Northeastern High-Elevation Areas: Ecological Values and Conservation Priorities

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Abstract - High-elevation habitats are a limited yet critical component of the northeastern landscape that provide important habitat and climate change adaptation values. This study examines the extent, conservation status, condition, and ecological values of high-elevation areas (defined as greater than 823 m [2700 ft] in elevation) in New England and New York. We identified a total of 765 distinct areas at least 4 ha (10 ac) in size. We assessed these areas for their level of conservation, the extent of development and recent timber harvesting, and 14 ecological values. We developed a quantitative scoring system that allowed us to rank areas for their conservation value and identify the most significant unconserved areas. While 86% of high-elevation land across the region has some form of conservation protection, significant areas remain unconserved, particularly in the Western Mountains region of Maine. We discuss the importance of additional high-elevation conservation to regional climate-change adaptation and the potential for mountains to serve as climate change refugia.

Introduction

High-elevation habitats are a limited yet critical component of the northeastern landscape (defined in this paper as New England and New York). They are the most natural and least impacted parts of a region with a long history of human use (Anderson et al. 2006, 2016a), containing the largest expanses of roadless, unfragmented forest in the region (Publicover and Poppenwimer 2002). They contain a disproportionate amount of mature *Picea rubens* Sarg. (Red Spruce)–*Abies balsamea* (L.) Mill. (Balsam Fir) forest in the region, a habitat specifically identified in state and regional wildlife conservation plans that has been heavily harvested at lower elevations. Subalpine Balsam Fir forest provides the primary habitat for the endemic *Catharus bicknelli* (Ridgway) (Bicknell's Thrush), one of the nation's rarest and most range-restricted migratory songbirds (Hill and Lloyd 2017), as well as other species of conservation concern. Because of their topographic diversity and high level of ecological connectivity, they are critical areas allowing species to adapt to future climate change, and they may potentially serve as climate change refugia (sensu Morelli et al. 2016) for spruce–fir-dependent species as this habitat declines at lower elevations in a future with a warmer climate.

Mountain regions have been a focus for conservation since the late 19th century, with many of the large public land units in the Northeast established before World War I (Table 1). This interest in mountain conservation has continued to the present day, though the rationale for protecting these areas has evolved (see Discussion).

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However, while the overall level of conservation of these areas is very high relative to other parts of the landscape (Anderson et al. 2006), there remains a need for a comparative and geographically explicit analysis of the conservation status and priorities for mountain areas across this region.

Some areas have seen significant human impacts. Some of the region's most prominent mountains (including Washington, Whiteface, and Greylock) had major access roads and summit developments constructed in the years between the Civil War and World War II. In the latter half of the 20th century, downhill ski area development and timber harvesting were major impacts. In the last 15 years, several areas have been impacted by commercial wind-power development, and additional areas have been considered for development.

This project assesses the conservation status, current condition, and ecological values of the numerous distinct islands of high-elevation land across New England and New York in order to prioritize the conservation of remaining unprotected areas and to inform future management and possible development decisions. While high-elevation areas also provide important scenic and recreational values, these factors were not considered in this study.

Table 1. Timeline of northeastern mountain conservation. Areas are primarily public ownership unless otherwise noted. Year refers to date of establishment or first acquisition, though conservation acquisitions within these areas may extend for many years after this date.

Year	State	Area
1885	NY	Catskill State Park
1892	NY	Adirondack State Park
1898	MA	Mount Greylock State Reservation
1911	VT	Camel's Hump State Park
1914	VT	Mount Mansfield State Forest
1915	NH	Monadnock Reservation (SPNHF)
1918	NH/ME	White Mountain National Forest
1931	ME	Baxter State Park
1932	VT	Green Mountain National Forest
1939	NH	Cardigan Mountain State Forest
1968	MA/VT/NH/ME	Appalachian National Scenic Trail
1976	ME	Bigelow Preserve
1977	ME	Mahoosucs Public Reserved Land unit
1986	VT	Long Trail State Forest
1988	NH	Nash Stream State Forest
1999	VT	Jay State Forest
2001	NH	Bunnell Preserve (TNC)
2002	ME	Mount Abraham
2002	ME	Tumbledown Mountain
2009	ME	Number 5/Number 6 Mountain (TNC)
2013	ME	Crocker Mountain
2015	ME	Baker Mountain (AMC)
2020	ME	Merrill Strip (Caribou Mountain) (TNC)

Defining "high-elevation areas"

High-elevation or "montane" forest ecosystems are upper-elevation areas dominated by spruce and fir where growth of northern hardwoods is restricted due to poor soils, low temperatures, short growing seasons, frequent immersion in clouds and fog, and damage from wind, snow, and ice. At higher elevations, spruce–fir forest transitions to subalpine Balsam Fir forest and to krummholz and alpine vegetation on the highest summits (Edinger et al. 2014, Gawlor and Cutko 2018, Sperduto and Nichols 2012, Thompson et al. 2019).

Both general accounts and detailed studies of montane forests describe the lower ecotonal boundary between spruce–fir and northern hardwood or mixed forest as occurring at 762–823 m (2500–2700 ft) in elevation (Anderson et al. 2012, 2016a; Cogbill and White 1991; Foster and D'Amato 2015; Griffith et al. 2009; Sperduto and Nichols 2012; Thompson et al. 2019; Wason et al. 2017a), though a source for New York reports the boundary at 915 m (3000 ft; Edinger et al. 2014). The zoning ordinances for the unincorporated territories of Maine and northern New Hampshire use 823 m (2700 ft) elevation to define the Protection-Mountain Area zoning subdistrict, while Vermont's Act 250 provides for additional development considerations above 762 m (2500 ft) elevation.

However, this ecotone is highly variable both locally and regionally in response to climate as well as topography, soils, and harvesting history. Within New Hampshire's Presidential Range, the lower boundary of the High-Elevation Spruce–Fir Forest natural community occurrence (as delineated by the NH Natural Heritage Bureau) averages 820 m (2690 ft) in elevation but varies from 490 to 1160 m (1600 to 3800 ft). Wason et al. (2017a) found the elevation of the mean ecotonal boundary of 11 mountain sites from the Adirondacks to Bigelow Mountain varied from 621 to 896 m (2040 to 2940 ft). The lower boundary of potential Bicknell's Thrush habitat (based on data from Lambert et al. 2005) varied from below 732 m (2400 ft) on Mount Katahdin to over 945 m (3100 ft) in southern Vermont and nearly 1037 m (3400 ft) in the Catskills; these figures for the southern part of the region are consistent with the elevations of lower montane ecotone reported by Cogbill and White (1991).

For this study, an elevation of 823 m (2700 ft) was used to define high-elevation areas, which is reasonably accurate for much of the area, though it likely slightly underestimates the extent of high-elevation ecosystems in the north and overestimates it in the south.

Habitat value of high-elevation areas

High-elevation coniferous forest is recognized as a distinct habitat (either directly or as a component of a broader habitat classification) in all state wildlife action plans in the region (MassWildlife 2015, MDIFW 2015, NHFGD 2015a, NYDEC 2015, VFWD 2015). Mountaintop forest is also recognized as a priority habitat in Partners in Flight Bird Conservation Plans for physiographic regions 24 (Alleghany Plateau; Robertson and Rosenberg 2003), 26 (Adirondack Mountains; Rosenberg 2000), 27 (Northern New England; Hodgman and Rosenberg 2000), and

28 (Eastern Spruce–Hardwood Forest; Rosenberg and Hodgman 2003), as well as the bird conservation blueprint for the Atlantic Coast Joint Venture region 14 (Atlantic Northern Forest; Dettmers 2003).

In all of these plans, the primary species of concern in montane habitat is Bicknell's Thrush (except for Massachusetts where it is considered extirpated). Other species listed in 1 or more of these plans are *Setophaga striata* (Forster) (Blackpoll Warbler), *Haemorhous purpureus* (Gmelin) (Purple Finch), *Falco peregrinus* (Tunstall) (Peregrine Falcon), *Aquila chrysaetos* L. (Golden Eagle), *Anthus rubescens* (Tunstall) (American Pipit), *Falcipennis canadensis* L. (Spruce Grouse), *Picoides dorsalis* (Baird) (Three-toed Woodpecker), *Perisoreus canadensis* L. (Canada Jay), *Martes americana* (Turton) (American Marten), *Microtus chrotorrhinus* (Miller) (Rock Vole), and *Synaptomys borealis* (Richardson) (Northern Bog Lemming). Only species that are specifically listed as priorities for high-elevation habitat, or which are strongly associated with or dependent on it, are included. Other species of concern that may utilize this habitat but occur in a range of other habitats are not included.

Mountains and climate change

Mean annual temperatures across New England and New York have increased 1.3 °C (2.4 °F) since 1900 (Janowiak et al. 2018), with the greatest increases occurring during the winter. Temperatures will rise further due to the continuing increase in atmospheric greenhouse gases and the lag from past emissions (Dupigney-Giroux et al. 2018). Associated changes in the region's climate include reduced snowfall and snowpack duration, longer growing seasons, and an increase in intense precipitation events (Janowiak et al. 2018). These changes are expected to alter the competitive balance of forest species, favoring those of more southern affinity and disadvantaging more northerly species that are at the warmer end of their range in this region.

Acadian and montane spruce–fir forests are considered particularly vulnerable to climate change, with the extent of suitable conditions to support this habitat expected to decline significantly over the next century (Fernandez et al. 2020, Frumhoff et al. 2007, Jacobson et al. 2009, Janowiak et al. 2018, Rustad et al. 2012, Swanston et al. 2018). Models of the projected late-21st century distribution of suitable climatic conditions for spruce and fir (Prasad et al. 2014, Tang and Beckage 2010) show these species becoming increasingly limited to the mountainous regions from the Adirondacks to western Maine. However, these models do not have sufficient spatial resolution to account for the localized climate regimes of the region's mountains. There are also many factors beyond mean temperature (such as soils, precipitation patterns, and natural and human disturbance) that govern the adjustment of vegetation to a changing climate that are not accounted for in these models.

While there is clear evidence of warming at the global and regional scales, studies specific to the region's mountains are more limited due to the small number of long-term data records. Wason et al. (2017b) document an upslope movement of temperature envelopes on Whiteface Mountain (NY) of 220 m (720 ft) since the

1960s. Wason et al. (2017a) estimate upward shifts of 377 m and 133 m (1240 and 440 ft) in mean average minimum and maximum temperatures, respectively, since 1960 on mountains from the Adirondacks to western Maine, with little difference in warming between higher and lower elevations.

These results are contradicted by those of Seidel et al. (2009), who found warming at Pinkham Notch, NH (elevation of 610 m [2000 ft]) from the 1930s to 2003 to be less than at lower elevations, and warming on the summit of Mount Washington (elevation of 1917 m [6288 ft]) to be even slower and statistically non-significant. In addition, Kimball et al. (2014) found the modeled advancement in the flowering of 3 alpine species on Mount Washington between 1935 and 2011 to be small (1–2 days) though statistically significant. These differences may be due to the differing analysis periods. The studies of Wason et al. (2017a, b) begin near the start of faster climate warming beginning around 1970, whereas the Seidel et al. (2009) and Kimball et al. (2014) studies begin near the start of a period of more stable climate from the 1940s through the 1960s but lack the most recent warming. An updated analysis of data from Mount Washington through 2018 indicates that warming on the summit has increased since 2003 (Murray et al. 2021).

Conventional wisdom holds that montane vegetation will respond to climate warming with species' ranges rising in elevation and high-elevation communities disappearing. There is strong evidence that range shifts in response to climate change have occurred in a variety of plant and animal taxa across the globe (Chen et al. 2011 summarized in Anderson et al. 2016a). However, studies of shifts in northeastern montane vegetation over recent decades present an inconclusive picture. Some have shown upward shifts of vegetation consistent with climate change (Beckage et al. 2008, Capers and Stone 2011), while others have shown downward shifts (Foster and d'Amato 2015, Vogelmann et al. 2012), no change (Wason et al. 2017b), or mixed results for different species and even different age classes within the same species (Wason and Dovciak 2017). These studies vary in their methodology. Some are based on repeated measurement of permanent plots, while others use a time series of remotely sensed imagery. Some examined the movement of individual species, while others looked at the more general hardwood–softwood ecotone.

