Native Plant Trust

State of the Plants

Challenges and Opportunities for Conserving New England's Native Flora

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Acknowledgments
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The mission of Native Plant Trust is to conserve and promote the region's native plants to ensure healthy, biologically diverse landscapes.

>>> Contents

>>> Why Plants Matter

Plants are the basis of all life on planet Earth. Via photosynthesis, they furnish oxygen and cleanse the air we breathe. Plants process 123 billion metric tons of carbon each year across the globe,[1] thus stemming the buildup of greenhouse gases. Plants are the anchors of terrestrial, marine, and aquatic ecosystems, which collectively deliver $125 trillion per year in services that benefit humans, including erosion control, climate regulation, water quality protection, food, and fuel.[2] Crop plants provide 90 percent of the world's food energy intake, with rice, maize, and wheat constituting the staples of more than 4 billion people.[3] More than 80 percent of the human population uses 50,000–80,000 species of medicinal plants; and of the top 150 pharmaceuticals prescribed in the United States, 75 percent are derived from plants.[4] Some 4 billion hectares of forest cover the globe and provide pulpwood, charcoal, fuelwood, fiber, and timber in addition to critical habitat for birds, mammals, and other organisms.[5] And plants are beautiful; the aesthetic appeal of healthy green spaces has demonstrable positive effects on people's psychological well-being.[6]

Yet the trends among plants worldwide are worrisome. Of more than 19,000 species examined by the International Union for the Conservation of Nature, an estimated 54 percent worldwide are classified as at risk; an additional 134 species are known to be extinct in the wild.[7] A burgeoning human population now appropriates 23.8 percent of global net primary productivity (the amount of carbon produced by plants) each year.[8] Approximately 60 percent of the Earth's ecosystem services examined during the Fifth Millennium Ecosystem Assessment are being degraded or used unsustainably; the quality of many ecosystem services has deteriorated as a result of attempts to increase the supply of other services, such as food.[9] And, although a few regions are witnessing modest regrowth of forests, land conversion takes 5.2 million hectares per year (an area the size of Costa Rica), principally in the most biodiverse tropical regions.[5] All the while, the number of botanists being trained is declining, and North America in particular is witnessing a shortage in the number of plant scientists who are qualified and positioned to tackle these issues.[10]

The flora of New England also shows some disturbing trends. At present, 540 taxa, 22 percent of the region's native plant taxa, are listed as globally, regionally, or locally rare or historical (see Appendices 1 and 2 for definitions of conservation status ranks); another 53 taxa (2.2 percent) face an uncertain future.[11] In areas in which exhaustive plant inventories have been completed, such as the city of Worcester, Massachusetts,[12] as many as 18 percent of historically documented native species have been searched for and determined no longer to exist. Invasive plant and invertebrate species are becoming more prevalent on the landscape, outcompeting and in certain cases contributing to widespread mortality of plants.[13] Patterns of invasion are correlated with levels of anthropogenic disturbance, especially new construction;[14] land in Massachusetts alone is being developed at the rate of nearly 2,000 hectares per year.[15] Natural community types such as coastal marshes and high-elevation zones may be disproportionately affected by the consequences of climate change, including sea-level rise, rising temperatures, and altered patterns of rainfall and storm intensity.[16] Uptake of carbon by New England's forests is predicted to decline by the end of the 21st century, thus diminishing the capacity of this ecosystem to mitigate greenhouse gas emissions.[17]

The outlook for New England need not be bleak, however, especially given opportunities for proactive conservation planning. A regional consortium of botanists and conservation biologists led by New England Wild Flower Society is developing strategies for prioritizing conservation and management activities, and members are mounting large-scale initiatives to protect and manage habitat. Some populations of rare species are rebounding as a result of projects to study and restore them *in situ*. Land trusts, state agencies, and other organizations are redoubling efforts to conserve land with critical habitats through modest funding, tax incentives, and increased outreach to landowners.[18]

White Mountain avens (*Geum peckii*) is one of nearly 600 plant taxa listed as rare in New England. *Photo: Arthur Haines*

The flora of New England also shows some disturbing trends. At present, 540 taxa, 22 percent of the region's native plant taxa, are listed as globally, regionally, or locally rare or historical

>>> Overview and Sources of Data

For the first time, this peer-reviewed report presents the most up-to-date data on the status of plants on the New England landscape. From these data, we can discern increases and declines in both rare and common species across all six states (encompassing 186,400 km^2). We identify hotspots of rare plant diversity and discuss factors that foster this diversity. We document the primary ecological and anthropogenic threats to both rare and common native species.

We approach our analysis of plant species in the context of habitats that support suites of related ecological communities (*sensu* Natureserve.org[19] and the U. S. National Vegetation Classification[20-21]), because plant species form relatively predictable assemblages under sets of particular environmental conditions. We highlight five widespread habitat types, from terrestrial to aquatic systems and from alpine to coastal environments, which broadly represent the variety of plant assemblages in New England (and, indeed, occur throughout northeastern North America). These case studies summarize the status of rare plants as well as more dominant or indicator species characteristic of these habitats; the diversity of other species supported by these plants; ecosystem services they provide; threats to these habitats; and opportunities for conservation and management. We also discuss other unusual habitats that harbor a high number of rare or endemic species.

