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Combining landscape variables and species traits can improve the utility of climate change vulnerability assessments

Christopher P. Nadeau [a,*], Angela K. Fuller [b]

[a] New York Cooperative Fish and Wildlife Research Unit, Department of Natural Resources, 211 Fernow Hall, Cornell University, Ithaca, NY 14853, United States
[b] U.S. Geological Survey, New York Cooperative Fish and Wildlife Research Unit, Department of Natural Resources, 211 Fernow Hall, Cornell University, Ithaca, NY 14853, United States

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ABSTRACT

Conservation organizations worldwide are investing in climate change vulnerability assessments. Most vulnerability assessment methods focus on either landscape features or species traits that can affect a species vulnerability to climate change. However, landscape features and species traits likely interact to affect vulnerability. We compare a landscape-based assessment, a trait-based assessment, and an assessment that combines landscape variables and species traits for 113 species of birds, herpetofauna, and mammals in the northeastern United States. Our aim is to better understand which species traits and landscape variables have the largest influence on assessment results and which types of vulnerability assessments are most useful for different objectives. Species traits were most important for determining which species will be most vulnerable to climate change. The sensitivity of species to dispersal barriers and the species average natal dispersal distance were the most important traits. Landscape features were most important for determining where species will be most vulnerable because species were most vulnerable in areas where multiple landscape features combined to increase vulnerability, regardless of species traits. The interaction between landscape variables and species traits was important when determining how to reduce climate change vulnerability. For example, an assessment that combines information on landscape connectivity, climate change velocity, and natal dispersal distance suggests that increasing landscape connectivity may not reduce the vulnerability of many species. Assessments that include landscape features and species traits will likely be most useful in guiding conservation under climate change.

1. Introduction

Conservation organizations worldwide are investing in climate change vulnerability assessments to help incorporate climate change into natural resource management plans. Vulnerability assessments have three primary objectives, to determine (1) which species will be most and least vulnerable, (2) where species will be most and least vulnerable, and (3) how to reduce climate change vulnerability (Williams et al., 2008; Watson et al., 2013). These objectives help ensure that conservation resources are devoted to the most vulnerable species and locations (Pacifici et al., 2015) and help identify areas where groups of species might be resilient to climate change (Klausmeyer et al., 2011; Nadeau et al., 2015). They also increase the likelihood that management actions designed to reduce climate change vulnerability will be effective (Mawdsley et al., 2009; Nadeau et al., 2015).

Most vulnerability assessments completed to date have estimated vulnerability by predicting the change in climatically suitable habitat for a suite of species (Urban, 2015). This approach has been heavily criticized for focusing too much on climate change exposure while ignoring important species traits and landscape features that can affect species sensitivity and adaptive capacity (Dormann, 2007; Beale et al., 2008; Randin et al., 2009; Sinclair et al., 2010; Willis et al., 2015). Many alternative vulnerability-assessment methods have been developed recently (Rowland et al., 2011); however, a large portion of these assessments focus on either species traits (e.g., dispersal ability; Galbraith and Price, 2009; Young et al., 2011; Moyle et al., 2013) or landscape features (e.g., landscape connectivity; Klausmeyer et al., 2011; Watson et al., 2013; Nadeau et al., 2015). Few assessments include both species traits and landscape features. This is surprising considering the likely influence of species traits, landscape features, and their interaction on all three primary objectives of vulnerability assessments.

Species traits strongly influence which species will be most vulnerable to climate change (Jiguet et al., 2007; Diamond et al., 2011). For example, fish species with broader diet breadths were less vulnerable to droughts similar to those predicted under future climate change (Chessman, 2013). Landscape features can also affect which species are most vulnerable if landscape features differ within and surrounding the distribution of different species. The amount of topographic diversity within and around a species distribution is a good example.

* Corresponding author.
E-mail address: christopher.nadeau@uconn.edu (C.P. Nadeau).

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Topographic diversity can decrease the distance between current and future suitable climates (Guralnick, 2007) and provide climate holdouts where species may persist for many years (Patsiou et al., 2014; Scheffers et al., 2014). Hence, species that have a large portion of their distribution in areas with high topographic diversity may be less vulnerable to climate change (Luoto and Heikkinen, 2008; Randin et al., 2009).

Landscape features within and surrounding a species distribution can also affect where species are likely to be most vulnerable (Klausmeyer et al., 2011; Nadeau et al., 2015). Species traits may interact with landscape features such that species with different traits are vulnerable in different locations. For example, many species with short dispersal distances will be vulnerable to climate change in flat areas because they will be unable to move fast enough to track changing climates (Loarie et al., 2009). However, species with long dispersal distances (e.g., many birds) may be less vulnerable in flat regions because they might be able to track suitable climates in these regions.

