Agency plans are inadequate to conserve US endangered species under climate change

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Abstract

Despite widespread evidence of climate change as a threat to biodiversity, it is unclear whether government policies and agencies are adequately addressing this threat to species[1–4]. We evaluate species sensitivity, a component of climate change vulnerability, and whether climate change is discussed as a threat in planning for climate-related management action in official documents from 1973-2018 for all 459 US animals listed as endangered under the Endangered Species Act (ESA). We find that 99.8% of species are sensitive to one or more of eight sensitivity factors, but agencies consider climate change as a threat to only 64% of species and plan management actions for only 18% of species. Agencies are more likely to plan actions for species sensitive to more factors, but such planning has declined since 2016. Results highlight the gap between climate change sensitivity and the attention from agencies charged with conserving endangered species.

Main text

Climate change is a threat to ecosystems and biodiversity globally[5,6], and has emerged as a driver of observed and potential species extinction[7–9]. Government laws and policies play a vital role in supporting climate change adaptation, especially for imperiled species that government authorities are required to manage and protect in many countries. Yet the politicization of climate change and funding shortfalls for environmental programs mean that governments may not be adequately addressing baseline threats to species, let alone more complex emerging threats from climate change[10,11]. Understanding whether and to what extent government authorities are supporting climate change adaptation, especially for imperiled species, is critical for improving tools and processes to reduce climate change impacts on biodiversity[12,13].

The primary law directing the prevention of species extinction in the US is the Endangered Species Act[14] (hereafter, ESA). Central to the listing and recovery processes under the ESA is the enumeration and abatement of threats to species. The law directs the Secretaries of the Interior and Commerce to use the "best available scientific and commercial data" to make listing determinations on the basis of five threat factors: habitat destruction and degradation, overutilization, disease or predation, inadequacy of existing protections, or other factors. While each factor may result from or be exacerbated by climate change, this threat is not explicitly described among the five factors, likely because the ESA was most recently amended legislatively in 1988[15], four years before the first detailed discussion was published on the consequences of climate change for biological diversity[16].

Nonetheless, the two agencies responsible for implementing the ESA, the US Fish and Wildlife Service (FWS) and the National Marine Fisheries Service (NMFS), have explicitly recognized the threat that climate change poses to species and the need to manage for its impacts.

The FWS first described climate change as a threat in its January 2007 proposal to list the polar bear (*Ursus maritimus*) as threatened, and later that year discussion of climate change appeared in FWS and NMFS' recovery plans for the Indiana bat (*Myotis sodalis*) and Hawaiian monk seal (*Monachus schauinslandi*) and in five-year reviews for the red wolf (*Canis rufus*) and five sea turtle species (for references to species ESA documents, see data in supplemental materials). The only assessment of climate change in ESA documents to date (to our knowledge) found that by the end of 2008, 87% of species recovery plans still did not address whether or not climate change was a threat[12]. Given that the scientific community has identified climate change as the "primary threat" to nearly 40% of ESA-listed animals and over 50% of ESA-listed plants in the US,[10] and agency options for climate-related management action under the ESA have been available for over a decade[17], it is vital to understand whether the lead agencies responsible for endangered species conservation have increasingly and more comprehensively used their authority to help species adapt to the threat of climate change.

Here we address this need by comparing the climate change sensitivity of species to agencies' discussion of climate change and plans for managing climate change threats for the 459 ESA-listed endangered animals found within US lands and waters. Because climate change vulnerability had not been systematically assessed for many of these species, we developed a trait-based climate change sensitivity assessment[18]. This assessment is a simplified derivation of existing vulnerability assessment tools (see Methods) and provides a preliminary evaluation of whether and which species' life history and biological characteristics contribute to sensitivity to climate change (see Table 1). Focusing on sensitivity greatly reduced the time required for each species, allowing the assessment to be applicable to large groups of species, like the >2,300 US and foreign species listed on the ESA. After assessing species sensitivity, we determined whether

climate change was described as a threat for species by reviewing official ESA documents (species listings, critical habitat designations, five-year reviews, recovery plans and outlines) published by FWS and NMFS. We then determined whether these agencies planned management action to address climate change threats as part of species recovery by evaluating the same the ESA documents (excluding listing decisions, which are not management-oriented). We compared species sensitivity to whether species ESA documents contained discussion of climate change as a threat and to what extent federal agencies planned to respond to climate change impacts.

