DIVERSITY, CONTINUITY AND RESILIENCE – THE ECOLOGICAL VALUES OF THE WESTERN MAINE MOUNTAINS

By Janet McMahon, M.S.

Occasional Paper No. 1

Maine Mountain Collaborative
P.O. Box A
Phillips, ME 04966

This paper is published by the Maine Mountain Collaborative as part of an ongoing series of informational papers. The information and views expressed in this paper are those of the author and do not necessarily reflect the views of the Maine Mountain Collaborative or its members.

Cover photo: Caribou Mountain by Paul VanDerWerf

https://www.flickr.com/photos/12357841@N02/9785036371/

https://creativecommons.org/licenses/by/2.0/

DIVERSITY, CONTINUITY AND RESILIENCE – THE ECOLOGICAL VALUES OF THE WESTERN MAINE MOUNTAINS

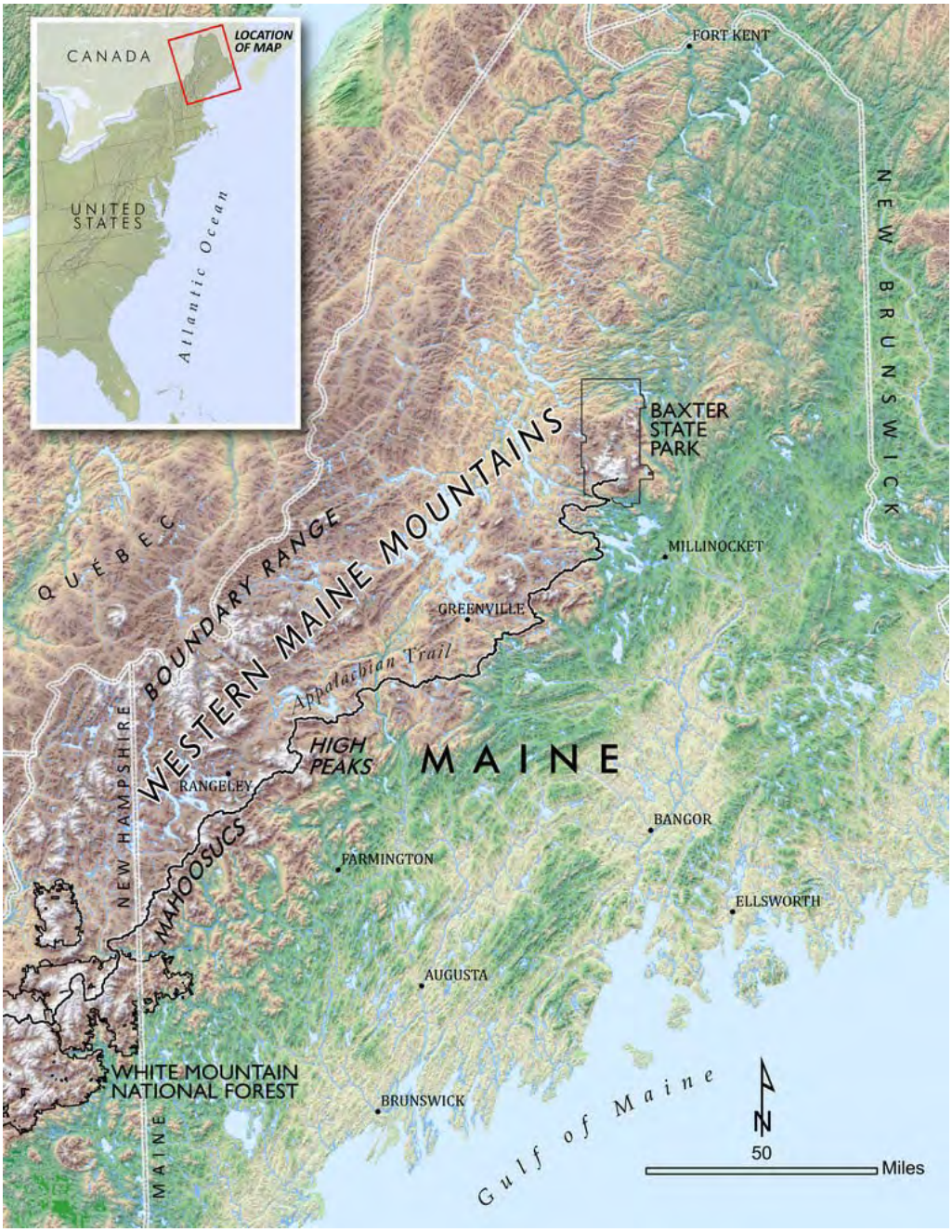
Dawn over Crocker and Redington Mountains *Photo courtesy of The Trust for Public Land, Jerry Monkman, EcoPhotography.com*

Abstract

The five million acre Western Maine Mountains region is a landscape of superlatives. It includes all of Maine's high peaks and contains a rich diversity of ecosystems, from alpine tundra and boreal forests to ribbed fens and floodplain hardwood forests. It is home to more than 139 rare plants and animals, including 21 globally rare species and many others that are found only in the northern Appalachians. It includes more than half of the United States' largest globally important bird area, which provides crucial habitat for 34 northern woodland songbird species. It provides core habitat for marten, lynx, loon, moose and a host of other iconic Maine animals. Its cold headwater streams and lakes comprise the last stronghold for wild brook trout in the eastern United States. Its unfragmented forests and complex topography make it a highly resilient landscape in the face of climate change. It lies at the heart of the Northern Appalachian/ Acadian Forest, which is the largest and most intact area of temperate forest in North America, and perhaps the world. Most importantly, the Western Maine Mountains region is the critical ecological link between the forests of the Adironcaks, Vermont and New Hampshire and northern Maine, New Brunswick and the Gaspé.

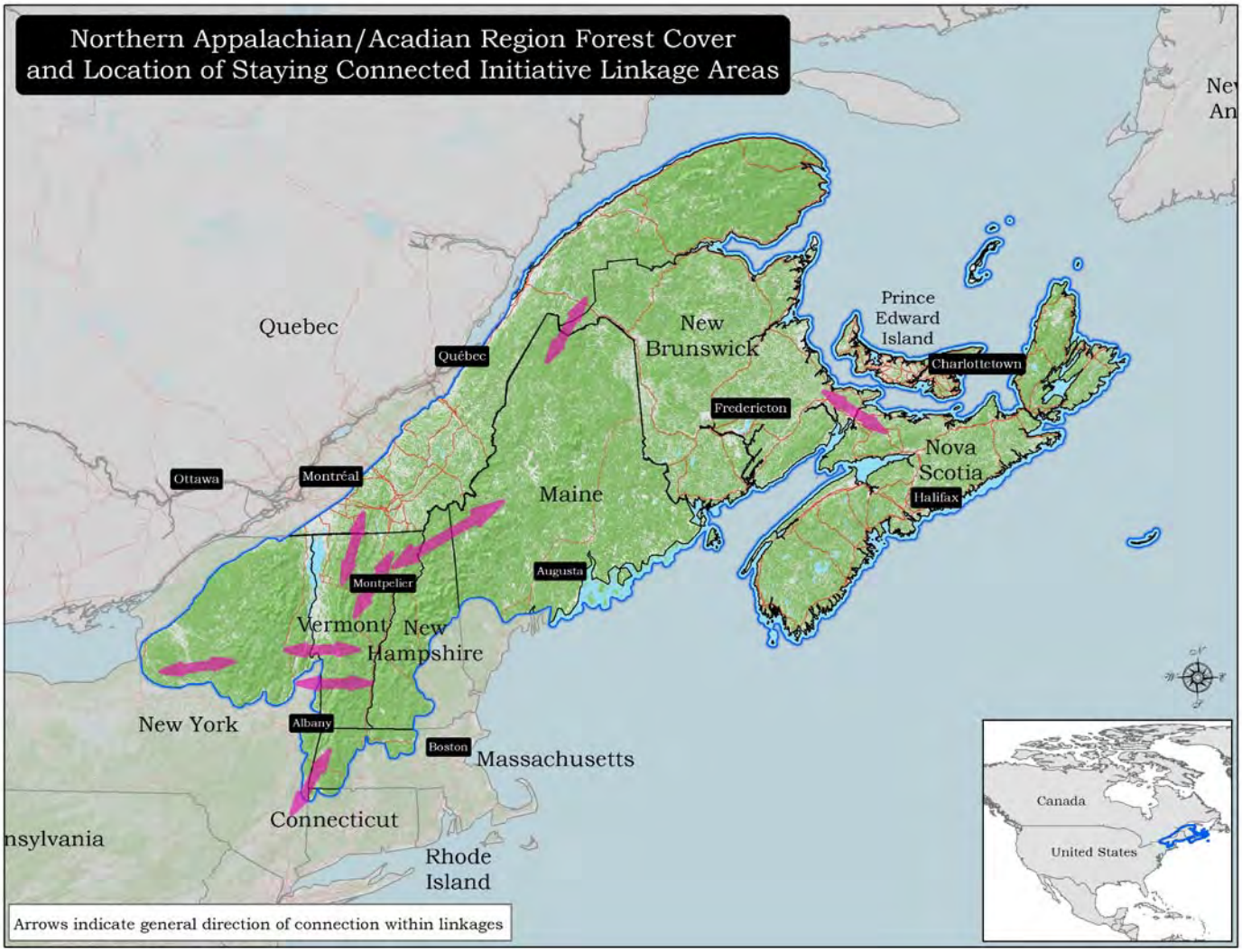
Introduction

In 1884, when Thoreau ascended Ktaadn, the Penobscot Nation's sacred "highest land," he was struck by the *"continuousness of the forest"* with *"no clearing, no house,"* uninterrupted except for *"the narrow intervals on the rivers, the bare tops of the high mountains, and the lakes and streams"* (Thoreau 1984). More than a century later, the view south and west from Mount Katahdin is much the same and, remarkably, with the exception of the wolf, cougar, and caribou which have been driven north and west, all of the animals Thoreau might have encountered more than a century ago still thrive in the Western Maine Mountains.