Analysis of trends is complicated by the impacts and recovery from past timber harvesting or acid deposition (Foster and d'Amato 2015, Wason et al. 2019) as well as variable seasonal patterns of temperature changes (Wason et al. 2017a). In addition, climate change is more complex than just increasing temperatures. In our region, while the lower montane ecotone may be strongly related to temperature (Wason et al. 2017a), upper montane (alpine and subalpine) vegetation is strongly influenced by disturbance (wind, snow, and ice) and exposure to severe weather (Kimball and Weihrauch 2000, Seidel et al. 2009). Changes in these factors (such as a shift in precipitation from snow to ice) may drive vegetation shifts but be poorly correlated with temperature increases.

Paleoecological evidence indicates that upper montane vegetation in the Northeast may be more resistant to a changing climate than lower-elevation vegetation.

In a study of post-glacial vegetation changes in the White Mountains, Spear (1989:148–149) found that during the post-glacial Hypsithermal warming period (5000 to 9000 YBP) subalpine forests showed little change during a time when low-elevation spruce–fir forest was greatly reduced, and stated:

> "The ecotones between the subalpine spruce–fir and fir forest, and the fir forest and alpine meadow, have not changed altitude much over the last 10,000 years and do not appear to be sensitive to climate change … In contrast to the continual changes in the vast lowland forests surrounding the White Mountain peaks, the high elevations have been remarkably stable. Changes in the lowland forest have had virtually no impact on the subalpine fir forest and alpine meadow."

However, in a later study, Miller and Spear (1999) found evidence for an upward movement of treeline into the Presidential Range alpine zone and a possible decline in alpine species richness during the warmer mid-Holocene.

Due to the lack of similar studies from other high-elevation areas, it is unclear whether these results are broadly applicable or are limited to the specific climatic conditions of the White Mountains. They are consistent with the results of Seidel et al. (2009) and Kimball et al. (2014), who found that changes in high-elevation temperatures and alpine plant phenology, while significant, were smaller than those observed at lower elevations. These studies suggest that upper montane vegetation may be to some degree uncoupled from and more resistant to the changes in regional temperature than lower-elevation vegetation (including the lower montane zone). This uncoupling may be related to the height of the planetary boundary layer which can often be below the alpine and subalpine zones, resulting in greater exposure to high winds and icing, particularly in winter (Kimball et al. 2021). Whether this resistance will continue in the future is unclear, as global average temperatures already exceed those of any time during the post-glacial period (Marcott et al. 2013) and will continue to rise, with unknown effect on the high-elevation weather conditions that may promote this resistance.

Methods

Detailed information on data sources and quantification procedures is provided in Supplemental File 1 (available online at http://www.eaglehill.us/ NENAonline/suppl-files/n28-sp11-N1872h-Publicover-s1, or for BioOne subscribers, at https:dx.doi.org/10.1656/N1872h.s1).

Data developed for each area

Delineation of study units. We identified areas above 823 m (2700 ft) in elevation across Maine, New Hampshire, Vermont, Massachusetts, and New York from USGS 30-m Digital Elevation Model data. We used the ArcView Spatial Analysis 'Create Contours' function to develop smoothed 823-m (2700-ft) contours, which were then converted to closed polygons. We retained only areas at least 4.05 ha (10 ac) in size. Comparison of selected areas with USGS contour-line data showed a very close correspondence.

Conservation status. We used publicly available data on conservation lands for each state to determine the proportion of each area conserved through public ownership, non-profit ownership, and conservation easement.

Current condition. We assessed the current condition of each area for 2 types of impact. (1) Development – existing development in each area was delineated on 2009 National Agricultural Imagery Program (NAIP) digital imagery and updated by examining the most recent Google Earth imagery. We used a variety of sources to identify the nature of the development. Logging roads and low-impact recreational facilities such as open-faced shelters were not considered. (2) Timber harvesting – we delineated timber harvests within high-elevation areas from Google Earth historical imagery, which in most areas are available back to the early to mid-1990s. We recorded the type of harvest (clearcut or partial) and the approximate date of the harvest .

Ecological values. We assessed 14 ecological values for each high-elevation area (Table 2). While most of these data sources are available and consistent across the entire study region, there were some exceptions. Inventory data from Natural Heritage programs on element occurrences (rare plants and natural communities) are incomplete, as surveys have not been undertaken in all areas. Habitat priority areas are based on data from individual states that was developed in different ways

Table 2. Ecological values assessed for each high-elevation area. AMC = the Appalachian Mountain Club. TNC = The Nature Conservancy.

Ecological value	Data source
Size	GIS-calculated
Elevation range	USGS Geographic Names Information System and other sources
Spruce-fir forest	2016 National Land Cover data
Documented rare plant occurrences	State Natural Heritage programs
Documented rare and exemplary natural community occurrences	State Natural Heritage programs
Subalpine forest	State Natural Heritage programs (documented); AMC delineation (potential)
Alpine areas	State Natural Heritage programs and AMC
Modeled Bicknell's thrush population	Vermont Center for Ecostudies data (Hill and Lloyd 2017)
Large roadless areas	AMC; updated from Publicover and Poppenwimer (2002)
Wildlife habitat priority areas	State Wildlife Action Plan data
Priority conservation target ecosystems	TNC (Anderson et al. 2006)
Underrepresented geological settings	TNC Ecological Land Unit data (Anderson et al. 2006, Barbour et al. 2001, Zaremba et al. 2003)
Estimated climate change resilience	TNC (Anderson et al. 2016a)
Average carbon stocking	2012 Northeast Forest Biomass dataset (Grand and McGarigal 2014)

and which represent similar but not identical habitat values, and data on habitat priority areas was not available for New York. The Nature Conservancy's Northern Appalachian/Boreal Ecoregional Assessment (the source for priority conservation target ecosystems) does not encompass the Catskills and some areas in southern Vermont, southern New Hampshire, and Massachusetts. The ecoregional assessments covering these areas did not identify similar target ecosystems.

Composite value assessment

We combined data on the condition and ecological values of each area into a single quantitative value, which allows areas to be ranked on a scale that reflects their relative conservation value. This type of multi-resource co-occurrence approach has been used (though sometimes more qualitatively) in a variety of resource evaluations (e.g., LURC 1987, MDOC 1982, Publicover et al. 2011). It is important to recognize that while the assessment produces a single numerical score for each high-elevation area, there is subjective judgement involved in determining how the individual resource values will be quantified and weighted. For example, how does one value greater size of an area against the presence of a rare natural community?

We developed the composite value scores as follows (see Supplemental File 1 for additional detail):

(1) The 2 condition and 14 ecological parameters were individually quantified and normalized to values from 0 to 1.
(2) Scores for the individual parameters were weighted and summed for each area.
(3) An adjustment to the total score was made to account for the fact that some parameters are not available for all areas. Scores for each area were adjusted based on ratio of the maximum possible score that the area could receive to the maximum possible score without the missing parameters, thus adjusting the scores for areas with missing data upwards. The primary data gap is for wildlife habitat priorities in New York. This resource received a moderate to high weight in the scoring, and the method chosen to account for this lack of data may have resulted in areas in New York being somewhat undervalued in the overall ranking.
(4) In order to test the sensitivity of the results to different weightings, we assessed and compared 4 different weighting schemes: no weighting and 3 schemes that emphasized different categories of parameters—condition, biodiversity values, and climate resilience values. Scores for each weighting were converted to z-scores, which show how many standard deviations the score for an individual area lies from the mean for all areas.
(5) The final composite score was calculated as the average of the z-scores from the 4 weighting schemes to provide a more balanced approach that did not overemphasize one particular set of parameters.

Results

More detailed results are presented in Supplemental File 1.

Extent of high-elevation area

A total of 765 distinct areas at least 4 ha (10 ac) in size were delineated across the 5 states (with a few areas astride the border extending into Canada, for which the entire area was included), encompassing in total over 314,000 ha (776,000 ac) (Fig. 1, Table 3). These areas represents about 1.2% of the total land area of these

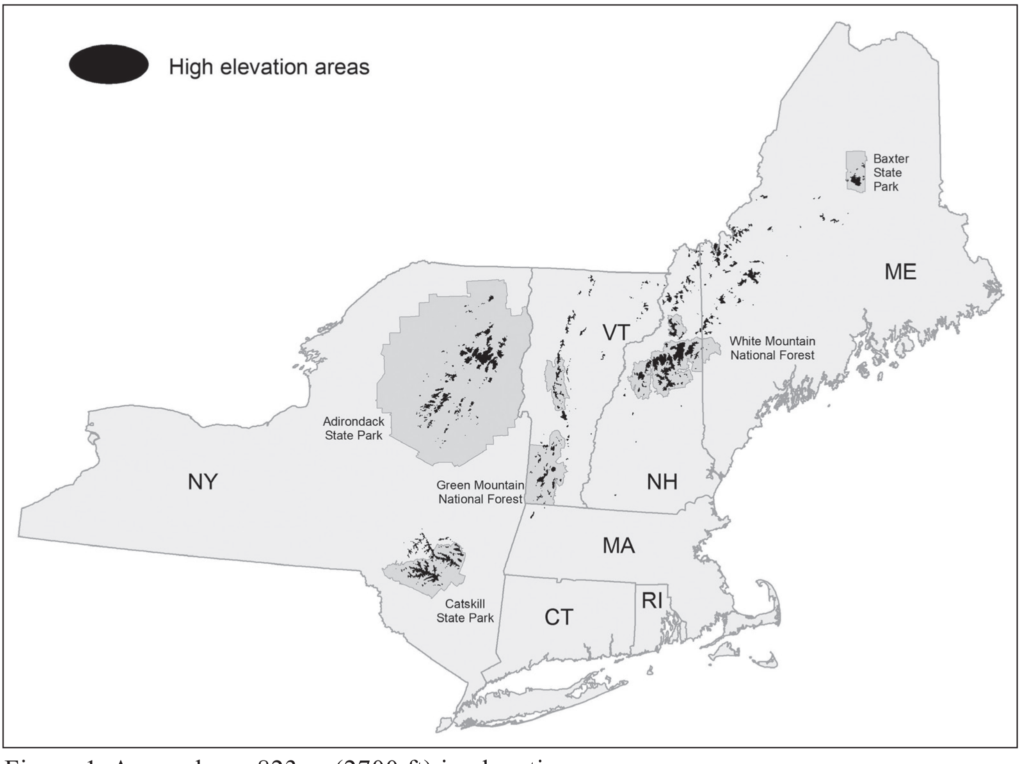

Figure 1. Areas above 823 m (2700 ft) in elevation.

Table 3. Extent of northeastern high-elevation area.

	Hectares	% of total	% of state
Maine	56,282	17.9%	0.7%
New Hampshire	92,505	29.4%	4.0%
Vermont	39,664	12.6%	1.7%
Massachusetts	758	0.2%	0.0%
New York	120,665	38.4%	1.0%
US total	309,874	98.6%	1.2%
Canada*	4389	1.4%	
Total	314,263	100.0%	

*Extension of areas lying along the Canadian border with Maine and New Hampshire.

states. New York has the greatest extent of high-elevation land (38% of the total across the region), while New Hampshire has the greatest proportion of the state in high-elevation land (4%).

Size and elevation

There are numerous small areas (which in many cases will be ecologically indistinguishable from the upper slope forest below 823 m [2700 ft]) and a much smaller number of large areas (which possess more of the defining characteristics of high-elevation ecosystems) (Table 4). The 39 areas >2023 ha (5000 ac) in size encompass over 60% of the total high-elevation land. These large areas are well-distributed across the region, with 12 in the Adirondacks, 10 in New Hampshire, 8 in Maine, 5 in the Catskills, and 4 in Vermont.