We find that nearly all endangered animals are sensitive to climate change impacts, yet agencies describe climate change threats for only slightly more than half of species and plan management actions to address those threats for only a small fraction of species. All but one (Hawaiian goose [*Branta sandvicensis*]) of the 459 species (99.8%) are sensitive to at least one of the eight sensitivity factors (Table 1), and three-fourths (74%) are sensitive to three or more factors (Fig. 1a). Yet ESA documents for only 64% of species consider climate change as a potential threat (Fig. 1b) and documents for only 18% of all species include specific management actions to address threats from climate change (Fig. 1c). Agencies are more likely to plan management actions for species that are sensitive to more climate factors than for species that are sensitive to fewer factors ($F(1,419)=6.57$, $p<0.01$; $\beta=-0.31$, $p<0.01$; Fig. 1a); documents for species sensitive to one vs seven factors are 10% vs 41% likely to contain management actions. This indicates some prioritization based on potential threat. However, species sensitivity is unrelated to whether climate change is considered as a threat ($F(1,458)=0.33$, $p=0.74$; $\beta=0.15$, $p=0.07$; Fig. 1a). Overall, these results identify a gap between the sensitivity of endangered

animals to climate change and the attention that climate change receives from the agencies charged with recovery of these species.

The prevalence of sensitivity factors varied considerably. The highest proportion of species across taxa were sensitive to isolation (mean across taxa=0.71, all taxa ≥0.50), whereas lowest proportion were sensitive to phenology (mean=0.09, all taxa ≤0.21; Fig. 2a). Hydrology and chemistry showed the highest variation in sensitivity across taxa (mean=0.60, sd=0.25, cv=0.95; mean=0.25, sd=0.22, cv=0.89, respectively); disturbance showed the least (mean=0.61, sd=0.11, cv=0.17; Fig. 2a). Of the taxa assessed, mammals were sensitive to the fewest number of factors (Fig. 2b). Amphibians, mollusks, and arthropods were sensitive to the greatest number of factors; many of these species exhibit an aquatic life cycle phase and are thus subject to hydrologic and chemical sensitivities. Furthermore, the latter two taxa also commonly depend on obligate species relationships, although glochidial host information was unavailable for many species. Our assessment, which relied on affirmative statements about biology and life history, represents a conservative estimate of sensitivity and likely underestimated actual sensitivity for some poorly-studied species.

Agencies have increasingly considered climate change as a potential threat to species in ESA documents over time, mirroring rising concern about climate change over the past few decades[19], yet have not reflected this concern via articulated management actions to adapt to climate change for the majority of species. After climate change was first addressed as a threat in 2007, the proportion of species with climate change discussed in their ESA documents rose and thereafter stabilized around 87% of species in 2015-2016 (Fig. 3a). More recently, however, in 2017-2018, this trend reversed and both the proportion of species with climate change addressed and the absolute number of endangered animals with new ESA documents declined. With regards to

management planning, climate change was briefly mentioned and identified as a topic for future study for two species in 2007, and the first discussion of management action occurred in a 2008 recovery plan for stellar sea lion (*Eumetopias jubatus*; Fig. 3b). The proportion of species with planned action each year generally increased until peaking in 2014. Since then, discussion of action has steadily declined; of documents published in 2017, one species' five-year review (Kaua'i cave amphipod [*Spelaeorchestia koloana*]) described a management response to climate change, and no 2018 documents mentioned actions to address climate impacts. In summary, although ESA documents have increasingly mentioned climate change over time, most species' documents either described climate change as a potential problem without including any actions to specifically address the issue, or the documents did not discuss climate change at all. Across years, the proportion of species with planned management action was low on average (mean=0.23, range=0.03-0.39; Fig. 1c), indicating a persistent, pervasive shortfall in planning of on-the-ground management for climate change that to date shows no sign of improving.

Despite limited improvement over time, agencies are addressing climate change for some taxa and management jurisdictions more than others. Arthropods and reptiles featured the greatest proportion of species for which climate change was evaluated as a threat (80% and 75%, respectively) and management action was described (29% and 28%, respectively), whereas mollusks featured the least (50% and 31%, respectively; Fig. 4a-b). The FWS' Region 3 (Midwest) addressed climate change as a threat for 88% of the terrestrial and aquatic species under their purview, in contrast to Region 5 (Northeast) which considered climate change for only 30% of its species (Fig. 4c). Both the FWS' Region 2 (Southwest) and NMFS planned climate-change related management action for 34% of their species, four times higher than the

trailing Region 4 (Southeast, 8%), which is notably the jurisdiction with the largest number of endangered animals (n=128; Fig. 4d).