This report aims to:

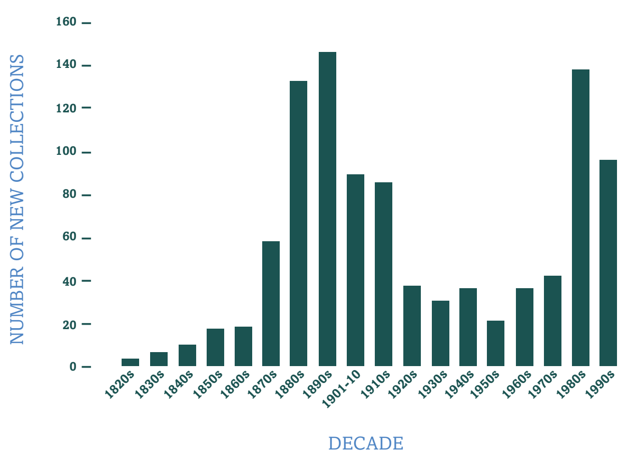
- document the status of and trends in the New England flora
- identify environmental and anthropogenic factors that impinge on plant species in the region
- articulate a research agenda to bridge gaps in our knowledge of plant species and ecological communities
- discuss frameworks for conserving and managing the thousands of species that together comprise our diverse and vibrant flora.

Recognizing that plant species and the challenges to them span across state lines, we hope to spur a coordinated suite of strategies that can become a model for conservation and research across species' ranges and throughout North America and beyond.

Sources of Data on the New England Flora

New England has long been a research hub, yielding a wealth of data on the ecology of the region. A large concentration of academic institutions and a vibrant array of active botanical societies[22] have engaged students, professors, and motivated amateurs to visit sites, collect and document floristics, contribute to herbaria, reconstruct site histories, and conduct research on the ecology of plants and community assembly.

To coordinate information-gathering, New England Wild Flower Society invited professionals from organizations and institutions involved in the protection of New England's endangered plants to form the New England Plant Conservation Program (NEPCoP),[23] which became the nation's first regionally integrated conservation program in 1991. Today, the Society administers a partnership consisting of approximately 120 professionals from 60 different government agencies, nonprofit organizations, universities and colleges, land trusts, state parks, environmental consulting firms, and all six state Natural Heritage programs. The Society coordinates hundreds of *in situ* field actions each year by NEPCoP members and volunteers (i.e., surveys and habitat management[24]) with *ex situ* (off-site) efforts including seed banking,[25] research, and propagation. NEPCoP field and research activities have generated data vital to rehabilitating and recovering rare species.



Number of new collections of New England rare plants by decade.
Spikes occurred during periods of intensive botanical surveys (1800s) and new discoveries (1980s on) by botanists of state Natural Heritage programs, conservation organizations, and volunteer monitoring programs.
Data: New England Wild Flower Society's Herbarium Recovery Project

Other sources of data on New England plants include:

- Paleoecological studies of pollen and charcoal profiles in sediment samples[26]
- Records of stand inventories, species of witness trees (used by colonists to mark boundaries between land parcels), and deed transfers showing the composition of New England forests around the time of European settlement, 400 years ago[27-29]
- Writings, journal data, and landscape paintings by natural history writers and artists, including Henry David Thoreau, Ralph Waldo Emerson, Thomas Cole, and many more[30]
- Herbarium specimens giving a record of plants collected over time and enabling reconstruction of past and present plant phenology;[31-32] the Consortium of Northeastern Herbaria now contains more than half a million digitized specimens contributed by 32 institutions from Canada to New Jersey[33]
- New England Wild Flower Society's Herbarium Recovery Project, completed in 2003 by botanist Arthur Haines and a committee of experts, which documented and annotated more than 18,600 specimens of regionally rare plants housed in 42 herbaria
- Data from historical and contemporary floristic inventories by many botanists[34-38]
- The *Atlas of the Flora of New England* compiled by botanists Ray Angelo and David Boufford (Harvard University)[39]
- Publications on the regional flora in two of the longest-running botanical journals in North America (>100 years old), *Rhodora* and *Journal of the Torrey Botanical Society,* as well as many other peer-reviewed journals
- Data and checklists compiled by biologists from all six New England state Natural Heritage programs[40]
- Observations and field forms completed by hundreds of plant enthusiasts, students, citizen-scientists, especially New England Wild Flower Society Plant Conservation Volunteers[41] and members of botanical societies[22]
- Peer-reviewed NEPCoP Conservation and Research Plans covering 117 species[42]
- *Flora Conservanda*: *New England*, a compendium of native plant taxa considered to be the most rare in New England, published by New England Wild Flower Society in 1996[43] and updated in 2012[44]
- The first definitive update of the region's plants in 50 years, the Society's *Flora Novae* Angliae,[45] with identification keys and much new information about plant nativity and distributions
- Continuous online updates of the *Flora* at the Society's Go Botany website.[46]

Collectively, these publications, an abundance of raw data, expert knowledge, and new analyses—the best that is known about thousands of plants in the region—provide a robust foundation for this "State of the Plants" report.

