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Climate change threats to Earth's wild animals

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We are entering an existential crisis for the world's wild animals. To date, the primary cause of biodiversity loss has not been climate change but, rather, the combined twin threats of overexploitation and habitat alteration (Maxwell et al. 2016); as climate change intensifies, we expect it to become a third major threat to Earth's animals. Shifts in temperature and weather patterns are starting to threaten ecosystems worldwide, which, in turn, endangers countless animal species, affecting their reproduction, migration, and survival and ultimately accelerating the alarming decline in global biodiversity (IUCN 2023). Although some species might benefit, increases in global temperature can lead to a variety of impacts on wild animals, including changes in their physiology, behavior, life cycle, distribution, and interactions among species (Warren et al. 2018). Sudden impacts on wild animal communities can involve mass mortality from exceeding temperature thresholds or extreme events such as heat waves, wildfires, droughts, and floods. Disruptions due to climate change can lead to population declines or collapses of sensitive taxa (Garrabou et al. 2019). Animals can encounter climate change thresholds simultaneously, potentially resulting in extensive disruptions or even collapse.

In this paper, we examine the risk of climate change to global wild animal populations, with a focus on potential detrimental impacts. Using two publicly available biodiversity data sets, we examine animal data for 70,814 species from 35 existing classes, compile described and assessed species by class, and report major climate change risks. To the best of our knowledge, our analysis of the International Union for Conservation of Nature's (IUCN) data on climate threats to the world's animals is novel. We also highlight recent examples of collapsing wild animal populations due to climate change and provide science and policy recommendations.

Climate threat assessment

We used the Catalogue of Life as our source for the numbers of extant named (i.e., described) animal species within various taxonomic groups (Bánki et al. 2024). We compared these estimates with the numbers of species assessed in the IUCN Red List (IUCN 2023), omitting species classified as data deficient, extinct in the wild, or extinct, although these species are technically considered assessed. Finally, we calculated the proportion of assessed species that are threatened—Red List category vulnerable, endangered, or critically endangered—and facing the specific threat climate change and severe weather, as is indicated in the Red List Threats Classification Scheme. Species threatened by climate change were also typically affected by other types of threats. Note that in many taxonomic groups, species suspected to be threatened may be more likely to have been assessed.

Our analysis is intended as a preliminary effort to assess climate risk to wild species. As part of a more advanced future analysis, the threat of climate change could be modeled while accounting for phylogeny, geography, traits, interaction with other threats, and possibly other correlates. IUCN Red List assessments of species threatened by climate change could benefit from more complete inclusion of climate-related traits (Trull et al. 2018). Incorporating specific traits into IUCN assessments could improve the accuracy and robustness of evaluations regarding species' vulnerability to climate change (Trull et al. 2018).

See supplemental file S1 for supplementary methods.

Climate imperiled animals

There are 70,814 wild animal species from only 35 of the 101 animal classes that have undergone assessment within the IUCN Red List to date, excluding those labeled as data deficient, extinct in the wild, or extinct (hereafter, *assessed species*; figure 1a, supplemental file S1). This is 5.5% of the 1,281,520 described species (including 962,178 insect species) and an even smaller proportion of the millions of extant animal species (Costello et al. 2013). The percentage of species assessed was approximately 46 times greater for vertebrates ($51,512 \div 70,911 = 72.6\%$) than for invertebrates ($19,302 \div 1,210,609 = 1.6\%$). Approximately one out of every four animal species evaluated face potential extinction, representing 23.9% of the assessed species (IUCN 2023). In addition, 778 are extinct and 39 species are extinct in the wild. Overall, 3585 assessed animal species were threatened by climate change, 5.1% of all assessed animal species.

