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Relative sensitivity to climate change of species in northwestern North America

Michael J. Case *, Joshua J. Lawler, Jorge A. Tomasevic

School of Environmental and Forest Sciences, University of Washington, Box 352100, Seattle, WA 98195-2100, United States

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ABSTRACT

Climate change affects plants and animals in myriad ways and to different degrees. Therefore, managing species in the face of climate change will require an understanding of which species will be most sensitive to future climatic changes and what factors will make them more sensitive. The inherent sensitivity of species to climate change is influenced by many factors, including physiology, life-history traits, interspecific relationships, habitat associations, and relationships with disturbance regimes. Using a combination of scientific literature and expert knowledge, we assessed the relative sensitivity to climate change of 195 plant and animal species in the northwestern North America. We found that although there were highly sensitive species in each of the taxonomic groups analyzed, amphibians and reptiles were, as a group, estimated to be the most sensitive to climate change. Not surprisingly, we found that the confidence that experts had in their assessments varied by species. Our results also indicate that many species will be sensitive to climate change largely because they depend on habitats that will likely be significantly altered as climates change. Although to date, many climate impact assessments for species have focused on projecting range shifts, quantifying physiological limits, and assessing phenological shifts, in light of our results, a renewed emphasis on the collection of basic natural history data could go a long way toward improving our ability to anticipate future climate impacts. Our results highlight the potential for basic information about climate-change sensitivity to facilitate the prioritization of management actions and research needs in the face of limited budgets.

1. Introduction

Conservation and natural resource practitioners are faced with the daunting challenge of managing species in the face of multiple challenges including climate change. Increasing temperatures, changing precipitation patterns, and alterations in disturbance regimes are already affecting species across North America (Root et al., 2003; Parmesan, 2006; Chen et al., 2011). Plants are flowering earlier (Cayan et al., 2001), species distributions have changed (Kelly and Goulden, 2008), and species are experiencing changes in the timing of life cycle events, such as migration, breeding, and hatching (Parmesan and Yohe, 2003). However, not all species respond similarly to climatic change (Davis and Shaw, 2001), making climate-informed management more difficult. Managing species in the face of such changes will require an understanding of which species will be most susceptible to future climate change and what factors will increase vulnerability or resilience.

Vulnerability can be defined as a function of sensitivity, exposure, and adaptive capacity (Dawson et al., 2011). Sensitivity to climate change can be defined as the degree to which a species is influenced by one or more aspects of climate (Dawson et al., 2011) and is largely determined by intrinsic factors, such as life-history traits, physiology, genetics, interspecific relationships, habitat associations, dispersal abilities, and its relationship to disturbance regimes (Pecl et al., 2014; Sandin et al., 2014; Williams et al., 2008). Exposure to climate change can be defined as the rate and magnitude of climate change likely to be experienced and adaptive capacity refers to ability of a species to cope with climate change by persisting *in situ* or moving to more suitable locations (Dawson et al., 2011).

Assessing the vulnerability of a species to climate change is challenging because it depends on a complex understanding of a species' natural history and ecology, projected climatic—and climate-induced environmental—change, as well as the genetic and phenotypic capacity for adaptation. Although progress has been made on projecting potential exposure to climate change (e.g., Watson et al., 2013), an understanding of the elements that define adaptive capacity and how to measure them, remains somewhat elusive and an area in which substantial theoretical and empirical work is still needed. The current understanding of sensitivity to climate change lies, arguably, between that of exposure and

* Corresponding author. Tel.: +1 206 913 1326.
E-mail address: mcase@uw.edu (M.J. Case).

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adaptive capacity. There is a general understanding of the factors that determine sensitivity (Williams et al., 2008), and much of the information needed to assess sensitivity exists. However, in comparison to work done on exposure, there have been relatively few attempts to thoroughly document sensitivity for a large number of species (Foden et al., 2013). Although there are uncertainties inherent in the assessment of all aspects of vulnerability, one could argue that the uncertainties associated with climate projections and environmental responses (exposure) as well as the uncertainties associated with our lack of understanding about adaptive capacity are generally greater than those associated with sensitivity. For these reasons, documenting species' sensitivities to climate change is potentially a pragmatic place to start to develop guidance for the management of species in a changing climate.