In short, across time and taxa, management agencies are inadequately assessing climate change threats or planning action to manage those threats to imperiled species. In terms of baseline assessment, this inadequacy affects species regardless of their endangerment, as we found no relationship between the number of sensitivity factors and the consideration of climate change as a potential threat. While documents for some species with sensitivity to only a single factor contained detailed discussion of climate change (e.g., jaguar [*Panthera onca*]), documents for other species sensitive to seven factors were silent on the topic (e.g., Shinyrayed pocketbook). Agencies may be prioritizing species for management planning based on their degree of sensitivity to climate factors, however we caution that the mere presence of management action in documents does not assure the adequacy of plans or, more importantly, the enactment of those plans. Even for species with planned actions, we observed substantial variation in the content: several five-year reviews merely recommended updating recovery plans to include climate change. More robust discussions for action entailed protecting refugia (e.g., Chinook salmon [*Oncorhynchus tshawytscha*] and white abalone [*Haliotis sorenseni*] recovery plans) and diverse microsites (e.g., Karner blue butterfly [*Lycaeides melissa samuelis*] five-year review), improving connectivity (e.g., jaguar recovery plan), establishing additional populations for redundancy in case of stochastic climate events (e.g., Sonoran pronghorn [*Antilocapra americana sonoriensis*] recovery plan), reducing non-climate-related threats (e.g., water allocations in spikedace [*Meda fulgida*] five-year review), and designating habitat in areas likely to persist or become important areas in the future (e.g., tidewater goby [*Eucyclogobius newberryi*] and Bartram's scrub-hairstreak butterfly [*Strymon acis bartrami*] critical habitat

designations). Our results offer suggestions for how different agency jurisdictions might prioritize the types of climate change adaptation options (Supplementary Fig. 1). For example, whereas hydrology and isolation potentially impact a high proportion of species in the FWS' Region 2 (Southwest), temperature and chemistry are more important for species in marine environments overseen by NMFS.

Three main issues may explain why the cognizant US agencies have yet to address climate change threats as part of their imperiled species conservation programs. First, the politicization of climate change has caused its prioritization to shift every 4-8 years with changes in Presidential administration. In 2017, the policies and commitments on climate change established by the Obama Administration, such as Executive Order 13653 on adaptation[20] and the Paris Global Climate Agreement focused on mitigation, were revoked by the Trump Administration[20,21], disrupting progress both nationally and internationally[3]. Imperiled species conservation in the face of climate change urgently requires the return of a bipartisan and durable commitment to both mitigation of and adaptation to climate change. For example, legislative bodies, such as the US Congress and central governments in other countries, could integrate climate change adaptation and mitigation into law rather than leaving these important processes to more labile policies.

Second, the infrequent and inconsistent inclusion of climate change in ESA species conservation may be a consequence of chronic underfunding and imbalanced funding of species recovery. In fiscal year 2012, 62% of species recovery funding was spent on the conservation of 10% of US listed species, resulting in as little as $60 for some species (e.g., Cumberland bean mussel [*Villosa trabalis*] which we found lacked discussion of climate change in its ESA documents)[10,22,23]. Another analysis of yearly appropriations from 1980-2014 found that <25% of

required recovery funding has been allocated annually[24]. These resource limitations may also explain regional disparities in addressing climate change threats: in FWS's Region 4 (Southeast), where a high number of species have no climate discussion in recovery documents, endangered fauna is dominated by mollusks, a taxa that faces particularly dire funding challenges[22]. Increased funding to the agencies responsible for species recovery, paired with a more informed allocation of resources, could largely resolve this problem[11,24].

Finally, climate change itself is a formidable conservation challenge that agencies may not yet have the logistical tools and capacity to address. The broad spatial and temporal scales and uncertainty of specific threats mean that agencies should pair conceptual models with mechanistic approaches to identify stressors that materialize as species threats[2,25]. Agencies would benefit from embracing the frameworks designed to enable systematic planning, implementing, and monitoring of complex conservation challenge, and integrate climate change with other threats[26,27]. Additionally, agencies should proactively seek and embrace innovative tools that enable efficient management of the 2,300+ imperiled species listed on the ESA. The assessment used in this study is one such example, offering a time-efficient method for initially evaluating species sensitivity to climate change.

Our study reveals that US government agencies have yet to adequately evaluate climate change threats to endangered animals listed on the ESA and plan commensurate action. Because the ESA serves as a model for conservation laws and policies and management implementation globally, it is possible that other countries are similarly failing to protect imperiled species from climate change impacts. Climate change poses an ongoing and accelerating threat to many, if not most, imperiled species, and recovery will be unattainable unless a feasible process is in place to account for and ameliorate its impacts.