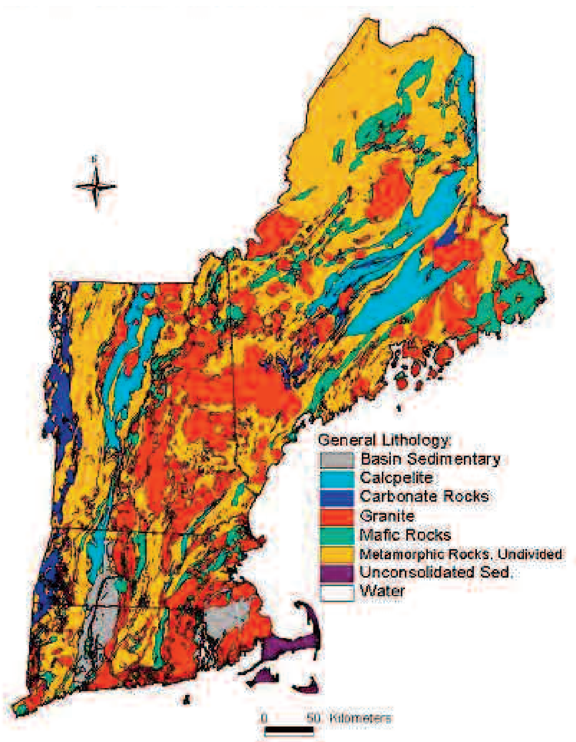
Concerted searches have recently discovered new populations of purple milkweed (*Asclepias purpurascens*). *Photo: Arthur Haines*

>>> Natural History of the New England Flora

To make sense of the biogeography of plants in New England, it is instructive to think of the landscape as a "layer-cake"[47] comprised of bedrock at the base (shaped by hydrology and climate), overlain by the mineral and organic strata of soil, and topped by the plants that depend upon them. To understand how these layers have formed and evolved, we briefly discuss the deep history of New England.

Geology influences plants. Plants are highly sensitive to the chemistry, depth, and water-holding capacity of soils weathered from bedrock. The complex bedrock underlying New England is the product of hundreds of millions of years of geological change involving continental collisions, mountain-building events (orogenies), rifting, and other upheavals, interspersed with quiescent interludes of erosion.[48-51] A full account of the region's geological history is beyond the scope of this report, and many excellent reviews exist.[48-50] In the following, we highlight some of the bedrock types and features that influence the biogeography of the flora.

- The region's oldest rocks, predominantly hard, acidic gneisses still visible in southern Vermont and the Adirondacks, are more than 1 billion years old.
- The limestone and marble bedrock of western Vermont, Massachusetts, and Connecticut derive from sediments laid down by corals and other carbonate-secreting organisms under an expanding tropical sea beginning 540 million years ago (mya), and today those areas are home to calcium-loving plant species.
- The Taconic Mountains of eastern New York, which extend through Bear Mountain (CT) to Mount Greylock (MA) and north to central-western Vermont, consist of tough schists and gneisses created during the Taconic Orogeny (450 mya); thus, they remain highlands today, whereas more erosible, marble-derived formations have formed valleys.
- Sediments from deep in the narrowing Iapetus Ocean (400 mya) were squeezed and pushed to the surface; these ultra-mafic rocks now leave trace signatures of rare talc and serpentine in the Green Mountains, northwestern Massachusetts, and southern Maine, which support unique plant communities.
- Other rocks of the Iapetus terrane consist of heavily metamorphosed, erosion-resistant gneisses and schists that today form Broomstick Ledges, Mica Ledges, and Mt. Pisgah in central Connecticut[49] and underlie a broad swath of central New England up to Maine.
- Hard, acidic, granitic bedrock (created during the Acadian Orogeny 380 mya), which contrasts sharply with the metasedimentary rocks of western New England, underlies eastern Connecticut, all of Rhode Island, and much of New Hampshire, Maine, and Massachusetts east of the Worcester Plateau.
- Granitic plutons of this age are exposed in the northeastern highlands of Vermont. Other granitic plutons created at various times in New England's turbulent history include Mt. Monadnock (NH), Pelham Dome (MA), Mt. Katahdin (ME), parts of the Presidential Range (NH), and Mt. Ascutney (VT).
- Rifting of the supercontinent Pangaea (240 mya) caused large block faults, volcanoes, and a rift valley to appear, through which copious basalt flowed. Today, the Metacomet Range, which extends from southern-central Connecticut to southern Vermont, consists of alternating layers of basalt and arkose redstone. Numerous plant species inhabit these mountains, with bedrock abundant in magnesium conducive to growth; subtle differences in the bedrock support different plant communities, enhancing species beta-diversity.[52]



General lithology distribution in New England
Bedrock chemistry profoundly influences the chemistry and texture of the derived soils, which in turn influence the plant species that grow in an area. *Source: U. S. Geological Survey*

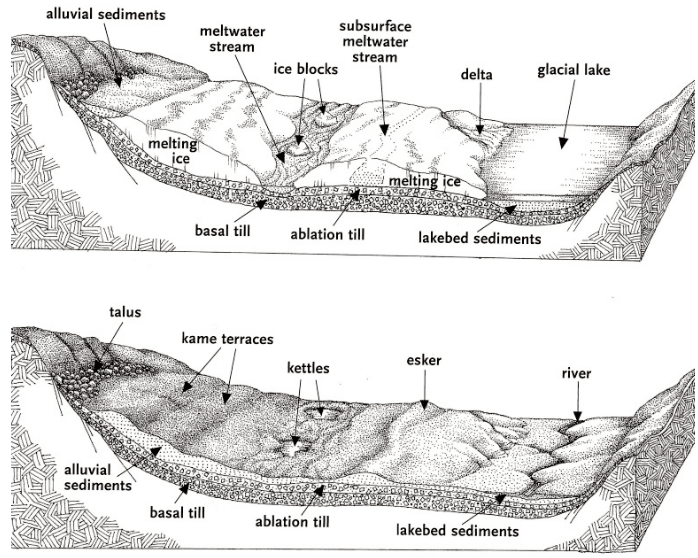
From 60 mya until the onset of Pleistocene glaciations 1.6 mya, a warm-temperate climate prevailed in a wide belt around the Earth, and forest covered much of the circumboreal region. Species of today's New England forests, including the genera *Nyssa*, *Carpinus*, *Acer*, and *Liriodendron*, were found throughout this forest, which stretched all the way to what is now southeast Asia. Subsequently cut off by glaciers, individual species evolved separately in North America and Asia, but the two regions still share many genera belonging to this "Arcto-tertiary flora."[53]