Two of the predominant sources of information about species' sensitivities are the scientific literature and expert knowledge. Scientific literature, including descriptions of both observational studies and experiments, can provide estimates of species' sensitivities, but often for only for well-studied species. In the absence of observational or experimental data, expert knowledge can augment published natural information. Experts tend to incorporate information from the published literature, empirical data, unpublished studies, and their experiences in general, as well as uncertainty from multiple sources such as incomplete natural history information (McBride and Burgman, 2012). Although expert knowledge can be susceptible to biases due to personal experiences and attitudes (Shrader-Frechette, 1996), for many species it is the best information currently available.

Here, we assess the relative sensitivity to climate change of 195 plant and animal species in northwestern North America. We combine information from literature reviews and expert knowledge to create a sensitivity metric. In addition to ranking each species' sensitivity to climate change, we summarize the factors that contribute most to climate sensitivity across taxonomic groups. We also assess the degree to which species' sensitivities are associated with their level of endangerment and how the level of assessed sensitivity relates to experts' confidence in their assessments. Finally, in addition to reporting results of this assessment here, we have built a publically available on-line database of this information to aid in the further collection of information on species sensitivities (see www.climatechangesensitivity.org).

2. Materials and methods

2.1. Study area

Our study area covers northwestern North America (the Pacific Northwest) and includes the states of Washington, Oregon, Idaho in the U.S. and the province of British Columbia in Canada. The region is bounded by the Pacific Ocean to the west, the Rocky Mountains to the east, the Great Basin to the south, and the boreal forest to the north, and is extremely diverse in climate, geology, topography, and vegetation. Species in northwestern North America reflect the diverse habitats they inhabit, which range from wet maritime coastal forests to arid shrub steppe in the dry interior. Many species can be found within a small area due to steep elevation gradients, a richness of environments, and complex disturbance histories and regimes.

2.2. Species

We assessed the sensitivity to climate change of 195 species: 113 birds, 35 mammals, 27 plants, and 20 amphibians and reptiles (Appendices A–D). The species were chosen based on common interests and priorities of multiple conservation and natural resource management groups (U.S. Forest Service, U.S. Park Service, U.S. Fish and Wildlife Service, Washington State Department of Fish and Wildlife, Oregon State Department of Fish and Wildlife, Idaho State Department of Fish and Game, and The Nature Conservancy).

2.3. Data acquisition

We identified species experts and invited them to participate in ten workshops or to work independently to record information about nine factors of sensitivity (described below). Approximately 300 experts with a diversity of backgrounds and experience participated and all held advanced graduate degrees in ecology, forestry, or biology. Experts were affiliated with the following agencies and organizations: U.S. Forest Service, U.S. National Park Service, U.S. Fish and Wildlife Service, U.S. Bureau of Land Management, Washington Department of Natural Resources, Washington Department of Fish and Wildlife, Oregon Department of Fish and Wildlife, Idaho Department of Fish and Game, University of Washington, University of Idaho, Idaho Cooperative Fish and Wildlife Research Unit, Washington Natural Heritage Program, Canadian Forest Service, Parks Canada, The Nature Conservancy, Defenders of Wildlife, and a number of Tribes and First Nations. All species accounts were completed between 2009 and 2012.

The goal of the expert workshops was to identify the sensitivities of species to climate change by answering a series of questions related to each of the sensitivity factors described below, details of which can be found online.[1] To counter some of the inherent biases of expert judgment, we formalized our workshop procedure by first having the group work methodically through one of the species on the list together. This process demonstrated the use of the database and calibrated the experts' scoring systems. The procedure of working through an example species as a group provided the experts some training on assessing sensitivity, provided them an opportunity to ask questions and get clarification, and ensured that they were interpreting the questions in a similar way. After the example species was completed, experts either broke into groups or worked independently to assess the sensitivity of additional species. Experts had access to relevant literature to help their sensitivity assessment, but many did not finish all assigned species during the workshops and completed them at a later date. In some cases, individual experts worked independently to assess the sensitivity of species and relied heavily on the scientific literature. Nonetheless, these individuals were also trained to assess sensitivity by working through an example species.

For each of the sensitivity factors below, experts provided both a sensitivity score ranging from one (low sensitivity) to seven (high sensitivity) and a confidence score ranging from one (low confidence) to five (high confidence). Confidence scores represent how certain experts were about their sensitivity score. Individual scores were averaged when more than one expert assessed the sensitivity of a species. Experts also provided more detailed comments and citations when they were available. For the majority of species, sensitivities were assessed across their entire range, but there were some for which the experts identified a smaller geographic region (e.g., Idaho). Hereafter, we identify these smaller geographic extents only for those relevant species.