Methods

We compared the climate change sensitivity of species to agency evaluation and management planning of climate change threats for ESA-listed endangered animals in the US. First, since systematic data did not exist for the climate change impacts on endangered species, we developed and conducted a trait-based, rapid assessment for evaluating climate change sensitivity. We focused the assessment on one element of species vulnerability: a species' potential "sensitivity" to the effects of climate change. Sensitivity "refers to innate characteristics of a species or system and considers tolerance to changes in such things as temperature, precipitation, fire regimes, or other key processes"[28]. We created and answered eight yes-or-no questions based on whether the species' habitat, ecology, physiology, or life cycle might be affected by changes in climate (Table 1). In doing so, we employed a biological approach to assessing sensitivity that considered the ecological impact to the species from the primary manifestations of climate change, including indirect impacts from effects on interacting species[18]. We derived the questions, or sensitivity factors, from factors listed in existing vulnerability assessment protocols, particularly the NatureServe Climate Change Vulnerability Index[29] and US Forest Service's System for Assessing Vulnerability of Species[30]. The goal was to create a simpler and quicker assessment than other frameworks (we completed most species in 30-60 minutes) so that the assessment could be useful to agencies for evaluating large numbers of species while still capturing the most critical elements of potential species sensitivity.

We assessed the climate change sensitivity of all animal species listed as endangered under the ESA (as of December 31, 2018) that are found in US states, territories, and surrounding waters (n=459; see http://www.fws.gov/endangered), with the exception of those deemed likely

to be extinct by agencies or which have not been observed for 20+ years and are likely extinct in the wild. We answered the assessment questions using freely-accessible species information from species listing decisions and other information published by agencies and conservation organizations about the species and its threats. We predominantly referenced the FWS' Environmental Conservation Online System (ECOS; https://ecos.fws.gov/ecp), NMFS' Endangered Species Conservation Directory (https://www.fisheries.noaa.gov/species-directory/threatened-endangered), and the NatureServe Explorer (http://explorer.natureserve.org). Using publicly available information enables the assessment to be used by the public or government, the latter of which requires decision data to be publicly visible[31,32].

To evaluate the degree of recovery action planned by agencies to address climate change impacts, we assessed the level with which climate change was discussed in official ESA documents published by the FWS and NMFS. First, for all endangered animals, we recorded whether climate change was considered as a potential threat in each species' publicly available ESA documents (listing decisions, recovery plans and outlines, critical habitat designations, and five-year reviews). We focused on the most recently published agency documents, which should reflect cumulative knowledge about the species. Then, for all endangered animals except those with only listing decisions (n=420; excluded species n=39), which are not management-oriented and thus not appropriate for evaluating management planning, we recorded what level of management action was discussed to address climate change in species recovery. We recorded the level of discussion as: "Action," indicating that the documents articulated specific actions in response to climate change impacts; "Further study," indicating that the agency acknowledged they require additional information before an action plan could be developed; "No threat, no

action needed," indicating that the documents discussed climate change and decided that climate change is unlikely to impede species recovery; and "No discussion," indicating that climate change was not mentioned.

We tested the relationships between the number of sensitivity factors and whether documents discussed climate change as a potential threat (yes/no) or discussed management action (by reclassifying discussion categories to create a binary variable of no action/action) using logistic regression run using the 'stats' package in R v.3.5.0.

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Author Contributions

A.D. and A.C. designed the study; A.D., A.C., K.E., R.K., S.M., K.T., and L.V. collected data; A.D. and J.R.B.M. analyzed data and wrote the manuscript; A.D., J.W.M., M.S., and J.R.B.M. interpreted results; all authors provided critical feedback on the manuscript.

Data Availability

Data is archived on Open Science Framework and available at https://osf.io/r9uca.

Competing Interests

The authors declare no competing financial interests.

Additional information

Supplementary information is available in the online version of the paper.