Pleistocene Glaciations. Glaciers were major drivers of bedrock weathering, frost-heaving, and soil creation in New England; soil type and texture in turn critically influenced the composition of plant communities. Four major glaciation events occurred between 1.6 million and 14,000 years ago—with continent-sized ice sheets spreading southward during periods of extreme cold, then receding as the climate warmed. Scoured, rounded bedrock summits and thousands of glacial erratics strewn across New England reflect the northwest-to-southeast glacial trajectory. Glaciers have left many characteristic landforms, each of which supports characteristic plant communities. These features include eskers, drumlins, kames, kettle ponds, outwash plains, and moraines formed as melting glaciers discharged their loads. Glacier-plucked boulders deposited as talus at the base of slopes provide cool, seepy substrates for plants. The predominant product of glaciers in New England is till: beds of soil replete with rocks, which lie as much as 30 meters deep atop the bedrock base. The fertility of till is largely dependent on the composition of its constituent rocks: if granitic, these rocks yield the acidic, uncompromising soil that covers much of eastern New England.

Moraines in contact with resistant bedrock occasionally dammed up melt-waters, creating glacial lakes; Lake Hitchcock in the Connecticut River Valley, which lasted 3,000 years, was one of the largest, stretching nearly 650 kilometers from New Britain, Connecticut, to St. Johnsbury, Vermont. Clays and fine sands deposited into the bottoms of these lakes are today among the most mesic and fertile agricultural soils (and some of the most botanically rich) in New England. Along the shores of glacial lakes and the outwash plain of New England's southern coast, rushing streams carrying coarser sands deposited their sediments in huge deltas. These sandy alluvial fans are now major zones of groundwater discharge[51] and support unique vegetation that is tolerant of xeric conditions; notable examples occur in the Connecticut River Valley (MA),[54] Waterboro Barrens (ME),[55] and throughout Cape Cod and the Islands.

Holocene Climate Change. Analyses of palynological (pollen profile) studies and lake varves (layers of relatively large particles carried by high-energy streams swollen with rain and snowmelt that are interspersed with layers of fine particles deposited by streams grown sluggish from a lack of rain) reveal several climatic changes in the wake of deglaciation. Holocene climatic periods included cold dry (14,600–12,900 years ago), very cold and dry (12,900–11,600 years ago, the Younger Dryas period), cool and dry (11,600–8200 years ago), warm and wet (8,200–5,400 years ago), warm and dry (5,400–3,000 years ago), and cool and wet (3,000 years ago to present).[56]

Sparse tundra vegetation dominated by sedges (*Carex* spp.) initially colonized newly opened terrain at the receding glacier's toe. Scattered birch (*Betula*) and the nitrogen-fixers—Dryas' mountain-avens (*Dryas drummdondii*) and alder (*Alnus*) species—were among the first woody colonists.[57-58] From 14,000 to 11,500 years ago, spruce (*Picea* spp.) and Jack pine (*Pinus banksiana*) prevailed throughout New England.[59] White pine (*Pinus strobus*) became a common member of the forest flora between 11,500 and 10,500 years ago, with hemlock (*Tsuga canadensis*) appearing around 10,500 years ago. A spike in the pollen of ragweed (*Ambrosia artemisiifolia*) and other forbs, however, suggests widespread forest decline as the region became significantly drier from 10,200 to 8,000 years ago; an enhanced charcoal signature from this period also indicates increased fire frequency.[60] From 9,500 to 8,000 years ago, oaks (*Quercus* spp.) predominated in southern, lowland areas (corresponding to the Lower New England and North Atlantic Coast ecoregions[61]) and *Tsuga* moved into higher-elevation, northerly regions (the



Contrasting plant communities occupy different landscape features created by glaciation, which influences soil texture and drainage. Top panel shows melting ice beginning to reveal features. Bottom panel shows landscape features that remain once the glacier is gone. *Drawing: Elizabeth Farnsworth, reprinted with permission from* The Nature of New Hampshire[121]

New England vegetation underwent large-scale changes following deglaciation, involving assembly, dissolution, and remixing of species at least in part in response to climatic change. Although some species were sensitive to temperature fluctuations, the majority appear to have reacted most strongly to protracted drought events.

Northern Appalachian ecoregion[61]). Larch (*Larix laricina*) and fir (*Abies balsamifera*) moved northward during this period.[57] The composition of the vegetation of these ecoregions began to diverge strongly due to conditions that favored drought-tolerant species in the lowlands of New England and the Adirondacks.[62] Circa 8,000–5,500 years ago, the region experienced the Holocene climate optimum event or Hypsithermal,[63] when temperatures rose several degrees in the northern hemisphere (attributed in part to periodic Milankovitch cycles), and beech (*Fagus grandifolia*) moved in.