There were six classes with at least 25% of assessed species threatened by climate change (figure 1a). Therefore, while climate change is not yet a dominant threat to many species, it may already be severely affecting some classes. The number of climate-threatened species varied widely across terrestrial (n = 1774 species), freshwater (n = 712), and marine systems (n = 441; figure 1b). Specific climate threats to these species were droughts (n = 1735 species), altered habitats (n = 1646), storms or flooding (n = 924), and temperature extremes (n = 792; figure 1b). Because moderate increases in average temperatures can lead to dramatic
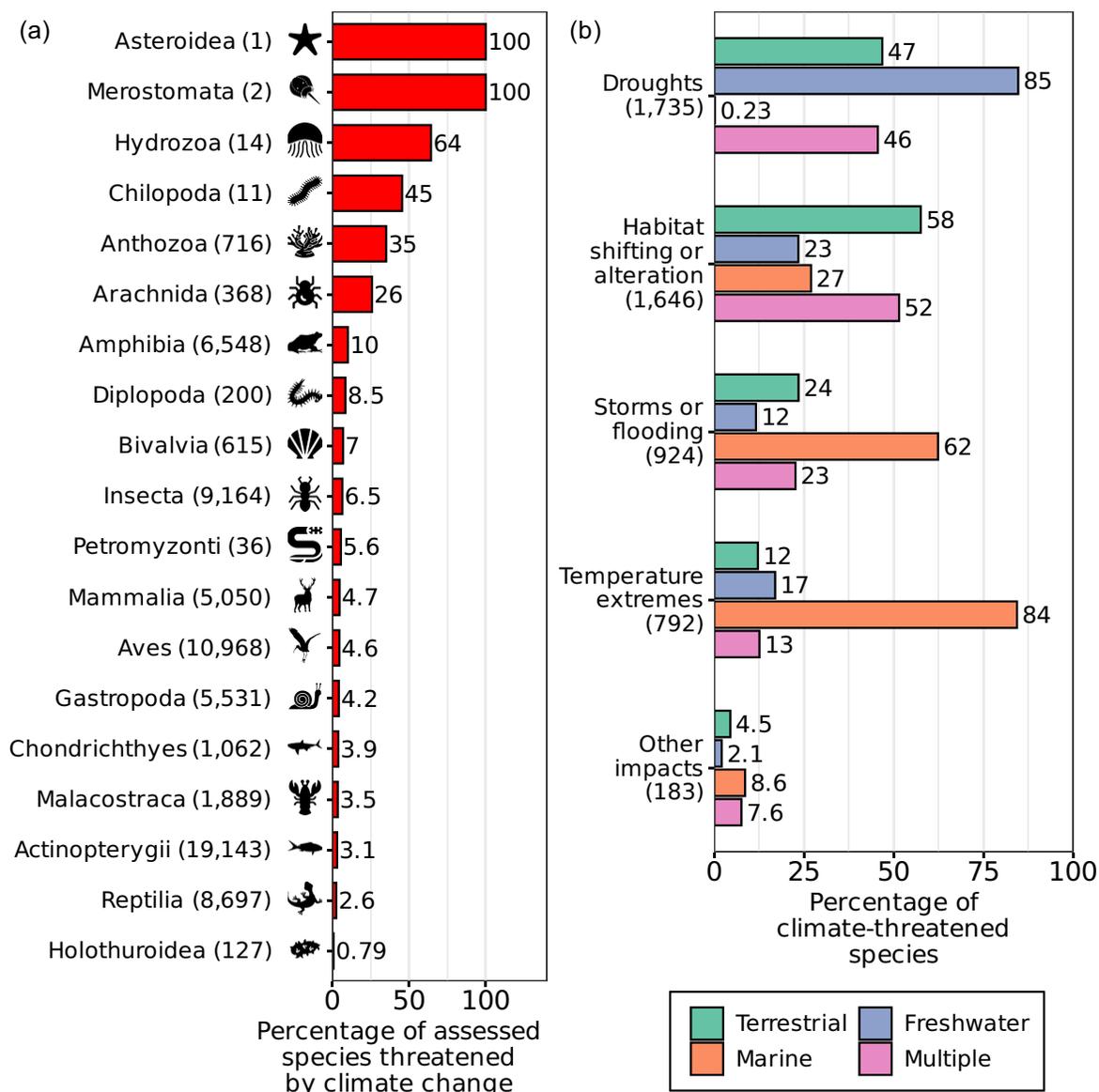
Figure 1. Climate risks to Earth's animals. (a) Percentages of assessed species that are threatened by climate change. Only classes with some assessed species threatened by climate change are shown. The number after each class indicates the total number of species assessed, while the number after each bar shows the percentage of assessed species that have been impacted by climate change. (b) Specific climate-related threats for each system type. The number below each category indicates the number of affected species. The number after each bar shows the associated percentage. See supplemental file S1 for absolute numbers and other relevant statistics.

increases in the incidence of extreme weather, we expect some of these threats will become much more serious in upcoming years.

