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A systematic assessment of threats affecting the rare plants of the United States

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ABSTRACT

Characterizing the distribution of threats facing species is a crucial, first step toward designing effective conservation strategy. The last comprehensive analysis of threats facing rare plants in the United States was conducted nearly 20 years ago. Here we systematically analyze the threats facing 2733 rare and vulnerable plants in the US using textual analysis of the most comprehensive database available. In the continental US plants are most commonly threatened by outdoor recreation (affecting 35% of species), especially from off-road vehicles (19%) and hiking and related activities (13%). The next-most common threats are from livestock (33%), residential development (28%), non-native invasives (27%), and roads (21%). In Hawaii invasives threaten 95% of species followed by increases in fire intensity/frequency (26%) then livestock (19%). Multivariate analyses indicate threats do not form distinct "syndromes" (clusters of threats) but rather a single "mega-syndrome" with high degrees of overlap between most threats. We also compared the prevalence of threats to the distribution of research effort. Nearly 75% of threats are understudied relative to their prevalence, including five of the six most common threats while a few rare threats (missing species like pollinators; pathogens; logging; climate-induced ecosystem movement; and crop-based agriculture) receive most of the attention. In comparison to a benchmark assessment from 1998 (Wilcove et al. *BioScience* 48:607-615) we find little difference in threat prevalence, though temporal trends suggest increasing frequency of nearly all threats. Overall rare plants in the US are affected by a dense network of threats across which research attention is disproportionately directed.

1. Introduction

Five major threats endanger biodiversity: habitat alteration, overharvest, invasive species, pollution, and disease (Millennium Assessment, 2005) with climate change expected to become yet another driver of biodiversity loss (Thomas et al., 2004). Each of these broadly-defined threats can be further divided into specific threats from diverse factors like urbanization, agriculture, native versus non-native invasive species, and so on. Detailed characterization of threats facing species is crucial for effective recovery planning (Lawler et al., 2002; Hayward, 2009), directing conservation strategy (Murray et al., 2014), allocating resources across conservation actions (Wilson et al., 2007), and estimating the political feasibility of abating threats (Prugh et al., 2010). Hence, there is a pressing need to describe the distribution of threats across species as specifically as possible. The last such analysis for plants in the United States was performed nearly 20 years ago (Wilcove et al., 1998).

Threats can act in concert to affect groups of species (Burgman et al., 2007; Budiharta et al., 2011). For example, agriculture, overexploitation, and urbanization each threaten generally distinct groups of carnivorous plants (Jennings and Rohr, 2011). These threat "syndromes" (sensu Burgman et al., 2007) can be related to geographic co-location of species (Jono and Pavoine, 2012), range size (Burgman et al., 2007; González-Suárez et al., 2013), habitat type (Burgman et al., 2007), taxonomy (Budiharta et al., 2011; McCune et al., 2013), or the fact that some kinds of human activities engender multiple threats to species (e.g., road construction can facilitate spread of invasives). Syndromes offer both opportunities and challenges for managers and researchers. On one hand, addressing sets of co-occurring threats increases efficiency and knowledge transfer because they may have a common origin (Burgman et al., 2007). On the other hand, addressing groups of threats can be difficult if they are diverse in nature and require very different strategies to ameliorate (Auerbach et al., 2015; Tulloch et al., 2016).

For science to adequately inform threat abatement, research effort should be apportioned in rough accordance to the actual incidence

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and severity of each threat. Nonetheless, it is likely that some threats receive disproportionate research attention. For example, climate change has gained increasing scientific and public attention in part because it is expected to become a major driver of biodiversity change in the coming century (Thomas et al., 2004). However, some conservation practitioners have warned that devoting too much attention to climate misses widespread, contemporary threats that will not only remain important but interact with climate change to further challenge biodiversity (Novacek, 2008; Tingley et al., 2013). Conservation would be better served if research attention matched the relative severity and distribution of threats facing species.

Here we assess the threats facing 2733 rare plant species in the United States using the most comprehensive database of rare species available (NatureServe, 2014). We used a systematic, transparent, replicable textual analysis to extract threat data for each species from the database. Our objectives were 1) to describe the distribution of threats across species; 2) identify syndromes of co-acting threats; and 3) compare the prevalence of threats across species to research effort devoted toward each threat.

2. Methods

2.1. Database and threat taxonomy

In December 2014 we acquired NatureServe data for all plant species in the US that are globally critically imperiled (NatureServe rounded rank G1—see http://www.natureserve.org/conservation-tools/conservation-status-assessment), imperiled (G2), suspected of being extinct (GH), or listed as threatened or endangered under the US Endangered Species Act (ESA). NatureServe employs a standardized method for assessing species' conservation status based on rarity and overall trend and (since 2012) threats (Faber-Langendoen et al., 2012; Master et al., 2012). The database includes information on 2733 species, subspecies, and varieties (hereafter "species") of vascular and non-vascular plants. For most species there are textual descriptions of threatening factors, though this information is spread across several fields and not necessarily standardized. These descriptions are obtained from multiple sources including field observations, experimental work, and the peer-reviewed and gray literature.