The Western Maine Mountains stretch in a broad band from the summits of the Katahdin group, southwesterly one hundred and sixty miles to Boundary Bald Mountain and the Mahoosuc Range on Maine's western border. In all, the region encompasses over five million acres. It is a landscape of superlatives. It includes all of Maine's high peaks. It contains a rich diversity of ecosystems, from alpine tundra and boreal forests to ribbed fens and floodplain hardwood forests. It is home to more than 139 rare plants and animals, including 21 globally rare species and many others that are found only in the northern Appalachians.

It includes more than half of the United States' largest globally significant bird area, which provides crucial habitat for 34 northern woodland songbird species. It provides core habitat for marten, lynx, loon, moose and a host of other iconic Maine animals. The region's abundant snowfall and cool summer rains feed hundreds of miles of cold clear headwater streams that are essential habitat for wild brook trout and other cold water species. Its unfragmented forests and complex topography make it a highly resilient landscape in



Credit: The Nature Conservancy

The Staying Connected Initiative, http://stayingconnectedinitiative.org, has identified critical linkages to maintain connectivity in the Northern Appalachian/Acadian Forest Ecoregion.

the face of climate change.[1] It lies at the heart of the Northern Appalachian/Acadian Forest Ecoregion,[2] which is the largest and most intact area of temperate forest in North America, and perhaps the world.[3] Within this vast forest, the Western Maine Mountains region is the critical ecological link between undeveloped lands to the north, south, east and west.

Northern Maine is the only place in the eastern United States where such a large area of contiguous land has remained continuously forested since pre-

The Western Maine Mountains region is a critical linkage in the Northern Appalachian/Acadian Forest Ecoregion, which is the largest and most intact area of temperate forest in North America, and perhaps the world.

1 Resilience is the capacity of an ecosystem to maintain or return to its essential composition, structure, and ecosystem function after disturbance (Holling 1973).

2 Ecoregions are large units of land with similar environmental conditions, especially landforms, geology and soils, which share a distinct assemblage of natural communities and species. The Northern Appalachian-Acadian Forest Ecoregion includes the mountainous regions and boreal hills and lowlands in Northern New England and Maritime Canada. The ecoregion includes the Adirondack Mountains, Tug Hill, the northern Green Mountains, the White Mountains, the Aroostook Hills, New Brunswick Hills, the Fundy coastal section, the Gaspé peninsula and all of New Brunswick, Nova Scotia and Prince Edward Island (Anderson et al. 2006).

3 Based on Riitters et al. (2000) and the author's analysis of Google Earth imagery. Other northern temperate forests at the same latitude have lower species diversity (Scandinavia) and are more fragmented (Europe, eastern Asia) than the forests of the Northern Appalachian/Acadian Forest Ecoregion.

settlement times (Barton et al. 2012). This is in large part because of the timber value and resilience of its vast forests, most of which have been in private ownership and actively managed for more than two centuries. Many of the ecological values of the Western Maine Mountains region remain because of this fact.

The following pages summarize the region's key ecological values, which include:

- High landscape diversity
- A high diversity of northern species and ecosystems
- More than five million acres of contiguous forest that lie at the heart of the largest intact temperate forest in the United States
- Some of the country's least disturbed forests
- A globally important bird area
- A U.S. stronghold for wild populations of brook trout
- Vital habitat for focal carnivore species such as lynx and marten
- An exceptionally resilient landscape today and predicted high resilience in the face of climate change
- A critical ecological link between the boreal and temperate forest biomes
- An important role in buffering and regulating global, regional and local climates

The region's latitudinal position, mountain topography, forest contiguity, and Atlantic influence are unique at a continental scale.

The Western Maine Mountains lie near the northern terminus of the Appalachian Mountains and include some of the chain's most rugged terrain. The western part of the region includes the Boundary Mountains to the north and the Longfellow Mountains to the south. These two mountain ranges are separated by a series of large lakes, including Umbagog, Upper and Lower Richardson, Rangeley and Flagstaff. To the north and east are the mountains and foothills of the Katahdin group as well as the highlands surrounding Moosehead and Chesuncook Lakes. The region has the greatest topographic relief in the state. Its eastern boundary roughly follows the 1,000 foot contour, but elevations range from 600 to 5,270 feet. The region includes Maine's fourteen peaks taller than 4,000 feet as well as all of the state's high elevation habitat.[4]

The region's climate is influenced by its latitude and weather systems that originate in both the Atlantic and the Arctic. It is characterized by cool summers, harsh winters, a short growing season and the highest snowfalls in Maine, which average 120 inches in a typical winter. Annual precipitation is about 40 inches, although some of the higher mountains produce a rain shadow effect, with precipitation as high as 50 inches on windward slopes and less than 35 inches to leeward (McMahon 1990; Lautzenheiser 1978). Thoreau called the land above tree line a *"cloud-factory–these were the cloud works, and the wind turned them off done from the cool, bare rocks"* (Thoreau 1884). The mountainous landscape is dissected by hundreds of cold, fast-flowing streams, which form the headwaters of four of Maine's major rivers, the Penobscot, Kennebec, Androscoggin and Allagash.

Because of their latitude, mountainous topography, continuous forest and Atlantic influence, Maine's Western Mountains are unique at a continental scale and are home to a diversity of rare species and ecosystems.

The region's latitudinal position, mountain topography, forest contiguity, and Atlantic influence are unique at a continental scale (McKinley 2007). And because species diversity is highly correlated with geophysical diversity in the eastern United States (Anderson and Ferree 2010), the Western Maine Mountains are home to a surprising diversity of both widespread and rare species and ecosystems.

4 The high elevation threshold in Maine is 2,700 feet. Subalpine and alpine habitats are typical above this point. About three percent or 139,222 acres of the region is classified as high elevation (Publicover and Kimball 2012).

The ecological diversity of the Western Maine Mountains is significant at multiple scales, ranging from state to continental.

On a summer day, the view from any mountain in the region is of seemingly endless forest, darker greens of spruce and fir on upper and northerly slopes, lighter greens of northern hardwoods on lower and southerly slopes. A closer look reveals a much more complicated picture. In fact, the Western Maine Mountains harbor the largest concentrations of high value ecosystems and natural features in the state (McKinley 2007; McCollough et al. 2003). The region's rich animal diversity ranges from large mammals, such as lynx and moose, to the rare Bicknell's thrush to bog lemmings and endemic[5] mayflies. This diversity is due to a combination of the region's location within the transition zone between the boreal forest biome to the north and the eastern deciduous forest biome to the south (Delcourt and Delcourt 2000), its complex topography, the continuity of the landscape, and the inherent diversity of forests, with their complex vertical structure, which provides habitat for a multitude of plants and animals. For example, of the 55 mammal species documented in Maine, at least 51 occur in the Western Maine Mountains (DeGraaf and Yamasaki 2001). Only the New England cottontail, the woodland vole, the Virginia opossum, a relative newcomer to Maine, and possibly the southern flying squirrel are absent. The region also retains all of the tree species that were here during presettlement times, including the thirty commercial species that are harvested today, as well as at least 41 of the 48 forest community types that occur in Maine.[6]

The rich ecological diversity of the Western Maine Mountains ranges from large mammals, such as lynx and moose, to the rare Bicknell's thrush to bog lemmings and endemic mayflies. This diversity is due to the region's location within the transition zone between the boreal forest biome to the north and the eastern deciduous forest biome to the south, its complex topography, the continuity of the landscape, and the inherent diversity of forests, with their complex vertical structure, which provides habitat for a multitude of plants and animals.

The most distinctive suite of species in the Western Maine Mountains occurs at high elevations—above tree line and in the subalpine fir forests just below. The globally rare boreal and tundra communities that occur here are among the most pristine areas in the Northern Appalachian-Acadian Forest and are classified as rare in all four northeastern states (Publicover and Kimball 2012). They cover about three percent of the Western Maine Mountains region, but contain a disproportionate number of rare species. Maine's alpine communities are remnant biogeographic islands from the last glacial period (Seidel et al. 2009), and as a result contain many local and regional endemics. The species names tell the story: Aleutian maidenhair fern, tundra dwarf birch, alpine azalea, Alaskan clubmoss, Arctic red fescue, Lapland rosebay, northern bog lemming, White Mountain tiger beetle, Katahdin Arctic butterfly. Maine's mountains include some of the lowest elevation alpine areas at similar or more northern latitudes anywhere in the world (Seidel et al. 2009). Mount Katahdin alone has nineteen rare alpine plant species that are found nowhere else in Maine (Maine Beginning with Habitat Program).

The globally rare boreal and tundra communities that occur here are among the most pristine areas in the Northern Appalachian-Acadian Forest.