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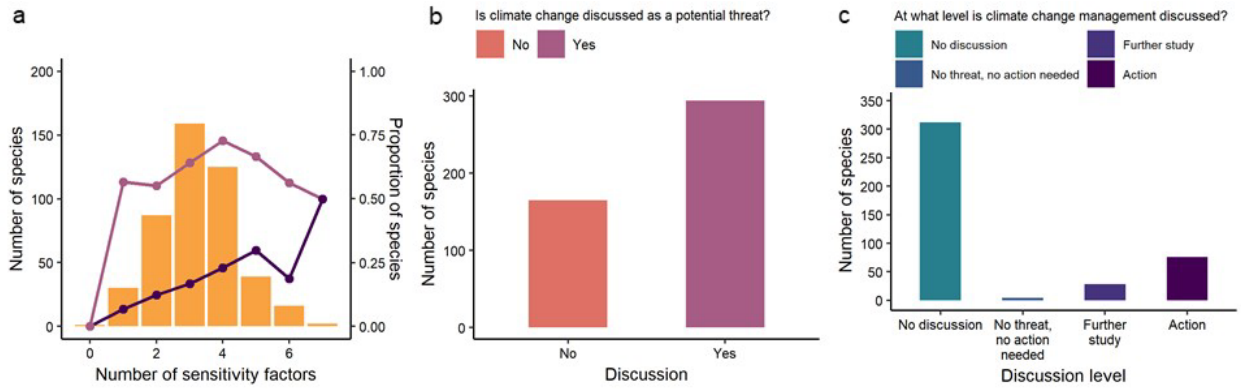

Figure 1. Despite sensitivity to one or more climate factors (a), US endangered animals are not often assessed for whether climate change is a potential threat (b) and most do not receive planning for management actions to address climate change impacts (c). (a) Species that are sensitive to more climate factors are more likely to receive management action planning (purple line; $p<0.05$) than species sensitive to fewer factors, but are no more likely to receive evaluation of climate change as a threat (pink line; $p>0.05$). All endangered animals except one (Hawaiian goose [*Branta sandvicensis*]) are sensitive to one or more of eight climate factors (see Table 1 for factors). The two most sensitive species (seven factors) were a fish, the Clear Creek gambusia (*Gambusia heterochir*), and a mollusk, the shinyrayed pocketbook (*Lampsilis subangulata*). Bars represent the number of species; lines represent the proportion of species within each number of sensitivity factors. Analysis in **(a)** and **(b)** contain all endangered animals on the ESA (n=459); analysis in **(c)** excludes species for which only listing decisions exist (excluded n=39; included n=420; see text for details).