The distribution of maximum elevations shows a similar pattern to size, with a large number of small areas reaching lower elevations and a small number of larger higher-elevation areas. Over 60% of the individual areas do not extend above 915 m (3000 ft). Ninety-three areas exceed 1067 m (3500 ft) in elevation and in total encompass nearly 80% of the total high-elevation area, while the 27 areas that exceed 1220 m (4000 ft) in elevation encompass about 45% of total high-elevation land.

Conservation status

Across the region, 86% of land above 823 m (2700 ft) has some form of conservation protection, with over three-quarters in public ownership and smaller amounts conserved through non-profit ownership or conservation easement (Table 5). Maine is the outlier with only 59% of its high-elevation land area conserved; it has by far the lowest proportion of high-elevation land in public ownership (36%) but the highest proportion protected by conservation easement (17%). The greatest expanses of unconserved high-elevation land are across the Western Mountains region of Maine extending into northern New Hampshire, as well as the northwestern part of the Catskills outside of the Catskill State Park.

The largest areas

The 14 areas over 4047 ha (10,000 ac) in size, which in total encompass over 40% of the region's high-elevation land, include many of the region's most iconic mountain ranges (Table 6.) Because these areas have been a focus of early

Table 4. Distribution of high-elevation areas by size class.

Size (ha) (ac)	Number of areas	% of number	Total area (ha)	% of total area
4–40 (10–100)	385	50.3%	5,668	1.8%
>40–202 (>100–500)	202	26.4%	20,559	6.5%
>202–405 (>500–1000)	50	6.5%	14,106	4.5%
>405–1011 (>1000–2500)	55	7.2%	34,451	11.0%
>1011–2023 (>2500–5000)	34	4.4%	43,978	14.0%
>2023–4047 (>5000–10,000)	25	3.3%	66,844	21.3%
>4047 (>10,000)	14	1.8%	128,657	40.9%
Total	765		314,263	

conservation efforts dating back to the 19th century, they have a very high level of conservation protection. The exception is the Sugarloaf/Abraham/Crocker area (the largest in Maine), which is only 65% conserved (this figure does not include the US Navy's SERE wilderness training facility, which encompasses an additional 9% of the area). This area has been a focus for conservation over the last 2 decades; in 2002 it was only 8% conserved, but 5 projects involving the state and private land trusts have been completed since that time.

Areas between 2023 and 4047 ha (5000 and 10,000 ac) also have a high level of conservation. Of the 25 areas of this size, 18 are at least 90% conserved and 23 are at least half conserved. The 2 exceptions are in Maine: Caribou Mountain along the Canadian border (44% of the US portion conserved) and Bemis/Elephant/Old Blue along the Appalachian Trail (18%). Prior to The Nature Conservancy's purchase of 44% of the Caribou Mountain area (lying within

Table 5. Proportion of high-elevation land conserved by category.

	Fee ownership						
State	Federal	State/ municipal	Total public	NGO	Total fee	Easement	Total
Maine	5%	31%	36%	7%	43%	17%	59%
Massachussets	0%	98%	98%	0%	98%	0%	98%
New Hampshire	80%	6%	86%	4%	90%	5%	95%
New York (overall)	0%	86%	86%	1%	87%	4%	92%
Adirondacks	0%	92%	92%	1%	93%	5%	99%
Catskills	0%	77%	77%	0%	77%	1%	78%
Vermont	51%	28%	79%	2%	81%	6%	86%
Total	31%	45%	76%	3%	79%	7%	86%

Table 6. High-elevation areas >4047 ha (10,000 ac) in size.

Name of area	State	Size (ha)	Maximum elevation (m)	% conserved
Adirondack High Peaks	NY	20,404	1629	100%
Presidential Range	NH	17,531	1917	100%
Franconia Range/Pemigewasset North	NH	13,093	1598	100%
Pemigewasset South/Sandwich Range	NH	10,363	1427	100%
Graham/Doubletop Mountains	NY	9512	1179	82%
Sugarloaf/Abraham/Crocker	ME	8418	1292	65%
Carter Range	NH	7035	1473	100%
Mount Katahdin	ME	7003	1606	100%
Kilkenny Range	NH	6533	1271	98%
White Cap/Kennebago Divide*	ME/CAN	6436	1163	83%
Slide Mountain	NY	6260	1274	99%
Dix Mountain	NY	5580	1470	100%
Pemigewasset East	NH	5434	1317	99%
Glastenbury Mountain	VT	5065	1143	99%

*3434 ha in the United States; proportion conserved is for US area only.

Merrill Strip township), this was the largest high-elevation area in the Northeast with no conservation protection.

Development

Notwithstanding that high-elevation areas are generally the most natural parts of the northeastern landscape, some areas have seen a relatively high level of human impact, including some of the region's highest and most significant mountains. Seventy-five areas (nearly 10% of the total) have some type of development that could be discerned on the NAIP imagery, including large public facilities (such as on Mount Washington) as well as lookout and communications towers and recreational huts with limited footprints. Notable development features include:

(a) Five areas with summit access roads and public visitor centers (Mount Washington, Mount Mansfield, Equinox Mountain, Mount Greylock, and Whiteface Mountain).
(b) One state highway: the Kancamagus Highway across the Pemigewasset South-Sandwich Range area.
(c) Thirty-four areas with downhill ski areas, though not all are still operating. Together these areas encompass >3640 ha (9000 ac) of high-elevation land (more than 1% of the total).
(d) Eight areas with commercial wind power development encompassing 4 active facilities (Kibby, Granite Reliable, Searsburg, and Deerfield) and 1 with an abandoned earlier project (Little Equinox Mountain). Five other areas have meteorological test towers and may be under investigation for wind power development. One (Sisk Mountain within the Caribou Mountain area) is the site of a permitted but never constructed project.

Timber harvesting

In many areas, timber harvesting above 832 m (2700 ft) is limited by difficult topography, low timber value, and the high level of conservation ownership. Across the region, >11,800 ha (29,200 ac) of high-elevation land (3.8% of the total) showed evidence of harvesting over the last 40+ years. About 14% of private land across the region, but less than 1% of public and non-profit ownership, showed evidence of harvesting. This data overstates the actual extent of harvesting on conservation ownerships, as most of this harvesting took place prior to the land being acquired for conservation. The actual amount of high-elevation harvesting detected on land that was in public or NGO ownership was negligible. Nearly three-quarters of the harvested acreage was located on private land in western Maine and northern New Hampshire, which is the domain of large commercial timber companies. Nearly 20% of the total harvested acreage was in just one area (Sugarloaf/Abraham Crocker). About one-quarter of the harvested acreage was clearcut, though this proportion increased to nearly 40% after 2000.

Ecological resources

The distribution of ecological resources shows 2 general patterns. Five resources (spruce–fir forest, modeled Bicknell's Thrush population, large roadless areas, wildlife habitat priorities, and high climate-change resilience) are present in over half of the 765 areas. With a few exceptions, areas over 2023 ha (5000 ac) score highly for all of these resources, and they may be considered broadly characteristic of the most valuable high-elevation areas. However, only the modeled Bicknell's Thrush population is strongly related to the size of an area; the others are present throughout areas of all sizes. The percent in spruce–fir forest shows a strong relationship to latitude (see "additional results" in Supplemental File 1), while for the other resources the landscape context (such as the proximity of small- and mid-sized areas to larger, high-value areas) is likely an important factor.

Spatially restricted resources identifying or associated with specific biodiversity elements (rare plant and natural community occurrences, subalpine forest, alpine areas, priority summit ecosystems, and underrepresented geological settings) are present in less than 20% of high-elevation areas. These resources provide valuable additional information for identifying the more ecologically significant high-elevation areas.

Composite value assessment

Distribution of composite scores. The distribution of composite value scores shows the following pattern (Fig. 2):

(a) A few areas with very low average z-scores (less than -1.5). These are smaller areas with few resource values and high levels of development or harvesting. The lowest-scoring area is Mine Hill, a 8.9-ha (22-ac) area on the northern edge of the Catskills with no identified resource values and which has extensive disturbance from mineral extraction.

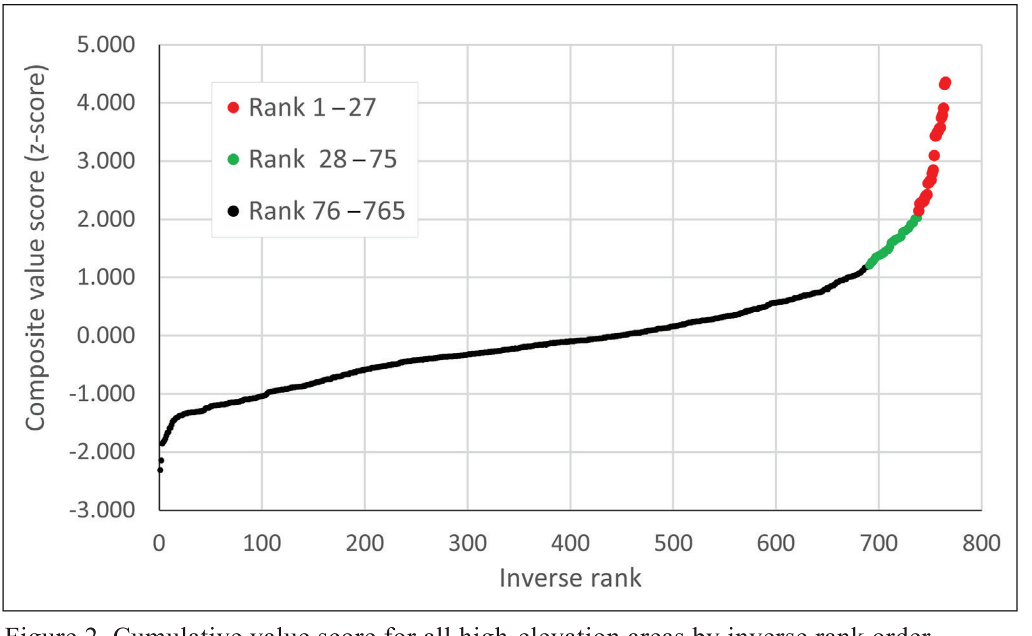

Figure 2. Cumulative value score for all high-elevation areas by inverse rank order.

(b) A large number of areas with moderate scores (-1.5 to 1.2). These areas contain some resource values, but their actual rank is fairly sensitive to how the resources are weighted. In evaluating these areas, their geographical context and the specific resources contained within them are more important than the specific rank.

(c) Seventy-five areas with scores >1.2, which reflects the inflection point toward increasingly higher scores in Figure 2. These locations are the high-elevation "gems" of the region that contain many resource values and which will rank highly no matter how these resources are weighted. Of these, 27 areas consistently rank at the top in all weighting schemes (26 score in the top 27 in at least 3 of the 4 weighting schemes). Below this rank, none do.

Sensitivity analysis. We calculated pairwise correlation coefficients (r^2) for the z-scores from the 5 different scoring schemes (4 different weightings plus the average). Of the 10 pairwise comparisons, 6 had correlation coefficients of >0.90, while 3 had coefficients of 0.80–0.90 and 1 (condition versus biodiversity values) had a coefficient of 0.69. All 3 weighting schemes were strongly correlated with the average (r^2 >0.88), indicating that the scores are relatively insensitive to how they are weighted.

However, below the top tier of the 75 highest-ranking areas, the sensitivity to the different weightings increases significantly, with many areas with very similar scores. Small differences in scoring and weighting can result in larger changes in ranking. These areas contain a smaller number of resource values, and how they rank will be much more dependent on how those particular resources are quantified and weighted.

The 27 highest scoring areas. The 27 highest-scoring areas include most of the iconic mountain areas in the region (Table 7). They are well-distributed, with 9 in New Hampshire, 8 in Maine (one of which extends into New Hampshire), 6

Table 7. The 27 highest value high-elevation areas in the Northeast.