Between tree line and an elevation of about 2,700 feet are extensive subalpine fir forests. This rare forest type provides nesting habitat for high elevation and coniferous forest specialist birds, such as spruce grouse, dark-eyed junco, bay-breasted warbler, blackbacked woodpecker, white-throated sparrow, blackpoll warbler, and the elusive Bicknell's thrush, a state endangered species that breeds only in subalpine forests and krummholz in the northern Appalachians (Maine Beginning with Habitat Program). In all, more than 52 upland rare plant species and 9 rare animals species have been documented on Maine's mountain tops.[7]

5 Endemic species are those that are found only in a defined geographic area, such as the Katahdin Arctic butterfly, which is found only on Mount Katahdin.

6 Determined from distribution maps in Gawler and Cutko (2010).

7 Estimated from descriptions and maps of the Ecological Focus Areas that occur in the Maine Mountain Collaborative study area.

The natural diversity of the Western Maine Mountains goes far beyond the species and communities found at higher elevations. The Maine Natural Areas Program and Department of Inland Fisheries and Wildlife have identified 20 landscape-scale focus areas of statewide ecological significance in the region. These focus areas encompass nearly 762,000 acres or about 13% of the region's land area. The relatively intact unfragmented landscapes of these focus areas have a high concentration of rare species and high quality natural communities, ecosystems, and wildlife habitats. These are the 'biodiversity hot spots' of the region. A small sample of some of the biological gems in these focus areas showcases the rich diversity of the Western Maine Mountains.

- Between the Moose River and Attean Pond is No. 5 Bog, a 1400+ acre peatland that is one of the largest, most diverse, and least disturbed peatlands in the eastern United States. It contains the southernmost example of a ribbed fen in North America and is considered nationally significant.
- Wild brook trout populations, which have never been genetically modified by stocking, thrive in the cold high elevation streams and lakes of the Western Maine Mountains, where entire watersheds are unimpeded by dams and culverts. Cold Stream in West Forks Plantation, Orbeton Stream in Redington Township, and Wassataquoik Stream, which flows out of Baxter State Park are just a few of the many pristine examples in the region.
- An outstanding 3,000+ acre Appalachian–Acadian Rivershore ecosystem along the lower Wassataquoik and the East Branch of the Penobscot River contains one of the least disturbed and most extensive hardwood floodplains in the state.
- The Klondike, located in the basin just west of the Tablelands on Mount Katahdin, is Maine's largest and most intact example of a black spruce bog.
- The highest concentration of pristine, remote ponds in New England occurs in the Nahmakanta area. Among its dozens of lakes and ponds, Third Debsconeag Lake, Rainbow Lake and Nahmakanta Lake are the largest and most well-known.
- The beech-birch-maple forest southwest of Speckled Mountain is one of the largest and best examples known in the White Mountains, with trees over 150 years old.
- Millinocket Lake Wetlands and West Branch Flowage chain of lakes and wetlands provide habitat for wild brook trout, the state's northernmost populations of the globally rare tidewater mucket and yellow lampmussel, and breeding habitat for the rusty blackbird, a special concern species that breeds in northernmost New England, Canada, and Alaska.
- The calcium-rich soils of the Twin Peaks area support enriched hardwood cove forests and some of Maine's rarest plant species, including Goldies fern, male fern silvery spleenwort, squirrel corn, and a host of others.
- The region's many cold, clear streams and ponds provide some of the state's best habitat for spring salamanders, wood turtles, freshwater mussels, and dozens of rare aquatic insect species, including at least three globally rare boreal species—the Katahdin Arctic butterfly, the Roaring Brook mayfly and the White Mountains tiger beetle.
- Big and Little Moose Mountains boast two exemplary spruce-fir-northern hardwoods ecosystems, one surrounding Big and Little Moose Ponds, and the other on the northern peak of Big Moose Mountain. Both examples are intact, mature forests that include a variety of hardwood and softwood community types.

- Six of Maine's twelve arctic charr populations occur in the Western Maine Mountains. This species thrives in Bald Mountain Pond and other cold clear ponds in the region. Maine and Alaska are the only states in the country with native populations of this species.
- The Lake Umbagog Wetlands focus area supports breeding pairs of peregrine falcons and bald eagles, and historically provided habitat for nesting golden eagles. Peregrines and golden eagles prefer to nest on rugged cliff faces. The majority of documented peregrine nest sites in Maine are in the Western Mountains, and this is the only region in the eastern United States with year round activity by golden eagles, Maine's rarest breeding bird (Morneau et al. 2015; Charlie Todd, personal communication).

The region lies within the largest and most contiguous forested landscape in the eastern United States.

On satellite images taken of North America at night, northern Maine stands out because of its darkness. The Western Maine Mountains lie at the heart of the 26 million acre Northern Appalachian/Acadian Forest, which spans four states and five Canadian provinces. This ecoregion contains the broadest extent of nearly contiguous natural forest east of the Rockies (Anderson et al. 2012; Anderson 2006) and is the only extensive region of interior temperate forest at middle latitudes worldwide (Riitters et al. 2000). Western and northern Maine are the least developed portions of the ecoregion—with few settlements, no large areas of cleared lands, few paved roads, and some of the region's largest unfragmented forested blocks. Less than two percent (~100,000 acres) of the Western Maine Mountains has been converted to date, compared to 28% of the Northeast as a whole (Publicover, personal communication 2016; Anderson and Sheldon 2011). Baldwin, et al. (2007) described Maine's forests as the ecological core of the Northern Appalachian-Acadian forest, important because of their extent, relatively light human footprint, and because they link the forests of the Northeast to those of the Canadian Maritimes. Within the Northern Appalachian-Acadian Forest, the Western Maine Mountains region provides the key link between the unfragmented forests to the west in northern New Hampshire and Vermont and the vast north woods of Maine.

> The Western Maine Mountains lie at the heart of the Northern Appalachian/Acadian Forest, which is the only extensive region of interior temperate forest at middle latitudes worldwide.

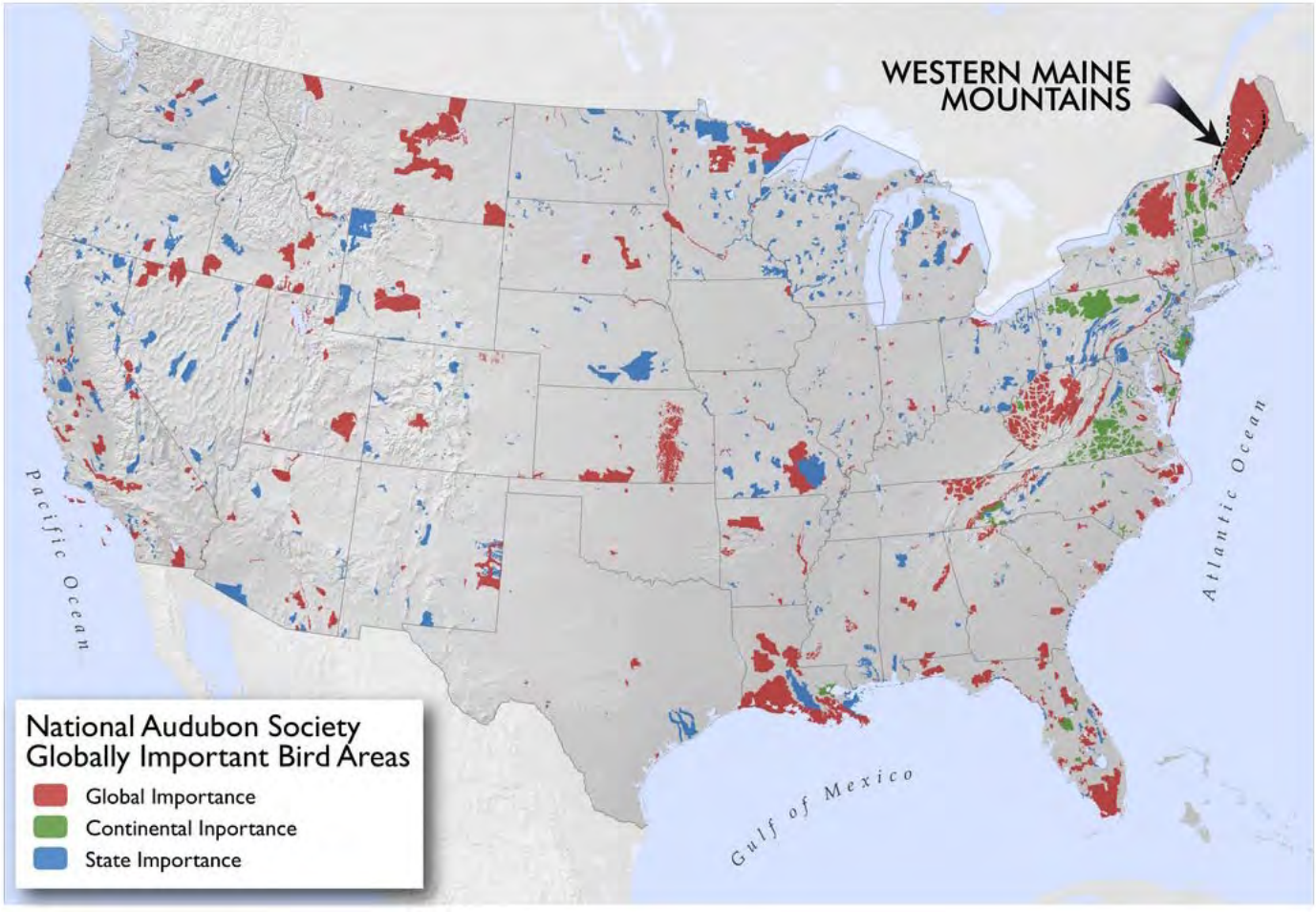
The Western Maine Mountains region includes some of the least disturbed forest landscapes east of the Mississippi.