2.4. Sensitivity factors

Individual species' sensitivities were assessed based on nine factors. These included: (1) whether the species is generalist or specialist, (2) aspects of physiology, (3) life-history characteristics,

[1] www.climatechangesensitivity.org.

(4) whether the species depends on sensitive habitats, (5) dispersal distances and the presence of barriers, (6) dependence on disturbance regimes, (7) climate-dependent ecological relationships, (8) interacting non-climatic stressors, and (9) other aspects of sensitivity not previously captured. These factors were chosen because they were identified as important in defining the sensitivity of species to climate change either in the literature or in preliminary discussions with the experts.

2.4.1. Generalist/specialist

Species that have unique dependencies or that have relationships that are dependent on a relatively small number of other species are more likely to be sensitive to climate change than species that do not have these dependencies (Gilman et al., 2010). Experts were asked to rank the degree to which a species is a generalist (low sensitivity) or a specialist (high sensitivity). They then identified which, if any, of the following factors make the species more of a specialist: predator–prey relationships, foraging dependencies, seed-dispersal dependencies, host plant dependencies, phenological dependencies, pollinator dependencies, or other dependencies.

2.4.2. Physiology

Climate change has the opportunity to effect the chemical and physical functioning of species with some being able to tolerate less change than others. Species were ranked as to how physiologically sensitive they are to climate, and climate-change related factors from low to high. Experts also identified which of the specific factors contribute to physiological sensitivity: temperature, precipitation, salinity, pH, carbon dioxide, and dissolved oxygen.

2.4.3. Life-history

The timing and magnitude of growth, reproduction, and mortality of a species influences its sensitivity to climate change. Species were ranked on a scale of being more r-selected—species with many offspring and a short generation time (low sensitivity)—to more k-selected—species with few offspring, high parental investment, and potentially longer generation time (high sensitivity).

2.4.4. Sensitive habitats

Species that depend on specific habitats that are known to be sensitive to climate change are likely to be more sensitive than species that do not rely on these habitats (Dawson et al., 2011). Examples of sensitive habitats include: coastal lowlands, marshes, estuaries, and beaches, seasonal streams, wetlands and vernal pools, seeps and springs, alpine and subalpine areas, grasslands and balds, rocky intertidal zones, ecotones, or other habitats not already listed. We recognize that some may interpret this factor as representing more than just sensitivity, nonetheless, this list was a product of expert input and was refined during the first three workshops. The scoring for sensitive habitats was either 7 (one or more sensitive habitats were identified) or 0 (no sensitive habitats were identified).

2.4.5. Dispersal ability

The capability of a species to move across the landscape will likely affect its ability to respond to climate change and thus will contribute to its overall sensitivity. Maximum annual dispersal distance—the maximum distance it would be feasible for a species to move within one year to establish a new population in a more suitable habitat—was identified on a scale of over 100 km (low sensitivity, "1") to less than 1 km (high sensitivity, "7"). Experts then identified and quantified the presence of dispersal barriers on a scale from low (1) to many (7). The scores for maximum annual dispersal distance and dispersal barriers were then averaged together for one overall dispersal ability score. Again, we recognize that this factor could also be used to assess adaptive capacity.

2.4.6. Disturbance regimes

Changes in the intensity and frequency of disturbances will likely affect some species more than others. Species were ranked as to how sensitive they are to one or more disturbance regimes, from not sensitive to the nature of any disturbance regime ("1") to highly sensitive to the nature of one or more disturbance regimes ("7"). Experts then identified the following relevant disturbance regimes: fire, flooding, wind, disease, drought, pollution, urbanization, pathogens, pests, or other.

2.4.7. Ecological relationships

Species that have ecological relationships that may be altered in the face of climate change will likely be more sensitive than those species that do not. If applicable, the following relationships were identified: forage, predator–prey, habitat, hydrological, competition, or "other". Then experts identified which types of the following climate and climate-driven changes in the environment affect these relationships: temperature, precipitation, salinity, pH, carbon dioxide, or other. Finally, the species' ecological relationships were ranked as to how sensitive they are to the effects of climate change.

