



Climate Change Trends, Impacts and Vulnerabilities for Great Smoky Mountains National Park and Blue Ridge Parkway, USA



Figure 1. Double rainbow image from Purchase Knob webcam, June 15, 2011

Climate in the Southern Appalachians citations 1-13

The Southern Appalachians have not showed the same warming trend as observed globally, though that has been changing recently. Ground level temperatures and extreme highs and lows, did not change significantly between 1976 and 2014 at high elevations, with the exception of spring temperatures, which have warmed slightly. Disagreement over the contribution of factors causing the recent climate stability makes predicting the future trends more difficult. The climate variables that may be most significant to local temperature, and which have the least clarity of projected future trends, are the amount and distribution of precipitation and cloud cover. These factors, in conjunction with topography, have a large impact on soil moisture, and by extension ground-level temperatures.

- Precipitation has been trending upward, though not significantly, from 1950 to 2010. Precipitation and cloud cover dampen increases in temperature. Climate models predict a warming in the region of three to five degrees Celsius (5-9 degrees Fahrenheit).
- There is no agreement between models as to whether rainfall will increase or decrease in the near-term, though most agree that summers will be drier, contributing to summers also being warmer. The best consensus is that climate change will lead to a decrease in summer precipitation, with possible increase in precipitation during the other months.
- Likewise, there is little model agreement as to the relative frequency of drought years and extreme wet years. Some models predict an increase in the number of dry years, such that half of each decade will be

in drought. At the other extreme, some models predict an elimination of local drought and a tripling in the number of extreme wet years.

- Tropical cyclones may increase in severity. From 1934 to 2010, Coweeta Hydrological Laboratory south of the Smokies experienced an increase in the intensity, but not the number of storms per month.
- Lower elevations and the western portion of the Smokies are most likely to follow regional trends, while higher elevations and stream-side areas are predicted to show less change. Stream-sides tend to be cooler in summer and warmer in winter than the surrounding landscape. High elevations tend to have more precipitation and cloud-cover, maintaining soil moisture and reducing warming.
- The elevation of the average cloud base has remained constant or lowered in the southern mountains over the past three decades, while rising in the north, meaning areas that used to be bathed in cloud have remained so thus far.
- Snowfall is predicted to decline, with increased melting between storms. From 1976 to 2014, there was a slight decline in mid-winter snowfall with a slight increase during spring and fall months.
- The number of days with frost has declined since 1950 and may farther decline by the end of the century by 25-50 days. Many plants depend on a certain number of days below freezing during dormancy.

Natural Resource Vulnerabilities: pollution and hydrology ^{citations 14-18}

As the parks and surrounding areas work to reduce their carbon impact in response to climate change, there may be both positive and negative impacts on pollution and hydrology in the parks.

- Models predict that visibility may increase as regulations are enacted to cut back on fossil fuel usage. Ground level ozone may also decrease.
- If summers are drier, streams may have summer and fall flows much lower than historic averages. Regionally, lower fall streamflow index values have been noted from 1980 to 2010. Longer growing seasons will mean that trees will be taking more water out of the soil through evapotranspiration before it can join streams. At the same time, drier, warmer conditions can cause changes in forest composition from mesophytic species (maples, etc.), that use a lot of water, to xerophytic species (oaks and pines), that use less of the available water, thus partially mitigating stream flow declines.
- Increases in storm intensity may contribute to more significant acidification events, putting greater stress on acid-sensitive aquatic species.

Natural Resource Vulnerabilities: forested communities ^{citations 19-40}

The easy way to think of climate change in the mountains—that cold-tolerant species at the tops of mountains would be pushed off as warmer conditions inch up the mountain side—is likely too simple and may be flat out wrong. Factors like distribution of rainfall, duration and frequency of drought, and cloud cover will influence which species and communities are most at risk. Forest communities may take decades to show climate-induced changes as mature trees are slow to die. Another key point to understand is that community types we see today may not reform themselves elsewhere, but rather whole new community types may develop in a “no analog future”. A possible future forest type for much of the Smokies is a subtropical humid forest unlike anything seen elsewhere in North America.

- Climate models predict that red spruce, Fraser fir, American mountain-ash, and other high elevation species may lose much of their habitat. There may be refugia in basins, drainages, and other areas where cloud, fog, and thermal inversions reduce warming. Not all high elevation plant and animal species may be able to successfully relocate to these refugia.