As noted above, the Northern Appalachian-Acadian Forest is the most intact unfragmented ecoregion east of the Mississippi. In addition, the forests, wetlands and riverine ecosystems of the Western Maine Mountains have experienced less human disturbance than lands to the south, northwest and east. Although the region has a long harvest history, because of its mountainous terrain and short growing season, settlements are few, most of the land was never cleared, plowed or drained for farming, and there are many large blocks of land that have not been fragmented by roads or development. Unlike most of New England, soils here have never been plowed and, as a result, are more likely to have an intact organic soil horizon with native fauna and flora, including native rather than introduced earthworms. Earthworms can have a dramatic effect on nutrient cycling, particularly in northern hardwood forests, where the species composition and richness of the herbaceous layer change markedly after nonnative earthworm invasions (Hopfensperger et al. 2011; Frelich et al. 2006; Burtelow et al. 1998). Invasive plants, which thrive on disturbed soils, have not gained a foothold in the region. In the U.S. Forest Service's 2008 inventory of Maine's forests, the Western Maine Mountains,

upper Saint John Valley and Washington County were the only places where invasive plant populations were not documented (McCaskell et al. 2008). In addition, the region's forests have not experienced overbrowsing by white-tailed deer, which are beginning to impact the ecology of forests to the south (Russell et al. 2001). Finally, compared to New Brunswick, there has been less stand conversion from one forest type to another and plantation forestry is rare (McCaskell et al. 2008). While forest practices have led to a forest that is more homogeneous and has a simpler structure than in presettlement times, all of the region's tree taxa still remain (Thompson et al. 2013). In short, the forests of the region demonstrate a huge natural capacity for renewal.

The Western Maine Mountains region includes more than half of the country's largest Globally Important Bird Area.

Intact forests are critical to the future of most forest birds (National Audubon Society 2015). Maine includes the largest forest blocks in the entire Eastern Atlantic Flyway, which is the major migratory route for hundreds of neotropical bird species, including most of the songbirds familiar to New Englanders. In 2012, National Audubon set out to identify a network of forest blocks that collectively include the best 10 to 25% of forest in the flyway. The "northern Maine forest block" was identified as a Globally Important Bird Area by National Audubon Society and Birdlife International (National Audubon Society 2012). The Western Maine Mountains region makes up more than half of this block and bridges the two avifaunal biomes of the flyway—the Eastern Deciduous Forest Biome and the Northern Forest Biome. The global designation was given because of the area's high bird richness and abundance as well as the extent and intactness of its forest, and is grounded in research that shows that breeding birds are more successful on larger blocks



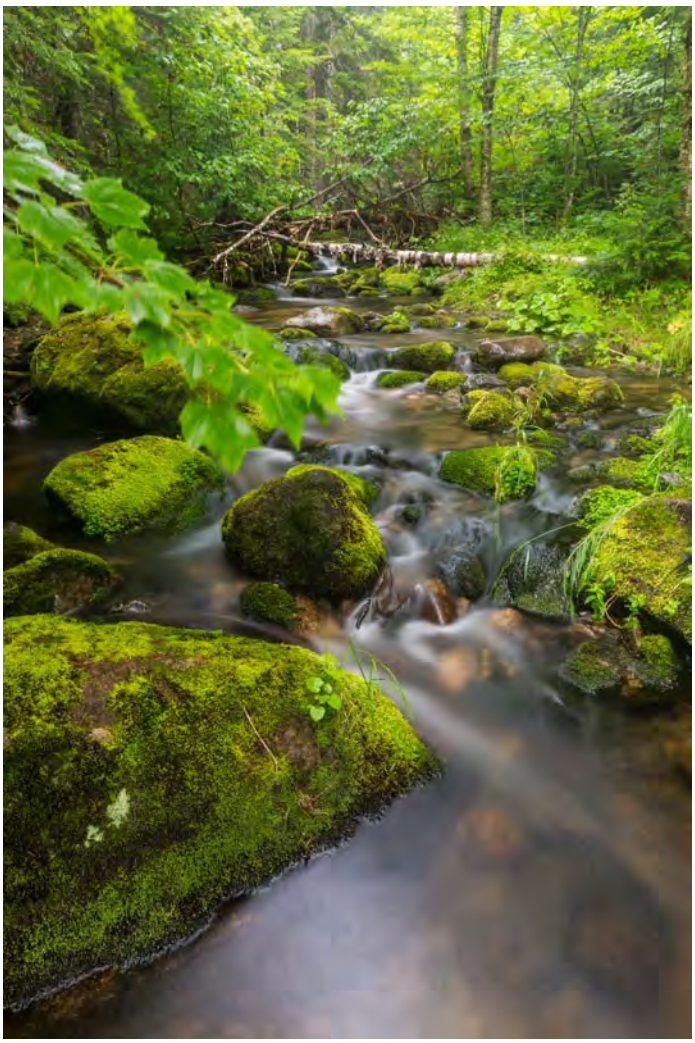
Maine includes the largest Globally Important Bird Area in the US, because if its large intact forests within in the Eastern Atlantic Flyway, the major migratory route for hundreds of neotropical bird species.

(John Guarnaccia, personal communication 2016; Nieme et al. 1998). It is the largest globally important bird area in the United States and is considered vital habitat for 34 priority songbird species whose global breeding distribution is restricted to the northern forest biome[8] (National Audubon Society 2012). The Western Maine Mountains region is a key part of what Maine Audubon biologist Sally Stockwell calls a *"baby bird factory."* Stockwell considers conservation of the forests of the region essential to the future of many of our most cherished bird species.

Northern Maine is the last stronghold for wild brook trout in the eastern United States. Nearly three quarters of the state's wild brook trout waters occur in the Western Maine Mountains.

Northwestern Maine is the last stronghold for wild brook trout[9] in the eastern United States (Whitman et al. 2013a; DeGraaf 2014), supporting 97% of its intact lake and pond wild trout populations. The highest concentration (about 73%) of wild brook trout lakes occurs in the Western Maine Mountains and many more lakes are dependent on the region's snowpack, which provides the clean, cool, well-oxygenated water and the narrow range of water temperatures trout and other cold water species need to survive (Bonney 2009; The Nature Conservancy 2008). In addition, the region's high elevation streams have more intact riparian habitat and are less fragmented by dams and other barriers than elsewhere in New England (Whitman et al. 2013; Anderson and Sheldon 2011). Five of these: the Magalloway, Kennebago, Moose, and East and West Branches of the Penobscot have been identified as particularly important for conservation by The Nature Conservancy because they are long connected stream networks with unaltered water flow and intact forested riparian areas (Anderson and Sheldon 2011).

The region's mountainous landscape is critically important to cold water stream and lake ecosystems, playing a particularly important role in maintaining the flow and high water quality required by brook trout, lake trout, whitefish, spring salamanders, and a variety of aquatic insects.



Perham Stream

Photo courtesy of The Trust for Public Land, Jerry Monkman, EcoPhotography.com

8 Biome-restricted species are those with at least 80% of their population concentrated within one avifaunal biome (US IBA Committee).

9 This number includes heritage brook trout ponds which have never been stocked and wild brook trout ponds, which were historically stocked but are now self-sustaining.

Mountainous landscapes play a particularly important role in maintaining the flow regimes and high water quality required by brook trout, lake trout, whitefish, spring salamanders, and a variety of aquatic insects. On average, the mountains of western and central Maine receive twice the annual snowfall of southern and midcoastal regions (Fernandez et al. 2015; Lautzenheiser, R.E. 1978). These mountains capture, store, purify and gradually release water stored in ice, snow, soils and vegetation into the headwater streams of the Penobscot, Kennebec, Androscoggin, and Allagash Rivers and into groundwater aquifers downstream. Three of the state's prized fish species—lake trout, brook trout, and whitefish—and many other cold water fish and invertebrates depend on this influx of cold water to survive. As the climate warms, snowfall in the mountains is expected to decline at a much lower rate than along the coast (less than 20% versus more than 40% along the coast) and will be all the more important in regulating river flow and maintaining water temperature and supplies in the state (Fernandez et al. 2015). Maine's mountains are and will continue to be critically important to cold water stream and lake ecosystems.

The Western Mountains Region and lands to the north provide the greatest remaining opportunity in eastern North America for maintaining lynx and marten populations, and reestablishing viable populations of the eastern gray wolf.

Nearly one quarter of all designated critical habitat for lynx, a federally threatened species in the United States (Simmons-Legaard et al. 2013) occurs in Maine. The Western Maine Mountains include more than half of this core habitat as well as core habitat for marten. Both lynx and marten are wide-ranging species that reach their southern range limits in the region (Laliberte and Ripple 2004) and, along with the eastern gray wolf, are considered important focal species for biodiversity conservation in the greater Northern Appalachians (Reining et al. 2006). Focal species play a critical ecological role that is of greater importance than we would predict from their abundance. They are wide ranging, so conserving their habitat would provide a protection umbrella for other species with similar requirements; they are sensitive to habitat quality, such as changes in climate; and they are charismatic (Trombulak et al. 2008). In short, if enough habitat is maintained to

Canada lynx

Maintaining habitat requirements for lynx and marten will also maintain the requirements of more than 85% of 110 other vertebrate species.

support viable populations of these species, many other species will also be conserved (Trombulak et al. 2008). Hepinstall and Harrison (in preparation) found that the habitat requirements for lynx and marten encompass the requirements of more than 85% of the 111 forest generalist, deciduous forest specialist, and coniferous forest specialist vertebrate species that occur in northern Maine.