2.4.8. Interacting non-climatic stressors

The sensitivity of species can be greatly affected by the degree to which other non-climate-related threats, such as habitat loss, already affect the species. Species that are greatly affected by other stressors may be more sensitive to climate change. Therefore, non-climate-related threats were identified from the following: habitat loss or degradation, invasive species, other interspecific interactions, direct human conflict (including harvesting), pollution, and other. Experts then ranked the degree to which those threats make the species more sensitive to climate change.

2.4.9. Other sensitivities

We found that the majority of the time experts were able to assess a species' sensitivity using the aforementioned factors. However, for species with unique natural histories, there were other aspects of sensitivity that could not be captured with the above set of criteria. These other factors have the potential to predispose species to be more sensitive to climate change. Therefore, experts had an opportunity to identify these factors, rank the degree of sensitivity to climate change and assign a relative weight of this factor ranging from 0.2 to 5. For example, a weight of 1.5 meant that the "other sensitivity" factor was 1.5 times the weight of any previous factor in influencing a species' sensitivity to climate change.

2.5. Sensitivity index

After the sensitivity factors were identified and scored, we then calculated an overall climate-change sensitivity score using a weighted, additive algorithm (Eq. (1)) and an overall confidence score by averaging the individual confidence scores for each sensitivity factor, for each of the 195 species. The range of possible sensitivity scores is from 14 to 100. Our weighting of the sensitivity index is, in part, the result of many discussions that we had with the experts about the relative importance of each sensitivity factor and the weights are based on collective expert input. However, we recognize that others might weight these factors differently and that other approaches of quantifying sensitivity could result in different rankings.

$$\begin{aligned}&[(1/2 * \text{Generalist/Specialist}) + \text{Physiology} + (1/2 * \text{Life-History})\\&+ \text{Sensitive Habitats} + \text{Dispersal Ability} + \text{Disturbance Regimes}\\&+ \text{Ecological Relationships} + \text{Interacting Non-Climatic Stressors}\\&+ (\text{Other} * \text{Weight})]/(49 + (7 * \text{Weight(if present)})) * 100. \qquad (1)\end{aligned}$$

2.6. Overall expert opinion

In addition to the nine factors above, we also asked experts for their overall opinion of how sensitive each species is likely to be to climate change. Although this overall ranking was not used in the calculation of the sensitivity score, it was used as a qualitative-control metric. For instance, if the ranking of all nine sensitivity factors resulted in a low sensitivity score but the expert's overall opinion was that the species was highly sensitive to climate change, it indicated that we missed an important factor in our assessment, the expert interpreted one or more of our questions differently than we did, or—and we suspect, less likely—the expert harbored some bias with respect to that species. Therefore, when there was a large discrepancy between the sensitivity score and the overall expert opinion, we followed-up with the experts to identify what was missed or misinterpreted. It was discrepancies such as these that led us to add the "other sensitivities" category described above. The addition of this category greatly reduced the number of discrepancies between the cumulative sensitivity scores and the general opinions of the experts.

2.7. Relationship between Sensitivity and Conservation Status

We explored the relationship between current conservation status and sensitivity to climate change for the 195 species by comparing sensitivity scores among species using a 2-sample *t*-test when groups were normally distributed and a Mann–Whitney *U* test when groups were not normally distributed ($\alpha = 0.10$ in both cases). However, some of the species that we assessed were chosen precisely because they are currently at-risk, that is they are listed as endangered, threatened, candidate, sensitive, species of concern, or species to monitor in federal or state-level listings. Therefore, we evaluated whether listed species were predisposed to having higher sensitivity scores than non-listed species by quantifying differences in (a) overall sensitivity scores among listed and non-listed species, (b) non-climatic stressor scores among listed and non-listed species, and (c) removing the non-climatic stressors factor from the overall sensitivity scores and evaluating differences among listed and non-listed species.

3. Results

The amphibians and reptiles that we analyzed were determined to be more sensitive to climate change (median score of 76) than were the birds (median score of 52), mammals (median score of 54), and plants (median score of 48) (Fig. 1, $P < 0.001$). Interestingly, the taxonomic group with the largest number of species, birds, also had the smallest range of scores: 21–71, compared to 36–90 (amphibians and reptiles), 19–80 (mammals) and 21–83 (plants). The overall confidence for each species also varied by taxonomic group; plants and amphibians and reptiles had a median confidence score of four (out of five), whereas birds and mammals had a median score of three (out of five). These results show that some species are clearly more sensitive to climate change than others and that experts had relatively high confidence in their scores (Fig. 2). Nonetheless, there were a number of species for which experts were much less certain about how sensitive they were to climate change.

