# North Carolina Ecosystem Response to Climate Change: DENR Assessment of Effects and Adaptation Measures

***DRAFT***

# Spruce Fir Forests

## Ecosystem Group Description:

Forests dominated by red spruce and Fraser fir occur on the high mountain tops in western North Carolina, generally over 5,500 feet in elevation. The cold climate of the high elevations is equivalent in some ways to the boreal forests of Canada. However, the climate differs from the north in being less continuously cold and in being much wetter, with both rain and fog tending to concentrate on the mountain tops.

Spruce-fir forests are divided into two natural community types: Fraser Fir Forest and Red Spruce-Fraser Fir Forest, each with several variants. Fraser Fir Forest occurs on the highest mountain tops, where Fraser fir is the only tree species able to survive the cold, wind, ice, and storms in large numbers. Red Spruce-Fraser Fir Forests occur in slightly less hostile environments where red spruce and yellow birch can also persist in large numbers. Both communities tend to have dense canopies under natural conditions. A variety of distinctive shrubs and herbs, many of them more common in the northern United States but some endemic to the southern Appalachians, occur beneath the canopy. Lush beds of moss and ferns cover the rocky soil and abundant fallen logs in some areas. All Fraser Fir Forests now exist as patches of dense young trees, resulting from balsam wooly adelgid infestations, an introduced insect pest that kills adult Fraser firs. Red Spruce-Fraser Fir Forests have canopies of remnant spruce trees, many of which are also dying. The least affected sites are the lowest elevation examples, which have relatively little fir.

## Ecosystem Level Effects:

### Predicted Impacts of Climate Change:

| Climate Change Factor: | Likelihood: | Effect: | Magnitude: | Comments: |
|---|---|---|---|---|
| Mild Winters | High | Neg | Med | |
| Wind Damage | Med | Neg | Med | Given the extreme weather already present in the high mountains, it is unclear if the increase in severe winds will be as great as at lower elevations. |
| Hot Spells | Med | Neg | Med | May depend on the behavior of cloud cover. |
| Fire | Med | Neg | High | Fire is extremely destructive to spruce-fir, but rarely occurs naturally under current conditions. |
| Drought | High | Neg | High | Potential for drought effects is uncertain, and depends on the effect of the climate on orogenic rainfall. |

We expect the future climate to include warmer temperatures, longer growing season, likely more hot spells and drought, and more severe storms. The cncm-cm3 model predicts 4.5 degrees warmer annual average temperature by 2050 (Maurer et al., 2007). The mid value of the 16 models in Climate Wizard is

about 4 degrees. Average annual rainfall is expected to increase, but only slightly. However, the uncertainty is high. Rainfall predictions among the models range from a loss of 12 inches to an increase of 15 inches. But the future climate of the high mountain sites is particularly uncertain. These model results are for the general area and do not account for the elevations. Much of the current climate in the high mountains is orographically determined, and is quite different from the general regional climate. The rainfall in many spruce-fir forests is as much as twice as much as the lower basins, and a similar amount of water may be input through fog drip. Much of the distinctive environment here depends on fog and orographic cloud cover. If these phenomena persist, they will ameliorate the effects of warming, drought, and fire. If they are disrupted, climate change effects will be much more drastic. These areas already experience more high wind than other areas, and it is unclear if an increase in storms will mean more wind damage than already occurs.

If drought led to potential for wild fire, it would be a severe threat. The natural vegetation virtually never burns under the current climate, and the biota are not adapted to fire. Many spruce-fir forests have not recovered from the logging slash fires of the early 1900s, after nearly 100 years.

