Adaptive responses in animals to climate change

Article by:

Mills, L. Scott Office of Research and Wildlife Biology Program, University of Montana, Missoula, Montana.

Global climate change can act as a stressor on wild animal populations in several ways. Direct effects can occur when a change in climate exceeds physiological optima for species, such as when waterfowl or amphibians confront dry breeding ponds, or polar bears face reduced sea ice. In other cases, the effects of climate change create mismatches with seasonal phenological processes (note that phenology refers to the timing of seasonal activities of animals and plants throughout the year). Examples of phenological events in animals include migration, hibernation, mating, and change of coat color to match winter snow (**Fig. 1**). Phenological processes in animals are often initiated by day length (or photoperiod) because it is a historically excellent predictor of seasonal environmental conditions (decreasing day length heralds the coming of autumn, whereas increasing day length tracks spring). However, if these seasonal environmental conditions are altered by climate change (for example, earlier times of snow melting or increases in spring temperatures), then a day length–controlled phenological trait in an animal may become mismatched with its optimal conditions. _See also:_ **Adaptation (biology) (/content/adaptation-biology/009800)**; **Climate modeling (/content/climate-modeling/140350)**; **Climate modification (/content/climate-modification/140400)**; **Global climate change (/content/global-climate-change/757541)**; **Hibernation and estivation (/content/hibernation-and-estivation/317700)**; **Migratory behavior (/content/migratory-behavior/425000)**; **Photoperiodism (/content/photoperiodism/511200)**; **Population ecology (/content/population-ecology/538150)**; **Protective coloration (/content/protective-coloration/550100)**; **Sea ice (/content/sea-ice/609500)**

Fig. 1 Different levels of seasonal coat color matching in snowshoe hares. [*Courtesy of L. S. Mills et al., Camouflage mismatch in seasonal coat color due to decreased snow duration, Proc. Natl. Acad. Sci. USA, 110(18):7360–7365, 2013*]

Adaptation

As environmental stress resulting from climate change increases, the persistence of wild animal populations depends on successful adaptation. Broadly speaking, adaptation means that the fitness of individuals and the persistence of animal populations are maintained in the presence of a stressor. One way to adapt is to move away from the stress. Changes in animal movements and species distribution have been widely documented, with many butterfly, bird, and small mammal species shifting ranges northward and/or upward in elevation as the result of increases in temperature. *See also:* **Biogeography (/content/biogeography/082300)**; **Population dispersal (/content/population-dispersal/537900)**; **Population dispersion (/content/population-dispersion/538000)**

However, in many cases, animals do not or cannot move or shift their geographic range in response to a sustained stress. In these cases, successful local adaptation is the force that stands between the environmental stressors and local extinction of the species. Local adaptation, or adaptive rescue in the face of climate change, can occur in two main ways: (1) phenotypic plasticity and (2) evolution via natural selection. *See also:* **Animal evolution (/content/animal-evolution/035500)**; **Endangered species (/content/endangered-species/757435)**; **Extinction (biology) (/content/extinction-biology/249000)**; **Macroevolution (/content/macroevolution/395700)**; **Organic evolution (/content/organic-evolution/475150)**; **Population viability (/content/population-viability/757600)**

Phenotypic plasticity

Phenotypic plasticity occurs when an individual adjusts its phenotype (for example, body structure, physiology, or behavior) to tolerate a stressor. For example, animals might avoid direct stresses of climate change by choosing cooler sites to inhabit or by modifying their physiology to disperse heat. Phenotypic plasticity to reduce phenological mismatch due to climate change can also occur. For example, as faster spring warming triggers earlier emergence of insects, some migrating birds have begun laying their eggs earlier to match the new peak of their insect prey. Thus, phenotypic plasticity can lead to ecological rescue of a species facing climate change by allowing individuals to survive environmental stressors.

Evolution by natural selection

The second way that animals can adapt to climate change is through evolution by natural selection. Unlike the individual-level ecological rescue that comes from phenotypic plasticity, evolutionary rescue through natural selection involves changes in gene frequencies in a population or species across generations. Importantly, meaningful evolutionary changes do not necessarily require long time periods to occur. In fact, under the proper conditions, contemporary evolution can adaptively mold phenotypes on ecological and management-relevant time scales. *See also:* **Gene (/content/gene/284400)**; **Genetics (/content/genetics/285300)**

Conditions for adaptation

What are the conditions by which ecological rescue through phenotypic plasticity and evolutionary rescue through natural selection most efficiently foster adaptation to climate change? First, populations that are large and with connectivity (gene flow) to other populations will have the greatest ability to adapt to climate change. Larger populations are more likely to contain individuals with traits that allow a plastic response to the stressor, and these populations can be shaped more efficiently by natural selection. Furthermore, populations that are large and connected to other populations generate potentially adaptive variability through mutations and gene flow. *See also:* **Mutation (/content/mutation/441200)**; **Population genetics (/content/population-genetics/538200)**

The second factor that most favors local adaptation is short generation times. Over a given time interval, species with short generation times will be exposed to more bouts of natural selection and therefore will have a greater potential to exhibit evolutionary rescue. Furthermore, species with short generation times tend to have higher growth rates, buffering them against the demographic costs of natural selection.

Third, more generalist species (that is, species able to survive in a wide variety of environmental conditions) will have higher potential for adaptation. For a given population size, more generalist species will tend to have more heritable variation in traits under climate-induced selection than highly specialized species. For example, many fruit fly (*Drosophila*) species have high heritable variation to endure desiccation stress, but a narrowly distributed specialist rainforest species has low heritability for this trait and is unable to evolve resistance to desiccation stress.