Marten

Lynx and marten are also important because their populations represent "peninsular extensions" of their boreal ranges (Carroll 2005). As a result, they are likely to be particularly sensitive to climate change—especially to changes in snowfall—and they represent unique ecotypes at the southern limit of their range (Carroll 2005; Reining et al. 2006). Models developed by Carroll (2007) and others indicate that the Western Maine Mountains region is likely to be of critical importance to the future of northeastern lynx and marten populations, since their ranges are expected to contract to the north and to higher elevations as the climate warms. The Western Maine Mountains region already serves as a north-south and east-west link between peripheral populations in the White Mountains and those in northeastern Maine and the Gaspé (Carroll 2007). Both species have used this link to recolonize New Hampshire (Daniel Harrison, personal communication). While the forests of the region currently support lynx and marten, recent research suggests that harvest practices on two thirds of Maine's commercial forestland are creating habitat that no longer serves the needs of these umbrella species, and many others, which may lead to population declines in the future (Simmons-Legaard et al. 2013; Fuller and Harrison 2005; Homyack et al. 2010). Lynx thrive in the young dense spruce-fir forests that regenerate after clearcutting, which provide ideal habitat for snowshoe hare, the lynx's principle prey. Over the past several decades, there has been a broad-scale decline of early-successional habitat and in the spruce-fir forest type overall (Simons-Legard et al. 2016).

Although breeding populations of a third focal species—the grey wolf—have not yet been documented in Maine, there are many reports of wolves along the region's western border. The Western Maine Mountains, along with much of northern and central Maine, is considered potential habitat for this wide-ranging carnivore (Laliberte and Ripple 2004). A number of organizations in Maine and elsewhere are working on recovery efforts for this federally endangered species.

The Western Maine Mountains region is poised to serve as a critical ecological linkage between the temperate and boreal forest biomes.

According to Whitman and others (2013b), the composition of nearly every plant community and wildlife habitat in Maine is likely to be affected by climate change (Jacobson et al. 2009). Although there is uncertainty about how individual species' ranges will respond to various climate change scenarios, most species will likely shift north and/or upwards in elevation. Maintaining a connected landscape is the most widely cited strategy

in the scientific literature for building resilience in the face of climate change (Anderson et al. 2012; Heller and Zavaleta 2009). The Western Maine Mountains region is the critical ecological link between the forests of northern Maine, New Brunswick and the Gaspé and the forests of New Hampshire, Vermont and the Adirondacks, as well as smaller forested areas to the south.

Within the northeastern United States, the Western Maine Mountains region is already considered a priority linkage for species such as lynx, marten and moose, because it contains a "highly concentrated east-west regional flow pattern" which connects resilient landscapes to the west and south to those in northern Maine (Anderson et al. 2012). This large-scale directional flow occurs here because the Western Maine Mountains region is sandwiched between the agricultural lands of the St. Lawrence Valley and developed lands in Vermont, New Hampshire and southern and coastal Maine.

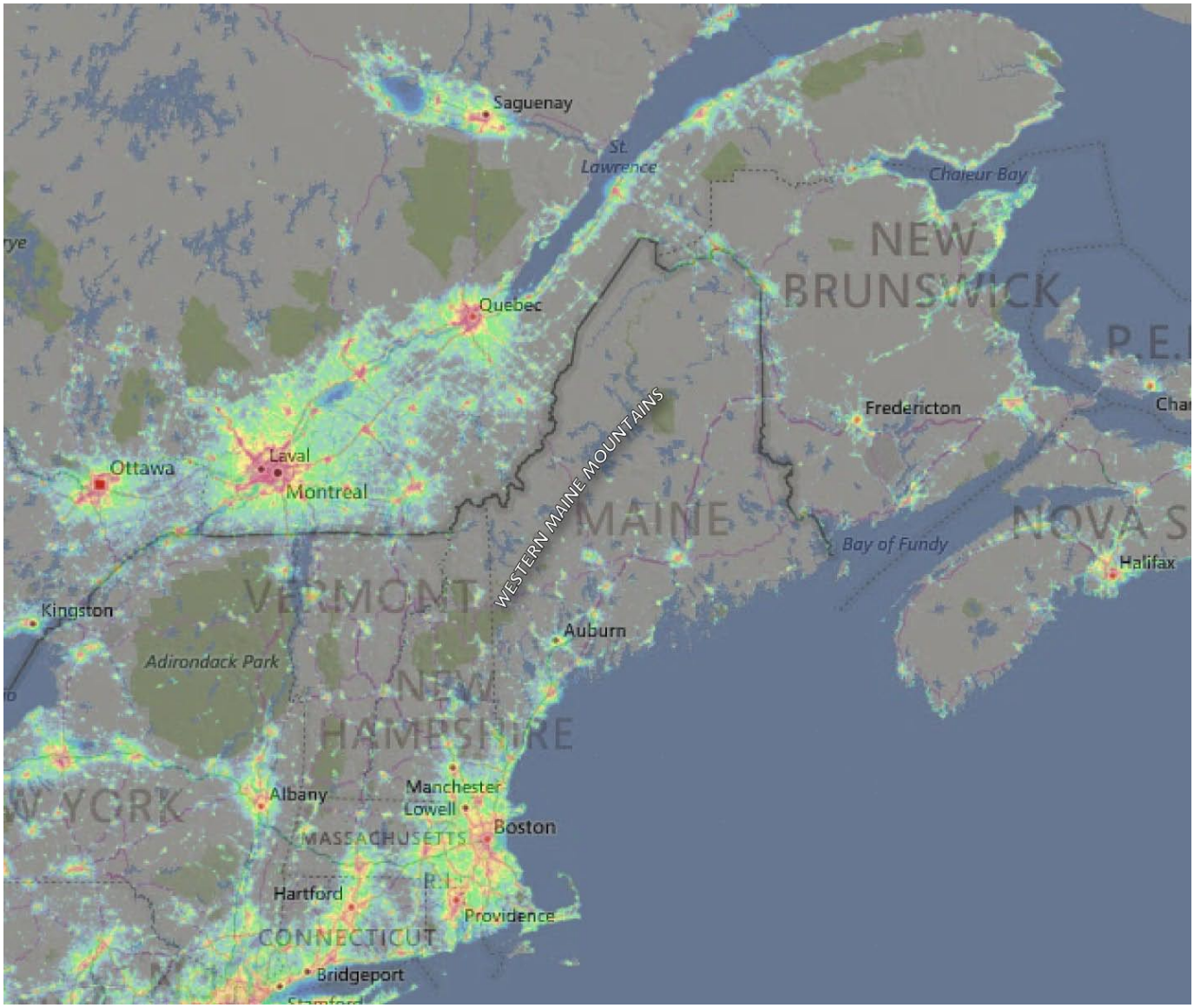


Image from Jurij Stare, www.lightpollutionmap.info, based on original data sourced from Earth Observation Group, NOAA National Geophysical Data Center. Western Maine Mountain text added.

This satellite image of the night sky illustrates the critical position of the Western Maine Mountains region as a link connecting the unfragmented forests in the Adirondacks, Vermont and New Hampshire to Maine's north woods and the forests of Canada, a connection critical to the entire Northern Appalachian-Acadian Forest Ecoregion.

The Wildlands Project has identified four 'megalinkages' that, if implemented, would tie North American ecosystems together to conserve and benefit native species in their current and projected natural patterns of range and abundance (Reining et al. 2006). The Western Mountains Region is a key part of the Atlantic Megalinkage, which extends from Florida to New Brunswick, mostly along the Appalachians. The megalink includes two core areas in Maine, both of which occur in the region—one centered around the Baxter region, the other around the Boundary Mountains and upper Androscoggin watershed. The Wildlands network highlights the great importance of northern Maine and the Gaspé Peninsula for long-term conservation in the Northern Appalachian region, not only for focal species like lynx, marten and (potentially) wolf, but also as the remaining places where large new wildlands could be established (Reining et al 2006).

The region's value as an ecological link would be greatly enhanced by connecting it to the boreal forest north of the St. Lawrence River through the remaining intact forest blocks in adjacent Quebec. Creating a more permeable and connected landscape would be an extremely ambitious project that would require regeneration of existing farmland to forestland and identifying potential corridors across major highways. Many studies have identified the Western Maine Mountains region as a key part of such a linkage (One Country Two Forests, National Audubon Society, Wildlands Project, The Nature Conservancy, Adirondack to Acadia, Boreal Songbird Initiative, Staying Connected). Over time, such a link could potentially enhance some of the other key ecological values of the Western Maine Mountains, for example, by connecting and expanding potential habitat for wide-ranging carnivores and breeding songbirds.

Maine's most extensive older forests are found in the Western Maine Mountains.