The Red List is taxonomically biased, primarily favoring vertebrates, which make up only a small fraction (5.5%) of Earth's named animal species (figure 1a). Because the number of assessed animal species (70,814) is much lower than the number of described animal species (1,281,520), which is, itself, lower than the number of extant animal species, it is likely that many species at risk due to climate change and other threats have not yet been identified as such. Understudied taxa of particular concern could include evolutionarily distinct species, foundational species, and alpine or island endemic species.

We are especially concerned with the fate of invertebrate animals in the ocean, which absorbs most of the heat from climate change. Benthic invertebrates face increased vulnerabil-

ity because limited mobility constrains their ability to promptly evade adverse conditions caused by climate change. For example, the phylum Bryozoa consists of colonial benthic marine calcifiers and contains over 20,000 species of which none have been assessed for extinction risk; increasing temperatures of oceans will likely have strong negative effects on their calcification and growth (Smith 2014). Tube worms belonging to the Annelid phylum and Serpulid family dwell within calcium carbonate tubes, which frequently form reefs crucial for a diverse set of marine life. Climate change could significantly affect these reefs, affecting both the tube worms and the many species that use the tube structures (Hill 2013). Unfortunately, none of the approximately 300 species of serpulid tube worms have been assessed.

Many invertebrate species in terrestrial and freshwater ecosystems are also exceptionally imperiled by climate change. For

Animal population collapse due to climate change

Snow crabs. Population declined by ~10 billion
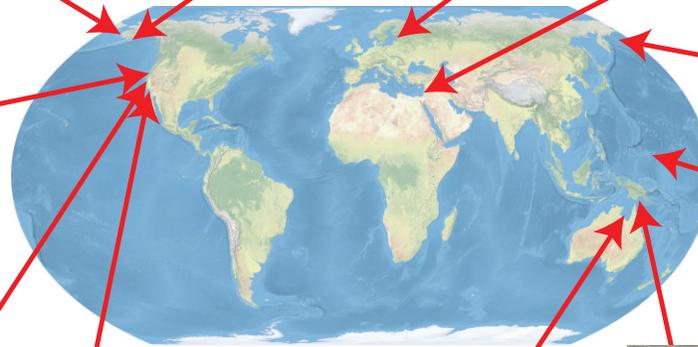
Pacific cod. 71% decline for these fish

Bumble Bees. Some populations collapsed

Molluscs. Population plummeted by ~90%

Humpback whales. ~7,000 died

Common murres. ~4 million birds died

Intertidal invertebrates. Billions of marine invertebrates killed

Sunflower seastars. Population declined 80–100%

Corals. 29% of the Great Barrier Reef died

Bramble Cay melomys. First mammal extinct due to climate change

Green Sea Turtles. 99% of hatchlings were female

Figure 2. Examples of animal population collapse likely due at least partly to climate change. Many populations recently experienced collapse due to climate change, including coral—a foundational species. Associated references are provided in the main text. This list of examples is not exhaustive.

example, under current climate pledges, nearly half of all insect species are projected to become extirpated from the majority of their geographic ranges by 2100 compared with roughly a quarter of vertebrate species (Warren et al. 2018).

Collapsing wild animal populations

The collapse of animal populations due to climate change has already begun across a wide range of taxa and locations around the world and has probably happened much more than has been documented (figure 2). In marine environments, the collapse of invertebrates is becoming common (Garrabou et al. 2019). The dramatic plummet of mollusk populations along Israel's coastline by an alarming 90% due to escalating water temperatures reflects the susceptibility of these creatures to changing climate conditions (Albano et al. 2021). The decimation of the sunflower sea star (*Pycnopodia helianthoides*) due to sea star wasting disease along with the widespread mortality of intertidal invertebrates during the 2021 Pacific Northwest heat dome underline the vulnerability of marine invertebrates to rising temperatures and associated diseases (Harvell et al. 2019, White et al. 2023). Equally distressing is the catastrophic die-off of corals across 29% of the Great Bar-

rier Reef system in the wake of a severe 2016 marine heatwave, signifying the extensive and immediate repercussions of extreme accumulated heat exposure on the biodiverse coral reefs (Hughes et al. 2018). Furthermore, due to a marine heatwave, more than 10 billion snow crabs (*Chionoecetes opilio*) in the Bering Sea have apparently disappeared because of starvation since 2018 (Szuwalski et al. 2023). Marine heatwaves also likely contributed to the deaths of approximately 7000 humpback whales (*Megaptera novaeangliae*) in the North Pacific Ocean (Cheeseman et al. 2024). There are likely many more cases of climate-related marine heatwave faunal die-offs given that among the 441 assessed, climate-threatened marine species, 84% (n = 372) are threatened by temperature extremes (figure 1b).