Notably, *Tsuga* declined abruptly ca. 5,500 years ago at many sites throughout New England and did not recover for nearly 3,000 years. This nosedive has been attributed previously to an insect outbreak comparable to the hemlock woolly adelgid invasion occurring today.[64-65] However, the broad geographical and temporal extent of the die-off, the simultaneous decline of oaks (*Quercus* spp.), an influx of drought-tolerant hickory (*Carya* spp.), and evidence for a fall in lake levels suggest that catastrophic drought was likely a major driver.[66] Such an explanation, however, does not exclude the potential importance of insects in hastening the decline of already-stressed trees; similar synergistic conditions are affecting dominant forest species today.

The next major shift occurred between 1500 and 1850 AD, when the Earth's climate cooled, ushering in the "Little Ice Age" and giving New England a reprise of cold summers and often deadly winters. The pollen record from Massachusetts shows only subtle signatures of change occurring during that period,[67] but pollen records from New Jersey indicate a southward expansion of species such as spruces (*Picea* spp.) and *Tsuga*[68] as they adapted to cold temperatures further south.

In summary, the paleoecological record demonstrates that the New England vegetation underwent large-scale changes following deglaciation, involving assembly, dissolution, and remixing of species at least in part in response to climatic change.[57] Some taxa tracked climate with migration better than others. Although some species were sensitive to temperature fluctuations, the majority appear to have reacted most strongly to protracted drought events. Nothing in the Holocene would exert a larger influence on New England plants, however, than the arrival of humans.

Jack pine (*Pinus banksiana*) was among the first trees to colonize soils forming after glacial retreat. Plant species differ in their ability to track climate change via migration. *Photo: Elizabeth Farnsworth*

>>> Human Influences on New England's Plants

The First Inhabitants. Archaeological finds of spear points and other hunting implements indicate that the first humans crossed the Bering land bridge to North America around 12,500 years ago and were firmly established at sites across the continent by 11,200 years ago.[69] Migration was swift, with bands of paleoindians migrating up to hundreds of kilometers in just a few decades to find rock appropriate for carving tools, as well as food and water sources that were shifting during the rapid environmental changes of the Younger Dryas.[70] The earliest artifacts from New England and the Maritimes date from 11,100 years ago; the Bull Brook site in northeastern Massachusetts is among the largest, containing thousands of tools.[71] Interestingly, many of these tools consist of chert from the Champlain Valley region of Vermont, testifying to the long-distance transport of materials by peripatetic peoples.[71]

The majority of the paleoindian sites occurred on sandy, well-drained soils along river systems.[71] During the Archaic Period (9,000 to 3,000 years ago), short-term settlements and seasonal camps followed the availability of plant and animal resources, with spring camps along rivers to exploit migrating fish, summer camps in open meadows and marshes, autumn camps in woodlands where fruits and nuts could be gathered, and winter camps in sheltered valleys.[72] A few plant remains from early Archaic sites indicate limited use of wild grapes (*Vitis* spp.), sarsaparilla (*Aralia* spp.), heathland berries (*Vaccinium* and *Gaylussacia* spp.), and bunchberry (*Chamaepericlymenum canadense*).[71] Beginning roughly 3,000 years ago (the advent of the Woodland Period), agricultural practices evolved, and populations began to manufacture clay pots and ceremonial artifacts. More intensive use of plant-based foods began around 2,000 years ago, involving horticultural practices to reduce cover of competing plants and to increase the yield of desirable species. Large villages began to congregate around cultivated fields in river floodplains ca. 1,000 years ago.[72]

Debate has long raged about the importance of Native American use of fire in altering New England vegetation, and understanding this history has implications for future habitat management. Charcoal layers collected from 1,000- to 500-year-old sediments indicate that more populous southern New England sites saw higher fire frequencies than northern New England sites.[73] The uncertainty lies in the ignition source for fire: lightning (striking dry fuels during periods of drought) or humans. Certain xeric natural community types, such as pitch pine-scrub-oak barrens and sandplain grasslands, which were more common in the southern New England states, were typically fire-prone, as they are today.[74] Spatially patchy charcoal deposits suggest that Native Americans used fire, possibly to open up habitats conducive to game and to favor certain fire-tolerant plants and trees with serotinous seeds, especially in southern New England. However, these small fires appear to have transformed landscapes at only local scales.[75] Other researchers assert that Native American planting, clearing, and burning practices both actively and passively encouraged the prevalence in the Northeast of trees and shrubs with large, edible fruits.[76] In truth, we may never be able to fully tease out the importance of pre-colonial burning on the ecology of New England, because that evidence has been profoundly obscured by the dramatic changes wrought in the 400 years since European colonization.[75]

