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Resilient Wilds: Unmasking the Surprising Adaptability of U.S. Ecosystems to Climate Change

Susan J. Crockford, PhD

The Intergovernmental Panel on Climate Change and others predict that global warming caused by increasing carbon dioxide emissions from the burning of fossil fuels will have profoundly negative effects on plant and animal ecosystems in the U.S. and around the world in the coming decades. It is predicted that effects will negatively impact the provision of market goods and services produced from these ecosystems. Although changes have occurred over the past two centuries—many of which have been due to entirely natural warming or human-use impacts since the late 1800s—with respect to several animal examples that occupy these ecosystems, recent ecological studies show that many species are actually more resilient to changes in ecological conditions than previously acknowledged.

On August 2, 2023, a new regulation that would allow the U.S. Fish and Wildlife Service to establish experimental populations of designated threatened and endangered species of plants and wildlife in areas outside of their normal historical range became effective. The regulation is based on the expectation that ongoing or predicted "irreversible" harms from invasive species or global warming caused by increasing carbon dioxide emissions from the burning of fossil fuels may make certain habitats so profoundly unsuitable for some species that their continued survival may depend on direct human interference.[1]

This is an unprecedented response to the perceived threat to U.S. biodiversity from climate change, yet it has received little attention from the media or conservation organizations. But are the actions made possible by this potentially game-changing new rule actually needed to deal with the effects of global warming, or was climate change simply "tacked on" to a rule meant to deal with the well-documented damage caused by invasive species like feral swine and Burmese pythons?[2]

It is claimed that over the 21st century, changes in climate will cause temperature-sensitive species to shift north and to higher elevations, thus fundamentally rearranging historical U.S. ecosystems. Coastal areas are said to face other adverse impacts, especially habitat loss from rising sea levels, including land loss due to inundation, erosion, and wetland submergence. Together, it is argued, these effects will negatively impact the provision of market goods and services produced from these ecosystems, including food, fuel, fiber, water, tourism and recreation, and pure aesthetic value.[3]

All of these predictions about 21st century habitat changes and associated wildlife survival depend on computer-simulated models of future climate conditions that are based on a mix of scientific principles, assumptions, and data collected over previous decades.[4] Presumably due to the potential inaccuracy of assumptions that must be made and the inability of the models to account for naturally occurring climatic variables (including clouds and wind), the output of these models is by no means certain yet is often presented as incontrovertible fact. As a consequence, it is not surprising that computer-modeled forecasts of wildlife survival often conflict with the results of recent ecological studies, which show that many animal species, in habitats ranging from sea ice to mountains and coastal regions, are actually more resilient to ecosystem changes than expected.

This *Special Report* explores a number of examples from animal ecological studies that have documented changes in habitat, some of which have been attributed to human-caused climate change, for decades if not longer. These examples provide convincing evidence that warming-associated changes in ecosystems, regardless of cause, are more likely than not to have an overall positive or neutral impact on the survival of the most critical animal species that they support. Other human-caused impacts, including land-use changes and wildlife management practices, influence animal survival and range shifts just as much as, if not more than, global warming does.

Loss of Polar Sea Ice Habitat

The U.S. manages the conservation of wildlife species that inhabit Arctic sea ice in the Bering, Beaufort, and Chukchi Seas off the coast of Alaska and since 1961 has had environmental protection interests in wildlife of the Southern Ocean under the Antarctic Treaty. The Earth has experienced mild natural warming since the end of a 400-year period of cold weather around 1850, and it is predicted that human-caused global warming will exacerbate this warming. Over the rest of the 21st century, declines in sea ice thickness and lengthening of ice-free seasons are forecasted to have a profound impact on critical habitat for ice-dependent species at both poles.[5]

Even though a small decline in sea ice extent during winter (March) has taken place in the Arctic, this loss has been small relative to the loss of summer sea ice in September. Most Arctic species that are considered ice-dependent need sea ice primarily from late autumn through late spring. Fortunately, all Arctic sea ice climate models produced so far predict the continued persistence of winter and spring ice (December–May) throughout the 21st century at close to current values.[6]

In contrast to the Arctic, it is normal for virtually all of the sea ice that forms around Antarctica in winter to disappear in the summer, because most of it is thin, first-year ice that is only about 1 meter (about 3 feet) thick. This means that ice-dependent species, like emperor penguins, only count on winter and spring ice for survival because summer ice is always scarce. Although early climate change models predicted Arctic and Antarctic sea ice to decline in similar fashion in response to human-generated carbon dioxide emissions, that is not what has happened: Antarctic sea ice so far has changed very little, and at least one new model, published in 2022, predicts continued stable winter sea ice conditions at least until 2050.

