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Research

Mountain golden heather lives in only seven places in North Carolina. Erosion from altered water flows and climate change have reduced its habitat more. Scientists believe that this plant might be able to survive in the north. EMILY WHITELEY

Northbound: Climate Change and Rare Plant Conservation in the Appalachians

Flowers in Concord, Massachusetts, are opening about eighteen days earlier than they did in the 1850s. Spring is arriving as many as twenty days earlier in the southern United States. Birds, butterflies, and frogs are breeding four to eight days earlier per decade, and many bird species are spending winters farther north. Entire terrestrial biomes such as grasslands and temperate forests are shifting northward, toward the poles or higher elevations. As many as half of all species are on the move, some as quickly as ten miles per decade.

Climate change is causing complex impacts to ecosystems worldwide. Plants and animals, faced with rapidly changing conditions, have been forced to either adapt or move, while threatened or sensitive ecosystems face severe challenges or extinction. Alpine plant communities, for instance, already occupy the highest available mountain habitat and may be at risk of extirpation from rising temperatures and shifting treelines.

Researchers and conservation agencies monitoring at-risk species across the Appalachian Mountains may soon need to take a more active role, such as directly assisting species on their journeys. The geologic and evolutionary history of the Appalachians may make them conducive to such an approach, but can people help wild species in that way? Should they?

A Chain of Islands

The Appalachian Mountains were formed between 400 and 270 million years ago when collision of the North American and African continents pushed huge masses of ancient sedimentary rocks westward along the continental margin, piling them into a long chain. Further stresses split them across the Atlantic and folded them into the mostly northeast–southwest trending ridges that exist today, stretching 1,500 miles from northern Georgia to Canada. Peaks across the region routinely rise higher than 4,000 feet and higher than 6,000 feet in a few places.

Four times over the last 3 million years, great ice sheets advanced from the poles, gouging and scraping many of the Appalachians' characteristic landforms and features: gaps, notches, kettles, and erratics. The southernmost extent of ice across eastern North America stretched roughly along what is now the New York–Pennsylvania border across to Long Island and Cape Cod. When the ice retreated about 14,000 years ago, it revealed a landscape with climatic conditions similar to northern Canada today. First to colonize were

tundra species such as grasses, sedges, mosses, and lichens, which adhered most closely to the glacial boundary. They were followed by shrubs and conifers, then finally by temperate deciduous forest. But latitude is not the only influence on plant communities. Climate also changes significantly with elevation, and that same stratification of plant communities can be seen along elevation gradients in the Appalachians. A good rule of thumb is that every 1,000 feet of elevation gained is roughly equivalent to traveling 500 miles north.

In the north, tundra plants (termed *arctic-alpine*) still persist on the highest peaks of New York (geologically non-Appalachian), Vermont, New Hampshire, and Maine where exposure to extreme wind, cold, and ice largely excludes all but the hardiest species. Northern alpine ecology, then, is driven by small differences in microtopography—the sheltering effects of rocks, depressions, or snowpack. Cushion and tussock plants, for example, have aerodynamic shapes that allow them to colonize open environments on windward slopes. Herbaceous snowbank communities, however, rely on the cover of late-melting snowpack for frost protection and are mostly found on leeward slopes or in depressions where they are sheltered from the worst conditions.

The southern Appalachians differ from the north in several respects. First, because they were never glaciated, plant communities there are ecologically "older." Southern species coevolved over a longer period than northern ones did, filling niches and increasing biological diversity. The southern Appalachians are considered a global biodiversity hotspot. Nearly all forest herbs endemic to the eastern United States live in southern forests, and diversity drops off significantly north of the area where ice sheets last covered the land.

Second, the south is warmer, and plants do not have to deal with some of the more extreme conditions encountered in the north, such as a truncated growing season, rime ice, and frost. Elevation stratifies plant communities as in the north, but summits are less commonly open. Southern summits instead tend to resemble northern lowlands and lack the cold- and wind-adapted tundra species.