Name	Score	Name	Score
1. Adirondack High Peaks	4.355	15. Saddleback Mountain	2.673
2, Mount Katahdin	4.313	16. Old Speck Mountain	2.666
3. Presidential Range	3.909	17. Baldpate Mountain	2.635
4. Mahoosuc Range	3.792	18. Kinsman Range	2.617
5. Franconia R./Pemigewasset No.	3.744	19. Baldface Mountain	2.422
6. Sugarloaf/Abraham/Crocker	3.578	20. Mount Mansfield	2.406
7. Carter Range	3.561	21. Santanoni Peak	2.374
8. Bigelow Mountain	3.520	22. Bolton Mountain	2.317
9. Mount Moosilauke	3.493	23. Mount Ellen	2.297
10. Dix Mountain	3.437	24. Bread Loaf Mountain	2.296
11. Camel's Hump	3.428	25. Sunday River Whitecap	2.281
12. Pemigewasset East	3.093	26. Glastenbury Mountain	2.267
13. Pemigewasset So./Sandwich R.	2.845	27. Slide Mountain	2.145
14. Kilkenny Range	2.787		

in Vermont, 3 in the Adirondacks, and 1 in the Catskills. For the most part, these important high-elevation areas have been largely conserved, with 19 out of the 27 being at least 98% conserved and only 2 less than two-thirds conserved (Sugarloaf/Abraham/Crocker and Saddleback Mountain, both in the Western High Peaks region of Maine). In total, the 27 highest scoring areas encompass about 45% of all high-elevation land; the top 75 encompass 64%. The full list of the 75 highest scoring areas (including details on resource values) is provided in Supplemental File 1.

Highest scoring unconserved areas. There are 10 areas across the region that are at least 405 ha (1000 ac) in size, are less than 50% conserved and have above average scores (>0) (Table 8). Two of these (Boundary Bald and Equinox Mountain) fall just outside of the top 75. The greatest concentration of these areas is in the northern Boundary Mountains region of Maine (Fig. 3).

Discussion

Changing drivers of mountain conservation

The mountains of New England and New York have been a focus of public attention and conservation efforts for 2 centuries, though the reasons for their conservation have evolved over time (Lilieholm et al. 2013). The 19th century saw the construction of the first recreational trail (Crawford Path in 1819), the Mount Washington Auto Road (1861), and the Cog Railway (1868), all in New Hampshire's Presidential Range. After the Civil War, the region's mountains (particularly the Adirondacks and White Mountains) supported a burgeoning tourist industry, with "sports" from the cities arriving by train and grand hotels and lodges providing a base for exploration (Waterman and Waterman 1989). The industry was promoted by the work of landscape artists, whose paintings presented a romantic view of these spectacular areas. The Appalachian Mountain Club was established in 1876, followed by the Green Mountain Club and Randolph Mountain Club in 1910 and the Adirondack Mountain Club in 1922. These organizations constructed extensive trail networks across the region's mountains.

Table 8. The highest value unconserved high-elevation areas in the Northeast (score > 0, >405 ha [1000 ac], and <50% conserved).

Name	State	Size (ha)	Maximum elevation (m)	% conserved	Score
Boundary Bald	ME	1017	1104	0	1.193
Equinox Mountain	VT	618	1171	27	1.191
Bemis/Elephant/Old Blue	ME	2927	1151	18	0.935
Caribou Mountain	ME/CAN	3473	1110	44	0.864
Crystal Mtn/Blue Ridge	NH	1485	1000	31	0.654
Snow Mountain	ME	1016	1207	28	0.595
Rice Mountain	NH	504	1027	0	0.579
Boil Mountain	ME	489	1098	24	0.345
Tumbledown Mtn (north)	ME	849	1094	0	0.332
Shultice Mountain	NY	405	1000	34	0.086

In the late 19th and early 20th centuries, widespread heavy logging and subsequent large fires devastated mountain areas and watersheds across the region. Public concern over these impacts led to the early efforts to conserve these areas and

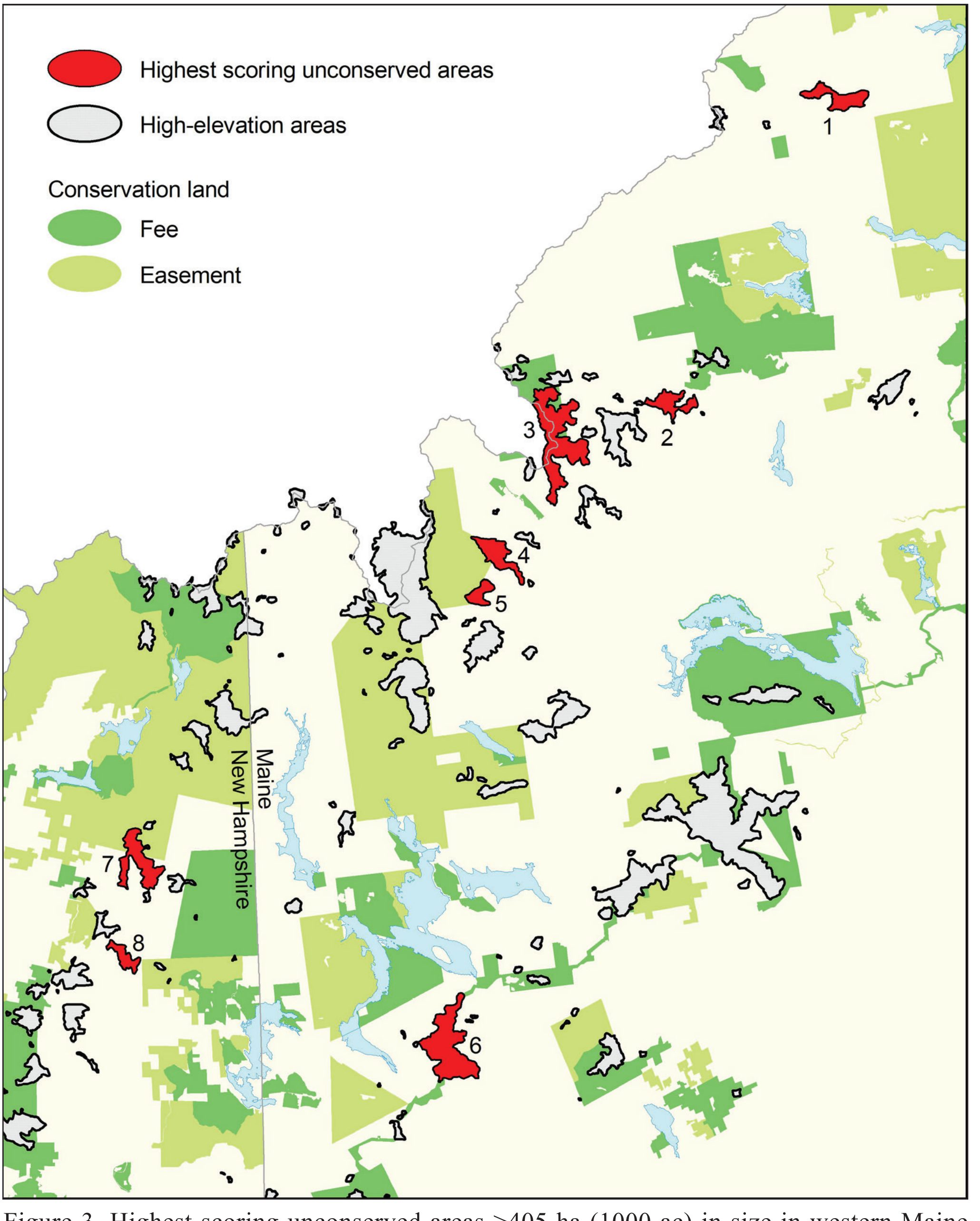

Figure 3. Highest scoring unconserved areas >405 ha (1000 ac) in size in western Maine and Northern New Hampshire. 1= Boundary Bald, 2 = Tumbledown Mountain, 3 = Caribou Mountain, 4 = Snow Mountain, 5 = Boil Mountain, 6 = Bemis/Elephant/Old Blue, 7 = Crystal Mountain/Blue Ridge, 8 = Rice Mountain. Equinox Mountain (VT) and Shultice Mountain (NY) are not shown.

resulted in the protection of the Adirondack and Catskill State Parks in the New York Constitution (1894), the federal Weeks Act authorizing the eastern National Forests (1911), and the establishment of the first large state forests and parks (APA 2021, WhiteMountainHistory.org 2021). While this concern was driven primarily by scenic and recreational concerns and a general sense of loss of wild nature, other factors were also considered important. For example:

(a) Adirondack Park Enabling Act (1892): The Park shall be "forever reserved, maintained and cared for as ground open for the free use of all the people for their health and pleasure, and as forest lands necessary to the preservation of the headwaters of the chief rivers of the State, and a future timber supply."
(b) Weeks Act (1911; P.L. 61-435, Ch. 186, 36 Stat. 961): The Secretary of Agriculture was authorized to recommend for purchase "such lands as in his judgment may be necessary to the regulation of the flow of navigable streams." Other benefits noted by Henry Graves, second chief of the Forest Service, include "continuance of a timber supply to meet the needs of the industries of the country" and "preservation of the beauty and attractiveness of the uplands for the recreation and pleasure of the people" (Graves 1911).
(c) Baxter State Park. In conveying lands to the state, Governor Baxter stated his wish that the Park "shall forever be retained and used for state forest, public park and recreational purposes … shall forever be kept and remain in the natural wild state … shall forever be kept and remain as a sanctuary for beasts and birds", while the Scientific Forest Management Area shall "become a show place for those interested in forestry, a place where a continuing timber crop can be cultivated, harvested and sold …" (BSP 2020)).

Conservation of large mountain areas during this period was enabled by the low economic value of these lands and their unsuitability for settlement, agriculture, and timber management once the most valuable trees were removed. In the years after World War II, most conservation continued to focus on these values. For example, the Act to Establish a Public Preserve in the Bigelow Mountain Area, approved by citizen's referendum in Maine in 1976, stated its purpose as "to set aside land to be retained in its natural state for the use and enjoyment of the public. The Preserve shall be managed for outdoor recreation such as hiking, fishing, and hunting, and for timber harvesting."

In the last quarter of the 20th century, concerns over the loss of biodiversity and the rise of the science of conservation biology put a greater emphasis on ecological values (beyond soil and water protection and wildlife habitat) in conservation efforts. Much of the focus shifted to the "representation" of the full range of biodiversity elements (species, communities, and ecosystems) on conservation lands (Anderson et al. 2006, Krohn et al. 1998, McMahon 1993). Conservation planning during this period emphasized the protection of underrepresented or higher-risk elements of biodiversity, which tended to be located in more fragmented lower-elevation landscapes. However, the value of mountains as the wild cores of networks of conserved lands, as well as their specific biodiversity values ,continued to be recognized. As stated by Anderson et al. (2006:15):

> "High elevations, cliffs, summits, ridge-tops, and ravines are the most extensively protected features in the region and are many times more common in protected lands than they are throughout the region. This indicates a strong bias in past conservation efforts towards scenic features that often occur on lands not suitable for other uses. Many of these settings, of course, have significant biodiversity components."

With the ever-increasing concern over climate change in the 21st century, the focus of conservation planning has shifted once again, with increasing emphasis on the concepts of "resilience" and "adaptation" (Anderson et al. 2016a, b). It is no longer sufficient to protect biodiversity in situ, though refugia where existing species may be maintained in a changing climate remain important (Morelli et al. 2016). However, conservation planning is taking a more strategic approach to the creation of diverse and well-connected natural landscapes that allow species to adapt to climate change and to shift their ranges (both locally and regionally) as conditions and habitats change (Anderson et al. 2014, OSI 2016). Conservation is increasingly focused on protecting areas that are most likely to support biodiversity into the future even as the species in any particular area change—an emerging concept known as "conserving the stage" (Anderson and Ferree 2010, Lawlor et al. 2015, TNC 2018). The most recent mountain conservation project in the region, The Nature Conservancy's acquisition of a portion of the Caribou Mountain high-elevation area in Maine, emphasized the importance of climate change resilience to this project (TNC 2020).

High-elevation conservation summary and priorities

The continued conservation value of mountain areas is indicated by their disproportionate representation as priorities in regional conservation assessments such as TNC's Resilient and Connected Landscapes analysis (Anderson et al. 2016a, 2016b) and state wildlife action plan habitat priorities. To some degree the value of areas is due to their existing level of conservation, which has maintained their unfragmented character and ecological integrity. However, this study has found that opportunities for additional conservation remain, both to protect site-specific values and as part of a broader connected conservation landscape.