Since 1978, daily winter sea ice extent in the Southern Ocean (as of September) has *increased* slightly overall, with record highs in 2014 and lows in 1986 and 2023. On September 10, 2023, daily sea ice extent reached 16.96 million kilometers^2 (mkm^2), a record low that was 1.03 mkm^2 below the previous low in 1986. Daily summer sea ice levels in February in the Antarctic have declined slightly since 1978 with the lowest and second-lowest daily minimum extents in 2017 and 2023, respectively. However, as for the Arctic, for most long-term comparisons and models, *average values* for September (winter) and February (summer) in Antarctica are used instead of daily minimum or maximum values, and these show a very slight increase over time for September and a slight decline for February.[7]

Two species of special interest from these polar regions—the Pacific walrus (*Odobenus rosmarus divergens*) in the Arctic and the emperor penguin (*Aptenodytes forsteri*) in the Antarctic—provide ample evidence that so far, reduced sea ice habitats since 1979 have not been harmful and these examples challenge the assumptions in modeled predictions that future sea ice changes are likely to cause quasi-extinctions by the end of the 21st century.

Pacific Walrus. The Pacific walrus lives exclusively in the marine region between Alaska and Russia in the Bering and Chukchi Seas. Like Atlantic walruses, Pacific walruses use seasonal sea ice over shallow waters from winter through spring (December–May) as a platform for resting, socializing, molting, giving birth, and nursing their young. They mate in the water and use ice floes and beaches to rest between feedings on a variety of bottom-dwelling invertebrates, especially clams and marine worms.[8]

For almost two decades, it has been claimed that ongoing and expected declines in sea ice in the Chukchi Sea threaten the immediate and long-term survival of this subspecies because of its perceived critical dependence on summer sea ice. In 2008, the Center for Biological Diversity, an activist conservation organization, requested that the Pacific walrus be listed by the U.S. as a threatened or endangered species under the Endangered Species Act (ESA) because it was "currently in danger of extinction in all or a significant portion of its range or likely to become so in the foreseeable future." A relentless barrage of lawsuits has been filed against the U.S. Fish and Wildlife Service (USFWS) since then in pursuit of this outcome.[9]

However, in 2017, the USFWS formally announced that the Pacific walrus, which has been safeguarded under the Marine Mammal Protection Act since 1972, did not require additional ESA protection because the population appeared to be stable and had demonstrated an unforeseen ability to adapt to changing conditions. So far, it has managed to hold this position in the face of additional lawsuits.[10]

By all available measures, the walrus is unexpectedly thriving despite a marked lengthening of the summer ice-free period in the Chukchi Sea since 1979. William Beatty and colleagues surveyed the Pacific walrus for five years ending in 2017 and estimated that its average *total abundance* was 257,193 (range 171,00–366,366). In early August 2023, the USFWS reported that the *minimum number* of walruses in 2021 was 214,008 animals—a notable increase from the minimum population of 129,000 estimated by the USFWS in 2006.[11]

Numbers seem to have remained high since 2017 despite the fact that in most summers, sea ice retreat has forced walruses to use beaches in Alaska and Russia as resting and socializing platforms between feeding bouts from July to October. In 2022, Tony Fischbach of the U.S. Geological Survey stated that in late October, he and his colleagues had seen via satellite an especially large number of walruses resting on the extensive beach complex of Cape Serdtse-Kamen, which lies along the Russia coast of the Chukchi Sea. Unfortunately, they were unable to confirm an accurate estimate of the size of the haulout with Russian colleagues, but enormous haulouts of more than 100,000 animals at that location have been documented, including in 2009, 2011, and 2017.[12]

Accurate estimates of walrus population size are notoriously hard to come by, but not since the late 1970s have total estimates of the Pacific walrus population been anywhere near 250,000 animals. At that time, it seemed that such an abundance was more than the habitat could support because beginning in 1978 and continuing into the 1990s, based on documented incidents of starvation and subsequent poor calf survival, the population almost certainly declined, although no accurate estimates were available to tell us by how much: There simply were not enough clams to feed that many walruses. However, the USFWS's 2023 assessment states explicitly that no evidence exists to suggest that walruses are currently "food limited," despite their abundance over the past five years and their extensive use of terrestrial haulouts from summer through fall as a result of sea ice declines.[13]