3.1. Drivers of sensitivity

Of the nine sensitivity factors that were assessed, a dependency on one or more sensitive habitats was the factor that was most often ranked highly (with scores of 5, 6, or 7 out of 7) for birds, mammals, and amphibians and reptiles—although physiology

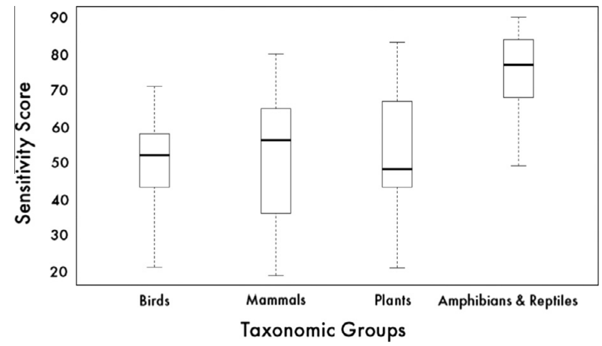

Fig. 1. Boxplot of the median relative sensitivity scores (represented by heavy lines) and ranges (represented by whiskers) for four taxonomic groups. Boxes represent 25–75% of the distribution and sample sizes vary by taxonomic group; birds = 113, mammals = 35, plants = 27, and amphibian and reptile = 20.

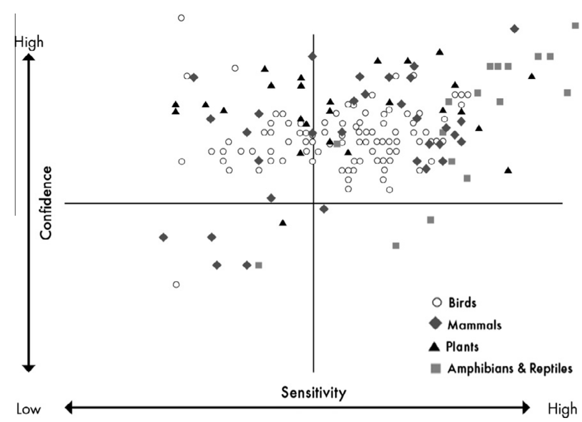

Fig. 2. Relative climate change sensitivity scores and confidence scores for 195 species.

had almost as many high rankings for amphibians (Fig. 3). Notably, 69% of the bird species, 61% of the mammals, and 90% of the amphibians and reptiles were identified as having at least one highly sensitive habitat upon which they depended. For the plant species in our dataset, dispersal ability was most often highly ranked. Most of these relatively high scores were 5′s (out of 7), which represented dispersal distances of 5–25 km.

Not surprisingly, the sensitive habitats that were identified for the four taxonomic groups differed greatly. For birds, the most frequently identified sensitive habitats included coastal lowlands, marshes, estuaries, beaches, and intact grassland and balds (Fig. 4a). For mammals and amphibians and reptiles, "other" habitats were most often listed as sensitive habitats. These other habitats included sagebrush steppe, salt desert, peat lands, sphagnum moss bogs, mature forests or late-successional forests, and ponderosa pine woodlands. The second most often identified sensitive habitat for mammals was "alpine/subalpine" (Fig. 4b). For amphibians and reptiles, seasonal streams and "other" were most often identified as sensitive habitats (Fig. 4c). The "other" category for amphibians and reptiles included microclimates within forests and forested talus, headwater streams, springs, and seeps of temperate, forested areas. The sensitive habitats most often identified for plants included alpine/subalpine areas and grasslands and balds (Fig. 4d).