## Predicted Ecosystem Reponses:

| Ecosystem Response: | Likelihood: | Effect: | Magnitude: | Comments: |
|---|---|---|---|---|
| Exotic Species Invasion | Med | Neg | Med | Tussilago farfara may increase with canopy disruption and warming |
| Structural Change | Med | Neg | High | In surviving patches, structural change may result from increased wind or drought damage. |
| Increased Fragmentation | High | Neg | Med | Spruce-fir forests are naturally fragmentary, but upward migration may create additional gaps in some patches. |
| Compositional Change | Med | Neg | Med | Uncertain how much change will occur in the higher elevation patches that survive. |
| Acreage Change | High | Neg | High | |
| Elevation Change | High | Neg | High | |

Many species are currently excluded from these communities because of the extreme climate, with winter cold the most likely cause. Mild winters presumably will lead to invasion by species from lower elevation. This will eventually lead to competitive exclusion of distinctive spruce-fir species from the lower parts of their elevational range. There is much uncertainty about how far this will go – particularly whether it will "push communities off the top of the mountains". Changes might be either gradual, resulting from shifts in reproductive success, or may be abrupt, tied to severe weather or fire. If spruce canopies are not too disrupted by disturbances, their deep shade and the shade-tolerance of their seedlings may allow them to exclude invaders for some time. If canopy disturbance increases in the places where spruce-fir forests remain, their composition and structure would also be changed. Increased severe wind storm frequency would decrease the proportion of spruce and increase that of fir and birch in the zone where they coexist. Fir captures gaps more readily than spruce and birch can sprout.

Heat or drought stress may possibly lead to mortality in some species, including canopy and other dominant plants. Spruce have been demonstrated to be subject to physiological temperature disruption such as premature breaking of winter dormancy and even cambium mortality from sun shining on their trunks. However, much of this depends on whether orographic clouds and fog persist. If fog is diminished, loss of moist sub-canopy microclimate and wet bryophyte layers may threaten many species even without mortality of trees.

Drought and warmer temperatures may accelerate organic matter decomposition, reducing soil organic

layer and threatening moist soil and litter species. Loss of soil organic matter is a particular concern in these systems because the soil sometimes consists largely of organic matter. However, increased primary productivity, which can be expected, may increase input of organic matter and offset this effect.

Fire would likely be catastrophic. Spruce-fir forests are not adapted to fire. Forests that burned would likely lose most species and never recover.

Effects of reduced area may be significant, reducing some species populations enough to cause demographic problems. Because the current area is limited and many patches have been reduced further in size, some species are likely already close to minimum viable population size. This concern can be expected to vary. Spruce-fir patches vary substantially in size and elevational range.

Most, if not all, of the expected effects of climate change were presumably experienced by spruce-fir forests during the warmer and drier Hypsithermal period about 6000 years ago. Spruce-fir forests are believed to have been "pushed off the top" over several lower mountain ranges where they now are absent. The magnitude of temperature changes then is not clear, and they were accompanied by a reduction of rainfall that is not expected in the near future climate. However, the Hypsithermal represents a "grace period" for future climate changes, in that all existing patches of it and all of its existing species pool survived that level of warming. However, their ability to survive similar levels of climate change now may be compromised by reduction of area by 20th century logging and slash fires, and by new stresses such as air pollution.

There is no potential for latitudinal migration of these systems. No high elevation areas exist for a considerable distance north of their current range. All patches are isolated by low elevation areas that are already unsuitable in today's climate.

## Habitat Level Effects:

### Natural Communities:

| Third Approximation Name: | Comments: |
|---|---|
| Red Spruce--Fraser Fir Forest | Will become restricted to higher elevations and smaller areas but less likely to be totally eliminated than Fraser Fir Forest. |
| Fraser Fir Forest | Will shrink drastically and may disappear entirely. Most species also occur in Red Spruce -- Fraser Fir forest, but may be less abundant there. We don't know the current status of many species. Already heavily disturbed and severely threatened by balsam woolly adelgid mortality. Intact stands are limited, and most are young. |

Fraser Fir Forest occurs only on the highest parts of the highest peaks. This community type is perhaps the most likely of any to entirely disappear from North Carolina with the changing climate. Most of the species that occur in it also occur in Red Spruce-Fraser Fir Forests, but some are less abundant there. The ecological driver for Fraser fir dominance at the highest elevations is not well known. It may include disturbance frequency as well as cold temperatures. If so, the effect of climate change on this community may not be a simple temperature-driven elevation shift.