The fact that walruses are not starving despite this remarkably large population is almost certainly due to abundant food resources fueled by high primary productivity in the Chukchi Sea that has been a direct result of longer than usual ice-free summers since 2003. In other words, contrary to predictions, less summer sea ice has been a *net benefit* to this species, as well as to others in the Arctic food chain including polar bears, ringed seals, and bearded seals (all of which are currently listed as "threatened" under the ESA). Similar positive effects on body condition and population size have been documented for populations of Atlantic walruses and polar bears in the Barents Sea, indicating that this not a purely local phenomenon.[14]

It appears that as long as sea ice continues to exist in the Chukchi and northern Bering Seas from winter through spring when walruses and other sea mammals truly require sea ice for critical feeding and reproductive activities—as most climate models predict—these animals will likely continue to thrive in U.S. waters and elsewhere across the Arctic. Native American hunters may have to adapt their hunting methods or timing to accommodate changing sea ice conditions, but history suggests that this is a challenge to which they have risen successfully in the past.[15]

Emperor Penguin. Standing about 39 inches or 100 centimeters (cm) tall, the emperor is the largest of the penguin species and the only one that depends on sea ice for reproduction. While other penguins incubate their eggs and raise their young to fledgling during the austral summer on ice-free beach rookeries, either along the coast of the Antarctic continent or on islands to the north, the emperor is unique in performing these critical reproductive activities on sea ice from winter to late spring. Emperors are therefore the only species of penguin that potentially could be directly affected by ongoing or anticipated 21st century declines in Antarctic sea ice extent.[16]

Emperor penguins arrive at their preferred rookery locations in early fall (March–April) after a period of intensive feeding in late summer when sea ice is at its minimum (early March). Eggs are laid by the female, are incubated by the male, and hatch from mid-fall to early winter (May–July). Newly hatched chicks must be fed a diet of small fish, squid, and krill as sea ice and cold reach their maximum extent during the winter and early spring (August–December). The parents take turns with this chore, which can mean many long walks to the edge of the ice to reach open water. By late spring (mid-December to mid-January), the chicks are close to adult-sized and fledge into the waterproof plumage they need to survive the frigid Southern Ocean. At this time, they leave the ice to feed on their own in open water, as do adults.

Competition with other penguin species for food and breeding sites may explain the unique emperor lifestyle. Emperors can dive deeply, including under sea ice, and are able to switch prey items depending on local or seasonal availability: If krill are scarce, fish or squid will do. While it seems that emperor penguins have always used sea ice for reproductive activities around the entire Antarctic continent, details of their evolutionary past are unclear because, like polar bears in the Arctic, they almost never leave fossil remains for us to find.[17]

As in the Arctic, pelagic phytoplankton blooms that peak over the austral summer feed the entire Antarctic food chain, but especially the astonishingly abundant shrimp-like crustaceans known as krill (*Euphasusia superba*), whose abundance has been relatively stable over the past two decades despite concerns to the contrary. Due to their dietary flexibility, emperors are somewhat less dependent on krill than are other penguin species, especially chinstraps (*Pygoscelis antarctica*). Populations of great whales that were decimated by commercial overhunting in the past two centuries, but especially the humpback whale (*Megaptera novaeangliae*), have rebounded in part due to continuous krill abundance in the waters off Antarctica. This has extended up the food chain to the Antarctic's apex predator, the killer whale or orca (*Orcinus orca*); small cetaceans (especially minke whales); and penguins, seals, and fish. Unlike in the Arctic, where killer whales have been rare summer visitors in recent years, in 2020, it was estimated that the Southern Ocean was home to about 70,000 killer whales, many of which lived and hunted in the offshore pack ice.[18]

By 2019, Emperor penguin population numbers were estimated to be over 600,000 (with about 282,150 breeding pairs), which was about 10 percent more than a similar estimate calculated in 2009. Up to 25,000 chicks were lost in 2016 when bad weather caused an ice shelf in the Weddell Sea to collapse, but this was barely a blip in the overall population health of the species because there were no deaths or other adverse effects on breeding-aged adults or independent subadults. Consequently, it is expected that the apparent loss of almost 10,000 emperor chicks from four small colonies off the Antarctic Peninsula in late 2022 as a result of strong winds driven by La Niña effects in the Southern Hemisphere will similarly fail to have a negative impact on numbers.[19]