Next to conversion of forest to some other land use, the loss of older forest age classes is a major threat to forest biodiversity worldwide (Hagan and Whitman 2004). Older forests of the temperate and boreal zones contain exceptional forest structure including large trees, large snags, large logs, large volumes of dead wood, and vertical structural diversity not found in younger forests (Whitman and Hagan 2007)[10]. In the United States, late-successional stands (those older than 100 years) now constitute less than 4% of forested areas (Ryan et al. 2010). In Maine, late successional forests cover somewhere between 3 and 6% of the state, and their extent continues to decline (Maine Department of Inland Fisheries and Wildlife 2015; Hagan and Whitman 2004). In Finland, where old forests comprise less than 0.5% of all forested areas, extinction-vulnerable old forest species now number more than 1,000 (Hanski 2000), and an estimated 5% of Finland's forest species are predicted to go extinct in the next 50 years (Hagan and Whitman 2004). Much of Maine's older forest is in the Western Maine Mountains at high elevations, in the Baxter area, in the White Mountains and in other ecological focus areas in the region. These areas are important for species such as marten, many woodland raptors and songbirds, mosses, lichens and other species that depend on mature interior forest, large cavity trees, downed wood, and the large number of forest niches present. Hagan and Whitman (2004) suggest that we may be accruing 'extinction debt' in Maine's forests. They describe the process as follows:

> *"Once old forest elements such as large trees or logs are lost from a stand (e.g., as a result of a clearcut, or even a selection cut), it can take centuries for the species to return to that location. A species first has to wait for these structural features to redevelop, and then the species has to find them. Scientists are beginning to understand that forest continuity is key to many forest species. Continuity refers to the persistence of big trees and big logs in a forest stand over a very long period of time (centuries), even though the stand might be subjected to many different disturbances, such as fire, wind, disease, or even selection logging. Species that move or disperse slowly through the landscape, and prefer large old trees or logs, are the species most at risk to the loss older forests."*[11]

10 Most forests in Maine are under 75 years in age. Pathological maturity—the age at which trees begin to suffer serious decay—is 150 years or older, depending on the species (Thompson et al. 2013).

11 These tend to be small and uncharismatic, such as insects, lichens, fungi, and mosses.

Although forest cover has remained relatively stable in Maine, the loss of older forest age classes from the vast Northern Appalachian-Acadian forest could be leading us down a biodiversity path that has already begun to unfold in Scandinavia (Hagan and Whitman 2004). The late successional forests that remain in the Western Maine Mountains are critically important, especially those that are large enough to protect source populations of plants and animals that may disperse to surrounding forests as they mature (Baldwin et al 2007).

Much of Maine's older forest is in the Western Maine Mountains at high elevations. These areas are important for species such as marten, many woodland raptors and songbirds, mosses, lichens and other species that depend on mature interior forest, large cavity trees, downed wood, and the large number of forest niches present in older forests.

The Western Maine Mountains region is expected to be a highly resilient landscape in the face of climate change.

Ecologist Aldo Leopold captured the concept of ecological resilience in two elegant statements (Anderson et al. 2012): "*Health is the capacity of the land for self-renewal. Conservation is our effort to understand and preserve this capacity*" (Leopold 1949). Climate change is expected to alter the distribution of Maine's flora and fauna. The process is well underway—we are already experiencing the northward migration of northern cardinals, Virginia opossums, deer ticks, northern shrimp, and a host of other species. Conservationists are urgently working on strategies that will conserve the maximum amount of biological diversity as species ranges shift.

The Nature Conservancy is at the forefront of developing the science to guide these efforts. Their approach is based on three observations. First, that species diversity is highly correlated with landscape diversity in the Northeast and Mid-Atlantic; second, that species take advantage of microclimates and microhabitats available in complex landscapes, and finally, that species can move to adjust to climatic changes if these landscapes are permeable[12] and connected (Anderson et al. 2012; Anderson et al. 2013). Anderson and others hypothesized that sites with a large variety of landforms and long elevation gradients will retain more species even as the climate changes by offering ample microclimates and thus more options for rearrangement. They then mapped key geophysical settings and land use patterns to identify the most resilient places in the landscape—the places most likely to be natural strongholds for species and nature into the future.

The Western Maine Mountains region is expected to be an important natural stronghold for biodiversity because of its elevation range and varied landforms (e.g., cool ravines, warm southern slopes, cold streams, wind-swept summits) as well as its high landscape connectivity. The region is considered very permeable—its relatively unfragmented landscapes allow the continuous flow of natural processes, including not only the dispersal and recruitment of plants and animals, but the rearrangement of existing communities. (Anderson et al. 2012). These characteristics should help buffer climate change effects and allow for directional range shifts, north-south and east-west migrations, and upslope dispersal (Anderson et al. 2012; Anderson et al. 2015).

The Western Maine Mountains region is expected to be an important natural stronghold for biodiversity because of its elevation range and varied landforms (e.g., cool ravines, warm southern slopes, cold streams, wind-swept summits) as well as its high landscape connectivity.

Mountain tops may be particularly important to the region's biodiversity, at least in the short term. Research suggests that, although the areal extent of high elevation habitat is expected to decline as temperatures rise (Whitman et al. 2013a; Beckage et al. 2008), subalpine and alpine community composition may be relatively stable because their distribution is thought to be more closely tied to icing and the low cloud ceiling typical of higher elevations rather than temperature (Spear 1989; Kimball et al. 2014; Randin et al. 2008). Mid and high

12 Landscape permeability indicates the number of barriers and degree of fragmentation within a landscape. A permeable landscape allows for range shifts and reorganization of communities.

elevation micorefugia[13] are likely to be critical for the survival of many species in the future, especially alpine flora and fauna and species that thrive where snowfall is high, such as lynx, marten, snowshoe hair and moose (Carroll 2005).

The Western Maine Mountains play an important role in regulating local, regional, and global climate.

A walk through the woods on a mid-summer day gives a sense of how forests at our latitude influence local and regional climate. Forests are likely to be much cooler and more humid than more open habitat types. This is in part because precipitation often exceeds evapotranspiration rates in forests. In addition, tree canopies are rougher than cleared or developed land, which decreases wind speed and water loss from evaporation. As a result, temperate forests are typically sources of surface water (Sun and Liu 2013). For example, it is estimated that over 60% of our water supply comes from forest lands in the United States (Brown et al. 2008). Forest soils are regarded as 'sponges' because their deep extensive root systems and layer of leaf litter on the forest floor soak up water. For this reason, soil erosion is rare in forests—they provide the best water quality among all land uses. Forests also affect microclimate by altering solar radiation and how rain and snow fall through large forest canopies (Lee 1981) and by keeping streams cool in summer.

The Western Maine Mountains region also plays a role in moderating climate at the global level. The mountain snowpack that accumulates in winter helps regulate the earth's climate by reflecting solar radiation that would otherwise be absorbed by a darker surface and reradiated as heat into the atmosphere. This phenomenon is known as the albedo effect. More importantly, because trees are tall and long-lived, they sequester a great deal of carbon. In most forests, 95% of the biomass is in woody tissue—boles, limbs and roots (Hunter 1990; Packham and Harding 1982). Soils also sequester carbon and, because decomposition is slow in the cool damp forests of northern and western Maine, these areas serve as a carbon sink. It is estimated that the world's forests store 45% of terrestrial carbon and that they have the potential to absorb almost half of global annual carbon dioxide emissions (Pan et al. 2011). In addition, research suggests that older forests sequester more carbon than younger ones (Kauppi et al. 2015; Stevenson et al. 2014; Birdsey 1992), making the older forests that exist at high elevations, in the Baxter area and in other ecological focus areas of the Western Maine Mountain region that much more important. A shift to sustainable forest management for long-lived wood products that can be used in place of energy intensive construction materials such as cement and steel has great potential to further reduce fossil fuel emissions (Oliver et al. 2014).

Conclusions

The Western Maine Mountains region is a spectacular and rugged landscape defined by forest, rock, snow, clouds, and distance. From its windswept summits to the deep clear lakes and wet meadows of its valleys, it is a region of exceptional diversity and beauty. Study after study highlights the region's significance—with its globally significant alpine and montane forest ecosystems embedded within the largest area of contiguous forest in the eastern United States; as part of the largest remaining block of unfragmented forest in the Atlantic Flyway; as the last stronghold for brook trout in the United States; as the link between marten and lynx populations in the United States and Canada. The combination of boreal and temperate species, steep elevation gradients, and continuous forest make it a resilient landscape in a changing climate—one that is expected to retain the rich diversity and coherency of its natural communities farther into the future than the surrounding lowlands, and one that will provide both refuge and an essential ecological linkage for species such as woodland songbirds, brook trout, moose, marten and lynx that are likely to shift their ranges north and east in response to a warming climate.

Study after study highlights the region's significance—with its globally significant alpine and montane forest ecosystems embedded within the largest area of contiguous forest in the eastern United States; as part of the largest remaining block of unfragmented forest in the Atlantic Flyway; as the last stronghold for brook trout in the United States; as the link between marten and lynx populations in the United States and Canada. The combination of boreal and temperate species, steep elevation gradients, and continuous forest make it a resilient landscape in a changing climate—one that is expected to retain the rich diversity and coherency of its natural communities farther into the future than the surrounding lowlands, and one that will provide both refuge and an essential ecological linkage for species such as woodland songbirds, brook trout, moose, marten and lynx that are likely to shift their ranges north and east in response to a warming climate.

13 Microrefugia are defined as areas with locally favorable environmental conditions in which small populations can survive outside their main distribution area (Rull 2009).

its globally significant alpine and montane forest ecosystems embedded within the largest area of contiguous forest in the eastern United States; as part of the largest remaining block of unfragmented forest in the Atlantic Flyway; as the last stronghold for brook trout in the United States; as the link between marten and lynx populations in the United States and Canada. The combination of boreal and temperate species, steep elevation gradients, and continuous forest make it a resilient landscape in a changing climate—one that is expected to retain the rich diversity and coherency of its natural communities farther into the future than the surrounding lowlands, and one that will provide both refuge and an essential ecological linkage for species such as woodland songbirds, brook trout, moose, marten and lynx that are likely to shift their ranges north and east in response to a warming climate.