The taxonomic groups also differed greatly with respect to their relative sensitivity to the other eight factors (Fig. 4). For example, many amphibian species were determined to be physiologically sensitive to climate change but relatively few bird and plant species were. Similarly, life-history played a large role in the

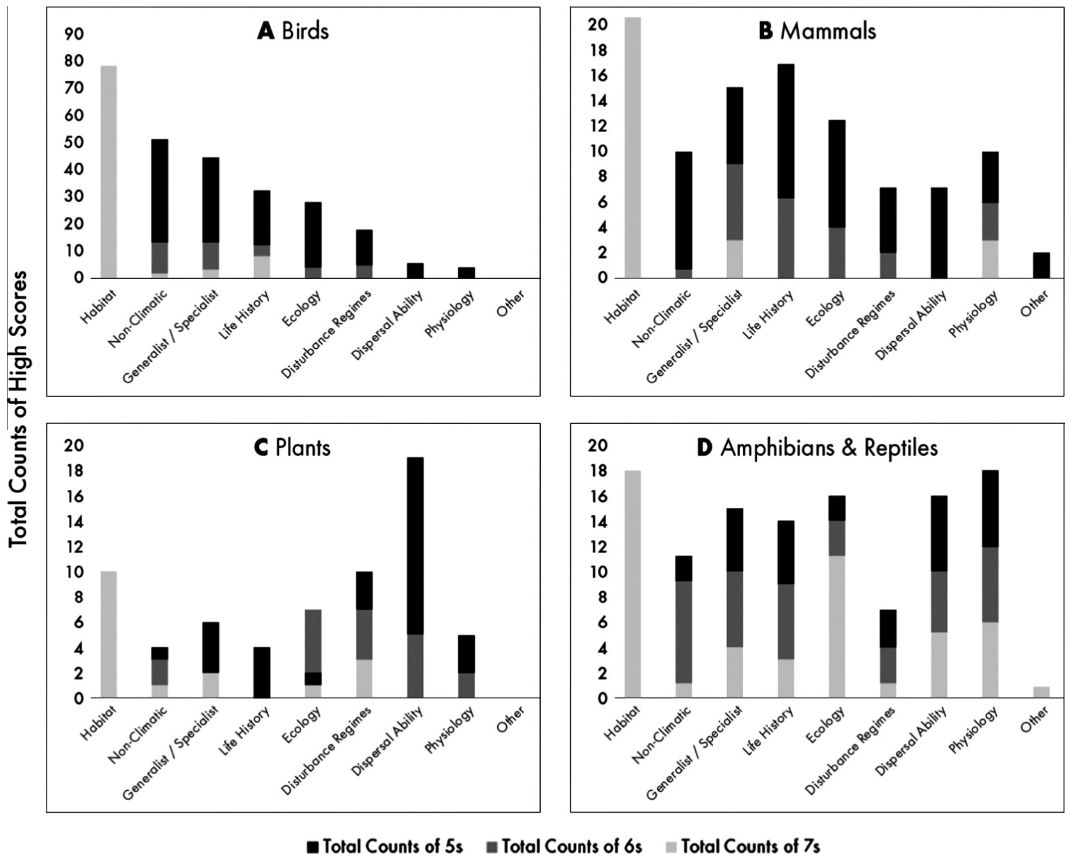

Fig. 3. The total number of high sensitivity scores (i.e., scores of 5, 6, and 7) for each of the nine sensitivity factors for: (a) bird species, (b) mammal species, (c) plant species, and (d) amphibians and reptiles.