Finally, natural selection works most efficiently one stressor at a time. In other words, reducing other stressors (for example, habitat destruction, urbanization, or pollution) on a wild animal population will effectively increase the scope for adaptive rescue in response to climate change.

Ironically, the types of species that tend most consistently to share these traits for optimal adaptive shifts (that is, large and connected populations, short generation times, and generalist habits) tend to be those that are considered to be invasive and pest species. Thus, without management to the contrary, it is likely that adaptive rescue from climate change stressors will tend to favor pest species (for example, disease organisms, rats, zebra mussels, and weedy plants). *See also:* **Invasion ecology (/content/invasion-ecology/757488)**

Sustaining wild animal populations

Knowledge of the conditions that foster adaptive rescue also provides guidance for sustaining wild animal populations. Conservation actions that minimize population fragmentation and lessen other stressors will inherently maximize adaptive potential in response to climate change. For example, this strategy is being studied in animals that molt their fur or feathers seasonally, from brown in summer to white in winter, as camouflage to match predictable seasonal snow cover. At least 20 species worldwide undergo seasonal color molts, including Arctic fox, weasels, hares, ptarmigan, and some hamsters. The molt is triggered by photoperiod, which is an exquisite mechanism to time the color molt to the average snow duration.

However, durations of snow seasons are decreasing globally as a result of climate warming, prompting the question of whether these species will be able to adapt to being increasingly white in color on brown snowless backgrounds. Extensive field studies on snowshoe hares (**Fig. 1**) found little plasticity either in the timing of the color molt or in behaviors to avoid being mismatched. Moreover, selection against color mismatch is strong, with mismatched hares substantially more likely to be killed by predators (**Fig. 2**). Still, adaptive rescue from this direct climate change stressor remains possible for hares and other species. Variability in the timing of the color molt exists both within populations and across populations, providing the template on which natural selection could act to shift the molt to match a shorter snow duration. Researchers are working with multiple species to understand the genetic inheritance of the coat color phenological trait and the ability for animals to adjust behaviors or molt timing. *See also:* **Predator-prey interactions (/content/predator-prey-interactions/757602)**
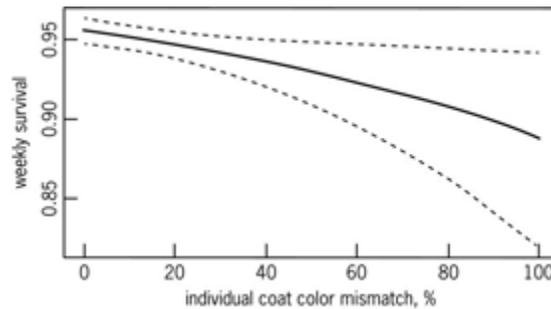
Fig. 2 Individual coat color contrast decreases snowshoe hare survival. Without adaptation, projecting these field-measured costs to the expected increase in contrast under climate change leads to an expected decline in the population growth rate. Dashed lines indicate 95% credible intervals, whereas the solid line depicts the mean survival at a given level of color contrast between an individual hare and its background. [*Adapted from M. Zimova, L. S. Mills, and J. J. Nowak, High fitness costs of climate change-induced camouflage mismatch, Ecol. Lett., 19(3):299–307, 2016*]

Outlook

Mismatched white animals on a brown snowless background underscore a charismatic example where adaptation will be required, and is possible, for these species to survive climate change. Successful adaptive response remains a possibility. Although the root drivers of climate change must be addressed to minimize its effects on wild populations, actions can be taken to foster adaptive rescue by maintaining large, connected populations and reducing other stressors. Adaptation is not a magic or all-powerful process; however, under appropriate conditions, it has real potential to help sustain animal populations facing climate change.

L. Scott Mills

Bibliography

S. Boutin and J. E. Lane, Climate change and mammals: Evolutionary versus plastic responses, *Evol. Appl.*, 7:29–41, 2014 DOI: 10.1111/eva.12121 (http://dx.doi.org/10.1111/eva.12121)

A. Gonzalez et al., Evolutionary rescue: An emerging focus at the intersection between ecology and evolution, *Philos. Trans. R. Soc. Lond. B Biol. Sci.*, 368(1610):20120404, 2013 DOI: 10.1098/rstb.2012.0404 (http://dx.doi.org/10.1098/rstb.2012.0404)

L. S. Mills et al., Camouflage mismatch in seasonal coat color due to decreased snow duration, *Proc. Natl. Acad. Sci. USA*, 110(18):7360–7365, 2013 DOI: 10.1073/pnas.1222724110 (http://dx.doi.org/10.1073/pnas.1222724110)

S.W. Running and L. S. Mills, *Terrestrial Ecosystem Adaptation*, Resources for the Future, 2009

E. Vander Wal et al., Evolutionary rescue in vertebrates: Evidence, applications and uncertainty, *Philos. Trans. R. Soc. Lond. B Biol. Sci.*, 368(1610):20120090, 2013 DOI: 10.1098/rstb.2012.0090 (http://dx.doi.org/10.1098/rstb.2012.0090)

M. Zimova, L. S. Mills, and J. J. Nowak, High fitness costs of climate change-induced camouflage mismatch, *Ecol. Lett.*, 19(3):299–307, 2016 DOI: 10.1111/ele.12568 (http://dx.doi.org/10.1111/ele.12568)

Additional Readings

National Public Radio: Climate Change Leaves Hares Wearing the Wrong Colors (http://www.npr.org/2013/09/08/220188619/climate-change-leaves-hares-wearing-the-wrong-colors)

Resources for the Future: Terrestrial Ecosystem Adaptation [PDF] (http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-Rpt-Adaptation-RunningMills.pdf)

University of California, Berkeley: Warming to Evolution (http://evolution.berkeley.edu/evolibrary/news/060701_warming)