We systematically analyzed these descriptions to classify threats to each species. Threats were classified using the 2.0 Beta version of the IUCN threats taxonomy developed by Salafsky et al. (2008; www.cmp-openstandards.org; Table A.1). The taxonomy is composed of three hierarchical levels, the first (L1) being the most general (e.g., "human intrusions and disturbance") and second (L2) more specific (e.g., "recreation") and the third (L3) the most detailed (e.g., "off-road vehicular recreation"). Not all L2 threats have an associated set of L3 threats. We added one more L1 and associated L2 categories for "other" threats, an additional L2 category for "missing species" (pollinators, grazers, symbionts, hosts), and several custom L3 categories based on a preliminary analysis (Table A.1). Since 2012 status updates by NatureServe have included assessment of threats using the IUCN system (Faber-Langendoen et al., 2012; Master et al., 2012). For these species ($n = 963$) we used the threats as they were recorded but in some cases made changes based on the textual description of threats. Prior to analysis we combined L2 or L3 categories affecting <1% of species with categories in the same higher-level category.

2.2. Replicability, transparency, and uncertainty

The textual descriptions of threats are not standardized and are thus open to alternative interpretations (cf. Hayward, 2009). We developed an extensive rubric populated with examples to ensure different assessors consistently identified threats (Appendix B). Following recent, similar assessments (McCune et al., 2013) we scored a threat regardless of whether the written description expressed uncertainty about the threat. For 23% of the species we also employed a cross-checking system in which pairs of assessors independently rated threats for the same species. Partners were rotated between sets of species. When issues arose the matter was resolved between partners or brought to the larger group. Agreement between assessors was very high (mean Cohen's Kappa = 0.98, minimum value across all species = 0.84; Fig. B.1). Initially we classified threats based on the time period in which they were noted to affect species ("past/present/future"), and whether threats were proximate ("direct"—e.g., industrial effluent) or ultimate ("indirect"—a nearby factory producing the effluent), but found few cases where threats did not occur in the present (1.4% "past", 1.8% "future") or were noted as being indirect (<1%), so we analyzed all threats regardless of their time of effect or causal distance. In the end we scored threats as "1" (threatens the species) or "0" (does not threaten).

Frequently threats could only be identified to a higher-level category. In these cases we assigned the threat to an "unspecified" category for that threat type (e.g., "unspecified transportation/utility corridors"). Upon assessing all species, we then assigned counts from these unspecified threats to each "specified" L2 or L3 threat in the same L1 category in proportion to the number of species in the specified threats. For example, among species threatened by the L1 category transportation/utility corridors, there were 465 affected by the L2 category roads/railroads, 98 by ecological management of rights-of-way, and 97 by utility/service lines. There were also 11 species affected by an unspecified threat from transportation or utility corridor. In this case the number affected by roads/railroads was increased by 7.75 species ($= 11 \times (465 / (465 + 98 + 97))$). We used this reapportioning procedure in all analyses using percentages of species affected by a given threat.

The conservation status of species in the database has been updated over time. To determine if the date of assessment influenced the prevalence of threats we divided species into three 6-year groups based on date of assessment: 1996 through 2002, 2003 through 2008, and 2009 through 2014 (the last year any species in the copy of the database we received was evaluated). We used January 1, 1996 as a cutoff date for the first period because the most comparable study to ours (Wilcove et al., 1998) evaluated species that had been assessed up to this date.

We emphasize that our results are limited by our interpretation of the original descriptions of factors threatening species. Some threats are also more evident than others (e.g., off-road vehicles versus climate change), while others may be over-reported (e.g., the presence of an invasive species may be interpreted to be harmful even if it is not). The descriptions also allow neither assessment of geographic extent, severity of threats, nor whether they act in a sporadic or continuous manner. As a result the prevalence of a threat in our analysis does not necessarily connote its overall role in causing a decline in rare plant diversity. Our analysis is also only able to identify threats that affect species in the present or recent past, and cannot for example, indicate effects of initial agricultural expansion that may have caused species in our data set to become rare in the first place. We also note that status updates are implemented on a rolling basis so do not necessarily reflect the most current threats to each species. The median date of last status update for CONTUS species was February of 2006 while the median date for Hawaiian species was May 1997. Hence, we urge care in interpreting results for Hawaiian species. In all these respects our analysis faces the same limitations experienced by similar studies (e.g., Wilcove et al., 1998; Venter et al., 2006; Burgman et al., 2007; Prugh et al., 2010; McCune et al., 2013). We also note that information on bryophytes in the data set is known to be incomplete or has not been reviewed, but given the small number of bryophyte species ($n = 22$) we did not expect them to bias the analysis and so retained them.

2.3. Identifying threat syndromes

We attempted to identify threat syndromes using multivariate and univariate analysis. Analyses were conducted in the R Version 3.3.1 (R Core Team, 2016) using the "vegan" package (Oksanen et al., 2015).