New York – Adirondacks. High-elevation lands in the Adirondacks (all of which lie within the Adirondack State Park boundary) are almost totally conserved, with 90% protected as Wilderness or Wild Forest.

New York – Catskills. Within the Catskills region, 83% of high-elevation land lies within the Catskill State Park boundary. Of this, 87% is conserved, with 96% of the conserved land being Wilderness or Wild Forest. The most notable unconserved area is a 1457-ha (3600-ac) block encompassing the summits and north slope of Graham and Doubletop Mountains, which is part of a larger property that has been in family ownership since the 19th century. Outside of the park boundary, only about 36% of high-elevation land is conserved, primarily in smaller state forests and watershed-protection lands. Shultice Mountain, at the northern end of the Vly Mountain ridgeline, was identified as a potential conservation priority (Table 8).

Vermont. About 86% of high-elevation land in Vermont is conserved, with unconserved areas scattered throughout the state. One area (Equinox Mountain) was identified as a potential conservation priority. Two other areas have at least 405 ha (1000 ac) of unconserved high-elevation land: Mount Ellen (ranked #23 in this study) and Dorset Mountain (ranked #37).

New Hampshire. About 95% of the high-elevation land in New Hampshire is conserved, with 84% in the White Mountain National Forest. Two areas were identified as potential conservation priorities: Crystal Mountain/Blue Ridge and Rice Mountain north of Dixville Notch (Fig. 3). They provide habitat for both Bicknell's Thrush and American Marten (both Species of Special Concern in the state). They have been considered for wind power development, but the current lack of transmission capacity constrains development in this area. The current status of this effort is unknown.

Maine. Maine has the greatest opportunity and the greatest need for additional conservation of high-elevation land. Less than 60% of the state's high-elevation land is conserved, and only 36% is in public ownership. The highest priority remains the on-going efforts in the Western High Peaks region (Sugarloaf/Abraham/Crocker and Saddleback Mountain areas). Considerable progress has been made in conserving these areas over the last 2 decades, but they still have the lowest level of conservation of any of the top-ranked areas (Table 7) and contain the only unconserved 1220-m (4000-ft) summit in the northeast (Redington Mountain).

The state includes 6 of the 10 potential conservation priorities that are greater than 405 ha (1000 ac) in size and less than 50% conserved (Table 8, Fig. 3). One of these (Bemis/Elephant/Old Blue) lies astride the Appalachian Trail corridor between the Mahoosucs and Saddleback, with the remainder in the Boundary Mountains. The Boundary Mountains have been the forgotten range in the region's long history of mountain conservation. In comparison to the more well-known ranges, they have long been less accessible, lack dramatic relief and open summits, and contain few hiking trails. They are the domain of large commercial paper and timber companies, and their gentler topography has led to higher levels of timber harvesting in recent decades than other areas. Prior to the Pingree Family easement in 2001, no high-elevation land in this region was conserved. Currently 2 working-forest easements and 3 Nature Conservancy projects encompass about 40% of the high-elevation land in this range, though there remains no public ownership.

The northern part of the Boundary Mountains contains the highest-scoring areas in the range, and represents the greatest expanse of unconserved high-elevation land in the northeast. The cluster of high-elevation areas in this region is characterized by forested summits between 915 and 1098 m (3000 and 3600 ft) in elevation (Snow Mountain being the highest at 1207 m [3960 ft]) with extensive spruce–fir and subalpine forest and a high potential to support Bicknell's Thrush, American Marten, and other species dependent on mature spruce–fir or subalpine forest. This part of the range has also seen less timber harvesting in recent decades than areas to the southwest. Kibby Mountain should also be considered as part of this cluster. Though scoring below average because of the presence of the Kibby Mountain wind power project, the northern two-thirds of the area encompassing about 1050 ha (2600 ac) is relatively intact and would clearly make the priorities list if considered separately.

Mountains as climate change refugia

A better understanding of how montane vegetation will respond to climate change can help inform the question of whether high-elevation areas can serve as climate change refugia for spruce–fir-dependent species, as this habitat is predicted to decline significantly in a future warmer climate (Janowiak et al. 2018, Rustad et al. 2012). This can in turn guide decisions about conservation and management priorities for these areas.

Mountains are warming along with the rest of the globe, though understanding patterns of mountain warming and the response of species to it is complicated by the complex topography, the lag between warming and species range shifts, and factors other than temperature such as soils, land-use history, and disturbance regimes. However, in the eastern United States there is a strong relationship between temperature and the lower montane forest ecotone, both latitudinally across the Appalachian range (Cogbill and White 1991) and elevationally at a more local scale (Wason et al. 2017a).

The Green Mountains provide an indirect illustration of this relationship. Data from this study show a clear relationship between the latitude of high-elevation areas greater than 40 ha (100 ac) in size and the proportion of spruce–fir forest within them (Fig. 4). This latitudinal variation may serve as a proxy for the changes that might be expected in the future as this ecotone adjusts to the warming climate.

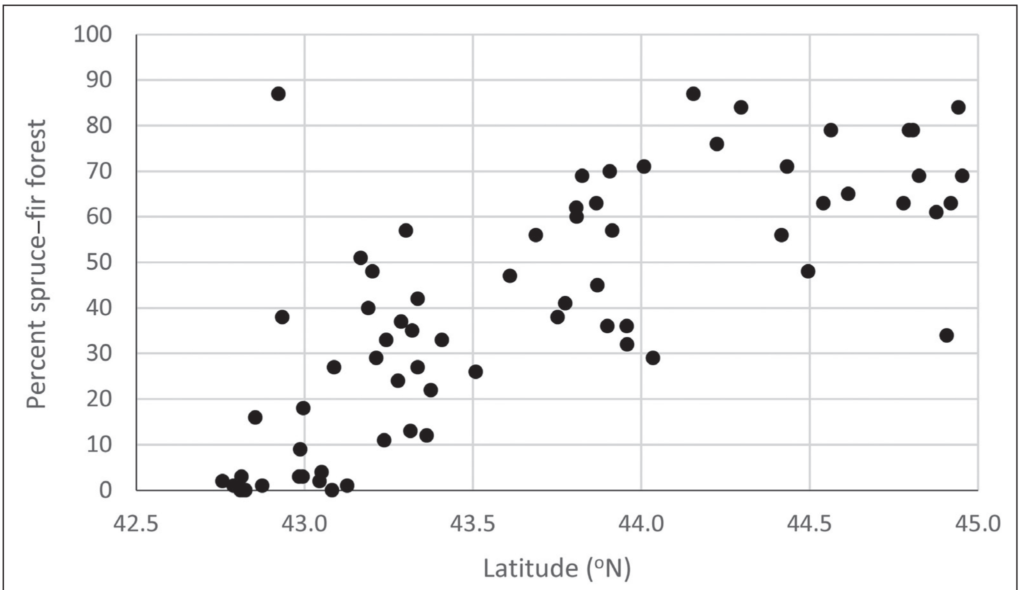

Figure 4. Proportion of spruce–fir forest within high-elevation areas >40 ha (100 ac) in size at different lattitudes in the Green Mountains.

Despite data indicating that the northeastern montane climate envelope has shifted upward by a few hundred meters (Wason et al. 2017a), evidence that vegetation is adjusting to this change by moving upward in elevation is mixed. Given the current findings, there are 3 possible scenarios for the future of northeastern mountains:

(1) Full transition – This scenario is what is predicted by currently favored theory. All vegetation eventually moves upward in elevation, though at different rates due to lag times and local conditions. Eventually montane, subalpine, and alpine communities are lost.
(2) Full resistance – Montane vegetation remains relatively stable, or at least changes much more slowly than lower-elevation vegetation, due to factors beyond temperature or growing season that limit the upward movement of hardwoods into the lower montane zone and forest into the alpine and krummholz zone. These could include soil conditions maintained under coniferous vegetation and mountain disturbance regimes (wind, snow, and ice).
(3) Partial resistance – The spruce–fir zone is squeezed between a rising hardwood zone at the lower ecotone and a more stable subalpine and alpine zone at the upper ecotone.

Given the observed relationship between temperature and the lower montane ecotone, the full resistance scenario is unlikely, and an upward retreat of this ecotone appears inevitable (Hill 2020, Wason et al. 2017a). This retreat will combine with the inexorable decline of total area with elevation. Based on an examination of USGS Digital Elevation Model data for New England and New York, above 810 m (2000 ft), the total area declines consistently by 50% with about every 115 m (285 ft) rise in elevation. Given the magnitude of observed climate shifts in our region's mountains, large parts of the montane spruce–fir zone may already be out of equilibrium with suitable climatic conditions, though coniferous vegetation may persist in areas where thin, acidic, and organic montane soils inhibit colonization by hardwood species (Lee et al. 2005).

However, the potential greater resistance of upper montane areas to climate change (which would distinguish between the full transition and partial resistance scenarios) remains an open question. Lu et al. (2020), in a meta-analysis of studies of treeline shifts across the Northern Hemisphere, found that the majority of montane treelines had advanced upwards in elevation, though the shifts were less than half of what would have been predicted just by temperature increases, and these shifts were less pronounced in temperate mountains as compared to subarctic regions. These results are consistent with the evidence of Spear (1989) and Seidel et al. (2009), though none of the studies included in Lu et al.'s (2020) analysis were from the temperate zone of eastern North America. Kimball et al. (2021) hypothesize that northeastern arctic–alpine vegetation may continue to persist through this century, at least under low to medium greenhouse-gas emissions scenarios.

Continued monitoring of temperature changes in high mountain areas compared to lower elevations, as well as studies of species range shifts in the upper montane zone, will be necessary to better understand how these habitats will likely respond to future climate change (Capers et al. 2013). Kimball and Weihrauch (2000) mapped treeline and the extent of alpine plant communities in the Presidential Range and on Mount Katahdin using aerial photography from 1978 and 1991, respectively, and revisiting these delineations to determine if changes have occurred over the past 3–4 decades would provide valuable information.

If montane ecosystems are able to maintain themselves in a future warmer climate, it will likely be on the region's largest and highest upper-elevation areas. Larger areas provide greater topographic and edaphic diversity that may allow spruce–fir forest to persist in some areas. Higher elevations provide greater opportunity for upward movement of species and greater potential that some level of resistance to climate change will be maintained. While the majority of such areas are fully conserved (or nearly so), the few areas that are less than fully conserved should be considered priorities for additional conservation. These have been described previously and include Sugarloaf/Abraham/Crocker, Saddleback Mountain, Caribou Mountain, and Bemis/Elephant/Old Blue in Maine, and Mount Ellen in Vermont. All of these are >2023 ha (5000 ac) in size, exceed 1067 m (3500 ft) in elevation, have more than 80% coverage in coniferous forest, and contain subalpine forest.

Whatever the future fate of northeastern montane species and communities, high-elevation areas will remain a distinct geophysical environment, characterized by complex topography that is colder, cloudier, wetter, and windier than lower-elevation areas. Mountains will continue to be an important component of regional biodiversity even if the species assemblages change over time, and mountain conservation will remain a priority.

In order to provide information on high-elevation areas to a wider audience, and to provide a resource for future conservation planning, we developed an online mapping application that shows the delineated areas, information on the various resource values for each area and selected other data layers. The application is intended to provide viewers the opportunity to understand the conservation status and resource values of all areas across the region. The application is available at Northeastern High Elevation Areas (https://www.arcgis.com/apps/webappviewer/index.html?id=a1efe98a69914d56b586084883529068).

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Supplementary File
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Online Supplementary File 1 to: Publicover, D.A., K.D. Kimball, and C.J. Poppenwimer. 2021. Northeastern high-elevation areas: Ecological values and conservation priorities. Northeastern Naturalist 28(Special Issue 11):129–155.

Supplementary File 1

Data sources

Delineation of areas. Derived from USGS 30-meter Digital Elevation Model data.

Elevation. The primary source for summit elevations was USGS (the Geographic Names Information System and topographic maps). Where summit elevations were unavailable, a range of other sources (including AMC guidebooks, Google Earth and Peakbagger.com) were examined or elevation was interpolated from USGS topo maps.