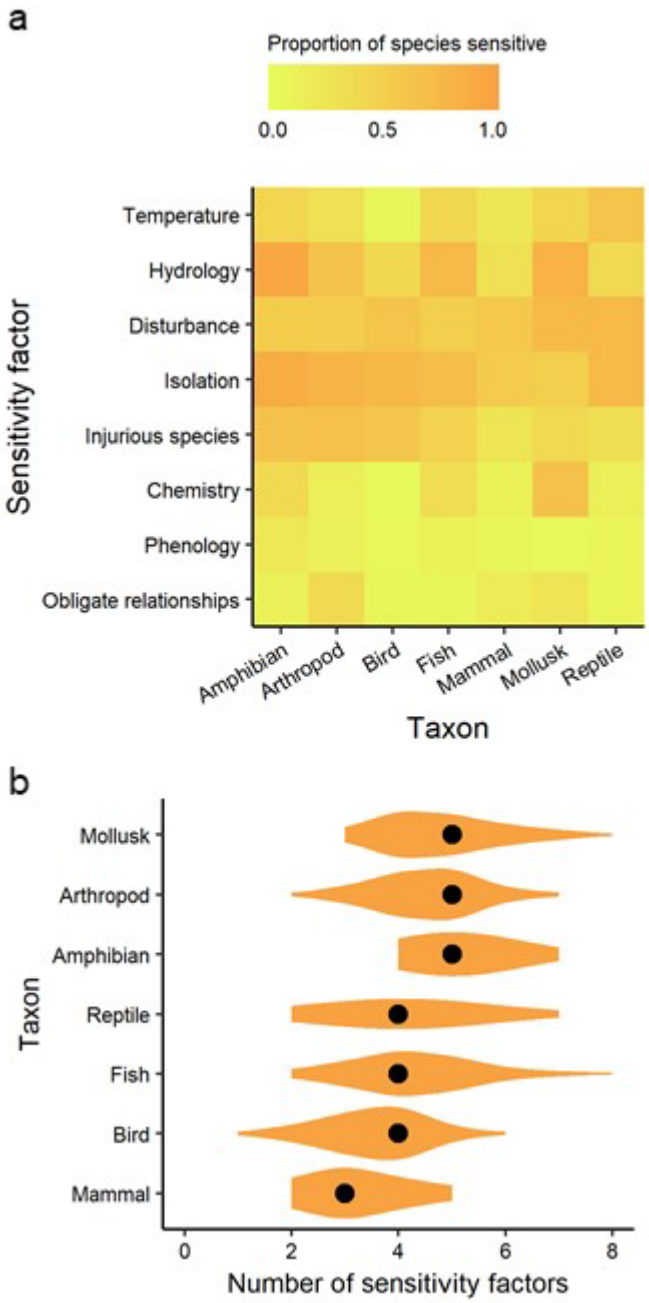

Figure 2. Taxa differ in sensitivity to the (a) type and (b) total number of climate factors. Analysis includes all 459 endangered species listed on the Endangered Species Act. See Table 1 for descriptions of factors, Supplementary Table 1 for the number of species in each taxa, and Supplementary Figure 1 for taxa sensitivity by factor across management agency and region.

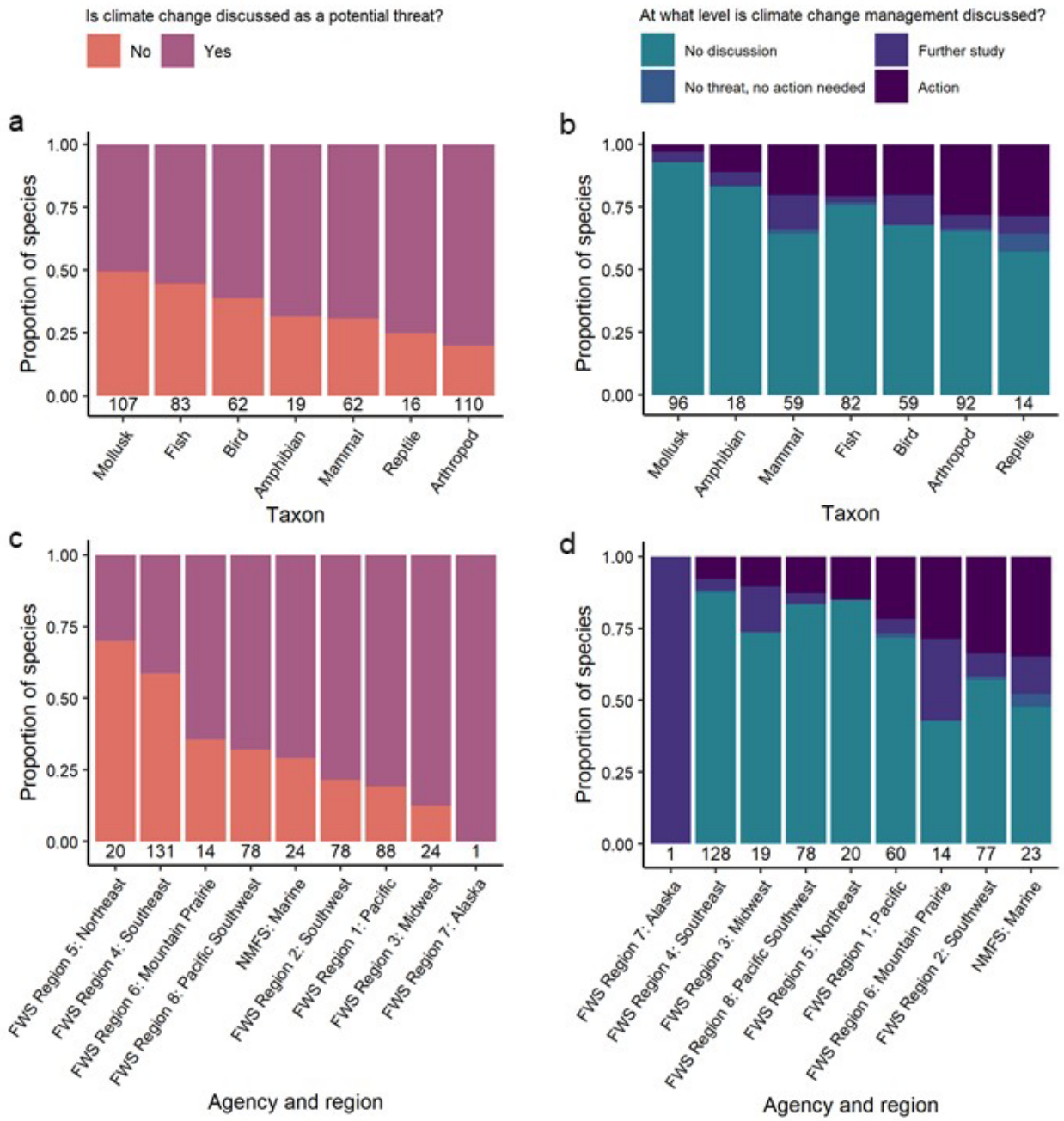

Figure 3. Over time US agencies have included discussions about climate change in official documents for more endangered animals, but (a) baseline assessments of climate change as a threat have increased at a substantially faster rate than (b) planning of management action. Analysis in **a** contains all 459 endangered animals listed on the Endangered Species Act;

analysis in **b** excludes species for which only listing decisions exist (excluded n=39; included n=420; see text for details). The number of species in each group is shown above the x-axis.