Apart from its many ecological values, the Western Maine Mountains region serves as a source of inspiration and spiritual renewal. It is impossible not to be impressed by the countless mountain streams singing over stone, mica sparkling in granite, the densely woven forests of dwarf balsam, the scree-covered ridges, the alpenglow of dusk and the 'fox fire' of northern lights in winter. Thousands are drawn to the region's heights, which are linked by the wildest one hundred miles of the 2,190 mile long Appalachian Trail. And thousands more are drawn to its forests, streams and lakes—to walk, watch, fish, hunt or simply escape the buzz of civilization.

In his book, *The Forest Unseen*, David Haskell describes the value of a small patch of old forest in the southern Appalachians, which applies equally well to the Western Maine Mountains. It is "a *relatively unfragmented, uninvaded forest where the old ecological rulebook has yet to be entirely torn up and blown away. These ants, these flowers, these trees contain the genetic history and diversity from which the future will be written. The more wind-tattered pages we can hold on to, the more materials evolution's scribe will have to draw upon as it reworks the saga."* The Western Maine Mountains region is one of the most intact forested landscapes in North America, one that retains nearly all of the plants and animals that were here before us. It serves as a reservoir, a refuge, and a resilient critical linkage. We are fortunate to be starting with pages that have yet to become "wind-tattered". By working to ensure that the mountains and forests of the region remain diverse, resilient and connected to forested landscapes to the north, south, east and west, we have an unparalleled opportunity to influence how the future will be written.

Literature Cited

Anderson, M.G., C. Ferree, and K. McGargial. 2015. Extending the Northeast Terrestrial Habitat Map to Atlantic Canada. Report to North Atlantic Landscape Conservation Cooperative, Hadley, Massachusetts. 23 pp.

Anderson, M.G., M. Clark, C.E. Ferree, A. Jospe, and A. Olivero Sheldon. 2013. Condition of the Northeast Terrestrial and Aquatic Habitats: A Geospatial Analysis and Tool Set. The Nature Conservancy, Eastern Conservation Science. Boston, MA. 171 pp.

Anderson, M.G., M. Clark, and A. Olivero Sheldon. 2012. Resilient Sites for Terrestrial Conservation in the Northeast and Mid-Atlantic Region. The Nature Conservancy, Eastern Conservation Science. 122 pp.

Anderson, M.G. and A. Olivero Sheldon. 2011. Conservation Status of Fish, Wildlife, and Natural Habitats in the Northeast Landscape: Implementation of the Northeast Monitoring Framework. The Nature Conservancy, Eastern Conservation Science. 289 pp.

Anderson M.G. and C. Ferree. 2010. Conserving the Stage: Climate Change and the Geophysical Underpinnings of Species Diversity. PLoS ONE. 5(7):E11554.doi:10.1371/journal. pone.0011554.

Anderson, M.G. 2006. The Northern Appalachian/Acadian Ecoregion: Conservation Assessment – Status and Trends. The Nature Conservancy.

Baldwin, R.F., S.C. Trombulak, K. Beazley, C. Reining, G. Woolmer, J.R. Nordgren, and M. Anderson. 2007. The Importance of Maine for Ecoregional Conservation Planning. Maine Policy Review 16(2):66-77.

Barton, A.M., A.S. White and C.V. Cogbill. 2012. The Changing Nature of the Maine Woods. University of New Hampshire Press, Durham, New Hampshire. 349 pp.

Beckage, B., B. Osborne, D. Gavin, C. Pucko, T. Siccama, and T. Perkins. 2008. A Rapid Upward Shift of a Forest Ecotone During 40 years of Warming in the Green Mountains of Vermont. PNAS 105:4197–4202.

Birdsey, R.A. 1992. Carbon Storage and Accumulation in United States Forest Ecosystems. General Technical Report WO-59. Northeastern Forest Experiment Station, Radnor, Pennsylvania.

Bonney, F. 2009. Brook Trout Management Plan. Maine Department of Inland Fisheries and Wildlife. Augusta, Maine.

Brown, T.C., M.T. Hobbins, and J.A. Ramirez. 2008. Spatial Distribution of Water Supply in the Coterminous United States. Journal of the American Water Resources Association. 44(6): 1474–1487.

Burtelow, A.E., P.J. Bohlen, and P.M. Groffman. 1998. Influence of Exotic Earthworm Invasions on Soil Organic Matter, Microbial Biomass and Denitrification Potential in Forest Soils of the Northeastern United States. Applied Soil Ecology 9 (1998):197-202.

Carroll, C. 2007. Interacting Effects of Climate Change, Landscape Conversion, and Harvest on Carnivore Populations at the Range Margin: Marten and Lynx in the Northern Appalachians. Conservation Biology, 21: 1092–1104.

Carroll, C. 2005. Carnivore Restoration in the Northeastern U.S. and Southeastern Canada: A Regional-Scale Analysis of Habitat and Population Viability for Wolf, Lynx, and Marten (Report 2: Lynx and Marten Viability Analysis). Wildlands Project Special Paper No. 6. Richmond, VT: Wildlands Project. 46 pp.

DeGraaf, D. 2014. Report Back to Legislature on Public Law 2013 Chapter 358, Section 8: Proposed Plan for Managing State Heritage Fish Waters. Maine Department of Inland Fisheries and Wildlife. Augusta, Maine.

DeGraaf, R.M. and M. Yamasaki. 2001. New England Wildlife: Habitat, History, and Distribution. University Press of New England. Hanover and London.

Delcourt, H.R. and P.A. Delcourt. 2000. Eastern Deciduous Forests. Pp. 357-396 in M.G. Barbour and W.D. Billings (Eds.) North American Terrestrial Vegetation. Cambridge University Press.

Fernandez, I.J., C.V. Schmitt, S.D. Birkel, E. Stancioff, A.J. Pershing, J.T. Kelley, J.A. Runge, G.L. Jacobson, and P.A. Mayewski. 2015. Maine's Climate Future: 2015 Update. University of Maine, Orono, Maine. 24 pp.

Flatebo, G, 1999. Vertical Structure and Crown Closure. Pp. 17-22 and Appendix H in C.A. Elliott (Ed.). Biodiversity in the Forests of Maine: Guidelines for land management. University of Maine Cooperative Extension Bull. #7147. University of Maine, Orono, Maine.

Morneau, F., J.A. Tremblay, C. Todd, T.E. Chubbs, C. Maisonneuve, J. Lamaitre, and T. Katzner. 2015. Known Breeding Distribution of Golden Eagles in Eastern North America. Northeastern Naturalist 22(2): 236-247.

Frelich, L.E., C.M. Hale, S., Scheu, A.R. Holdsworth, L. Heneghan, P.J. Bohlen, and P.B. Reic. 2006. Invasion into Previously Earthworm-free Temperate and Boreal Forests. Biological Invasions 8: 1235-1245.

Fuller, A.K. and D.J. Harrison. 2005. Influence of Partial Timber Harvesting on American Martens in North-Central Maine. Journal of Wildlife Management 69(2):710-722.

Gawler, S.C. and A. Cutko. 2010. Natural Landscapes of Maine: A Guide to Natural Communities and Ecosystems. Maine Natural Areas Program. Maine Department of Conservation, Augusta, Maine.

Hagan, J.M, and A.A. Whitman. 2004. Late Successional Forest: A Disappearing Age Class and Implications for Biodiversity. Forest Mosaic Science Notes-2004-2. Manomet, Brunswick, Maine.

Hansk, I. 2000. Extinction Debt and Species Credit in Boreal Forests: Modeling the Consequences of Different Approaches to Biodiversity Conservation. Annales Zool. Fennici 37:271-280.

Haskell, D.G. 2012. The Forest Unseen: A Year's Watch in Nature. Viking, New York. 168 pp.

Heller, N.E. and Zavaleta E.S. 2009. Biodiversity Management in the Face of Climate Change: A Review of 22 Years of Recommendations. Biological Conservation 142: 14-32.

Hepinstall, J.A. and D.J. Harrison (in preparation). Department of Wildlife Ecology, University of Maine.

Homyack, J.A., D.J. Harrison, and W.B. Krohn. 2010. Effects of Precommercial Thinning on Snowshoe Hares in Maine. Journal of Wildlife Management 71(1):4-13.

Holling, C.S. 1973. Resilience and Stability of Ecosystems. Ann. Rev. Ecol. Syst. 4: 1-23.

Hopfensperger, K.N., G.M. Leighton, and T.J. Fahey 2011. Influence of Invasive Earthworms on Above and Belowground Vegetation in a Northern Hardwood Forest. The American Midland Naturalist 166(1):53-62.

Hunter, M. L. Jr., 1990. Wildlife, Forests, and Forestry. Prentice Hall, New Jersey. 358 pp.

Jacobson, G. L., I. J. Fernandez, P. A. Mayewski, and C. V. Schmitt (editors). 2009. Maine's Climate Future: An Initial Assessment. Orono, ME: University of Maine. Accessed online at: http://www.climatechange.umaine.edu/mainesclimatefuture/.

Kauppi, P.E., R.A. Birdsey, Y. Pan, A. Ihalainen. P. Nöjd and A. Lehtonen. 2015. Effects of Land Management on Large Trees and Carbon Stocks. Biogeosciences, 12:855–862.

Kimball, K.D., M.L. Davis, D.M. Weihrauch, G.L.D. Murray, and K. Rancourt. 2014. Limited Alpine Climatic Warming and Modeled Phenology Advancement for Three Alpine Species in the Northeast United States. American Journal of Botany 101(9): 1437–1446.

Laliberte, A.S. and J. Ripple. 2004. Range Contractions of North American Carnivores and Ungulates. BioScience 54(2):123-138.