Conservation lands.

- Maine: CONSERVED LANDS shapefile (2020 version) downloaded from Maine Office of GIS.
- New Hampshire: Conserved/Public Lands (NHCONS) shapefile (2018 version) downloaded from NH GRANIT.
- Vermont: VERMONT PROTECTED LANDS DATABASE shapefile (2017 version) downloaded from the Vermont Center for Geographic Information.
- Massachusetts: PROTECTED AND RECREATIONAL OPEN SPACE shapefile (2019 version) downloaded from the Massachusetts Office of Geographic Information.
- New York: NEW YORK PROTECTED AREAS DATABASE shapefile (2017 version) downloaded from the NYPAD website; data on additional conserved lands data in the Catskills region was provided by the Open Space Institute.

Development. Development features and areas were delineated on Google Earth and identified from a range of sources.

Timber harvesting. Harvested areas were identified on Google Earth imagery; identification of older harvest units was supplemented by examination of satellite imagery. The approximate date of each harvest unit was determined by bracketing Google Earth historical images. It was not possible to assign a starting date to harvest units appearing in the earliest historical image. Clearcuts from the 1970s (and possibly earlier) were clearly evident in aerial photos from the 1990s, but the date of partial harvests visible in the earliest 1990s photography is unclear. Harvesting that took place prior to the 1970s or 1980s but was not evident in the earliest imagery was not included.

Spruce-fir forest. Areas classified as Evergreen Forest in 2016 National Land Cover Data (NLCD).

Documented rare plant and natural community occurrences.

- Maine: The number of rare plant and natural community occurrences within each high-elevation polygon was provided by the Maine Natural Areas Program.
- New Hampshire: The number of rare plant and natural community occurrences within each high-elevation polygon was provided by the New Hampshire Natural Heritage Bureau.
- Vermont: Information was extracted from the ECOLOGICALOTHER_RTENATCOM shapefile downloaded from the Vermont Center for Geographic Information.
- Massachusetts: Information on natural communities was obtained from the NHESP NATURAL COMMUNITIES shapefile downloaded from the Massachusetts Office of Geographic Information. Information on rare plants at Mount Greylock was obtained from the Mount Greylock Forest Reserve Long Term Ecological Monitoring report (de la Cretaz et al. 2009).

- New York: The number of rare plant occurrences within each high-elevation polygon was provided by the New York Natural Heritage Program. Natural community information was obtained from the NATURAL HERITAGE COMMUNITY OCCURRENCES shapefile downloaded from the New York State GIS Clearinghouse.

Subalpine forest. "Documented occurrences" are those included in state Natural Heritage databases:

- Maine: Shapefile data for occurrences on public lands were provided by the Maine Natural Areas Program. Extensions of these occurrences onto adjacent private land were delineated by AMC from National Agricultural Imagery Program (NAIP) aerial photography. A few additional documented occurrences on private lands have been publicly identified in development permitting applications. These areas were delineated by AMC based on application maps and NAIP aerial photography.
- New York: Occurrences in New York were extracted from the NATURAL HERITAGE COMMUNITY OCCURRENCES shapefile downloaded from the New York State GIS Clearinghouse.
- Massachusetts: Occurrences in Massachusetts were extracted from the NHESP NATURAL COMMUNITIES data layer downloaded from the Massachusetts Office of Geographic Information.
- New Hampshire and Vermont: Subalpine forest is not separately mapped by the Natural Heritage programs in these states, but is considered part of the broader high-elevation spruce-fir forest community. All occurrences in these states were mapped by AMC and classified as "potential", though many lay within documented occurrences of high-elevation spruce-fir.

"Potential" occurrences at least 8 ha (20 ac) in size were delineated by AMC from NAIP aerial photography by comparison with the appearance of documented occurrences. The delineation was conservative, encompassing only obvious patches of relatively uniform dense short balsam fir. Areas of taller fir that blend into adjacent spruce-fir forest, as well as more heavily disturbed areas with a high component of birch, were generally not included. Neither the presence nor the boundaries of these potential occurrences have been verified in the field by AMC and they should not be considered definitive. Only the most evident areas have been delineated; additional occurrences (particularly smaller ones) may be present.

Alpine areas. The presence of alpine vegetation was based on information from state Natural Heritage programs and AMC. Areas containing only krummholz (e.g., Killington Peak) were not included. Alpine-like vegetation (such as ericaceous heath) is also present on some lower-elevation barren summits but was not included.

Modeled potential Bicknell's thrush populations. Data on potential Bicknell's thrush populations based on a model developed by Hill and Lloyd (2017) was provided by the Vermont Center for Ecostudies.

Large roadless areas. Areas greater than 2,000 ha (4,942 ac) without evidence of roads or recent heavy harvesting were delineated by AMC. Areas in northern Maine, New Hampshire and Vermont were delineated in an earlier study, which describes the methodology and criteria for delineation (Publicover and Poppenwimer 2002). Areas overlapping high-elevation areas were updated using recent NAIP imagery. Roadless areas beyond the extent of the previous study in New York, Massachusetts, and southern New Hampshire and Vermont were delineated from NAIP imagery using the same criteria.

Wildlife habitat priorities. Habitat priorities were derived from the following sources:

- Maine: Beginning with Habitat Focus Areas as delineated on a statewide map developed as part of Maine's 2005 Comprehensive Wildlife Conservation Strategy (MDIFW 2010); digital data was provided by the Maine Chapter of The Nature Conservancy.
- New Hampshire: "Highest Ranked Habitat in NH" (Tier 1) as delineated in data developed for the New Hampshire Wildlife Action Plan (NHFG 2015b) and downloaded from NH GRANIT.
- Vermont**:** Tier 1 and 2 habitats as delineated in the "Tiered Contribution to Biodiversity" data layer (ECOLOGICOTHER_BIOFINDER) developed for the Vermont BioFinder program.
- Massachusetts**:** NHESP PRIORITY HABITATS OF RARE SPECIES shapefile downloaded from the Massachusetts Office of Geographic Information.
- No equivalent data is available for New York.

Priority conservation target ecosystems. Priority occurrences of three target terrestrial ecosystems (summits, cliffs/steep slopes and bowls/hollows/ravines) were extracted from data developed for The Nature Conservancy's *Northern Appalachian/Boreal Ecoregional Assessment* (Anderson et al. 2006) and downloaded from TNC's Conservation Gateway website. Priority occurrences were those listed as "Critical" or "Critical Protected" in the PRTCAT0603 field of the shapefiles for the three ecosystems.

Underrepresented geological settings. Geological settings were derived from Ecological Land Unit data developed for TNC's ecoregional assessments for the Northern Appalachian, Lower New England and High Allegheny Plateau ecoregions (Anderson et al. 2006, Barbour et al. 2001, Zaremba et al. 2003) and downloaded from TNC's Conservation Gateway website.

Estimated climate change resilience. Data on estimated climate change resilience was developed by The Nature Conservancy's Resilient and Connected Landscapes project (Anderson et al. 2016a) and downloaded from TNC's Conservation Gateway web site.

Average carbon stocking. Data were derived from the 2012 Forest Above-Ground Biomass data layer for the Northeastern United States developed by the North Atlantic Landscape Conservation Cooperative (Grand and McGarigal 2014) and downloaded from the Data Basin web site. The dataset estimates aboveground forest biomass as kg/m^2 times ten in 30-meter grid cells, with non-forested areas classified as "no data".

Quantitative scoring process

Scoring of individual parameters. The two condition and fourteen ecological resource parameters were converted to quantitative values as follows. Scores for all parameters were assigned within or prorated to a range of 0 to 1.

Development: For all areas with development, a score ranging from 0.05 to 1 was assigned by inspection based on the type, extent and impact of development within the area. When calculating the composite value score the development scores were converted to negative values.

Timber harvesting: In order to give greater weight to the impact of clearcuts and recent harvesting, the extent of harvesting within each area were adjusted as follows.

- Clearcuts since the mid-1990s: hectares x 1
- Clearcuts prior to the mid-1990s: hectares x 0.75
- Partial harvests since the mid-1990s: hectares x 0.75
- Partial harvests prior to the mid-1990s: hectares x 0.5

For each high-elevation area, the adjusted extent of harvested areas was summed, divided by the size of the area and converted to a negative value.

Size: Using area as the basis for scoring without adjustment resulted in a small number of very large areas receiving a high score and the great majority of areas getting very low values (Fig. S1). Using $\log_{10}$(hectares) overvalued relatively small areas. The chosen transformation of $(\log_{10}(\text{hectares}))^2$ gave an appropriate balance, with the maximum value of 1 assigned to areas of 10,117 ha (25,000 ac) or larger.

Elevation: As with size, using unadjusted elevation resulted in scores that were overwhelmingly dominated by a few very high areas. We used the prorated value of the square root of elevation range (elevation minus 823), with the maximum value of 1 assigned to areas of 1,524 m (5,000 ft) or higher.

Spruce-fir forest, large roadless areas, and wildlife habitat priority areas: For these parameters the score represents the proportion of the area within or classified as that characteristic.

Documented rare plant occurrences: Areas with at least 20 occurrences received 1 point, areas with 1 occurrence received 0.1 points, and areas with between 2 and 19 occurrences received a prorated score between 0.1 and 1.

Documented rare and exemplary natural community occurrences: Areas with at least 10 occurrences received 1 point, areas with 1 occurrence received 0.25 points, and areas with between 2 and 9 occurrences received a prorated score between 0.25 and 1.

Subalpine forest: Scores were based on the size ranges used by the Maine Natural Areas Program as part of the determination of the quality (EO rank) of an occurrence (Table S1). Because of the greater uncertainty surrounding potential areas, the size needed to obtain a specific score was doubled as compared to documented occurrences. Scores were based on the total extent of subalpine forest within an area.

Alpine areas: One point was given to the largest alpine areas (Presidential Range, Mount Katahdin and Adirondack High Peaks), 0.75 points to moderate sized occurrences, and 0.5 points to the smallest occurrences.

Modeled potential Bicknell's thrush population: The VCE model estimates the potential Bicknell's thrush population within 0.785-ha polygons across the region. The estimated population was summed for all polygons within each high-elevation area.

Priority conservation target ecosystems. 0.2 points were given for the presence of each of the three different conservation target ecosystems within a high-elevation area, plus 0.4 times the proportion of the area encompassed by these ecosystems.

Underrepresented geological setting. The proportion of each geological setting identified by TNC across all high-elevation areas was calculated. While most were common, three settings (calcareous sedimentary/metasedimentary, moderately calcareous sedimentary/metasedimentary and ultramafic) comprised 1% or less of the total high-elevation area. Occurrences of each of these settings within high-elevation areas were identified. Within each area 0.5 points was given for the presence of one of the three underrepresented geologic settings within a high-elevation area, plus 0.5 times the proportion of the area encompassed by these settings.

Estimated climate change resilience. TNC's analysis estimates climate change resilience within 30-meter grid cells across the eastern United States. Resilience is expressed as z-scores. We calculated the average resilience value of all cells within each high-elevation area.

Average carbon stocking. The average value for all cells within each high-elevation area was calculated, with non-forested areas assigned a value of zero. Results were converted from biomass to carbon stocking assuming that biomass is 50% carbon.

Composite value assessment. Scores for all parameters for each area were weighted and summed. Four weighting schemes were used – no weighting (all parameters counted equally) and three schemes emphasizing different sets of values (condition, biodiversity values and climate change values), though all parameters were included in each scheme (Table S2).

An adjustment was made to account for fact that some data is not available for all areas. For areas with unavailable data, the total score for each weighting was multiplied by the ratio of the maximum possible score with the unavailable parameters to the maximum possible score without the unavailable parameters. This adjusts the scores of areas with missing data upward.

The scores for each weighting were converted to z-scores, and the final score was calculated as the average of the z-scores from the four weightings.