Nearly 300 bumble bee (*Bombus* spp.) species exist (Bánki et al. 2024), and they play a crucial role as essential pollinators. Data from North America and Europe indicate that the rise in unusually hot days contributed to heightened local extinction rates, diminished colonization, reduced site occupancy, and decreased bumble bee species richness (Soroye et al. 2020). Vertebrate populations have not been spared from direct effects. In 2015 and 2016, roughly 4 million common murres (*Uria aalge*) died off of the west coast of North America due to starvation and an altered

food web from an extreme marine heat wave (Renner et al. 2024). The same marine heat wave caused a 71% decline in Pacific cod (*Gadus macrocephalus*) because of an increase in metabolic demand and a reduced prey base (Barbeaux et al. 2020). Droughts are also a major climate-related risk to vertebrates, especially in freshwater ecosystems where they threaten 85% (n = 603) of climate-threatened species—primarily fish (figure 1b). The harrowing extinction of the Bramble Cay melomys (*Melomys rubicola*), attributed directly to rising sea levels spurred by climate change, stands as a stark example of the irreversible toll on species and habitats (Waller et al. 2017).

These events highlight that climate change is already affecting the intricate web of life on our planet. Despite being in the early stages of the climate crisis, these occurrences sound alarms not only for species and local ecosystems but also for broader processes including ecosystem services. Although some affected populations may recover, the cascading effects of more and more mass mortality events could potentially affect carbon cycle feedbacks, nutrient cycling, and—perhaps most notably—species interactions, which can be vital for avoiding ecosystem collapse. Climate change in combination with other anthropogenic stressors continues to affect diverse ecosystems, posing significant harm to marine and terrestrial organisms, both invertebrate and vertebrate, manifesting in a myriad of distressing scenarios with the potential for mass extinction. For example, climate change could cause the widespread loss of coral reefs, which would almost certainly have devastating consequences for the roughly a million or more reef-associated species (Hoegh-Guldberg et al. 2017). More broadly, a recent synthesis of threats to 2766 US imperiled species found that climate change is now the leading threat to species listed under the Endangered Species Act, with most species facing multiple, compounding threats from other major drivers of biodiversity loss (Niederman et al. 2025).

Ecosystems are intricately woven tapestries of interdependent relationships among various species. While the loss of individual species is often highlighted, the collapse of ecosystems can result from the extinction of critical animal interactions. Interactions such as predation, competition, mutualism, parasitism, commensalism, and pollination are examples of relationships that play pivotal roles in maintaining the structure and function of ecosystems (Valiente-Banuet et al. 2015).

Future directions

It is crucial to understand the impact of climate change on wild animals and their interactions to guide global policy decisions on the biological consequences of an unabated climate crisis and to establish conservation plans for the most threatened animals. Given the urgency and trends that we describe here, we recommend the development of a global database on mass mortality events due to climate change for animal species in all ecosystems, similar to the database to track mass mortality in the Mediterranean Sea (Garrabou et al. 2019). Such a database could include information on type of event (e.g., heat wave), affected taxa, and event severity—ideally using standardized metrics. It could serve as a valuable resource that supports climate impacts research collaboration, efforts to identify species currently most vulnerable to climate change, and the development of predictive models to forecast future climate impacts. The database could also track any recoveries after mass mortality events. We also recommend a great acceleration to assess ignored species, including a bigger effort in making Red List assessments for invertebrates highly vulnerable to climate change. This is vital partly because many species have not yet been severely affected by climate change; therefore, such early assessments could serve as a useful baseline for future climate impact research. There is also a need for more frequent climate risk assessments of all species and better consideration of species' adaptive capacity. Finally, we recommend robust efforts to address habitat loss and overexploitation. Furthermore, the integration of biodiversity and climate change policy planning at the global scale is needed to ensure cohesive efforts in tackling these two interconnected crises. For example, policies based on protecting carbon stocks in natural ecosystems can yield significant benefits for climate mitigation and biodiversity conservation.

We may be approaching tipping points regarding the impact of climate change on Earth's animals. We anticipate future extinction risks and mass mortalities due to climate change not only to rise but also greatly accelerate with each fraction of a degree increase in global temperatures. Therefore, rapid and effective climate mitigation is crucial now more than ever for saving the world's biodiversity.

Acknowledgments

Supplemental material

Supplemental data are available at *BIOSCI* online.

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