Lautzenheiser, R. E. 1978. Climates of the States: Maine. Pages 426-448 in Climates of the States, National Oceanic and Atmospheric Administration. Gale Research Co., Detroit, Michigan.

Lee, R. 1981. Forest Hydrology. Columbia University Press, New York. pp. 498–509.

Leopold, A. 1949. A Sand County Almanac and Sketches from Here and There. Oxford University Press, New York. 226pp.

Maine Department of Inland Fisheries and Wildlife. 2015. Maine's Wildlife Action Plan. Maine Department of Inland Fisheries and Wildlife. Augusta, Maine.

McCaskill, G.L., W.H. McWilliams, C.J. Barnett, B.J. Butler, M.A. Hatfield, C.M. Kurtz, R.S. Morin, W.K. Moser, C.H. Perry, and C.W. Woodall. 2011. Maine's Forests 2008. Resource Bulletin NRS-48. Northern Research Station. U.S. Forest Service. Newtown Square, Pennsylvania.

McCollough, M.A., B. Todd, P. Swartz, P. deMaynadier, and H. Givens. 2003. Maine's Endangered and Threatened Wildlife. Maine Department of Inland Fisheries and Wildlife, Augusta, Maine. 117pp.

McKinley, P. 2007. An Ecological Study of the High Peaks Region of Maine's Western Mountains. Maine Appalachian Trail Land Trust. Portland, Maine. 63 pp.

McMahon, J.S. 1990. The Biophysical Regions of Maine: Patterns in the Landscape and Vegetation. M.S. Thesis. University of Maine, Orono. 120 pp.

Maine Beginning With Habitat Program (Maine Natural Areas Program and Maine Department of Inland Fisheries and Wildlife, Focus Areas of Statewide Significance Descriptions. on line: (www.beginningwithhabitat.org/about_bwh/focusareas.html)

National Audubon Society. 2015. Audubon's Birds and Climate Change Report: A Primer for Practitioners. National Audubon Society, New York. Contributors: G. Langham, J. Schuetz, C. Soykan, C. Wilsey, T. Auer, G. LeBaron, C. Sanchez, and T. Distler. Version 1.3.

National Audubon Society. 2012. Atlantic Flyway Priority Forest Mapping Summary Report. (shared by Sally Stockwell, Maine Audubon Society).

Niemi, G., J. Hanowski, P. Helle, R. Howe, M. Mönkkönen, L. Venier, and D. Welsh. 1998. Ecological Sustainability of Birds in Boreal Forests. Conservation Ecology [online] 2(2):17. http://www.consecol.org/vol2/iss2/art17/.

Oliver, C.D., N.T Nassar, B.R. Lippke, and J.B. McCarter. 2014. Carbon, Fossil Fuel, and Biodiversity Mitigation with Wood and Forests. Journal of Sustainable Forestry 55: 248-275.

Packham, J.R. and D.J.L. Harding. 1982. Ecology of Woodland Processes. Arnold, London. 262 pp.

Pan, Y., R.A. Birdsey, J. Fang, R. Houghton, P.E. Kauppi, W.A. Kurz, O.L. Phillips, A. Shvidenko, S.L. Lewis, J.G. Cnadell, P. Ciais, R.B. Jackson, S.W. Pacala, A.D. McGuire, S. Piao, A. Rautianen, S. Sitch, and D. Hayes. . 2011. A Large and Persistent Carbon Sink in the World's Forests. Science 333:988-993.

Publicover, D.A. and K.D. Kimball. 2012. High-elevation Spruce-fir Forest in the Northern Forest: An Assessment of Ecological Value and Conservation Priorities. Appalachian Mountain Club Research Department, Gorham, New Hampshire.

Randin, C.F., Engler, R., Normand, S.. Zappa, M.. Zimmermann, N., Pearman, P.B., Vittoz, P., Thuiller, W. and A. Guisani. 2008. Climate Change and Plant Distribution: Local Models Predict High-elevation Persistence. Global Change Biology 15(6):1557-1569.

Reining, C., K. Beazley, P. Doran and C. Bettigole. 2006. From the Adirondacks to Acadia: A Wildlands Network Design for the Greater Northern Appalachians. Wildlands Project Special Paper No. 7. Richmond, Vermont. 58 pp.

Riitters, K., J. Wickham, R. O'Neill, B. Jones, and E. Smith. 2000. Global-scale Patterns of Forest Fragmentation. Conservation Ecology 4(2):3.

Rull, V. 2009. Microrefugia. Journal of Biogeography 36:481-484.

Russell, F.L., D.B. Zippin and N.L. Fowler. 2001. Effects of White-tailed Deer *(Odocoileus virginianus)* on Plants, Plant Populations and Communities: A Review. American Midland Naturalist 146:1-26.

Ryan, M.G., M.E. Harmon, R.A. Birdsey, C.P. Giardina, L.S. Heath, R.A. Houghton, R.B. Jackson, D.C. McKinley, J.F. Morrison, B.C. Murray, D.E. Pataki, and K.E. Skog. 2010. A Synthesis of the Science of Forests and Carbon for U.S. Forests. Issues in Ecology Report No. 13. Ecological Society of America.

Seidel, T.M., D.M. Weihrauch, K.D. Kimball, A.A.P. Pszenny, R. Soboleski, E. Crete, and G. Murray. 2009. Evidence of Climate Change Declines with Elevation Based on Temperature and Snow Records from 1930s to 2006 on Mount Washington, New Hampshire, U.S.A. Arctic, Antarctic, and Alpine Research 41(3):362-372.

Simmons-Legaard, E.M., D.J. Harrison, W.B. Krohn, and J.H. Vashon. 2013. Canada Lynx Occurrence and Forest Management in the Acadian Forest. The Journal of Wildlife Management 77(3):567-578.

Simons, E., D. Harrison, A. Whitman, and J. Wilson. 2010. Quantifying Biodiversity Across Managed Landscapes in Northern and Western Maine. Final Report to the Maine Cooperative Forestry Research Unit, University of Maine, Orono. 29 pp.

Spear, R.W. 1989. Late-Quaternary History of High-Elevation Vegetation in the White Mountains of New Hampshire. Ecological Monographs, 59(2): 125-151.

Stephenson, N. L., A. J. Das, R. Condit, S. E. Russo, P. J. Baker, N. G. Beckman, D. A. Coomes, E. R. Lines, W. K. Morris, N. Ruger, E. Alvarez, C. Blundo, S. Bunyavejchewin, G. Chuy-ong, S. J. Davies, A. Duque, C. N. Ewango, O. Flores, J. F. Franklin, H. R. Grau, Z, Hao, M. E. Harmon, S. P. Hubbell, D. Kenfack, Y. Lin, J. R. Makana, A. Malizia, L. R. Malizia, R. J. Pabst, N. Pongpattananurak, S-H, Su, I-F Sun, S. Tan, D. Thomas, P. J. van Mantgem, X. Wang, S. K. Wiser, and M. A. Zavala. 2014. Rate of Tree Carbon Accumulation Increases Continuously with Tree Size. Nature 507:90–93.

Sun, G. and Y. Liu. 2013. Forest Influences on Climate and Water Resources at the Landscape to Regional Scale. Pages 309-333 in B. Fu and K. B. Jones (Eds.), Landscape Ecology for Sustainable Environment and Culture. Springer Science.

The Nature Conservancy. 2013. Staying Connected in the Northern Appalachians: Mitigating Fragmentation and Climate Change Impacts on Wildlife Through Functional Habitat Linkages. Final Performance Report-Summary. New Hampshire Fish and Game Department and the U.S. Fish and Wildlife Service.

The Nature Conservancy. 2008. Life in Maine's Lakes and Rivers: Our Diverse Aquatic Heritage. The Nature Conservancy, Brunswick, Maine. 32pp.

Thompson, J.R., D.N. Carpenter, C.V. Cogbill, and D.R. Foster. 2013. Four Centuries of Change in Northeastern United States Forests. PLoS ONE 8(9): e72540. doi:10.1371/journal. pone. 0072540

Thoreau, H. D. 1984. The Maine Woods. Thomas Y. Crowell and Co., New York.

Trombulak, S.C., M.G. Anderson, R.F. Baldwin, K. Beazley, J.C. Ray, C. Reining, G. Woolmer, C. Bettigole, G. Forbes, and L. Gratton. 2008. The Northern Appalachian/Acadian Ecoregion: Priority Locations for Conservation Action. Two Countries, One Forest Special Report No. 1.

Whitman, A., A. Cutko, P. deMaynadier, S. Walker, B. Vickery, S. Stockwell, and R. Houston. 2013a. Climate Change and Biodiversity in Maine: Vulnerability of Habitats and Priority Species. Manomet Center for Conservation Sciences (in collaboration with Maine Beginning with Habitat Climate Change Working Group) Report SEI-2013-03. Brunswick, Maine. 96 pp.

Whitman, A., B. Vickery, P. deMaynadier, S. Stockwell, S. Walker, A. Cutko, and R. Houston. 2013b. Climate Change and Biodiversity in Maine: A Climate Change Exposure Summary for Species and Key Habitats (Revised). Manomet Center for Conservation Sciences (in collaboration with Maine Beginning with Habitat Climate Change Adaptation Working Group) Report NCI-2013-01. Brunswick, Maine. 29 pp.

Whitman, A. and J.M. Hagan. 2007. An Index to Identify Late-successional Forest in Temperate and Boreal Zones. Forest Ecology and Management 246:144–154.