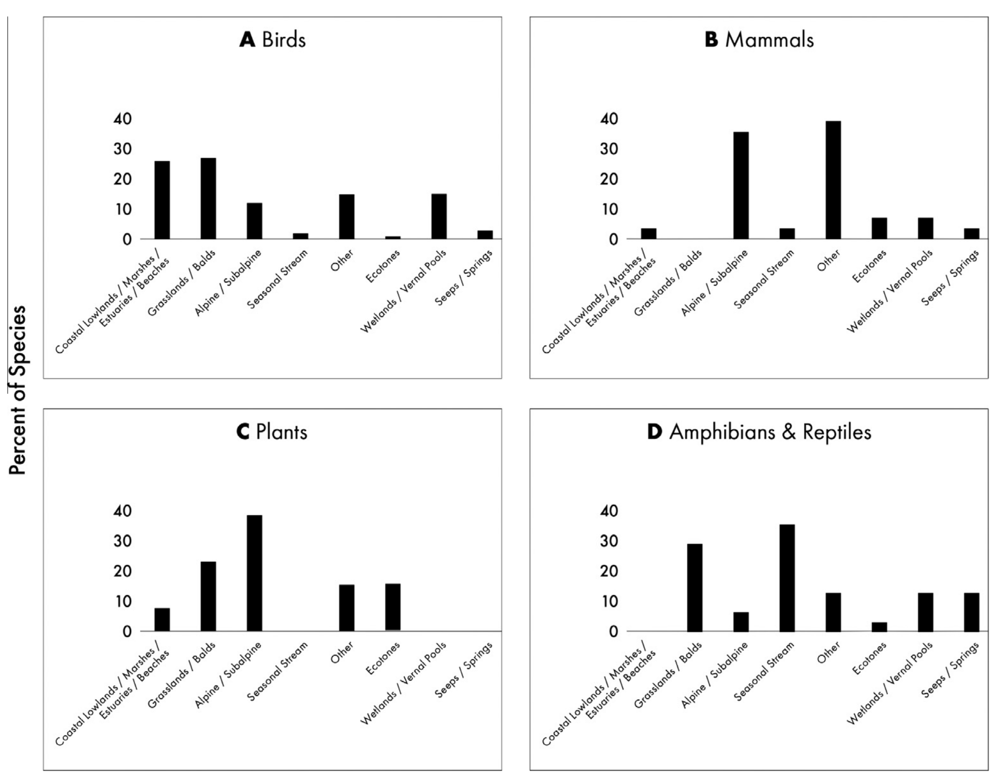

Fig. 4. The percent of species that were identified within each sensitive habitat for: (a) bird species, (b) mammal species, (c) plant species, and (d) amphibians and reptiles.

sensitivity of many mammal species, but did so for far fewer of the species in the other taxonomic groups. Finally, non-climatic factors were more important for a higher percentage of bird species than for any of the other groups.

3.2. Climate-change sensitivity and conservation status

Of the 195 species that we analyzed, 92 were considered to be at-risk (i.e., listed as endangered, threatened, candidate, sensitive, species of concern, or species to monitor for federal or state-level listings). Overall, the sensitivity scores for species with these designations were significantly higher than sensitivity scores for species without the designations ($P < 0.05$). The species that had designations also had higher non-climatic stressor scores ($P < 0.05$) and higher sensitivity scores without the interacting non-climatic stressors ($P < 0.05$) compared to species with no designations.

There were 64 bird species that were considered to be at-risk. However, the sensitivity scores for bird species with these designations were not significantly different than sensitivity scores for bird species without the designations ($P > 0.1$). There was also no difference between (1) interacting non-climatic stressor scores for bird species that had federal or state designations and bird species with no designations ($P > 0.1$) and (2) sensitivity scores without the interacting non-climatic factors for birds with and without listing designations ($P > 0.1$).

One third of the mammal species that were analyzed were considered to be at-risk species. The sensitivity scores for mammal species with these designations were significantly higher than sensitivity scores for mammal species without the designations ($P < 0.05$). The species that were listed also had higher non-climatic stressor scores ($P < 0.05$) and higher sensitivity scores without the interacting non-climatic stressors ($P < 0.05$) compared to species with no designations.

The majority of amphibian and reptile species analyzed (64%) are listed as endangered, threatened, candidate, sensitive, species of concern, or species to monitor for federal or state-level listings. The sensitivity scores for these species were significantly higher than sensitivity scores for amphibian and reptile species without the designations ($P < 0.05$), even after the non-climatic stressors factor was removed ($P < 0.05$). Amphibian and reptile species that were listed also had higher non-climatic stressors scores compared to species with no listing designations ($P < 0.05$). Only two plant species, slickspot peppergrass (*Lepidium papilliferum*) and whitebark pine (*Pinus albicaulis*), were considered to be at-risk species. Both species had relatively high sensitivity scores and non-climatic stressors scores compared to the rest of the plant species without listing designations.

4. Discussion

Our results indicate that the dependence on habitats that are known to be particularly sensitive to climate change is a major determinant of how sensitive a species is likely to be to climate change. Many amphibians in the Pacific Northwest and elsewhere depend on seasonal wetlands and streams, which are, in turn, sensitive to climate-driven changes in hydrology (Elsner et al., 2010). Several of the mammals in our study were dependent on alpine and subalpine habitats—habitats that will shrink leaving populations more isolated as temperatures increase (Gottfried et al., 2012). Many birds in the region depend on coastal lowlands and marshes as well as on grasslands and balds. Many coastal lowlands are threatened by sea-level rise and many grassland systems are threatened by changes in precipitation and fire (Raymond and McKenzie, 2012) as well as by land-use change and invasive species, such as cheatgrass (*Bromus tectorum*) (Bradley, 2009).