Last, the plant communities. Above treeline (red oak and American beech) on southern summits is a mix of stunted conifers (red spruce and Fraser fir), heath balds, and grass balds. Though considered a rare and threatened community type, grass balds can be found on summits and upper slopes from Georgia to Virginia. They are usually dominated by mountain oatgrass

(*Danthonia compressa*), sedges (*Carex brunnescens, C. flexuosa, C. pennsylvanica*), and assorted forbs, some of which are found only in that habitat. Though not considered a true alpine community, climate seems to play a role in the persistence of grass balds on the highest summits of the southern Appalachians, preventing the establishment of trees and shrubs (although fire, historical disturbance by native peoples, and more recent use as pasture could be contributing factors in some areas). Several other unique or rare community types also exist at high-elevation seeps, rock outcrops, and talus slopes.

Regardless of their geologic history, mountaintops worldwide act according to Island Biogeography Theory. That is, plant communities on peaks across a region resemble each other, but miles of inhospitable lowland habitat separate them. Rates of emigration and colonization of plants and propagules (such as seeds or pollen) across those gulfs determine plants' survival and extinction, as does the distance to suitable neighboring peaks. (Habitat size also affects the number of species living there.) High-elevation communities along the Appalachians are a chain of habitat islands rising above a sea of lowland forest. Their isolation and relative stability have allowed a high degree of diversity and regional endemism. But, of course, the seas are rising, changing habitats at all elevations.

Mounting Risk

The high rate of climate change occurring, combined with habitat fragmentation caused by human development and agriculture, may trigger a major extinction crisis in the coming decades. High-elevation and alpine plant species are particularly vulnerable to warming or extreme weather because they survive in small ranges or highly specific habitats. Fires, floods, and hurricanes are becoming more frequent and more intense as the climate warms, which could bring irreplaceable losses to isolated populations. They would suffer unless they have high genetic diversity (that is, many individuals with a wide range of inherited traits). But scientists know little about whether these isolated groups of species have the genetic diversity to bounce back from such disturbances.

Plants typically move over long periods of time as climates change. But the world's alpine areas are warming faster than other areas, and scientists fear that plants may not be able to keep pace. Being cold-adapted, many alpine plants have long life spans and typically migrate slowly over many generations. Northeast alpine species, for example, have been through several cycles of glaciation and recolonization and are considered somewhat hardy to slow,

natural climatic shifts. Southern species, lacking that history, may not be so adaptive. Already, grass balds in the southern Appalachians are being invaded by shrubs and trees; models predict as much as 93 percent habitat loss for endemic high-elevation lichens in the southern Appalachians; even lowland trees may not be able to adapt or migrate at rates sufficient to track their preferred climatic envelope.

Researchers and conservationists must work to better understand how climate change will affect mountainous and high-elevation plant communities throughout the Appalachians. They must plan for the inevitability of migration—identify core habitat for threatened species and areas that may become habitat in the future. They must also continue to protect migration corridors—contiguous parcels of suitable habitat that allows for natural migration—between those habitats. Of course, even if suitable habitat awaits farther north, many high-elevation species have limited seed dispersal capabilities and may lack the ability to migrate. Protecting migration corridors may therefore prove crucial. The Yellowstone to Yukon Initiative, for example, is a nonprofit collaboration of government agencies, concerned groups, and individuals working to protect a 2,000-mile-long stretch in the greater Rocky Mountain ecosystem. Elk, wolves, deer, and waterfowl migrate along this corridor, and it is a viable route for plants that need to move north. The Nature Conservancy's Cumberland Forest Project aims to create a similar migratory "escape route" along 253,000 acres of land from Tennessee to Virginia. In addition to storing immense amounts of carbon, the tracts would allow the natural passage of plants and animals on their journey northward. However, that effort is focused mostly on lowland habitats, not high-elevation areas.