In 2022, the U.S. listed the emperor as "threatened" under the Endangered Species Act based on models that unfortunately used the most extreme "business as usual" climate change scenarios to drive home their message. These extreme scenarios—called RCP8.5 (Representative Concentration Pathway 8.5) and SSP5-8.5 (Shared Socioeconomic Pathway 5-8.5)—have been severely criticized in recent years as being so implausible as to be completely useless for forecasting purposes, undermining the validity of the ESA ruling on emperor penguins. In contrast, the International Union for Conservation of Nature and Natural Resources (IUCN) has not changed its 2018 assessment for this species, which listed the emperor as "near threatened," because of the "considerable uncertainty" of the climate models used by penguin biologists to forecast future impacts on sea ice habitat and prey resources.[20]

As a consequence, it is apparent both that sea ice habitat in the Antarctic has not responded as projected to recent CO_2 emissions and that, despite an anomalously abrupt decline in September extent in 2023 (about 1 million km^2 less than 2022), the one species that is most dependent on winter sea ice—the emperor penguin—has continued to thrive. Even if winter sea ice were to register a decline of several million km^2 over future decades, this would not bring breeding habitat for emperor penguins anywhere near zero across the entire Antarctic continent because September ice extent is typically around 18.5 million km.[21] As in the Arctic, recent declines in summer sea ice (that is, in February) will likely boost overall primary productivity in the Southern Ocean, resulting in a net benefit to the entire food chain with particular advantages for species at or near the top including seals and whales.

Coastal Challenges: Temperature and Sea-Level Change

Anticipated melting of continental ice sheets and coastal mountain glaciers in Greenland and West Antarctica due to human-caused global warming forms the basis of scary-sounding predictions of sea-level increases by 2100, particularly in the U.S. Two of the most plausible, middle-of-the-road Intergovernmental Panel on Climate Change (IPCC) models predict a *global* sea-level rise of 19–21 cm (7.5–8.3 inches) by 2050 and 44–56 cm (17–22 inches) by 2100 compared to 2014 levels, while the comparable projections for the *contiguous U.S.* are a rise of 36–40 cm (14–15.7 inches) by 2050 and 70–120 cm (27.5–47 inches, or about 2–4 feet) by 2100 compared to 2000 levels.[22]

Higher sea levels are asserted to exacerbate the damage to coastal and estuary ecosystems caused by erosion and wetland loss that occur naturally in many areas due to high tides and storm surges. As a consequence, coastal ecosystems are forecasted to experience a variety of negative impacts leading to habitat loss, including land loss due to inundation, erosion, and wetland submergence. In addition, land and water temperature increases due to general climate warming, both natural and human-caused, are predicted to have adverse effects over the coming decades on a number of animal species that depend on coastal and estuary habitats.

A prime example of expected adverse impacts of future global warming vs. observations of real-world conditions comes from work on marine turtles, which lay their eggs in sandy beaches. While some authors consider these species to be at particular risk from the temperature effects of future climate warming and the impacts of inundation and erosion of beaches because of rising sea levels, the detailed studies summarized below reveal that these risks are likely to be much smaller than projected.[23]

First, however, a brief outline of the information we have about past sea-level and temperature changes compared to those that are predicted for the future is in order.

Rising Sea Levels and Global Temperatures. Global sea level has been rising since the peak of the Last Glacial Maximum (about 20,000 years ago) when sea levels had fallen an astonishing 125–134 meters (410–440 feet) because so much of the world's water froze when global temperatures sank 6–8 degrees Celsius below 2018 levels. As conditions warmed rapidly afterwards, sea levels rose well into the 21st century—with some short-term reversals or periods of stall—due to the melting of continental ice sheets and glaciers worldwide. This means that global sea-level rise is nothing new: The issue for the future is whether there is some degree of acceleration of an ongoing natural process due to the effects of human-caused global warming.[24]

In other words, even without global warming driven by carbon dioxide emissions, global sea level will continue to rise over the next seven decades as a result of naturally occurring processes. At issue is how much more than this natural amount might be contributed by ice melt blamed on human activities.