**LHI Guilds:**

| Guilds with Significant Concentration in Ecosystem Group: | Comments: |
|---|---|
| Spruce-Fir Forests | |
| High Elevation Montane Mesic Hardwood and Mixed Forests | |

Members of two guilds have a high concentration of habitat within this overall habitat group. One is composed of specialists on spruce-fir forests, but which occur to at least some extent in adjoining areas of northern hardwoods, particularly where spruce and fir penetrate into them. The other consists of species that either are associated with high elevation forests, using spruce-fir and northern hardwoods about equally, or species that occur primarily within high elevation hardwoods but that extend into at least mixed stands having a significant proportion of spruce and fir. Both guilds are at high risk due to habitat loss, fragmentation, and degradation due to climate change and other factors, such as acid precipitation and the effects of the balsam wooly adelgid. Consequently, they are among the most threatened guilds in the state, if not the most threatened of all.

## Species Level Effects:

**Plants**

| Species: | Element Rank: | Endemic | Major Disjunct | Extinction/ Extirpation Prone | Status: US/NC | Comments: |
|---|---|---|---|---|---|---|
| Leptohymenium sharpii | G1/S1 | Yes | | | /SR-L | Known from about 10 localities, endemic to the Southern Appalachian mountains. |
| Frullania appalachiana | G1?/S1? | Yes | | | /SR-L | Poorly known Southern Appalachian endemic. |
| Leptodontium excelsum | G2/S1 | | | | /SR-L | The distribution of this taxon is in the Southern Appalachians is associated with the spread of the Balsam Woolly Aphid---damaged defoliating bark is preferentially colonized by this moss. |
| Sphenolobopsis pearsonii | G2?/S2 | | | | FSC/E | |
| Bazzania nudicaulis | G2G3/S2 | Yes | | | /SR-T | |
| Brachydontium trichodes | G2G4/S1 | | Yes | | /SR-D | |
| Stachys clingmanii | G2Q/SH | | | | /SR-T | Currently believed more-or-less endemic to the southern Appalachian highlands ("mostly Tennessee and North Carolina with some possible outliers", J. Nelson pers. comm. 2009). Mostly found in high elevation forests in NC and TN. |
| Plagiochila sullivantii var. sullivantii | G2T2/S2 | | | | FSC/SR-T | Largely restricted to deeply shaded and overhung rock walls and ledges, often around waterfalls, where very high, constant atmospheric humidity prevails but where plants are protected from disturbance by rain or submersion. |
| Sphagnum flavicomans | G3/SH | | | | /SR-T | |
| Rugelia nudicaulis | G3/S3 | Yes | | | FSC/T | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Acrobolbus ciliatus | G3?/S1 | | | | /SR-D | The species evidently does not tolerate desiccation (Schuster 1980). Grows on damp to moist, usually shaded rocks, almost always in areas with high atmospheric moisture (and/or spray), near waterfalls or cascades, in the gorges of the Southern Appalachians. Often occurring in only small quantity, with other bryophytes. |
| Metzgeria temperata | G4/S1S2 | | | | /SR-D | |
| Plagiochila corniculata | G4?/S2 | | | | /SR-D | In North America, limited to densely shaded, humid, often fog-enshrouded mountain summits. Most commonly exists on Fraser fir (Abies fraseri). |
| Leptoscyphus cuneifolius | G4G5/S2 | | | | /SR-D | |
| Hylocomiastrum umbratum | G5/S1? | | | | /SR-P | |
| Phegopteris connectilis | G5/S2 | | | | /SR-P | |
| Streptopus amplexifolius | G5/S1 | | | | /SR-P | NC and TN are at the southern limit of this circumboreal species' range. |
| Poa palustris | G5/S1 | | | | /SR-P | |
| Sphagnum squarrosum | G5/S1 | | | | /SR-P | |
| Rubus idaeus ssp. strigosus | G5T5/S2? | | | | /SR-P | May benefit from increased canopy disturbance. |
| Nardia scalaris ssp. scalaris | G5T5/S1 | | | | /SR-D | |

Many bryophyte species are endemic to the Southern Appalachian mountains, in moist forests on shaded rocks and trees. If rainfall, cloud cover, and/or fog decrease, this could have a drying effect on the forests, making the habitat unsuitable for many species.