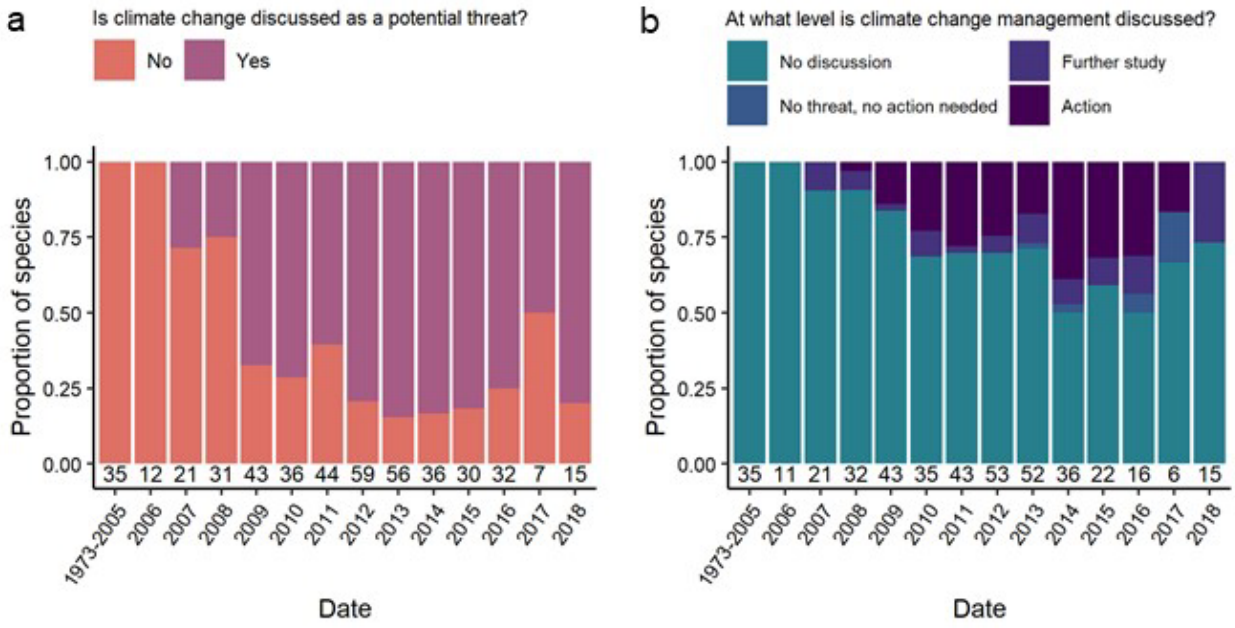

Figure 4. (a, b) Taxonomic and (c, d) agency and regional differences occur in whether climate change is discussed in official documents for endangered animals. Analysis in **a** and **c** contains all 459 endangered animals listed on the Endangered Species Act; analysis in **b** and **d** excludes species for which only listing decisions exist (excluded n=39; included n=420; see text for details). The number of species in each group is shown above the x-axis; in **c** and **d**, FWS indicates US Fish and Wildlife Service and NMFS indicates US National Marine Fisheries Service.

Table 1. Questions in the rapid sensitivity assessment related to eight climate change sensitivity factors.