For example, mountain glaciers discharging into the sea (called outlet glaciers) in both hemispheres, including those in Greenland, retreated, stalled, and expanded prior to the intensive industrial period (about 1950, well before human-caused warming could have been a major factor). This is because the expansion and retreat of a glacier respond to a complex mix of factors, including local temperature, snowfall, tidal action, and local topography (including the glacier's height above sea level and the offshore sea floor's configuration). Moreover, even though many large outlet glaciers have been in retreat for at least two centuries, they have contributed less to global sea levels since 1900 than has the melting of continental glaciers in such places as the Rocky Mountains, which resulted in an overall sea-level rise of about 20 cm (7.9 inches) between 1901 and 2018. An acceleration of this slow yearly rise in sea level has been documented only since about 1970. Critically, about half of the total sea-level increase since 1970 has come from the expansion of sea water as it has warmed rather than from ice melt.[25]

Although far less detail is known about historical changes in Antarctic glaciers, it has been documented that both glaciers and sea ice expanded significantly around the continent during the Last Ice Age, just as they did in the Northern Hemisphere, and have responded similarly to continued natural warming since then.[26]

Another confounding factor is that sea level, as measured by tide gauges and satellites at coastal locations around the world, varies considerably because of differences in local conditions. In some places, the coast is still rebounding (rising) long after the weight of Ice Age continental ice sheets was relieved, as occurs in many places in Western Canada and Southeast Alaska. In others, local subsidence (sinking) of coastlines is taking place due to compaction of soft sediments, extraction of water for human needs, or the continuing collapse of ancient offshore areas of continental shelves that had been pushed upward by the weight of continental ice sheets during the Last Glacial Maximum (called a forebulge effect). Some locations, including many points along the northeastern U.S., are subject to subsidence from a combination of these processes. Naturally occurring subsidence means that many low-lying U.S. marshlands, barrier islands, and beaches that do not currently have flood protection measures are indeed quite vulnerable to future sea-level rise, but this risk is not due primarily to global warming.[27]

Global temperatures have followed a similar pattern of overall increase with some reversals and stalls since the extreme cold of the Last Glacial Maximum. The global average temperature in 2019 was about 1 degree Celsius higher than it had been from 1850–1900. Predictions using climate models that attempt to account for contributions to future warming from human activities, with numerous caveats about known and unknown natural factors, forecast an *additional* rise in global temperature of 0.7–1 degree Celsius by about 2050 and yet another 0.1–0.7 degree Celsius by 2100 for a total increase over 2019 temperatures of less than 2 degrees Celsius by 2100. More extreme outcomes are considered variously unlikely, although possible, and there is disagreement about how much of recent and forecasted warming should be attributed to natural causes.[28]

Nevertheless, a "global average temperature" is not something experienced by any individual person or animal, including marine turtles coming ashore to lay their eggs: What matters is the actual temperature at each location. As a consequence, the response of animals to recent warming recorded at specific locations is critical evidence for assessing what might happen several decades in the future at these and similar locations if the impact of human-caused global warming turns out to be as predicted.

Marine Turtles. Six of the seven marine species of turtles that exist in the world occur in U.S. waters. All six are designated "endangered" under the Endangered Species Act, and within the contiguous U.S., most nest primarily or exclusively on the East Coast or Gulf of Mexico. Loggerheads (*Caretta caretta*) are the most numerous and widely distributed globally but in the U.S. use only East Coast and Gulf of Mexico beaches when laying their eggs. Green sea turtles (*Chelonia mydas*) and leatherbacks (*Dermochelys coriacea*) have similar distributions and nesting preferences. The hawksbill (*Eretmochelys imbricata*) is also widely distributed worldwide but within the contiguous U.S. nests only in a few places on the southeast coast of Florida and the Florida Keys (preferring Puerto Rico and the U.S. Virgin Islands). Olive ridley turtles (*Lepidochelys olivacea*) are distributed fairly widely worldwide but in the U.S. are sighted only in southern California waters and nest only further south in Mexico. Kemp's ridley turtle (*Lepidochelys kempii*) has the most restricted distribution, being found only along the U.S. East Coast and the Gulf of Mexico, and nests in the southern part of this range.[29]

Every two or three years, pregnant female marine turtles choose sandy beaches in tropical and subtropical waters on which to lay their eggs, usually at night during high tide and often (but not always) on the same beach where they hatched from an egg years before. Dozens of females may crawl up on the same beach to lay eggs at the same time, but only Kemp's ridley and Olive ridley turtles do so by the thousands. The gravid females sometimes go only to the high-tide line on very flat sand beaches, but they more often go much higher up on beaches with greater slope where they dig a shallow hole for a clutch of soft-shelled eggs the size of ping-pong balls. Each female then uses her flippers to cover the nest loosely with sand and returns to the sea; she may return two–eight times to repeat the process at two-week intervals.

