**Title:**

At a global scale, climate vulnerable species also face a greater number of non-climatic threats

**Abstract**

Climate change has emerged as one of the greatest challenges to biodiversity conservation in the 21st century. However, for many species the threats of climate change occur in a context of multiple existing threats. Given the current focus of global change ecology in identifying and understanding species vulnerable to climate change, we performed a global analysis to characterize the multi-threat context for species threatened by climate change. Utilizing the International Union for Conservation of Nature’s Red List data for 30,053 species, we sought to evaluate if species vulnerable to climate change are more likely threatened by a greater number of non-climatic threats than species deemed not vulnerable to climate change. Our results show that species vulnerable to climate change are generally impacted by 21% more non-climatic threats than species not vulnerable to climate change. Across all species, this pattern is related to IUCN risk status, where endangered species vulnerable to climate change have >30% greater number of non-climatic threats than endangered species not vulnerable to climate change. Our findings serve as a reminder that research on climate impacts on species should seriously consider the potential synergism and compounding threat interactions, especially for species under elevated conservation concern.

**Introduction**

Climate-related threats may pose the greatest challenges to conservation in the 21st century (Hooper et al. 2012; Parry 2007; Rosenzweig et al. 2008; Thomas et al. 2004). Past ecological research has vastly improved our understanding of climate impacts on biodiversity and how species respond to change (Dickinson et al. 2014; Rahel & Olden 2008; Walther et al. 2002); including, for example, range (Parmesan & Yohe 2003) and habitat shifts (Crossman et al. 2012; Pimm 2008) and food web disruption (Winder & Schindler 2004; Pörtner & Knust 2007). Still, despite these and other advances, there is increasing recognition that the interaction between climate stress and other threats can be extremely important (Keith et al. 2014) and must be understood comprehensively (Berglund et al. 2013). The multi-threat context of ecological climate impacts has been the subject of an increasing number of studies at various scales, from populations (Moe et al. 2013) to species (Halpern et al. 2007). In some cases, the potential synergy between climate change and other existing threats may exceed the expected sum of all combined effects (Brook et al. 2008). Until recently, few analyses have explored the magnitude of this multi-threat context at broader scales. Laurance and Useche (2009), for instance, found that because of environmental synergies, species in the tropics are more likely to suffer from a combination of climatic and non-climatic stressors.

Using categorized species threat information from the IUCN (International Union for Conservation of Nature) Red List (RLI), we give a first approximation of the multi-threat context faced by species at a global scale. Given the current focus of global change ecology in identifying climate change vulnerable species, we sought to evaluate if species ranked as vulnerable to climate change are more likely threatened by a greater number of non-climatic threats than species deemed not vulnerable to climate change.

**Methods**

*RLI data:* The IUCN RLI is the largest collection of global species risk assessments (Keith et al. 2014) and the most widely cited resource for species evaluations and decision-making (Fourcade et al. 2013). Quality standards are rigorous for the nearly 11,000 volunteer reporting IUCN experts – each requiring, at minimum, a master’s degree in relevant disciplines (IUCN 2014). Since 2011 the IUCN RLI adopted the Conservation Management Partnerships’ Unified Classification of Direct Threat (UCDT) metric that is used to associate each species to a comprehensive array of 118 threats arranged within 12 comprehensive categories. We used count of threats within the 10 anthropogenic threat categories (excluding “geological events” and “other threats”) as the basis for our analyses.

*Data processing*

The RLI (v3.2) information, including taxonomy, IUCN status, and threat information, was retrieved from the IUCN website (<http://www.iucnredlist.org/search>) using a combination of a web interface and a set of R scripts for information extraction (Supporting information). 76,199 IUCN evaluated species were available for our analysis. At the onset, ‘Fungi’ (*n*=5) and ‘Protista’ (*n*=15) were excluded from the dataset because sample size limitations would eventually lead to under-representation of these groups. Categories for ‘Wild Extinct’ (*n*=69) and ‘Extinct’ (*n*=832) were also omitted. We did not include species with data deficient (*n*=12,775) assessments, as they have distribution and population gaps (Morais et al. 2013) and their use is discouraged (IUCN 2014).

After inspecting the data for outliers, *Cnidaria* (corals – *n*=858) were removed from the analysis, as all species in the group were associated with 15 identical non-climatic threats. Following these outlier removals, distribution of the dataset largely conformed to an expected Poisson distribution. Lastly, since our analysis solely focuses on species under multiple threats, we excluded all species that had no threat information available. Following these removals, a total of 30,053 species were kept for the analysis.

*Data analysis*

We calculated the total number of non-climatic threats associated with each RLI assessed species (hereafter, “non-climatic threats”) as our dependent variable (DV), which describes the magnitude of a species’ multi-threat context. We considered several independent variables (IV) to explain the number of non-climatic threats across species. First, all species were differentiated as climate vulnerable or not based on whether it was listed as threatened by any threat under the “climate change and severe weather” IUCN threat category. We also considered IUCN conservation status (*CR* - critically endangered, *EN –* endangered, *VU* – vulnerable, *NT* – near threatened and *LC* - least concern) and kingdom (*Plantae* versus *Animalia*) as additional independent variables.

Since our IVs were all categorical without a measure of rank, we used factorial ANOVAs to test their relationships to our DV, both with and without interaction terms. We used Poisson family grouping to address over-dispersion of parameters and additional Chi-square tests to determine the significance and goodness of fit among our explanatory variables.