Factor	Question and description
Temperature	Does the species have specialized thermal tolerance or depend on habitat with an important temperature threshold)? Species were considered temperature sensitive if available information indicated the species has or depends on habitats with (e.g., sea ice) obligate or preferential temperature thresholds.
Hydrology	Is the species dependent on habitat with a specialized hydrology? Species were considered sensitive if available information indicated they require narrow ranges of water depths, flow rates, timing, or seasonality (e.g., vernal pools or intermittent streams).
Disturbance	Is the species or its habitat sensitive to or dependent on a specific disturbance regime? This includes species in fire-adapted systems, species that rely on certain flood regimes, and species impaired by disturbance, such as old-growth forest obligates and species sensitive to excessive flooding.
Isolation	Is the species or its habitat geographically restricted or confined by natural and/or anthropogenic barriers)? While many endangered species are found in small, isolated populations, we deemed species as sensitive if available information indicated they are confined to mountains, islands, or headwaters; are narrowly endemic; or if species movement to other suitable habitat is limited by habitat loss, development, dams, or other anthropogenic pressures.
Injurious species	Is the species or its habitat threatened by an invasive species, pest and/or disease organism that might benefit from climate change? We did not consider the species in question sensitive where the injurious species is ubiquitous or human-oriented (e.g., cats, rats, livestock).
Chemistry	Is the species sensitive to changes in chemical concentration, such as atmospheric CO_2, water pH or dissolved oxygen?
Phenology	Does the species rely on specific triggers for life cycle events, such as breeding, migration, or color change, that are likely to become out of sync with seasonal changes in resource availability or environmental conditions (i.e., phenologic mismatch)?
Obligate relationships	Is the species dependent on one or a few species such as a host, dominant food source, with limited alternatives if the required species declines due to climate change? We did not consider the species sensitive if it requires a host but can succeed in association with four or more species.

Supplemental Information

Agency plans are inadequate to conserve US endangered species under climate change

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Table 1. Taxonomic breakdown of species listed as endangered on the Endangered Species Act (n=459).

Taxon	Number of species	Percentage of all species
Amphibian	19	4
Arthropod	110	24
Bird	62	14
Fish	83	18
Mammal	62	14
Mollusk	107	23
Reptile	16	3

Table 2. Breakdown by agency and region of species listed as endangered on the Endangered Species Act (n=459). FWS indicates US Fish and Wildlife Service and NMFS indicates US National Marine Fisheries Service.

Region	Number of species	Percentage of all species
FWS Region 1: Pacific	88	19
FWS Region 2: Southwest	79	17
FWS Region 3: Midwest	24	5
FWS Region 4: Southeast	131	29
FWS Region 5: Northeast	20	4
FWS Region 6: Mountain Prairie	14	3
FWS Region 7: Alaska	1	1
FWS Region 8: Pacific Southwest	78	17
NMFS: Marine	24	5

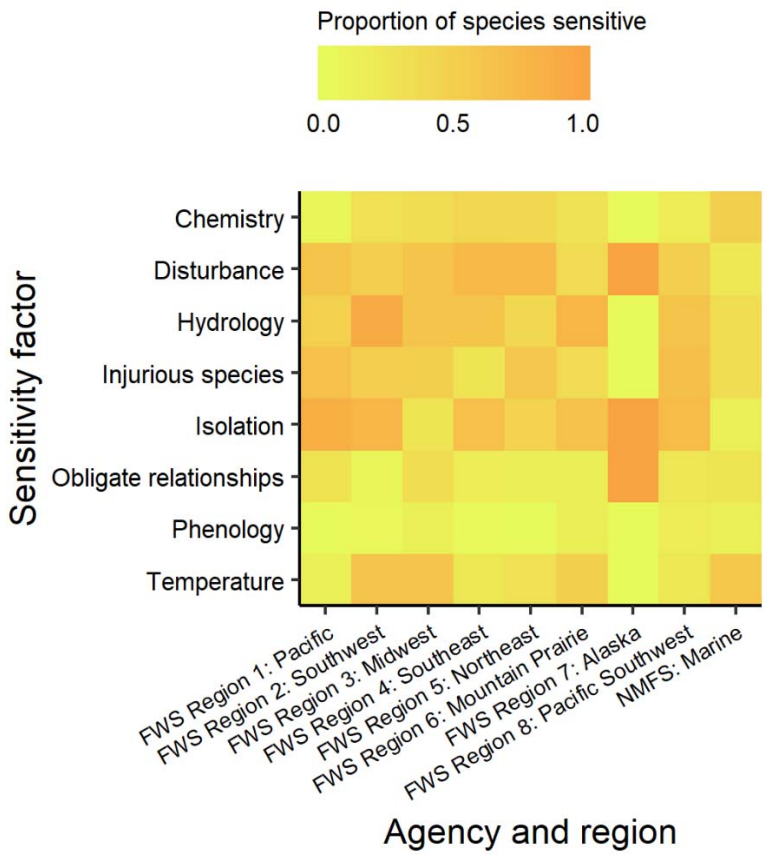

Figure 1. The sensitivity of US endangered animals (n=459) differs by climate factor across management agency and regions. FWS indicates US Fish and Wildlife Service and NMFS indicates US National Marine Fisheries Service. See Supplementary Table 2 for the number of species in each region and Table 1 for descriptions of climate sensitivity factors.