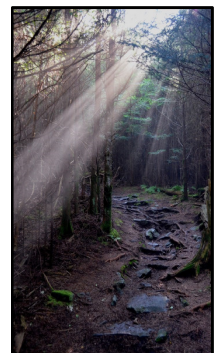


Figure 2. Spruce-fir forest, Richland Balsam, BLRI

- Climate change may have less impact on adult trees than on seedlings, especially if droughts increase. The impact on park forest communities may therefore be delayed for decades until mature trees start to die-off and are replaced by different species better adapted to the new climate, or until a catastrophic event, such as a fire or windfall, clears out mature trees.
- Tree species expected to benefit in this region from climate change include slash pine, willow and post oak, hickories, and the exotic Chinese tallow tree (none yet found in GRSM), as well as sweetgum and both southern red and post oaks. Species that require certain mycorrhizal fungi symbionts may not be as successful at colonizing if their associated fungi are not already present or are not moving at the same rate.
- Species that have been replacing pine/oak forest in the absence of fire—such as red maple—may benefit from warmer conditions, however many of these species are less drought tolerant and may suffer from increased fire activity under hotter and drier climate.
- Less intense deep freezes in the winter and drought stress in the summer could lead to more severe outbreaks of forest pests like southern pine beetle and less overwinter mortality of hemlock wooly adelgids, however heat waves of >30C can also cause summer mortality of hemlock wooly adelgids.
- Many invasive exotic species, such as kudzu and Japanese honeysuckle, are able to use increased CO2 concentrations and temperatures to increase growth, competitiveness and elevational range.
- Increased average drought indexes from early summer to early fall would lead to increased fire potential by mid-century, with both spring and fall fire seasons extended by warmer temperatures. The increasing likelihood of severe droughts, complexity and costs associated with more severe wildfires, and greater air-quality restrictions may limit the use of prescribed burning to manage fuels, creating a negative feedback loop which would exacerbate potential climate change effects.

Natural Resource Vulnerabilities: non-forested communities citations 41-46

Specialized habitats, such as caves, balds, rock faces, springs, seeps, and wetlands may be impacted by climate change, but again, it may take a long period to see the changes.

- Warmer average temperatures above ground will eventually warm cave temperatures. Drier conditions above ground may alter humidity and hydrology in caves. Changes in vegetation outside caves may alter energy flow into cave ecosystems by impacting species like cave crickets who forage outside the caves and bring nutrients back into the caves.
- Warmer temperatures and drier conditions may make some existing high elevation bogs unsuitable to species of *Sphagnum* moss. Drier, warmer conditions could also turn high elevation bogs and forest floor from a carbon sink into a carbon source as they decompose at a faster rate.
- Ground water will warm slower than surface water, meaning seeps and springs may take longer to become unsuitable for temperature-sensitive species.
- Should cloud-levels rise, warming and drying cliff face habitats, 58-83% of current habitat for the federally threatened spreading avens (*Geum radiatum*) may fall below minimum suitability levels by 2080.
- Models predict that up to 93% of current habitat for narrowly endemic, high elevation lichens will be lost under climate models, with little suitable habitat farther north becoming available.
- Drier and less-cloudy conditions may make it harder for some woody species to invade grassy balds by making it harder for seedlings to become established, but may also herald in species that are more drought and temperature tolerant as seedlings.

Natural Resource Vulnerabilities: phenology citations 47-56

Warmer conditions earlier and later in the year can increase growing and reproductive periods, but can also put species at greater risk from spring freezes and fall snow events. Some species have been observed to adapt to phenological change, but there may be limits.

- The late winter period in the Smokies and at Oak Ridge have both showed increased warming, while the date of last hard freeze has not tracked in any pattern. This has resulted in wildflower-related events being scheduled after the targeted species have stopped flowering and many species of tree and flower getting damaged by frosts after they've broken their winter dormancy. Fruit trees have also experienced major frost damage in the southern mountains some years, such as in 2012.
- Variability in flowering dates are most pronounced in early spring species. There may be less variability in summer and fall species of flowering plant.
- Migratory birds in Europe have been observed to have fallen out of synchrony with the caterpillars they feed to their young. These birds time their return to the breeding grounds based on day-length, while caterpillars develop in response to temperature. Warmer spring temperatures mean the birds return to the breeding grounds too late to take advantage of peak caterpillar populations, resulting in reproductive failure. In New Hampshire, black-throated blue warblers were not changing the timing of their arrival on the breeding grounds, but were initiating nesting more quickly after they arrived, an adaptive response that has limits and possibly metabolic costs.
- Climate changes may lead to a disconnect in the timing of when biocontrol agents are active and when their target pests are available.
- Changes in the timing of breeding activity could change the soundscapes that visitors experience.
- European studies have found that fruiting of fungi is happening earlier in the spring and later in the fall.