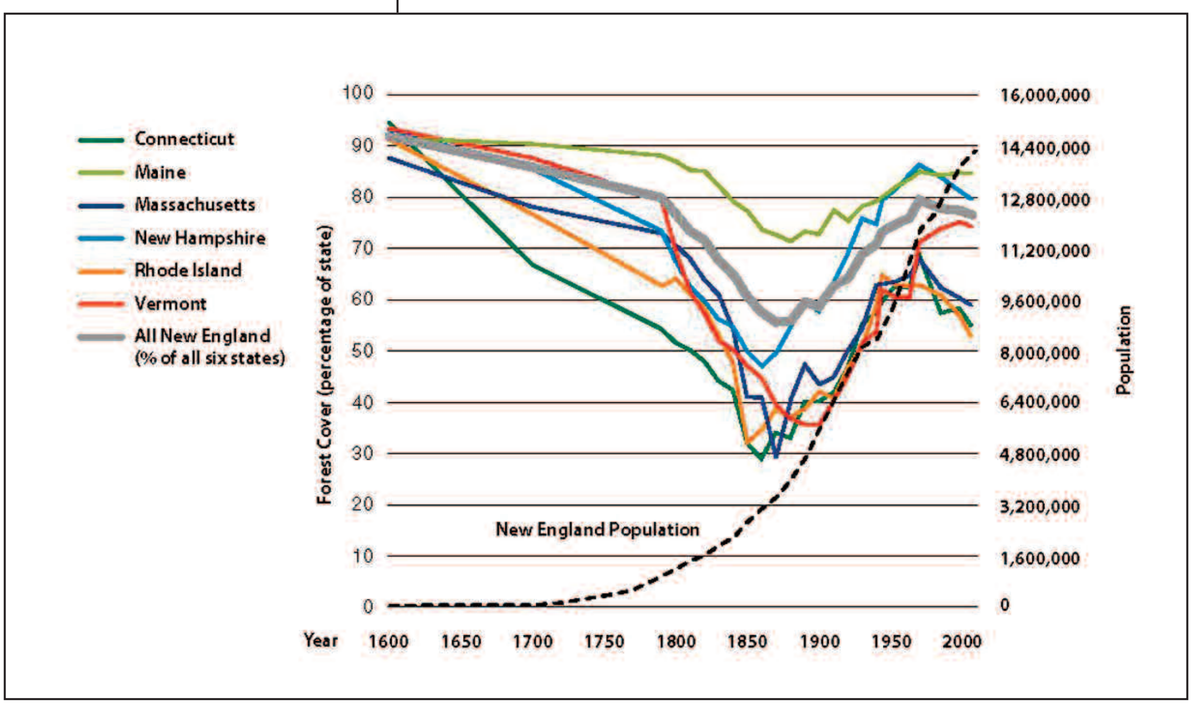
Today, wildfires are quite rare in New England, but are important for maintaining plant diversity in open habitats such as barrens and sandplains. *Photo: Michael Batcher*

The Colonial Era. Early writings, inventories of old-growth forests, and witness tree data together give a broad sense of the vegetation encountered by the first colonial explorers (1400–1600) and settlers (1600 onward). Trees were the most significant commodity for early settlers and thus were relatively well documented, which gives us more information about forest composition than other vegetation. In southern New England, visitors encountered hemlock-northern hardwoods at high elevations such as the northern Worcester Plateau; oak and hickory mixed with pine and chestnut at lower elevations in the Connecticut River Valley, southern Worcester Plateau, and mainland coastal plain; pitch pine and oak species on Cape Cod and the Islands; and swamp forests and transitional mixed hardwoods and conifers in other areas.[77] Visitors to Maine and other parts of northern New England described extensive stands of spruce species, fir, northern white cedar, and yellow birch in the interior north, whereas beech, sugar and red maples, white pine, and hemlock predominated in southern regions,[78] split along a boreal-temperate divide broadly termed a "tension zone."[79-80] The southern Maine coast hosted oaks, whereas the downeast coast (northeast of Penobscot Bay) supported spruce species and hemlocks.[78] Some areas were open and park-like, or even devoid of trees, especially along the coast.[81] New colonists also remarked at length on the abundance of plant and animal life—a bounty such as they had never experienced in resource-depleted Europe and such as we, today, cannot imagine.[81] According to the astonished reports by settlers, birds, fish, lobsters, even ants[82] swarmed in the millions during the height of summer.

After the first landfall of pilgrims at Cape Cod in 1620, the influx of new settlers arriving from Europe exploded to 14,000 by 1640.[83] Settlers soon fanned out to protected embayments near Plymouth, to the rich floodplains along the Connecticut and Quaboag rivers,[77] and to Connecticut and Rhode Island.[83] Early attempts at settling in coastal Maine in 1607 failed due to the challenging winter conditions, but by the 1700s, Maine's forests were being deeded to many new colonists.[78] By 1810, towns were distributed fairly evenly across southern New England.[84] Major land-clearing efforts ensued. By 1850, forest cover in the more densely populated states such as Massachusetts had declined to just 20 percent, with the majority of cleared land being grazed and the rest tilled.[81] Deforestation took place more slowly in Maine, but forest cover still dropped to only 65 percent of its original extent by 1850. With the disappearance of forest cover, many mammal species dependent on these habitats, such as bear, declined precipitously.[84] Others, such as deer and beaver, declined due to hunting and overharvesting. Still others, such as grassland birds, thrived in newly opened fields.[84]

The frequency of fire, as indicated by charcoal deposits throughout New England, increased dramatically following colonial settlement, with a sharp, unprecedented uptick beginning 300 years ago.[75] The size and extent

Forest cover and population change in New England
Forest cover declined between 1600 and 1850 in New England, but rebounded when farmers abandoned their lands to pursue opportunities in rapidly industrializing cities or migrated west. Since the 1950s, forest cover has been declining again due to development.
Reprinted with permission from Harvard Forest