Most species deposit about 100 eggs in each nest, but only 50–85 percent of these eggs survive long enough to hatch. On hatching, the newborn turtles must scurry en masse to the water, as they are at high risk of being picked off by winged and four-legged predators, but they are not out of danger even in the sea, because a multitude of marine predators await them: In the end, few hatchlings make it to the two-year mark, and fewer still survive to adulthood.[30]

Since eggs produce more females than males under warmer conditions, marine turtle species have been considered at particular risk from the temperature effects of future climate warming. However, a recent study showed that in one species with profoundly skewed sex ratios (about 95 percent females to 5 percent males), the few available males mated with many females in many locations, resulting in almost normal fertilization rates. Therefore, it is likely that if future high temperatures result in extremely skewed sex ratios, behavioral changes could compensate for this when the breeding season rolls around.[31]

As for the predicted inundation of coastlines as a result of future rising sea levels, in the U.S., the areas where coastal flooding is considered most likely are Louisiana along the Gulf of Mexico, the Chesapeake Bay on the northern East Coast, and southern Florida. Fortunately, marine turtles nest in only a few locations along the Louisiana coast, and none nest in the Chesapeake Bay estuary, where relative sea level is already about twice the global average due to ground subsidence caused by groundwater removal and the continued collapse of land that was pushed upward by the weight of ice during the Last Ice Age. Only one beach location in Florida used by nesting loggerhead turtles—St. George Island on the northern Gulf coast—is actually flat enough to be considered at risk from habitat loss due to future sea-level rise.

In the U.S., as elsewhere worldwide, only a few very flat, low-lying beaches used by nesting marine turtles are at risk from future habitat loss, which means that the anticipated destruction of low-lying beach habitats is likely to affect only small proportions of populations even if the actual rise in sea level is toward the extreme of predictions. Even then, while it is known that loggerheads and leatherbacks are flexible enough to switch nesting beaches if necessary, it is unknown to what extent these and other species would permanently abandon low-lying beaches that are subject to frequent flooding and whether they would simply nest further upslope, beyond the reach of storms, on beaches where this option is currently possible.[32]

Historically, for all marine turtle species, accidental capture in fishing gear and the direct harvest of adult turtles and turtle eggs have caused the largest declines in overall population numbers, and these two factors continue to present the greatest human-caused threat to their survival. Based on the impact of recent changes, the future effects of human-caused climate change on sea level and global temperature seem to present a minimal risk to marine turtle survival both in the U.S. and around the world, although this risk is often overstated by conservation organizations and the media.[33]

Other studies show a similar unexpected lack of response to recent climate change effects on coastlines, such as for Atlantic puffin (*Fratercula arctica*) populations in Maine and Florida manatee (*Trichechus manatus latirostris*) populations in southern Florida. In another example, an apparent sudden die-off of shallow-water coral reefs that provide critical habitat for a large number of near-shore marine animals in the Florida Keys was attributed exclusively to short-term high water temperatures in 2023. However, reports from the South Pacific on similar coral reef systems suggest that Florida's coral may also have been impacted by other factors such as recent storms and that the apparent damage is nevertheless unlikely to be permanent.[34]

Continental Habitat Changes and Range Shifts

Across the continental U.S., changes in climate due to global warming are expected to cause the ranges of some animal species to shift north or to higher elevations, or else to precipitate profound contractions of boundaries through population declines, thus fundamentally rearranging historical ecosystems.[35] Such climate-driven changes negatively impact the ecosystem primarily through changes in inter-species interactions, including competition and predator–prey relationships. This climatic effect must be distinguished from range shifts facilitated by direct human transformations of the landscape, including effects from forestry, farming, fire suppression, and damming of rivers, that have precipitated the range expansion of coyotes (*Canis latrans*) and raccoons (*Procyon lotor*).

In many cases, both global warming *and* land-use changes have impacted ecosystems and together explain the range shifts of continental species, including the northward and westward expansion of Virginia opossum (*Didelphus virginiana*) populations since 1900, as well as the northward expansion of the southern flying squirrel (*Glaucomys volans*) into territory around the Great Lakes, which was formerly the exclusive bastion of the larger and less aggressive but ecologically similar northern flying squirrel

(*Glaucomys sabrinus*). Similarly, the northward expansion of several disease-causing tick species is often blamed exclusively on global warming and therefore is predicted to become more pronounced over the 21st century, but honest appraisals acknowledge that human-caused land-use changes are often equally to blame for these shifts.[36]

The American pika (*Ochotona princeps*) and wolverine (*Gulo gulo luscus*) are two species that once were considered to be at extreme risk of extinction due to anticipated harms from range contraction caused by global warming, because mountain peaks have already warmed in recent decades and are expected to warm even more in the future, potentially isolating declining local populations.[37] However, details from recent ecological and genetic studies contradict these pessimistic forecasts. These examples should alleviate concerns that historical ecosystems across the contiguous U.S. will be irrevocably transformed because terrestrial animal species lack the resilience and adaptability to survive habitat changes caused by warmer mountain temperatures.