Natural Resource Vulnerabilities: animals citations 57-74

- A stonefly species in the Little River catchment of GRSM has shifted its range upstream from 1976 to 2005, roughly consistent with observed water temperature change. Aquatic invertebrates that prefer colder temperatures may be more impacted by climate change than species with more moderate preferences, possibly allowing for creation of a biomonitoring protocol for temperature stress.
- Drier summers may reduce hydroperiod—the water budget of a wetland—meaning that vernal ponds where some amphibians breed may dry up before larvae can metamorphose, and degrading the suitability of upper reaches of watersheds for stream salamanders (e.g. Dusky salamanders). Drier conditions, especially at night, may reduce salamander ability to forage, leading to increased mortality over winter.
- High elevation species may have difficulties dispersing to climate refugia, though genetic markers indicate that species like red-cheeked salamanders have successfully passed through previous conditions that limited them to isolated refugia.
- Changes in hybrid zones may be the first place to see the results of climate change. GRSM has 41 years of data from monitoring the hybrid zone between red-cheeked, southern gray-cheeked, and Appalachian salamanders along Balsam Mountain Road.
- Models indicate that 82-89% of existing brook trout streams in North Carolina and Virginia would become unsuitable for this species under a climate increase of 3.8°C. Populations will become more isolated, unable to disperse upstream because of acidification of headwaters, and more susceptible to disease because of thermal and other stress. Disease resistance may also decline as thermal stress increases. Increased precipitation could mitigate some temperature increase but prolonged draught would decrease survival of populations.
- Increased mast failures and shifts in timing of mast may increase stress on bears, causing more wandering outside the park and more bear/human encounters.
- New species that may move into these parks include nine-banded armadillo, bird-voiced treefrog, and even Burmese python.
- Core winter ranges of bird species are observed to be shifting northward on average 2.35 km/year, which may result in increased winter records for many species in these parks. Breeding ranges are shifting north

at a rate of 1.27 km/year, though elevational shifts in bird breeding ranges may track precipitation and habitat changes more than temperature, causing some species to shift downslope rather than upslope.

Built Resource Vulnerabilities: roads, infrastructure, maintenance ^{citations 75-80}

If precipitation becomes more sporadic and intense, this could lead to flooding, which could disrupt transportation within the Park and weaken or wash out the soil and culverts that support roads, tunnels, and bridges.



Figure 4. Landslide and road wash-out on US 441, January 2013

- In general, increased precipitation projected for spring, fall, and winter can accelerate degradation of materials made from wood and metal, and decrease the number of days available to maintenance staff to make outdoor repairs.
- Infrastructure designed to accommodate historic systems may not be sufficient to withstand increased storm intensities or seasonal shifts in storm timing. Climate change will exacerbate existing uncertainties and associated risks of failure.
- With projected warmer temperatures and more winter precipitation that could fall as rain instead of snow, winter flooding, wash-outs, and landslides could occur more

frequently, especially if the frozen ground cannot absorb precipitation, or if the ground has already been saturated.

- Increases in the intensity of storm events could accelerate trail erosion and landslides.
- Disturbance events could harm historic structures and climate-induced range-shifts of species may do considerable harm to historic landscape integrity, as species important to a cultural story can no longer grow where they are culturally important.
- Use of more energy-efficient lighting to reduce climate impacts also reduces light pollution.

Sociological Vulnerabilities: visitation, development, health ^{citations 81-86}

Temperature and precipitation changes in the park and surrounding areas may alter visitation patterns, though other factors such as economic trends may be more important. As regional temperatures increase, more people may seek the cooler mountains for vacations or resettlement.

- Visitation for the Smokies and Blue Ridge Parkway are predicted to increase from 101-120% over the next 30-50 years. Visitation at NPS sites tends to increase until temperature reach 25C, after which they trend downward.
- Increases in minimum temperatures could increase tick and mosquito populations. *Aedes aegypti*, the better vector, has been documented only once in the park and is highly tied to human habitation, thus it is not likely to spread into the park. *Aedes albopictus*, which feeds on other hosts besides humans, is more common in the park but may be a poorer vector of disease.
- Studies that have elevated atmospheric CO₂ in an intact forest ecosystem found increased photosynthesis, water use efficiency, growth, and population biomass of poison ivy, as well as a more allergenic form of urushiol, the main chemical causing a rash in sensitive people.
- Though development may increase in neighboring communities, both Great Smoky Mountains National Park and the Blue Ridge Parkway have some buffering from development provided by National Forests.

Management Trends Options ^{citations 87-91}

Park managers are often faced with a choice between managing their resources to a “desired future condition” (DFC) or to a “historical range of variability” (HRV). Should a park’s climate trajectory extend outside the HRV, park managers will have to determine what features can be protected in a DFC rather than fighting against the change, forcing a reevaluation of “how things have always been done”.

- Modeling error and complex interactions between climate change and other stressors mean the ability to predict the locations of refugia is severely limited, though research should still be encouraged to identify candidate locations, especially based on past conditions.
- Reducing impacts of other non-climate stressors, such as air pollution and exotic species becomes even more important than before climate change.
- It is increasingly possible to map landslide-prone areas with reliability.
- To the extent that future microhabitats can be mapped, it may be possible and necessary to transplant narrowly endemic lichens and other species from areas where their microhabitat is eroding.
- Increasing disturbances alter habitats within the park, making it important to monitor for invasive species internally and not just at the margins. It is also important to monitor native species recovery after disturbance to identify areas where the climate has not altered the species composition.
- It is important to continue to monitor the impacts of climate change through the parks’ ongoing Vital Signs Monitoring Programs and supporting independent studies such as GRSM-00414 (Erin Tripp, University of Colorado), and the NEON relocatable site centered on Twin Creeks in GRSM.

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