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Invited Review

Uncertain future and uncertain projections: assessing extinction risks in European salamanders from projected chytrid fungus invasion using IUCN Criterion E

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Abstract. Amphibians are among the most threatened vertebrates globally, and their conservation status continues to decline. In the updated Global Amphibian Assessment (GAA2), the use of IUCN Criterion E, which projects extinction risks through quantitative models, highlighted southern Europe as a hotspot for salamander extinction risk due to the risk of invasion by the fungal pathogen *Batrachochytrium salamandrivorans* (*Bsal*). In particular, for five Italian salamander species, risk categories were elevated significantly based on Criterion E, from Vulnerable or lower to Endangered or Critically Endangered. This increased reliance on Criterion E raises concerns regarding its treatment of uncertainty, as these projections depend heavily on assumptions about *Bsal* spread, environmental suitability, and host dynamics. Limited exploration of alternative scenarios and reliance on extreme parameter values may result in inflated extinction risk estimates. We emphasize the need for improved documentation of uncertainty and integration of diverse expert opinions in extinction risk assessments, to balance proactive conservation planning with robust scientific methodology.

Keywords. Chytridiomycosis, pathogen modeling, conservation priorities, *Batrachochytrium salamandrivorans,* environmental suitability, salamander disease.

SOUTHERN EUROPE: A HOTSPOT OF SALAMANDER STATUS DETERIORATION?

Amphibians are among the most threatened animals, and a recent updated assessment (Global Amphibian Assessment 2 [GAA2]; Luedtke et al., 2023) reports that their conservation status is worsening globally. However, this new evaluation also shows a shift in the criteria used for species assessments. The first global amphibian assessment (GAA1; Stuart et al., 2004) was exclusively based

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on observed and inferred data on species declines, range, and abundance (IUCN Red List criteria A-D). Criterion E (projected extinction risk, for example from population viability analysis) has traditionally been less used because it requires high-quality data and is of more complex application (Collen et al., 2016). Consequently, no species had been listed under this criterion in the GAA1 (Stuart et al., 2004).

The GAA2 used Criterion E to determine the extinction risk of European salamanders, particularly in light of the threat posed by chytridiomycosis, a disease caused by the fungus *Batrachochytrium salamandrivorans* (*Bsal*). *Bsal* has been introduced and it is invasive in Europe and has been linked to the severe population declines of fire salamanders (*Salamandra salamandra*) in the Netherlands and Germany (Spitzen-van der Sluijs et al., 2016). Using a pathogen spread model developed by Akçakaya et al. (2023), and assuming that any salamander could be infected by *Bsal*, the GAA2 found that species from the Italian peninsula could face a significant or complete distributional overlap with the pathogen's spread area in the future. Consequently, for five of these species (Fig. 1), the application of Criterion E led to a substantial uplisting to higher extinction risk categories compared to previous assessments. In particular, *Speleomantes italicus*, *S. strinatii*, and *Salamandrina perspicillata*, with a projected