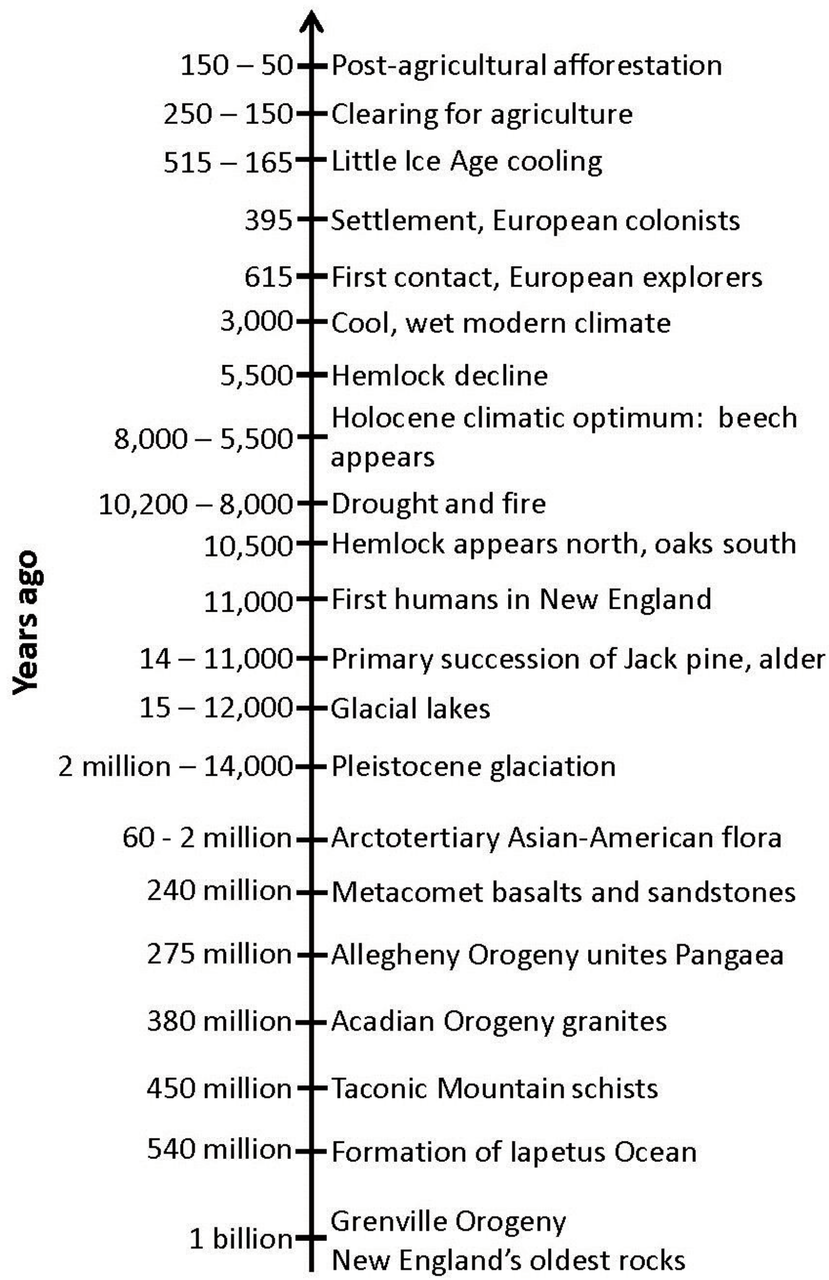
of this signature was particularly strong in already fire-prone, xeric areas such as coastal and interior sandplains. Today, many open grasslands and pitch-pine barrens exist on sites created by colonists through fire and/or cultivation, but those sites were later abandoned for more promising grounds.[85]

Industrial Era and Forest Recovery. As the Industrial Age created opportunities for employment from 1830 on, New England cities grew. At the same time, many colonists migrated—to till rich, deep Midwest soils or to seek their fortune in the goldfields of the West. Large areas of cropland in New England were abandoned, and early-successional woodlands overtook the fallow fields. Gradually, forests matured, but they would bear only superficial resemblance to the forests that the early settlers had encountered. Certain tree species were favored in the new mix, either because of their utility (such as sugar maple, *Acer saccharum*, used for maple syrup) or because of their inherent tolerance of a wide range of environmental conditions (such as red maple, *Acer rubrum*).[77]

Today, New England forest cover has rebounded to as much as 80 percent (60 percent in suburban areas near cities), although it is currently undergoing a new decline due to development.[86] It is difficult to detect the signs of past land use under a dense canopy of trees, although new satellite technologies reveal many such signs,[87] and a walk through a "natural" New England woodland passes by ubiquitous stone walls and cellar holes. The understory vegetation of these secondary forests is species-poor compared to that of previously uncultivated forests, even in areas with rich, mesic soil that supports rapid plant growth.[88] Certain species may be less able to recolonize disturbed areas because their large seeds are difficult to disperse and/or because the soil profile has been profoundly altered by plowing. In contrast, certain non-native plant species readily colonize or persist on former homestead sites, further pre-empting available habitat.[89]

New England forest cover has rebounded to as much as 80 percent, although it is currently undergoing a new decline due to development. The understory vegetation of these secondary forests is species-poor compared to that of previously uncultivated forests, even in areas with rich, mesic soil that supports rapid plant growth.

Forest cover declined between 1600 and 1850 in New England, but rebounded when farmers abandoned their lands to pursue opportunities in rapidly industrializing cities or migrated west. Since the 1950s, forest cover has been declining again due to development. *Photo: Aaron Ellison*



Timeline summarizing the geological, glacial, and human history of New England, highlighting significant events that have influenced bedrock types, soil formation, and the flora of the region.