The dependence on habitats that are themselves sensitive to climate change has implications for the way the landscape is managed. For example, changes in forest management, such as restricting clear-cut logging along seasonal streams, may be warranted in some places to retain canopy cover. Full canopy cover will help maintain cooler stream temperatures and minimize overall temperature and moisture stress for amphibians (Bury and Corn, 1988). Buffer zones that provide shade and reduce sedimentation may be required to ensure suitable habitat for cold-water amphibian species (Bury, 2004; Olson et al., 2007).

However, the importance of the dependence of sensitive habitats has broader implications. To date, most assessments of climate impacts on species have focused on physiological sensitivities, projected range shifts, and changes in phenology (e.g., Parmesan and Yohe, 2003; Chen et al., 2011; Pinsky et al., 2013). Our findings, however, imply that an increased focus on ecosystem responses to climate change may be warranted. When and how will state-shifts occur? What will make some ecosystems and habitats more resilient to climate change than others and how can management actions increase the resilience of those systems? These questions become even more relevant if one of the leading drivers of sensitivity to climate change is the dependence on habitats that will likely be significantly altered as climate changes.

Another important finding of this study is that mammals, plants, and amphibians and reptiles that currently have federal or state-level listing designations tend to be more sensitive to climate change than those that do not. Although these species often have more non-climatic stressors that will make them more sensitive to climate change, these other stressors are not necessarily predisposing them to be more sensitive to climate change. After removing the non-climatic stressors score from the sensitivity index, listed mammals, plants, and amphibians and reptiles still had significantly higher sensitivity scores than non-listed species. Interestingly, listed bird species do not appear to be more sensitive to climate change than non-listed bird species.

Our study highlighted many species that are likely to be highly sensitive to climate change for which experts were highly confident in their rankings (Fig. 2). These species could merit higher priorities for management actions aimed at addressing climatic impacts. We also identified several species with relatively low sensitivity to climate change for which the experts were highly confident in their rankings. These species could be assigned a lower priority for climate-change related management actions. However, our results also identified a number of species for which experts had relatively low confidence in their assessment. These species would be candidates for monitoring and further assessment. This lack of confidence, however, is also a sign that even the most basic information about many species is still lacking and that the importance of natural history information should not be underestimated (Tewksbury et al., 2014).

It is important to note that our study examines sensitivity to climate change and not vulnerability or risk. Just because a species is sensitive to climate change does not mean that it will be vulnerable to climate change. For instance, even if a species is highly sensitive to climate change, if it will not be exposed to much change or it is capable of adapting to that change, it will not necessarily be vulnerable. Other studies have more fully explored vulnerability to climate change (Gardali et al., 2012; Foden et al., 2013; Heikkinen et al., 2006) and tools similar to the index that we created have been built to assess vulnerability (e.g., the NatureServe Climate Change Vulnerability Index, Young et al., 2012).

It is also important to remember that it is exceedingly difficult to combine disparate types of information into a coherent metric. Thus, most indices have their drawbacks. The one we produced here is no exception. However, we did find that our assessment was robust to different formulations of the index, including the incorporation of different subsets of the factors and different approaches for synthesizing the scores. For example, we removed sensitivity factors one at a time and calculated an overall score using a multiplicative equation and a multivariate approach to combining the factors and each of these investigations resulted in very similar rankings. That is not to say that other formulations of an index or other approaches to combining the information would not produce different results. It is important to note that sensitivity factors were weakly correlated with one another. It is also possible that we neglected some factors that influence sensitivity. Again, we tried to guard against this by having a "catch-all" type category that experts were encouraged to use to address factors that our assessment missed, but it is still likely that some factors were overlooked for specific species. It is also possible that the "catch-all" category allowed for the inclusion of additional expert bias, particularly because experts were allowed to weight this factor as they saw fit. Such bias likely played only a minor role if any, in shaping the results presented here because the "other sensitivities" factor was rarely used.

If nothing else, our results reinforce the growing body of evidence indicating that many species will be affected by climate change. However, our results have implications that go beyond this simple conclusion. Although there are many areas in which research is needed to address potential future impacts of climate change on plant and animal species, our findings imply that a renewed emphasis on the collection of basic natural history data could go a long way toward improving our ability to anticipate future climate impacts.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2015.04.013.

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