Additional results

Development. Of the 765 areas at least 4 hectares in size, 75 have some type of development that could be discerned on the NAIP imagery, with some having more than one type of development:

- Eleven areas have notable roads (not including logging roads), including one state highway (the Kancamagus Highway) and six summit access roads (Mount Washington, Mount Mansfield, Equinox Mountain, Mount Greylock, Whiteface Mountain and Mount Utsayantha).
- Thirty-four areas have downhill ski areas, though not all are still operating. Together these areas encompass over 3,640 ha (9,000 ac) of high-elevation land (more than 1% of the total).
- Eight areas have commercial wind power development encompassing four active facilities (Kibby, Granite Reliable, Searsburg and Deerfield) and one has an abandoned earlier project (Little Equinox Mountain).
- Five areas have meteorological test towers and may be under investigation for wind power development. One (Sisk Mountain within the Caribou Mountain area) is the site of a permitted but not yet constructed project.
- Seven areas have mixed uses (generally recreation and communications), including the summit complexes on Mount Washington, Whiteface Mountain and Mount Greylock.
- Eight areas have recreational facilities (such as AMC's huts in the White Mountains).
- Nine areas have lookout towers.
- Ten areas have utility corridors.
- Eight areas have residential development (six of which are in the Catskills).
- Four areas have communications facilities.
- Five areas have miscellaneous other development (including the Mount Washington Cog Railway, an abandoned radar site in Vermont, a garnet mine in the Adirondacks and a Buddhist monastery in the Catskills).

Timber harvesting. The most extensive high-elevation harvesting has taken place on private lands (mostly large commercial timber company ownerships) in western Maine and northern New Hampshire (Table S3). Only about 1% of land currently in conservation ownership showed evidence of harvesting, but most of this took place prior to the acquisition of this land for conservation. About 70% of this harvesting occurred in just three high-elevation areas

(Sugarloaf/Abraham/Crocker and Caribou Mountain in Maine and Bunnell Mountain in New Hampshire) while the land was still in private ownership.

Ecological resources. The presence of individual resource values within high-elevation areas is summarized in Table S4. Information on the presence of these resources within the 75 highest-scoring areas is given in Table S5, while information on all areas may be found by consulting the Google Earth application (under development). Notable results include:

- Overall about 58% of high-elevation land is classified as spruce-fir forest in NLCD data. However, the latitudinal variation in the lower spruce-fir ecotone is evident. North of latitude 43.66°N (the latitude of Route 4 through the Green Mountains just north of Killington Peak) over 70% of the high-elevation area is spruce-fir forest, but south of it just 15% is.
- Subalpine forest natural community occurrences encompassing nearly 19,425 ha (48,000 ac have been documented in 32 high-elevation areas by state Natural Heritage programs in Maine and New York. Potential occurrences encompassing about 40,000 ha (100,000 ac) have been delineated by AMC in an additional 106 areas. In total, documented and potential occurrences of subalpine forest encompass about 18% of the land above 823 m (2,700 ft).
- The climate resilience scores for high-elevation areas are far above the average for the eastern United States as a whole, emphasizing the importance of these areas in a broader landscape that is adaptable to climate change.
- The average above-ground carbon stocking for all high-elevation areas was 225 mT CO^2/ha, which is 38% higher than the average for the full five-state region of 163 mT CO^2/ha. When only forested areas are considered, the average for high-elevation areas (264 mT CO^2/ha) was 8% higher than the average for the five-state region (245 mT CO^2/ha).

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The top 75 scoring areas – detailed results

Rank	Name	State	Size (ha)	Size (ac)	Elevation (m)	Elevation (ft)	% federal ownership	% state ownership	% municipal ownership	% public ownership	% NGO ownership	% conservation ownership (total)	% conservation easement	% conserved (total)	Development	% harvested	% spruce-fir forest	# plant EOs	# community EOs	Subalpine forest	Alpine area	Modeled Bicknell's thrush population	% roadless	Habitat priority	# target ecosystems	Underrepresented geosetting	Climate resilience (z-score)	Carbon stocking (mT CO2e/ha)	Score
1	Adirondack High Peaks	NY	20,404	50,419	1,629	5,344	0	98	0	98	0	98	2	100		0	80	205	43	Doc	Yes	7608	100	0	3		1.822	221.2	4.355
2	Mount Katahdin	ME	7,003	17,304	1,606	5,267	0	100	0	100	0	100	0	100		0	48	63	9	Doc	Yes	4655	100	100	3		1.731	165.6	4.313
3	Presidential Range	NH	17,531	43,320	1,917	6,288	99	1	0	100	0	100	0	100	Summit complex; Auto Road; Cog Railway; Jefferson Notch Rd; AMC huts (3); RMC cabins (2)	0	79	364	29	Pot	Yes	7575	97	98	3	Yes	1.383	212.8	3.909
4	Mahoosuc Range	ME/NH	2,151	5,316	1,180	3,870	21	68	0	88	0	88	0	88		0	95	24	3	Doc	Yes	457	98	99	2	Yes	1.551	209.3	3.792
5	Franconia Range/Pemigewasset North	NH	13,093	32,353	1,598	5,240	99	1	0	100	0	100	0	100	AMC huts (2)	0	66	67	19	Pot	Yes	4940	99	18	3		1.652	232.0	3.744
6	Sugarloaf/Abraham/Crocker	ME	8,418	20,802	1,292	4,237	8	38	0	46	5	51	14	65	Sugarloaf ski area	29	86	20	16	Doc	Yes	2010	46	97	3	Yes	1.317	210.8	3.578
7	Carter Range	NH	7,035	17,384	1,473	4,832	100	0	0	100	0	100	0	100	Wildcat Mountain ski area; AMC hut	0	79	13	18	Pot		2308	98	97	3		1.584	233.3	3.561
8	Bigelow Mountain	ME	1,041	2,572	1,264	4,145	0	100	0	100	0	100	0	100		0	90	12	2	Doc	Yes	226	100	100	3	Yes	1.381	208.6	3.520
9	Mount Moosilauke	NH	3,610	8,921	1,464	4,802	58	0	0	58	42	100	0	100		0	82	5	3	Pot	Yes	1091	100	92	3	Yes	1.409	226.6	3.493
10	Dix Mountain	NY	5,580	13,789	1,470	4,823	0	96	0	96	0	96	4	100		0	59	13	9	Doc	Yes	1653	100	0	3		1.797	210.8	3.437
11	Camel's Hump	VT	1,317	3,255	1,244	4,080	0	88	0	88	0	88	6	94		0	84	21	2	Pot	Yes	224	100	100	3		1.534	269.1	3.428
12	Pemigewasset East	NH	5,434	13,428	1,317	4,320	95	4	0	99	0	99	0	99	Bretton Woods ski area	0	67	12	7	Pot		974	99	98	3		1.313	229.3	3.093
13	Pemigewasset South/Sandwich Range	NH	10,363	25,607	1,427	4,680	100	0	0	100	0	100	0	100	Kancamagus Highway	0	73	2	3	Pot		1946	100	54	3	Yes	1.553	227.3	2.845
14	Kilkenny Range	NH	6,533	16,144	1,271	4,170	96	0	2	98	0	98	1	98		1	61	4	2	Pot		1494	97	98	2		1.443	230.8	2.787
15	Saddleback Mountain	ME	2,369	5,855	1,255	4,116	34	0	0	34	15	50	5	55	Saddleback ski area; private cabin	2	96	7	5	Doc	Yes	894	74	86	2		1.4	201.6	2.673
16	Old Speck Mountain	ME	1,539	3,804	1,274	4,180	0	74	0	74	0	74	0	74		3	93	2	1	Doc		400	92	100	3		1.449	219.9	2.666
17	Baldpate Mountain	ME	681	1,682	1,152	3,780	0	100	0	100	0	100	0	100		0	98	6	4	Doc		165	100	100	2		1.513	216.0	2.635
18	Kinsman Range	NH	2,610	6,450	1,329	4,358	84	16	0	100	0	100	0	100	Cannon Mountain and Mittersill ski areas; AMC hut	0	88	9	3	Pot		686	86	93	3		1.332	238.0	2.617
19	Baldface Mountain	NH	1,051	2,597	1,099	3,606	100	0	0	100	0	100	0	100		0	52	5	1	Pot	Yes	138	99	93	2		1.485	233.5	2.422
20	Mount Mansfield	VT	1,195	2,952	1,339	4,393	0	98	0	98	0	98	0	98	Summit House; access road; Stowe Mountain ski area; communications tower	0	63	72	9	Pot	Yes	454	77	100	2		0.932	185.6	2.406
21	Santanoni Peak	NY	3,225	7,969	1,404	4,606	0	89	0	89	11	100	0	100		0	96	7		Pot		846	100	0	1		1.726	228.8	2.374
22	Bolton Mountain	VT	1,021	2,522	1,122	3,680	11	71	0	82	0	82	1	83	Bolton Valley ski area	0	71	7	2	Pot		148	91	100	3		1.554	228.6	2.317
23	Mount Ellen	VT	2,189	5,410	1,245	4,083	58	9	0	66	0	66	0	66	Mad River Glen and Sugarbush ski areas	0	87	6		Pot	Yes	514	75	98	2		1.106	262.4	2.297
24	Bread Loaf Mountain	VT	2,768	6,841	1,169	3,835	100	0	0	100	0	100	0	100		0	71	2		Pot		352	99	100	1		1.398	255.5	2.296
25	Sunday River Whitecap	ME	227	562	1,017	3,335	0	8	0	8	0	8	49	56		0	88	4	3	Pot		32	95	100	3	Yes	1.328	195.0	2.281
26	Glastenbury Mountain	VT	5,055	12,491	1,143	3,748	99	0	0	99	0	99	0	99		0	18	1	1	Pot		262	95	88	2	Yes	1.166	259.2	2.267
27	Slide Mountain	NY	6,260	15,470	1,274	4,179	0	96	0	96	0	96	3	99		0	11	2	6	Doc		903	100	0	n/a		1.594	272.8	2.145
28	Tumbledown/Jackson	ME	875	2,162	1,088	3,568	0	85	0	85	0	85	9	94		1	92	3	2	Pot		172	95	90	2		1.4	118.9	2.026
29	Long Mountain	NH	1,284	3,173	1,116	3,661	0	100	0	100	0	100	0	100		2	91		2	Pot		320	72	100	1		1.203	207.1	2.024
30	Worcester Mountains	VT	1,079	2,666	1,092	3,583	0	98	2	100	0	100	0	100		0	56	3	1	Pot		175	100	100	1		1.367	233.3	2.014
31	Seward Mountain	NY	2,749	6,792	1,320	4,331	0	100	0	100	0	100	0	100		0	96			Pot		629	100	0			1.852	225.4	2.010
32	Mount Chocorua	NH	222	548	1,067	3,500	100	0	0	100	0	100	0	100		0	85	7	1	Pot		28	100	64	2		1.68	210.8	1.941
33	Whiteface Mountain	VT	942	2,327	1,133	3,715	0	94	0	94	0	94	0	94	Stowe Mountain and Smugglers Notch ski areas	0	79	10	3	Pot		167	73	100	2		1.319	234.3	1.936
34	Killington Peak	VT	3,229	7,979	1,291	4,235	13	76	0	89	0	89	0	89	Killington and Pico Peak ski areas; access road	0	47	5	3	Pot		572	63	99	2		1.175	263.2	1.915
35	Cranberry Peak	ME	109	270	980	3,213	0	100	0	100	0	100	0	100		0	95		1	Doc		15	100	100	1	Yes	1.173	163.8	1.914
36	Whiteface Mountain	NY	2,243	5,542	1,483	4,865	0	100	0	100	0	100	0	100	Summit complex; access road; Whiteface Mountain ski area	0	85	16	5	Doc	Yes	930	48	0	3		0.98	223.6	1.871
37	Dorset Mountain	VT	1,001	2,473	1,146	3,760	48	0	0	48	0	48	5	53		0	57			Pot		147	100	100	n/a		1.253	273.1	1.838