American Pika. Pikas are small, hamster-like rodents most closely related to rabbits that live in small, isolated populations called colonies in high alpine and subalpine areas of the western U.S. from the Cascade Mountains of Washington and Oregon to the Sierra Nevada Mountains of California and the Rocky Mountain states of Montana, Idaho, Colorado, Utah, Nevada, and New Mexico. Their preferred habitats are dominated by broken rock left behind by ancient glaciers (talus), and they eat nearby abundant vegetation that sprouts up in the mountains over the spring and summer. When they are not actively eating, pikas store grasses and leaves to feed on over the winter when they stay warm by living under the snow.[38]

Based on the disappearance of some well-studied colonies between 1999 and 2008, it has been argued that pikas are particularly susceptible to the effects of global warming—veritable canaries in a coal mine that are so threatened with extinction that they require ESA protection. Conservation organizations and some scientists have argued that by 2009, warm weather resulting from human-caused global warming had reduced the ability of pikas to colonize new habitats when necessary; caused individuals to die from overheating during the summer; and (due to extended periods of higher than average temperatures) reduced the ability of colonies to gather enough forage over the summer to last them through the winter. In addition, researchers have claimed that reduced snowpack compounded these effects by exposing pikas to lethal freezing temperatures in winter, which in turn led to the extirpation of whole colonies.[39]

However, in 2010, the U.S. Fish and Wildlife Service rejected petitions to list the species as "threatened" with extinction, stating that only a small portion of all U.S. pikas were at risk from climate change and that the rest were safe for the foreseeable future. Since then, additional research has strengthened that decision with data showing that pikas are far more resilient than previously thought. Despite continued warming over the past three decades, established colonies of pikas in alpine and even some lower-elevation sites across their range are thriving, in part because snow has not disappeared during the coldest months and individuals have adapted their behaviors when it gets hot in the summer. Although a few pika colonies at low-elevation sites have indeed disappeared, it seems that this response was more likely due to human disturbance than to high temperatures alone.[40]

Continued scientific monitoring of populations has demonstrated that this species is able to tolerate a much larger range of temperatures than previously thought. Nevertheless, U.S. activists continue to insist that global warming is putting the American pika at risk of extinction.[41]

Wolverine. The wolverine is the largest member of the weasel family. It resembles a small bear with a long bushy tail, about the size of a large cat or small dog (20–40 pounds), but is strong and ferocious enough to kill deer, elk, and caribou. Historically, the wolverine was a rarely encountered but widely distributed species across the contiguous U.S., living in remote snow-covered areas of western and Pacific Coast mountain ranges and east into North Dakota, Minnesota, and Michigan (with a few historical records from the Northeast in the 1800s, including New York State).

Active year-round, individual wolverines can travel hundreds of square miles over deep snow, especially during the mating season and when young animals seek new territory. Alpine habitats seem to be preferred, although conifer forests may also be acceptable where there is enough winter and spring snow cover. Females seem to need at least five feet of persistent snowpack throughout the spring to maintain their maternity dens, which they may inhabit with their litters of kits from about February to mid-May.[42]

Frost that forms on wolverine fur falls off almost immediately, and this makes their fur ideal for trimming the hoods of winter jackets as it prevents thick frost that otherwise builds up from the moisture in expelled breath. This unique quality made the wolverine a prized target of trappers for centuries. Known to be particularly vicious when cornered, wolverines also had a reputation for raiding traplines, stealing food, and destroying trappers' cabins, and they were often killed as vermin with poison bait.

Wolverine populations were reduced markedly by overhunting and wanton destruction in the contiguous U.S. during the 1800s, and by about

1920, they had been effectively extirpated. Later, during the 1930s, animals from Canada began to move south into western Montana, and viable populations were established there by the 1960s. By the 1970s, colonizers from these Montana populations had spread south into a few formerly occupied areas in the mountains of Idaho and Wyoming. Then, in the late 1900s and early 2000s, Canadian wolverines were discovered to have moved into the Cascade Mountains in northern Washington State from southern British Columbia, and viable populations are now established in the Oregon Cascades. As a consequence, all wolverines in the contiguous U.S., which number less than 300 in total, are both closely related to each other and recent "immigrants" from Canada.

