the assessment, a 3-generation time scale may be sufficient to project impacts on many short-lived species.

Restricted distribution

Criterion B is used to list species with restricted ranges or in restricted habitats, which are also currently undergoing declines or extreme fluctuations, are severely fragmented, or exist in few locations. Location is defined as a geographically or ecologically distinct area in which a single threatening event can rapidly affect all individuals of the taxon present. The size of the location depends on the area covered by the threatening event. Thus, when climate

change is the most important threatening factor for a species, the number of locations may be defined as one, regardless of the number of subpopulations. Under the current criteria, this would allow red-listing of such a species only if (i) it has a restricted range (with an EOO of <20,000 km^2) or is in restricted habitat (with an AOO of <2,000 km^2), and (ii) at least one of two other subcriteria are met: extreme fluctuations or continuing decline (in habitat, range, abundance, or subpopulations) (see Table 1). Although climate change may be projected to create these conditions (range/habitat restriction, fluctuations, and decline), the criteria require that, for the species to be red-listed, these conditions be met under current conditions. Species which are currently not threatened but could potentially meet these conditions in the future due to projected effects of climate change could be listed as Near Threatened (NT), as an interim solution.

Criterion D2 is used to list species in the Vulnerable category (only) if they exist at few (typically five or fewer) locations, even if they are not decreasing. As described above, the definition of location is based on the most threatening factor; thus, some species projected to be affected by climate change may be listed under this criterion as Vulnerable (but not as Endangered or Critically Endangered). Using this criterion would require guidelines for determining that climate change is the most important threat for the species.

Risk of extinction
Criterion E is used to list species under any category, based on a quantitative prediction of the probability of extinction over specified timeframes, which are different than the timeframes for Criterion A (see Table1). The major difficulty in applying Criterion E is that for most species available data are not sufficient for building models that can be used to estimate the probability of extinction. Typically, the required data include population size and distribution, demographic parameters (survival, fecundity, dispersal rates), their variation (in time and space), and dependence on population density and age or other characteristics of the individuals (although with certain loss of habitat, this criterion can be used without any population data).

A solution to this would be to develop guidelines for assigning species to threat categories using Criterion E, based on a combination of life history parameters, characteristics of the landscapes in which they live, and projected range changes. Such guidelines could be informed by developing a variety of models with dynamic spatial structure to estimate extinction risks. The models would represent combinations of life history characteristics such as dispersal ability, generation time, degree of population fluctuations, and population growth rate. Although such an approach would require considerable simplification of the variety of life histories, it is important to note that what is needed is not a precise estimation of the extinction probability, but an estimate sufficient for assigning each species into one of the threat categories.

In addition to allowing red-listing of particular species threatened by climate change, this approach would also provide general insights into the interaction between spatial and demographic factors in making species vulnerable to climate change. Sensitivity analysis with such models would help to identify the life-history characteristics under which the effects of climate change on species viability are exacerbated beyond the effects predicted by change in available habitat area.

Conclusions

The IUCN Red List criteria have been developed through a long consultative process with scientists, conservation practitioners and naturalists, with the aim of providing an explicit, objective framework for the classification of species according to their extinction risk. The quantitative thresholds in the criteria were set during this process against a common standard to provide broad consistency between criteria and to allow comparisons across taxonomic groups (IUCN 2001). Therefore, we strongly recommend that assessments of climate change impacts based on the IUCN criteria avoid arbitrary changes to the thresholds, and temporal and spatial scales specified in the criteria and associated guidelines. To do otherwise is likely to introduce substantial bias and uncertainty to projections of climate change impacts, cause confusion among the users of the IUCN Red List, and result in inconsistencies among the assessments. We believe these are serious problems even when the assessments are not meant to contribute to the IUCN Red List and any deviations from the IUCN criteria are explicitly mentioned (as in some cases in the papers discussed here), and regardless of whether the deviations from the criteria result in more or less conservative conclusions about the effects of climate change on biodiversity.

While we have outlined some methodological problems with a number of recent studies estimating the biodiversity impacts of climate change, we do not doubt their central conclusions that climate change will potentially lead to significantly elevated extinction rates. Indeed, some of the misapplications of the criteria will have led to conservative estimates of the impacts of climate change. Furthermore, using an approach based on Red List criteria forms only part of some of the papers discussed here. For example, Thomas *et al.* (2004) obtained comparable estimates of the proportion of species committed to extinction using an approach based on species-area relationships.

Observed changes in natural populations during the past several decades indicate that global climate change is already becoming a major threatening factor for a large number of species. An effective response to this threat by the conservation community requires reliable information on which species are threatened, an understanding of the interactions between species, their habitats, and climate, and a comprehensive assessment of the uncertainties involved. We believe that the ideas outlined in this paper (for assigning species to threat categories using Criterion E, based on a combination of life history parameters, characteristics of the landscapes in which they live, and projected range changes) provide a starting point for a more consistent use of IUCN Red List criteria in determining these threats and their uncertainties. Climate change modelers will have a key role to play in developing these ideas further.

However, we also believe it is important to remember that climate change impacts were not specifically considered in the development of the IUCN criteria, which are designed for classification of the widest set of species facing a diversity of threatening processes. Thus, these criteria may not be the best tool for assessing biodiversity impact of specific threats operating at long time horizons, especially on short-lived species. Where sufficient data and models are available, as is increasingly the case for climate change impacts, researchers might consider using case-specific models, rather than relying on a general system designed for another purpose.

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Table 1. Simplified overview of thresholds for the IUCN Red List Criteria (for details, see IUCN 2001).

Criterion	Red List Categories			Qualifiers, additional subcriteria, and notes
	Critically Endangered (CR)	**Endangered (EN)**	**Vulnerable (VU)**	
A1: Past reduction in population size	$\geq 90\%$	$\geq 70\%$	$\geq 50\%$	Over 10 years/3 generations, where causes are reversible, understood and have ceased
A2: Past reduction in population size	$\geq 80\%$	$\geq 50\%$	$\geq 30\%$	Over 10 years/3 generations
A3: Future reduction in population size	$\geq 80\%$	$\geq 50\%$	$\geq 30\%$	Over 10 years/3 generations
A4: Reduction in population size	$\geq 80\%$	$\geq 50\%$	$\geq 30\%$	Over a 10-year/3-generation window, which includes the present
B1: Small range (extent of occurrence)	$<100 \text{ km}^2$	$<5,000 \text{ km}^2$	$<20,000 \text{ km}^2$	Plus two of (a) severe fragmentation/few localities (1, ≤ 5, ≤ 10), (b) continuing decline, (c) extreme fluctuations
B2: Small occupied range (area of occupancy)	$<10 \text{ km}^2$	$<500 \text{ km}^2$	$<2,000 \text{ km}^2$	Plus two of (a) severe fragmentation/ few localities (1, ≤ 5, ≤ 10), (b) continuing decline, (c) extreme fluctuations
C: Small and declining population	<250 mature individuals	<2,500 mature individuals	<10,000 mature individuals	Continuing decline either (1) over specified rates & periods or (2) with (a) specified population structure or (b) extreme fluctuations
D1: Very small population	<50 mature individuals	<250 mature individuals	<1,000 mature ind.	
D2: Very small range	n/a	n/a	$<20 \text{ km}^2$ or ≤ 5 locations	Capable of becoming CR or EX within a very short time
E: Quantitative analysis (extinction risk)	$\geq 50\%$ in 10 years/3 generations	$\geq 20\%$ in 20 years/5 generations	$\geq 10\%$ in 100 years	Probability of extinction using quantitative models e.g. population viability analyses