The top 75 scoring areas – detailed results

Rank	Name	State	Size (ha)	Size (ac)	Elevation (m)	Elevation (ft)	% federal ownership	% state ownership	% municipal ownership	% public ownership	% NGO ownership	% conservation ownership (total)	% conservation easement	% conserved (total)	Development	% harvested	% spruce-fir forest	# plant EOs	# community EOs	Subalpine forest	Alpine area	Modeled Bicknell's thrush population	% roadless	Habitat priority	# target ecosystems	Underrepresented geosetting	Climate resilience (z-score)	Carbon stocking (mT CO2e/ha)	Score
38	Haystack Mountain	VT	212	523	974	3,195	0	71	0	71	19	90	0	90		0	69	8	2	Pot		34	100	100	2		1.276	185.6	1.832
39	Sawtooth Mountains	NY	2,310	5,709	1,170	3,839	0	100	0	100	0	100	0	100		0	90			Pot		353	100	0			1.963	216.2	1.817
40	Scar Ridge	NH	2,025	5,003	1,317	4,320	100	0	0	100	0	100	0	100	Loon Mountain ski area	0	85	2	1	Pot		411	99	12	2		1.453	222.1	1.800
41	Percy Peaks	NH	129	319	1,042	3,418	0	100	0	100	0	100	0	100		0	75	1	2	Pot		20	98	100	2		1.177	156.2	1.797
42	West Royce Mountain	NH	144	355	979	3,210	100	0	0	100	0	100	0	100		0	98			Pot		14	100	99	2		1.398	184.1	1.792
43	Giant Mountain	NY	2,986	7,378	1,410	4,626	0	100	0	100	0	100	0	100		0	57		3			930	100	0	3		1.579	200.2	1.781
44	Mount Tecumsuh	NH	1,159	2,865	1,220	4,003	100	0	0	100	0	100	0	100	Waterville Valley ski area	0	82			Pot		196	90	91	1		1.334	215.2	1.701
45	Gillespie Mountain	VT	433	1,070	1,026	3,366	100	0	0	100	0	100	0	100		0	63	5		Pot		33	100	100	1		1.187	251.3	1.687
46	Belvidere Mountain	VT	159	394	1,024	3,360	0	55	0	55	42	97	0	97		0	63			Pot		28	99	100	2	Yes	1.228	203.9	1.686
47	McKenzie Mountain	NY	1,437	3,552	1,168	3,832	0	100	0	100	0	100	0	100		0	88		1	Pot		249	100	0	1		1.587	200.9	1.668
48	Bunnell Mountain	NH	2,479	6,125	1,135	3,723	0	30	0	30	63	93	2	95		23	66	5	2	Pot		589	0	100	2		1.399	215.7	1.664
49	Bloodroot Mountain	VT	1,193	2,949	1,074	3,522	100	0	0	100	0	100	0	100		0	60			Pot		108	100	100			1.336	245.4	1.663
50	Peru Peak	VT	1,323	3,270	1,044	3,425	100	0	0	100	0	100	0	100		0	37			Pot		60	94	100		Yes	1.134	263.4	1.656
51	Sentinel Range	NY	2,358	5,827	1,183	3,881	0	100	0	100	0	100	0	100		0	77			Pot		459	100	0			1.454	217.7	1.617
52	Little Bigelow Mountain	ME	115	285	915	3,001	0	100	0	100	0	100	0	100		0	62		1	Doc		12	100	100	1	Yes	1.212	154.4	1.616
53	North Jay Peak	VT	391	967	1,048	3,438	0	25	0	25	60	85	0	85		0	69			Pot		72	100	100		Yes	1.331	207.3	1.612
54	Mount Wolf	NH	620	1,533	1,061	3,480	100	0	0	100	0	100	0	100		0	85			Pot		50	100	85			1.479	229.3	1.599
55	Snowy Mountain	NY	3,330	8,228	1,188	3,898	0	86	0	86	0	86	14	100		0	50	1	1			358	100	0	3		1.641	223.1	1.533
56	Mullen Mountain	ME	186	460	1,052	3,450	0	100	0	100	0	100	0	100		0	38		1	Doc		87	100	100			1.823	198.9	1.488
57	Bald Cap	NH	275	679	934	3,065	100	0	0	100	0	100	0	100		0	99	2	2	Pot		25	0	100	1	Yes	1.534	201.6	1.475
58	Whitcomb Mountain	NH	575	1,420	1,023	3,354	0	67	0	67	0	67	0	67		9	89			Pot		87	92	99			0.994	213.0	1.469
59	Fishing Brook Range	NY	2,425	5,993	1,099	3,606	0	69	0	69	0	69	31	100		0	76		2	Doc		229	100	0			1.627	207.3	1.454
60	Graham/Doubletop Mountains	NY	9,512	23,504	1,179	3,868	0	80	0	80	1	81	1	82	Belleayre/Highmount ski area; Buddhist monestary	0	1	6	1	Doc		660	97	0	n/a		1.447	292.1	1.448
61	Whitecap Mountain	ME	692	1,710	1,114	3,654	51	0	0	51	39	90	0	90		0	95		2	Doc		203	100	0	2		1.318	196.9	1.416
62	West Baldpate	ME	70	174	910	2,985	0	100	0	100	0	100	0	100		0	99		1	Doc		7	100	100			1.356	163.6	1.410
63	Blue Ridge Mountain	NY	1,014	2,506	1,183	3,881	0	100	0	100	0	100	0	100		0	82			Pot		121	100	0			1.68	226.3	1.410
64	Dewey Mountain	VT	185	458	1,015	3,330	0	99	0	99	0	99	0	99		0	48		2	Pot		20	100	100	1		1.456	186.6	1.384
65	Jay Peak	VT	568	1,403	1,176	3,858	0	100	0	100	0	100	0	100	Jay Peak ski area	0	63	2	2	Pot		196	61	100	2		1.054	175.7	1.378
66	East Royce Mountain	ME	57	141	955	3,133	100	0	0	100	0	100	0	100		0	100			Pot		6	100	100	1		1.368	188.0	1.371
67	Panther Mountain	NY	2,496	6,167	1,134	3,720	0	75	0	75	0	75	25	100		0	45		3	Doc		267	100	0			1.631	227.6	1.367
68	Black Dome	NY	2,131	5,266	1,213	3,980	0	94	0	94	0	94	1	95		0	4	2	2	Doc		250	100	0	n/a		1.36	253.5	1.356
69	Wakeley Mountain	NY	2,239	5,532	1,143	3,750	0	100	0	100	0	100	0	100		0	61			Pot		222	100	0			1.51	235.0	1.348
70	Baker/Lily Bay	ME	902	2,229	1,073	3,520	0	0	0	0	61	61	39	100		1	90		1	Doc		261	94	0	1		1.379	194.2	1.314
71	Blue Ridge Mountain	VT	414	1,022	999	3,278	91	0	0	91	0	91	0	91		0	56	1	1			21	100	100	1		1.068	257.5	1.288
72	South Turner Mountain	ME	121	300	952	3,122	0	100	0	100	0	100	0	100		0	49		1			48	100	100	2		1.596	187.3	1.267
73	Traveler Mountain	ME	503	1,244	1,080	3,541	0	100	0	100	0	100	0	100		0	17		2			361	100	100	1		1.541	152.7	1.265
74	Rump Mountain	ME/NH	792	1,958	1,114	3,654	0	0	0	0	0	0	67	67		19	81	2	2	Pot		135	73	65			1.081	202.1	1.233
75	Boreas Mountain	NY	1,255	3,101	1,151	3,776	0	0	0	0	50	50	50	100		1	86		2			160	100				1.476	100.9	1.208

Table S1. Scoring of subalpine forest occurrences.

	Subalpine forest (acres)	
Points	Documented	Potential
1	>750	>1500
0.75	100-750	200-1000
0.5	25-100	50-200
0.25	5-25	10-50

Table S2. Weighting factors used in composite value assessment.

Parameter	Condition	Biodiversity values	Climate change values
Development	-4	-2	-3
Timber harvesting	-3	-1	-2
Size	2	2	3
Elevation	2	2	3
Spruce-fir forest	1	2	3
Rare Plant EOs	1	2	1
Rare community EOs	1	2	1
Subalpine forest	1	2	1
Alpine area	1	2	1
Bicknell's thrush	1	2	1
Roadless area	4	1	2
Habitat priority	3	3	2
Target ecosystems	1	2	1
Geosettings	1	2	1
Estimated resilience	3	2	3
Carbon stocking	1	1	2

Table S3. Extent of high-elevation land harvested over approximately the last 40 years. (Note that "Public and non-profit ownership" represents current ownership; much of the harvesting on these lands took place prior to its acquisition for conservation.)

	Public and non-profit ownership		Private land (incl. easements)		Total	
	Hectares	%	Hectares	%	Hectares	%
Maine	1,473	6.1%	6,415	19.9%	7,888	14.0%
New Hampshire	819	1.0%	2,151	24.1%	2,970	3.2%
Vermont	110	0.3%	651	8.4%	762	1.9%
Massachusetts	0	0.0%	0	0.0%	0	0.0%
New York	130	0.1%	57	0.4%	188	0.2%
Total	2,533	1.0%	9,274	14.5%	11,808	3.8%

Table S4. Presence of ecological resources in high elevation areas.

Resource value	Number of areas	% of areas
Spruce-fir forest		
≥75% of area is spruce-fir forest	204	27%
50 - 74% of area is spruce-fir forest	136	18%
25 - 50% of area is spruce-fir forest	136	18%
1 - 25% of area is spruce-fir forest	131	13%
0% of area is spruce-fir forest	158	20%
Rare plant element occurrences		
≥10 occurrences within area	15	2%
2 - 9 occurrences within area	40	5%
1 occurrence within area	23	3%
Rare natural community element occurrences		
≥5 occurrences within area	12	2%
2 - 4 occurrences within area	58	8%
1 occurrence within area	57	7%
Subalpine forest		
Areas with documented occurrence(s)	32	4%
Areas with potential occurrence(s)	106	13%
Alpine area	15	2%
Bicknell's thrush modeled potential population		
≥500	25	3%
100 - 500	60	8%
10 - 100	134	18%
0.1 - 10	233	30%
Large roadless areas		
100% of area is within large roadless area	412	54%
75 - 99% of area is within large roadless area	42	5%
1 - 74% of area is within large roadless area	24	3%
Habitat priority area*		
100% of area is habitat priority	134	30%
50-99% of area is habitat priority	71	16%
1 – 49% of area is habitat priority	37	8%
Priority target ecosystems		
Areas with 3 target ecosystems	22	3%
Areas with 2 target ecosystems	30	4%
Areas with 1 target ecosystems	54	7%
Underrepresented geologic settings	54	7%
Average estimated climate resilience (z-score)		
>2 (far above average)	35	5%
1 – 2 (above average)	595	78%
0.5 – 1 (slightly above average)	121	16%
<0.5 (average to below average)	14	2%
Average carbon stocking (mT CO_2e/ha)		
>250	104	14%
175 – 250	346	45%
100 - 175	223	29%
<100	92	12%

*Percentages are for ME, NH, VT and MA only as this information is not available for NY.

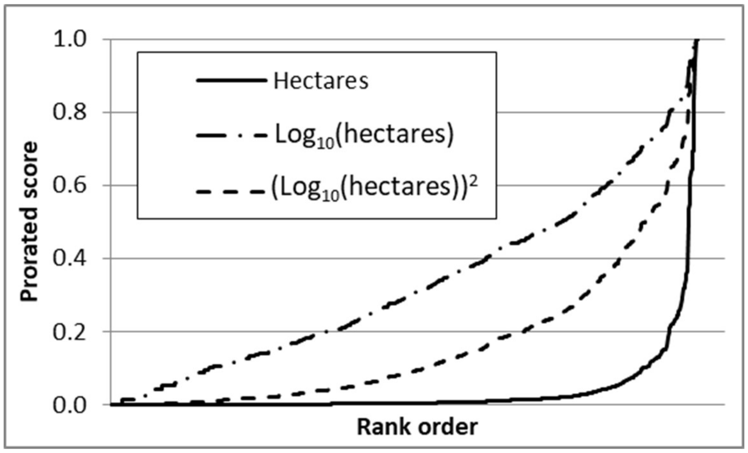

Figure S1. Options considered for scoring of size.