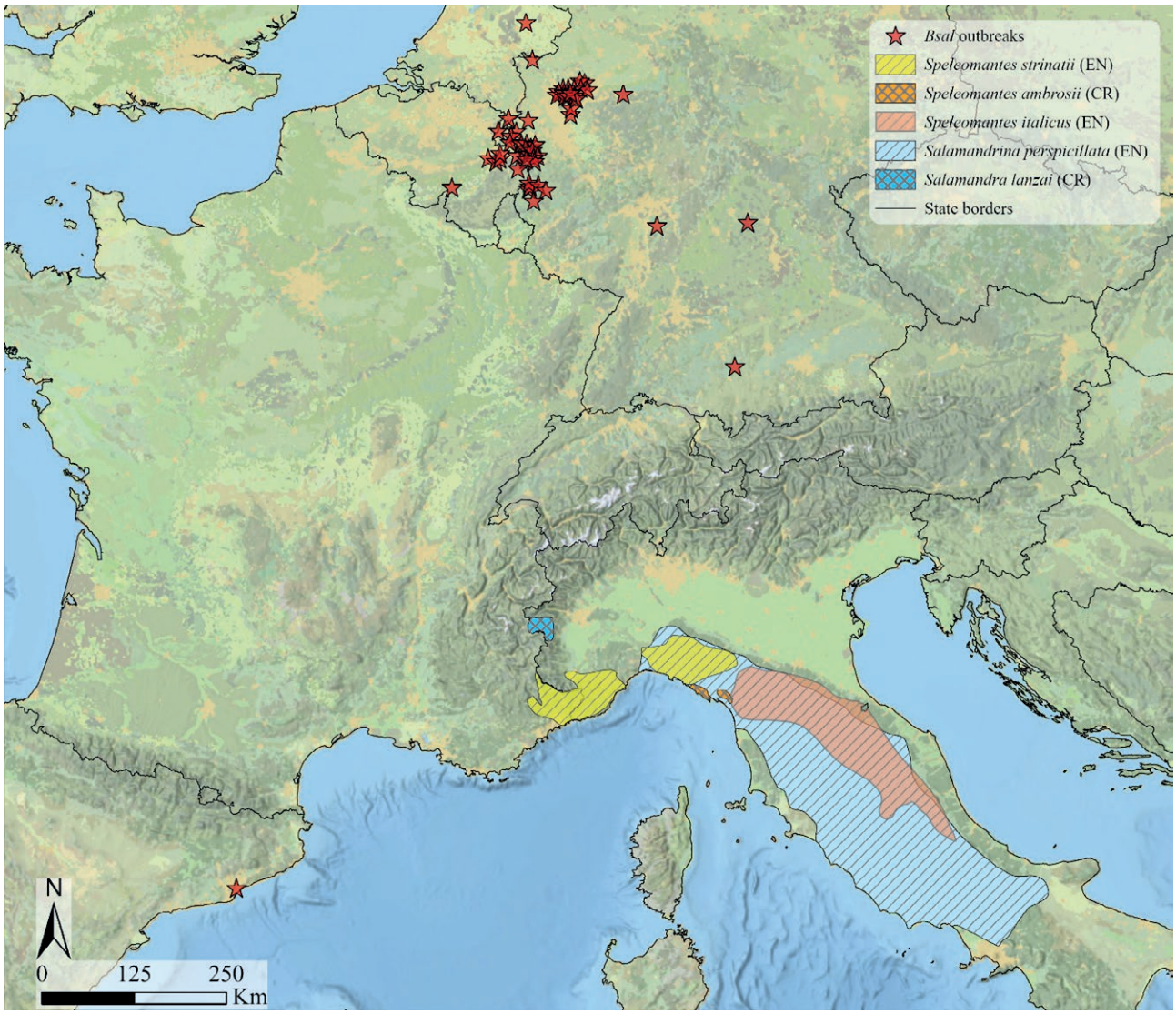

Fig. 1. IUCN ranges of Urodela species (IUCN, 2024) that changed conservation status (hatched pattern: reclassified as Endangered; double-hatched pattern: reclassified as Critically Endangered) and the distribution of *Bsal* outbreaks, as indicated by data from bsaleurope.com (accessed November 2024).

extinction probability of over 20% within the next five generations, have moved from the lowest risk category (Least Concern) to a high-risk category (Endangered). Similarly, *Speleomantes ambrosii* and *Salamandra lanzai*, with a projected population decline of more than 50% within the next three generations, were reclassified from Near Threatened and Vulnerable, respectively, to Critically Endangered. These new assessments of GAA2 conflict with the results of the recent IUCN assessment of Italian vertebrates (Rondinini et al., 2022) and with evidence suggesting stable trends for some of these species (e.g., Ficetola et al., 2018, 2024).

As a consequence of the GAA2 reclassification, Italy appears as one of the hottest spots of amphibian status deterioration globally; this evaluation is strongly linked to projected impacts by pathogens. Furthermore, for most amphibians threatened by *Bsal* (237 out of 240 species), the impacts of the pathogen are exclusively projected for the future (Luedtke et al., 2023). This increased reliance on Criterion E requires particular attention to assumptions and uncertainty, particularly if it contradicts evidence from other sources. We are concerned that, for these European salamander species, the treatment of uncertainty appears incomplete despite its substantial influence on projected extinction risks.