Will the Northeast be prime habitat for southern high-elevation species in 20, 50, 100 years? Will species use corridors set aside for migration? How quickly can they get here? Will they? Such initiatives may not be enough, and if it turns out that species cannot adapt or migrate or that natural migration will not be sufficient, we must also consider other options.

Can Humans Help Species Move?

Managed relocation (also called assisted migration) is a strategy wherein people "assist" poorly dispersing or threatened species to move north as the climate changes. Climate change's unprecedented challenges have led scientists to consider taking up this still largely theoretical practice. Proposals typically involve moving climate-threatened species beyond their native range into

new geographic regions where they have not lived before but are predicted to survive in the future as the climate warms.

Such projects could take many forms. Whole plants could be transplanted between locations. Seeds could be collected and planted directly in analogous northern habitats or first germinated in a greenhouse. Plants could remain in cultivation in greenhouses for a longer period until natural conditions in northern sites become suitable. Seeds or genetic material could be stored and deployed in the event of experimental failures or extinction or be bred with other plants to create climate-resilient genotypes. Then there is the question of scale. Should we go big, moving species to the northern limits of their projected future range once, which would cost less but be risky, or should we emulate natural migration by moving them in a series of shorter steps, which would cost more and be less risky? Do we wait until the last moment, or do we act before they are threatened?

Using managed relocation would require appraising several complicating factors. Researchers must make sure that any action does not harm or further endanger southern source populations. Transplanting live individuals, for example, risks depleting or further stressing natural populations, should it go poorly. Moving seeds poses less risk and working with genetic material almost none. Relocation can also threaten genetic diversity if not done carefully.

How confident are we that it will work? Can we trust our ecological modeling to guide us such that species will be secure in their new homes? Do suitable habitat analogs exist (or will they exist) in northern sites? What about soil and bedrock chemistry, interactions between fungi and plants, the length of days, ways to ensure that seeds germinate, and necessary weather factors such as low clouds providing necessary moisture for plants? No relocation habitat will be perfect, but will it be good enough?

We must also make sure not to harm northern plants in the process, either through disrupting where they grow or introducing disease. Initial attempts would be experimental—small, isolated, controlled, and highly monitored. Locations would be selected so as to minimally disturb existing populations or where the existing community is widespread or not threatened. Recent research indicates that southern species are unlikely to become invasive if introduced in the north. Within North America, species prone to high population growth rates and rapid spread have most likely already done so thousands of years ago. The repeated glaciation of the Appalachians caused several cycles of shuffling and reorganization of North American flora, and the communities themselves have not been isolated for long enough for additional

invasive interactions to have developed. There are also indications that the north is still recovering from those cycles and is not yet "saturated." Ecological niches remain to be filled, and southern species, which share evolutionary heritage (and many genera, for example, *Amelanchier*, *Carex*, *Houstonia*, *Juncus*, *Nabalus*, *Potentilla*, *Vaccinium*, and so on) may occupy them nicely. Before release, greenhouse or laboratory studies could be conducted to ensure that hybridization with northern species is not a possibility and that no outside pathogens are present.

Aside from our technical understanding, the biggest pushback against managed relocation might be aesthetic. The colors and structures of our high-elevation communities might change. Transplants might seem "unnatural." Our public discourse on conservation is still largely beholden to twentieth-century conceptions of wilderness derived from sense of ecological harmony or "purity." But we now know that that no such time ever existed. Native peoples have been a factor shaping the land (such as fire and selective cultivation) since their first arrival, and the Appalachians are still in flux following the radical changes of the Ice Age. Human hands are already implicated in the current extinction crisis, so we shouldn't fear additional interventions if it would save species. Wouldn't it be better to muster what effort we can to mitigate or undo some of the damage?