**Terrestrial Animals**

| Species: | Element Rank: | Endemic | Major Disjunct | Extinction/ Extirpation Prone | Status: US/NC/ WAP | Comments: |
|---|---|---|---|---|---|---|
| Microhexura montivaga | G1/S1 | Yes | | Yes | LE/SR/ | Dependent on cool, mesic forest floor habitats. Highly vulnerable to heat, drought, and fire. At high risk of extinction. |
| Plethodon welleri | G3/S2 | Yes | | | /SC/P | |
| Desmognathus imitator | G3G4/S3 | Yes | | | /W2/ | |
| Desmognathus wrighti | G3G4/S3 | Yes | | | FSC/SR/P | |
| Desmognathus santeetlah | G3G4Q/S2S3 | Yes | | | /SR/ | |
| Desmognathus imitator pop. 1 | G3G4T1Q/S1 | Yes | | | /SR/ | |
| Itame subcessaria | G4/S1S3 | | | | /SR/ | |
| Carduelis pinus | G5/SUB,S4N | | Yes | | /W3/P | |
| Catharus guttatus | G5/S2B,S5N | | Yes | | /SR/ | |
| Certhia americana | G5/S3B,S5N | | | | /SC/P | |
| Dendroica magnolia | G5/S1S2B | | Yes | | /SR/P | |
| Eilema bicolor | G5/S1S2 | | Yes | Yes | /SR/ | Known in the Southern Appalachians from just a couple of specimens collected in the Great Smoky Mountains. |

| | | | | | | |
|---|---|---|---|---|---|---|
| Lithophane georgii | G5/S1? | | Yes | | /SR/ | Next nearest population is in the White Mountains of New Hampshire |
| Xestia perquiritata | G5/S1S3 | | Yes | Yes | /W5/ | |
| Polygonia progne | G5/S1 | | Yes | | /SR/ | |
| Syngrapha alias | G5/SU | | | | /W5/ | |
| Troglodytes troglodytes | G5/S3B,S5N | | | | /W2,W5/ | |
| Glaucomys sabrinus coloratus | G5T1/S2 | Yes | | | LE/E/P | Likely to face increased competition from southern flying squirrels |
| Loxia curvirostra pop. 1 | G5TNR/S3B,S | Yes | | | FSC/SC/P | |
| Aegolius acadicus pop. 1 | G5TNR/S2B,S | Yes | | | FSC/T/P | |
| Poecile atricapillus practica | G5TNR/S3 | Yes | | | FSC/SC/P | Likely to face increased competition from Carolina chickadees |
| Trechus balsamensis | GH/SU | Yes | | Yes | /W3/ | Dependent on cool, mesic forest floor habitats. Highly vulnerable to heat, drought, and fire. At high risk of extinction. |
| Trechus rosenbergi | GH/SU | Yes | | Yes | /W3/ | Dependent on cool, mesic forest floor habitats. Highly vulnerable to heat, drought, and fire. At high risk of extinction. |
| Trechus roanicus | GH/SU | Yes | | Yes | /W3/ | Dependent on cool, mesic forest floor habitats. Highly vulnerable to heat, drought, and fire. At high risk of extinction. |
| Trechus novaculosus | GH/SU | Yes | | Yes | /W3/ | Dependent on cool, mesic forest floor habitats. Highly vulnerable to heat, drought, and fire. At high risk of extinction. |
| Trechus mitchellensis | GH/SU | Yes | | Yes | /W3/ | Dependent on cool, mesic forest floor habitats. Highly vulnerable to heat, drought, and fire. At high risk of extinction. |
| Trechus carolinae | GH/SU | Yes | | Yes | /W3/ | Dependent on cool, mesic forest floor habitats. Highly vulnerable to heat, drought, and fire. At high risk of extinction. |
| Korscheltellus gracilis | GNR/S2S3 | Yes | | | /W5/ | |
| Entephria separata | GNR/SH | | Yes | Yes | /SR/ | Known in the Southern Appalachians from a single specimen collected on the top of Mount Mitchell. |
| Eulithis propulsata | GNR/SU | | | | /W3/ | |
| Hydriomena exculpata | GNR/SH | | Yes | | /SR/ | Known in the Southern Appalachians from a single specimen collected on the top of Mount Mitchell. |
| Gazoryctra sciophanes | GU/S1S3 | Yes | | | /SR/ | |
| Trechus uncifer | GU/SU | Yes | | Yes | /W2/ | Dependent on cool, mesic forest floor habitats. Highly vulnerable to heat, drought, and fire. At high risk of extinction. |
| Trechus valentinei | GU/SU | Yes | | Yes | /W2/ | Dependent on cool, mesic forest floor habitats. Highly vulnerable to heat, drought, and fire. At high risk of extinction. |