THE IMPORTANCE OF DOCUMENTING UNCERTAINTY IN ASSESSMENTS BASED ON CRITERION E

Extinction risk models project alternative trends of current phenomena, which can then be used to inform mitigation strategies against climate change, biological invasions, pathogen spread, and human development (IPBES, 2023). The IUCN Red List Criterion E seeks to harness this potential. However, alternative projection scenarios can radically differ depending on assumptions, methods, data types and quality (IPBES, 2023). Because projections require more assumptions than analysis of empirical data, they also suffer from greater linguistic, epistemic and stochastic uncertainty (Regan et al., 2002). Criterion E is thus fundamentally different from other Red List criteria, as recognized implicitly by its limited application to date (Cazalis et al., 2022) and more explicitly by the Red List Guidelines (IUCN, 2022), which clearly state that "uncertainty in the data or quantitative model must be documented". This means, for example, using ranges and distributions to represent uncertain parameters, and alternative scenarios or model structures to represent different assumptions, documenting the effect of uncertainty on projected extinction risks and justifying choices.

ISSUES IN THE APPLICATION OF CRITERION E TO EUROPEAN SALAMANDERS

In the GAA2, southern Europe emerges as a global hotspot for extinction risk, and Italy in particular, with five species of salamanders (Fig. 1) showing significant status deterioration based on quantitative projections of *Bsal* spread (Luedtke et al., 2023). When projecting the impacts of such a largely unknown threat in its early stages of invasion, optimistic and pessimistic scenarios should, at the very least, assess different patterns of pathogen spread, different levels of environmental suitability, and different host dynamics. For a recent invader like *Bsal*, these parameters are both highly influential and severely uncertain (Akçakaya et al., 2023). The GAA2 states that "uncertainty in the data [was] documented as a range of values" (Luedtke et al., 2023), but supplementary information and published IUCN entries do not reflect such evaluation of alternative scenarios for critical determining factors. Several key parameters are set at their extreme values, often relying on personal communications without formal expert elicitation and quantification of uncertainty.

For example, in the model used for the criterion E projections, environmental suitability for *Bsal* is implicitly assumed to be at its maximum possible value (100%) over the whole area reachable through its natural dispersal, whereas past research suggests that current and future environmental suitability for *Bsal* can vary significantly but is never perfect (Sun et al., 2023; Xie et al., 2016). *Bsal* dispersal is set as a chordal distance, ignoring host and pathogen ecology (Spitzen-van der Sluijs et al., 2018), plausible human-mediated dispersal (Martel et al., 2020), and barriers to hosts and the pathogen besides the Mediterranean Sea and mountains above 2500 m asl (Akçakaya et al., 2023). However, estimates of extinction risk are highly susceptible to even minimal changes in those parameters. Assuming a linear spread and disregarding environmental factors that might limit *Bsal* spread (thus assuming perfect environmental suitability across different types of European environments), the most vulnerable species are paradoxically located in areas where studies incorporating environmental suitability indicate very low levels of current and projected *Bsal* suitability (Sun et al., 2023; Katz et al., 2018; Beukema et al., 2021).

CONCLUSIONS

In the GAA2, in the case of European salamanders, criterion E was applied to risks by emerging invasive pathogens. However, in principle, this approach to the criterion E could also apply to other threats, such

as interactions with invasive species, climate change, and land-use change. The widespread use of modelling might lead to a more frequent use of this criterion, and accounting for uncertainty is crucial for any of these projected risks (Williams et al., 2021). In the face of rapid and dynamic global change, quantitative projections of imminent but not yet realized threats must play an increasing role in listing decisions.

For amphibians, the recognition in the GAA2 of the substantial threat posed by emerging diseases, even where they have not yet struck, is a step in the right direction. However, this increased application of model-based projections should be accompanied by a step up in adopting established best practices in the treatment of uncertainty (Sutherland and Burgman, 2015; Ladle, 2009). Unclear and overestimated projections of extinction risks can inflate conservation language, diverting attention from ongoing, ascertained threats to potential but uncertain ones, and deteriorating the crucial trust needed for promoting conservation actions (Ladle, 2009). Listing decisions undeniably influence the allocation of limited conservation resources for threatened species, critically affecting their future. Providing clear information about uncertainty, and integrating feedback from multiple local and global experts, should be a guiding principle of extinction risk assessments.

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