Struggling Southern Plants That Could Persist in the North

Consider some of the species that have the potential to benefit from managed relocation:

Spreading avens (*Geum radiatum*) is an endangered species known from only eleven locations in North Carolina and Tennessee. It grows on exposed, cool, humid high elevations, primarily in the crevices of northwest-facing cliffs, but also at the base of talus slopes or openings in heath balds on isolated summits. It doesn't spread easily, and hikers and rock climbers have collected and disturbed it. A study found that between 53 and 83 percent of current habitat for the species is likely to become unsuitable by 2080.

Heller's blazing star (*Liatris helleri*), a threatened species, lives in just 27 locations in the Blue Ridge Mountains of North Carolina, Virginia, and West Virginia, totaling about 3,000 individuals. It grows on open summits and in full sun on rock outcrops, cliff ledges, and rocky openings in heath balds at elevations between 5,200 and 6,200 feet. Heavy recreational use of the rocky cliffs has put this plant in serious decline.

Gray's lily lives on Roan Mountain and might survive in the north as the climate warms. WADE HARRISON

Mountain golden heather (*Hudsonia montana*), a threatened species, is known to grow in only seven locations in North Carolina. It can be found in shallow soils over quartzite or mica/gneiss rock ledges, usually where bare rock transitions to heath balds, at elevations of 2,800 to 4,000 feet. It is losing habitat because of climate change and erosion caused by alteration of water flow.

Gray's lily (*Lilium grayi*), a species of special concern, lives in acidic soils in moist meadows, bogs, and seeps on the Roan Mountain massif and Blue Ridge Mountains in Tennessee, North Carolina, and Virginia. Pollinated by hummingbirds, this plant is threatened by overcollection and the encroachment of shrubs and trees.

Some southern mountain plants not federally listed but potentially threatened by climate change include the Roan Mountain rattlesnakeroot (*Nabalus roanensis*), clustered goldenrod (*Solidago glomerata*), umbrella-leaf (*Diphylleia cymosa*), and Schweinitz's ragwort (*Packera schweinitziana*). A warming climate could significantly affect the Roan Mountain rattlesnakeroot.

An irony of modern conservation is that avoiding the upheavals of the Anthropocene may require additional, more intensive interventions. Yes, managed relocation might change the composition and function of some ecosystems. But since extinctions are permanent and irreversible, that decision is one that some managers might be willing to make. Managed relocation will never be a substitute for land protection or a sustainable global climate policy. Rather, as one study said, it is a "prudent, proactive, inexpensive strategy . . . to help maintain forest resilience, health, and productivity in a changing climate." As conservationists and researchers begin to develop priorities and guidelines for protecting rare and threatened species along the Appalachian corridor, we should consider it another tool in our kit.

Kevin Berend is an environmental scientist in Buffalo, New York. His master's thesis for SUNY Brockport, about plants and snowmelt on Mount Washington in New Hampshire, led to three articles in the journal *Rhodora.*

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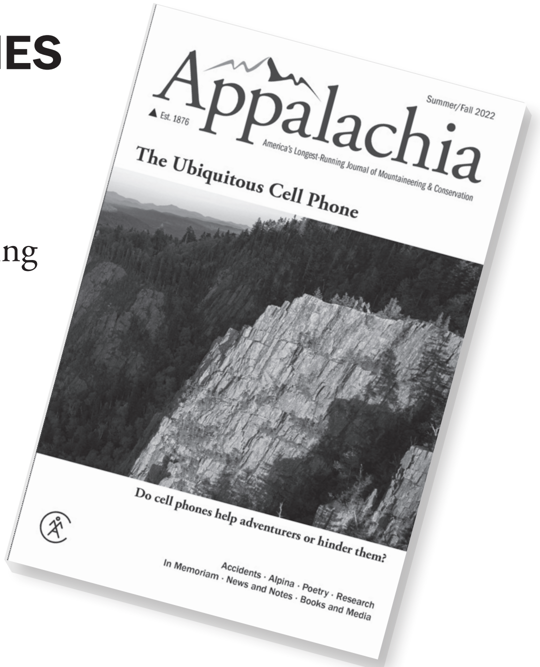

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