Twenty of the species or subspecies of animals included in this group are endemic to spruce-fir forests in the Southern Appalachians. Another nine are highly disjunct within this region, with their next nearest populations located in New England or Canada (some may turn out to be distinct species once genetic studies are done). Still more such species exist within other insect orders and in other invertebrate taxa such as myriapods, Tardigrades, and land snails. For terrestrial animals, this level of endemism/disjunction is unmatched by any other habitat group in the state. This group is also among the most vulnerable to climate change. Many of these species are flightless, including the four species of salamanders and the eight species of ground beetles (Trechus sp.). As is generally true for "sky island" species, even those capable of flight (or ballooning in the possible case of Microhexura), probably rarely disperse out of their habitat, if at all. All of these species depend on cool, moist microclimates but the spruce-fir moss spider, ground beetles, and salamanders are particularly susceptible to desiccation and are among the species most likely to be affected by climate change of any in the state.

## Combined Threats and Synergistic Impacts:

### Importance of Climate Change Factors Compared to Other Ecosystem Threats:

| Threat: | Rank Order: | Comments: |
|---|---|---|
| Climate Change | 1 | |
| Invasive Species | 1 | |
| Air Pollution | 1 | |
| Fire | 2 | |
| Development | 3 | |
| Logging/Exploitation | 4 | |

Balsam woolly adelgid, climate change, air pollution (acid rain, ozone, lead deposition) are all major threats. Most examples of this Ecosystem Group are protected and managed as natural areas. Logging and development are, consequently, of minor importance, but are still possible on private tracts. While wind turbine farms are unlikely to be built where stands of spruce-fir forests are still present, there is some potential for them to be sited on ridge-tops where spruce-fir once occurred and could be potentially restored.

## Recommendations for Action:

### Interventive Measures:

| Intervention: | Importance: | Feasibility: | Comments: |
|---|---|---|---|
| Reintroduce Species | Mediu | Medium | e.g., Microhexura, mosses? |
| Restore/Maintain Landscape Connections | High | Medium | |
| Restore Extirpated Areas | High | Medium | |
| Protect/Expand Existing Examples | High | High | |
| Protect from Wildfire | High | Medium | |

Protection from wild fire is one of the most important actions that can be taken to save the remnants of these communities. Fire suppression is probably already the policy of all current land managers, but suppression may take increased vigilance and effort if conditions become drier. Spruce-fir forests are not very flammable under the current climate, but may become more so in the future.

Past logging and slash fires have greatly reduced the extent of several large spruce-fir patches, and broken them into fragments that may not be well connected. Restoration of spruce and fir canopy in these areas, especially in the higher elevation portions, would allow the species pool to expand back through a larger area, producing larger, more robust, and better distributed populations that would be better able to survive the future loss of lower elevation portions. Reintroduction of rare species to patches or mountain ranges where they have been lost, as well as to restored areas, would improve their prospects for survival in the future climate. The Great Balsam Mountains, Black Mountains, and logged portions of the Smokies are the places with the greatest potential for restoration.

## Ecosystem Group Summary:

This ecosystem is among the most vulnerable to the effects of climate change of any in the state. Given the high number of endemics and disjuncts, it is also the one where threats to biodiversity are the greatest. Several of the species face outright extinction and others, if lost, are unlikely to ever recover within the region. On the other hand, this ecosystem survived through the Hypsithermal, when temperatures were substantially higher than they are now. Neither these species, nor their ecosystem more generally, should be simply written off as a lost cause. Priority should, instead, be given to several measures that may secure them enough time and space to survive both short term environmental disturbances as well as adapt to longer term changes in the climate. Since virtually all examples of this Ecosystem Group are located on public lands and already managed to preserve their natural features, implementation of recommended interventions should be more feasible than for many of the other groups.

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