**Results**

Among the IUCN Red List species in our study, climate vulnerable species are threatened by 21% more non-climatic threats than non-vulnerable species. The mean number of non-climatic threats for climate vulnerable species is 3.67 versus 3.04 for non-climate vulnerable species (P << 0.001; Supporting information). Although animals have a greater mean number of non-climatic threats compared to plants (Figure 1), the percent increase in the number of non-climatic threats associated with climate vulnerability is significantly greater for plantscompared to animals (31% vs 15%, respectively; Pr(>F) = 0.002; Supporting information).

Considering the results across all species, the percent increase in the number of non-climatic threats associated with climate vulnerable species shows a clear relation to species’ IUCN status (Figure 2; Pr(>F) << 0.001; Supporting information). However, this relationship to IUCN status is made less clear when animals and plants are analyzed separately, primarily because the increase in non-climatic threats for climate vulnerable species is relatively high for least-concern plants and near-threatened animals. These inter-dependencies across IVs were reflected in a two-way *Chi-square* test that showed that interactions are highly significant (Pr(>CHI) << 0.001; Supporting information).

**Discussion**

Our results show that species vulnerable to climate change are generally impacted by more non-climatic threats than species not vulnerable to climate change. Furthermore, across all 30,053 RLI species considered, the magnitude of increase in the number of threats associated with climate vulnerability relates to species IUCN status. This relative increase means these observed differences are not simply due to species with higher IUCN risk status naturally having a greater number of associated non-climatic threats. As such, these findings highlight the need to consider the full set of threats that may impact species of conservation concern that are often the target of ecological research.

We hypothesize there are two general mechanisms that account for the observed increase in number of non-climatic threats for climate vulnerable species observed in our results. First, our results may reflect the compounding nature of anthropogenic threats where the impacts of existing threats reduce the ability of species to cope with additional stressors (Przeslawski et al. 2015). For instance, species that have suffered from significant habitat loss and fragmentation from non-climatic threats may be more sensitive to newer climate threats (Swab et al. 2012).

Second, our results may partially reflect that threatened species likely have a set of species traits and characteristics that make them generally more vulnerable to anthropogenic threats and change. A species’ ability to endure environmental change is controlled by their intrinsic life-traits and tolerances to environmental stress (Cabrelli & Hughes 2015). Certain traits (e.g. limited dispersal abilities, slow/low reproduction, specialization, etc.) are likely to render species vulnerable to a host of different threats (Foden et al. 2013). For instance, endemic plants with narrow niches are generally at higher risk of extinction than indigenous plants regardless of climate change (Caujapé-Castells et al. 2010; Sakai et al. 2002). Corals also are known to have characteristics making them highly sensitive to multiple stressors (Hughes et al. 2014).

The generality of our analysis is aligned with these two potential underlying processes where, in essence, anthropogenic threats beget more anthropogenic threats. By replicating our analyses but using each of the other 9 IUCN anthropogenic threat categories as a focus of the analysis (instead of the climate threat category), we show that in most but not all cases, species threatened by any given threat category are more likely to be threatened by a larger number of other threats from the other threat categories (Supporting information). One unquantified potential bias in the analysis is the possibility that experts that list any given threat for a species are more likely to list additional threats for the same species. While this may be the case for some species, we doubt that the relatively strong patterns observed across all species are entirely due to this bias. For instance, species threatened by agriculture/aquaculture and biological resource use categories actually have a smaller number of other threats than species not under those threat categories.

Past assessments have assumed that multiple stressors lead to cumulative linear effects (Allan et al. 2013; Griffith et al. 2012) with little interaction among threats considered (Brown et al. 2014; Rhodes et al. 2011; Wernberg et al. 2012). A common thread across numerous recent studies is the need to better understand if and why the combined effects of multiple stressors are greater than the sum of individual effects (Crain et al. 2008; Pereira et al. 2012; Parmesan et al. 2013; Tingley et al. 2014; Brown et al. 2014). As a first step, future threat analyses must contextualize extinction risk predictions more comprehensively in order to better target management (Akçakaya et al. 2014; Przeslawski et al. 2015). Our findings serve as a reminder that these assessments should seriously consider the potential synergism and compounding threat interactions, especially with stressors that are as complex as climate change.

**Supporting information**

Appendices S1-S7 are available online. Appendix S1 provides scripts for recreating analyses;

Appendix S2 includes a t-test for mean number of non-climatic threats as a function of CC threatened species and not CC threatened species; Appendix S3 includes the factorial ANOVA for mean number of non-climatic threats as a function of climate change vulnerability and kingdom;

Appendix S4 describes the percent increase of number of non-climatic threats associated with climate vulnerability for plants compared to animals; Appendix S5 includes the factorial ANOVA for mean number of non-climatic threats as a function of climate change vulnerability and IUCN status; Appendix S6 describes the Chi-square test for all IV with and without interactivity; Appendix S7 provides analogous results for each of the other IUCN threat categories considered in our analyses.

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**Figures**

Figure 1. Mean number of other threats by Kingdom and climate vulnerability. Error bars represent standard errors.

Figure 2. Percent increase in number of non-climatic threats between climate vulnerable and not climate vulnerable species in relation to IUCN status. Error bars represent the 95% confidence interval of increases.