Species traits and landscape features can also affect the utility of an assessment for identifying management actions to reduce vulnerability. Many landscape features can be manipulated (e.g., landscape connectivity) or protected (e.g. topographic diversity) to reduce vulnerability. Including landscape variables in a vulnerability assessment can therefore increase the utility of the assessment for identifying potential management actions to reduce vulnerability. Including the interaction between species traits and landscape variables could further improve the utility of vulnerability assessments because species with different traits may require different management actions to reduce vulnerability. For example, many species may not be able to move fast enough to track changing local climates even in perfectly connected landscapes (Loarie et al., 2009; Schloss et al., 2012). Therefore, increasing landscape connectivity in fragmented landscapes may not reduce climate change vulnerability for all species.

Here, we evaluate how landscape features and species traits interact to affect all three primary objectives of climate change vulnerability assessments. We focus on 113 species of birds, herpetofauna, and mammals in the northeastern United States (Supplementary Fig. S1 and Table S1). We compare estimates of which species will be most vulnerable to climate change among a landscape-based vulnerability assessment, a trait-based assessment, and an assessment that combines landscape variables and species traits. We also compare predictions of where species are likely to be most vulnerable and the types of management actions recommended for each species between a landscape-based assessment and an assessment that combines landscape variables and species traits. Our aim is to better understand (1) which species traits and landscape variables have the largest influence on each of the three primary objectives and (2) which types of vulnerability assessments are most useful for each objective.

2. Methods

2.1. Focal species

We evaluated the vulnerability of terrestrial and semi-aquatic species on the list of New York State Species of Greatest Conservation Need (New York State Department of Environmental Conservation, 2005) that do not occur primarily in marine or coastal environments, are aquatic for the minority of their life, and have mapped distributions (Supplementary Table S1). This included 12 mammals, 72 birds, 10 amphibians, and 19 reptiles. Hereafter, reptiles and amphibians are grouped as herpetofauna. We excluded marine and coastal species because these species will be affected by aspects of climate change not included in our analysis (e.g., sea-level rise, ocean acidification). We did not include plants because plants are not included in the list of New York State Species of Greatest Conservation Need.

2.2. Assessing which species will be most vulnerable to climate change

We calculated three relative vulnerability scores for each species: a landscape-based score, a trait-based score, and a combined landscape and trait-based score. Each of the three vulnerability scores was scaled between zero and one, where zero is considered least vulnerable and one is considered most vulnerable to climate change. We considered scores exceptionally high or exceptionally low if they were greater or <1.5 times the interquartile range of scores, high or low if they were >75th percentile or <25th percentile of scores, and moderate otherwise.

We calculated the landscape-based score using an existing model of the vulnerability of biodiversity to climate change (Nadeau et al., 2015). The model combines five spatial landscape variables to assign a relative vulnerability score to each cell of the landscape (Table 1). The model assigns a relative vulnerability score to each landscape cell by taking the average score of the five variables in each cell. Each of the variables is mapped with a 0.125° (~13 km) resolution, which is the resolution of the finest-scale climate change projections available for the northeastern United States at the time of the study. Each variable is scaled between zero and one, where zero is least likely to have a negative effect on species (e.g., low landscape resistance) and one is the most likely to have a negative effect on species (e.g., high climate change magnitude). We measured climate change magnitude as the overlap between multivariate probability distributions representing historical and projected future climates (Nadeau and Fuller, 2015). We included the following four climate variables in the joint probability distributions: average summer (June to August) and winter (December to February) temperature, and total summer and winter precipitation. See Nadeau et al. (2015) for a more detailed description of each landscape variable.

We estimated a landscape-based relative vulnerability score for each species by averaging the vulnerability score from landscape cells that fell within the species distribution in the northeastern United States. We obtained species distribution information from NatureServe (Ridgely et al., 2007; Patterson et al., 2007; NatureServe, 2008) and the International Union for the Conservation of Nature (IUCN et al., 2004). We buffered the species distributions to include landscape cells adjacent to the distribution because species will need to move through these cells to shift their distribution. We buffered the distribution by one landscape cell (i.e., 13 km) for species with natal dispersal distances < 19.5 km (i.e., the resolution of 1.5 landscape cells) or by two landscape cells for species with natal dispersal distances > 19.5 km.

We worked with 43 species experts from state and federal agencies, non-profit natural resource agencies, and universities to assign trait scores for six species traits to each species (Table 1). We scaled all trait scores to be between zero and one. We derived the score for the ability of a species to keep pace with regional climate change velocity by evaluating how the expert's estimate of the species average natal dispersal distance related to the minimum, maximum, and median climate change velocity in the northeastern United States (Table 1). We derived the life history variable as the number of offspring per reproductive event multiplied by the number of reproductive events over the course of a species lifetime, divided by the species lifespan. We rescaled life history scores to be between zero and one, where zero is a species that produces many offspring over the course of a short lifespan and one is a species that produces few offspring over the course of a long lifespan.

We estimated the trait-based vulnerability score for each species by averaging scores for the six species traits. We gave all the traits equal weight because there is no information available to assign weights to each trait.

We used a combination of the landscape variables and the species-traits to produce a combined vulnerability score (Table 1). We multiplied the climate change magnitude variable by the species physiological tolerance score to produce a species-weighted climate change magnitude variable. For example, if a species had a physiological tolerance score of 0.33, suggesting that it will be positively affected by climate change (Table 1), then the climate change magnitude variable