So far, formerly occupied territory in Colorado, California, and the eastern U.S. remains wolverine-free.[43] Recently, there have been a few sightings of lone wolverines in California (two different animals, in 2008–2018 and 2023) and in coastal Oregon outside their usual mountain habitat, which may be the random wandering of far-ranging individuals or the beginnings of dispersal events into formerly occupied territory.[44]

As happened with the Pacific walrus, activist conservation organizations have been petitioning the U.S. government to list the wolverine as "threatened" under the ESA for more than two decades. These organizations have argued that reductions in deep snow cover since 1955 and anticipated reductions over future decades as a result of global warming put the wolverine at risk of extinction throughout its range. Some pessimistic models predict that by 2050, the snowpack required by wolverines in spring for hunting and denning will be restricted to small areas of the southern Rocky Mountains, the Sierra Nevada range, and greater Yellowstone National Park. Because wolverines currently live only in Yellowstone, it is considered unlikely that they would be able to colonize the other two "refuge" areas.

In 2020, the U.S. Fish and Wildlife Service rejected a petition to list the species as "threatened," as it had done in 2014, based largely on the argument that even if the wolverine in the U.S. is in danger of extinction due to its small population size, it is not genetically distinct from populations in Canada, which are stable and abundant. However, after continued legal pressure from special-interest groups, this decision was reversed based on a new 2023 assessment that showed in part that U.S. wolverines may be more genetically distinct than previously thought and that population declines in southern Canada caused by trapping could limit critical movement of animals into the U.S. As a consequence, a final ruling listing the wolverine as "threatened" based on possible future concerns was released on November 29, 2023.[45]

Nevertheless, it is apparent that the current distribution of wolverines in the U.S. reflects the recent successful movement ("dispersal") of individuals from Canada across rugged and isolated terrain into U.S. habitat formerly occupied by the species. Despite a declining trend in snowpack across the western U.S., wolverine populations have continued to expand both geographically and in overall abundance since 1970. This is partly because there are still sizable areas in the western mountains with suitable habitat where, despite the overall declining trend in snowpack, there have been years when snowfall has been substantial and has persisted into spring, as happened most recently in 2022 and 2023.

Such heavy snow years, either locally or across the entire western region, are likely to recur in future decades even if overall snowfall continues to decline. If these heavy snow events are not too infrequent, they should allow existing wolverine populations at least to replace themselves and perhaps to expand even further south. Moreover, a genetic study in 2020 concluded that it is not only a lack of snow that restricts wolverines from dispersing long distances between preferred habitats; they are also deterred by housing developments and similar human transformations of the landscape, which means that global warming is not the only factor potentially restricting the growth and expansion of existing U.S. populations.[46]

Conclusion

The expectation that changes caused by global warming will fundamentally rearrange historical U.S. ecosystems does not hold up to critical examination. Animals and species do not experience a change in "global average temperature;" they are affected by a variety of local and regional effects, some of which are positively associated with rising temperatures.

Contrary to past projections, massive loss of sea ice either has not happened (the Antarctic) or has not caused harm to ice-dependent species (the Arctic). Rising sea levels in the eastern U.S. have not resulted in reduced survival of marine turtles, and mountain pikas and wolverines are thriving despite reduced mountain snowpack in the western U.S. As a consequence, there would be no scientific basis for the establishment of experimental populations of American pikas, wolverines, or marine turtles by the U.S. Fish and Wildlife Service in areas outside their historical ranges to avoid future extinction due to climate change.

The potential negative impacts of human-caused global warming on animal species inhabiting sea ice, mountain tops, and coastal beaches in the U.S. have been exaggerated: Actual data show a much more nuanced effect. Overall, despite a global temperature increase of more than 1 degree Celsius since 1900, there has been little to no impact on the provision of market goods and services produced from these "sensitive" U.S. ecosystems.

This situation will likely continue throughout the 21st century, partly because the animal species that inhabit these regions are more flexible and adaptable than previously argued and because, contrary to predictions, some potentially adverse conditions have not persisted year after year. Consequently, there seems to be little rationale for lawmakers and the public to worry unduly about the effects of future human-caused global warming on the animal inhabitants of natural landscapes.

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