>>> New England's Plants Today

Overview. New England is a diverse mosaic of environments, with complex landforms, elevations ranging from sea-level to 1,900 meters, a gradient of continental to maritime climates, and a complicated history of land use. As such, the region supports a diverse flora: 3,514 plant taxa have been recorded to date,[45] but new native and non-native species are continually being discovered.[90] This species richness is similar to states of comparable size and latitude (Table 1).

Table 1. Comparison of native and non-native vascular plant species richness with states of comparable size and latitude to New England. Sources of information on number of plant taxa are indicated by a superscript.

Region	Area (km^2)	Number of vascular plant species	Species/km^2 × 100
New England	186,443	3,514 [45]	1.88
New York	141,297	3,899 [91]	2.76
Missouri	180,540	3,384 [92]	1.87
Washington State	184,661	3,670 [93]	1.99

New England's native plant diversity is all the more impressive considering that the region's states are among the most densely populated in the nation.[94] Southern New England states document higher numbers of native and non-native taxa per unit area than northern New England states,[95] possibly reflecting a climatic gradient from more to fewer growing degree-days per year.

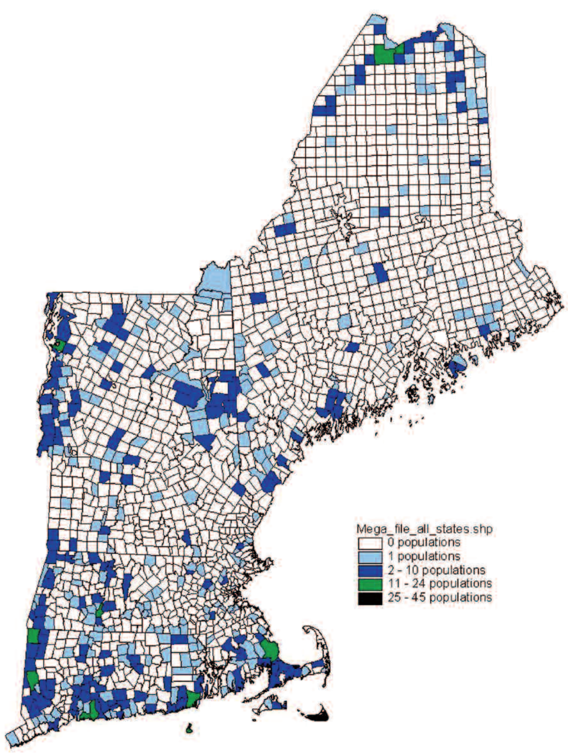
An estimated 31 percent of the plant taxa in New England are non-native (introduced since 1500),[96] most of which have been brought accidentally or intentionally from Europe and Asia. Of the non-native taxa, 111 (10 percent) are listed as invasive or potentially invasive by the Invasive Plant Atlas of New England, comprising about 3 percent of the total New England flora.[97]

Rare Species. The Society's *Flora Conservanda*, which presents data from nearly 25 years of research and annual monitoring of rare plant populations throughout New England, indicates that 22 percent of the region's native plants are now considered rare (Table 2). Among them are 62 globally rare taxa and 10 endemic taxa, three of which are now considered extinct.[98] An additional 96 taxa have been extirpated from their New England range and, in many cases, are imperiled in the remainder of their range; seabeach amaranth (*Amaranthus pumilus*), for example, has declined precipitously everywhere due to beach development.[95] Indeed, an analysis of 71 rare species showed that on average, they have lost 67 percent of their historical range in New England, and many populations of rare plants now cluster at the peripheries of their former regional ranges. That pattern highlights the importance of conserving marginal populations as well as occurrences in the heart of the range.[99]

Today, 22 percent of the region's native plants are now considered rare. Among them are 62 globally rare taxa and 10 endemic taxa, three of which are now considered extinct. On average, they have lost 67 percent of their historical range in New England.

Table 2. A profile of rare plant species in New England	
Percent of total native New England flora listed in *Flora Conservanda* 2012[11]	22%
Total number of globally rare plant taxa (Division 1, *Flora Conservanda*)*	62 taxa
Total number of regionally rare plant taxa (Division 2, *Flora Conservanda*)	325 taxa
Total number of rare plant taxa that are declining regionally (Division 3a, *Flora Conservanda*)	6 taxa
Mean percentage loss of previously recorded range area per taxon based on a comparison of the area of extent of historical and extant populations (analyzed for 71 Division 1 and 2 taxa)99	67%
Mean percentage of previously recorded occurrences now considered historical (analyzed for 71 Division 1 and 2 taxa)[99]	56%
Total number of taxa considered historical in New England (Division 4)[11]	96 taxa
Taxa endemic to New England (found nowhere else): Robbin's milk-vetch (*Astragalus robbinsii* var. *robbinsii*), Jesup's milk-vetch (*Astragalus robbinsii* var. *jesupii*), Orono sedge (*Carex oronensis*), Dawn-land sedge (Carex waponahkikensis), Bicknell's hawthorn (*Crataegus bicknellii*), Kennedy's hawthorn (*Crataegus kennedyi*), cleft-leaved hawthorn (*Crataegus schizophylla*), smooth-glumed slender crabgrass (*Digitaria filiformis* var. *laeviglumis*), New England thoroughwort (*Eupatorium novae-angliae*), Robbins' cinquefoil (*Potentilla robbinsiana*)[45]	10 taxa
Endemic New England species considered globally extinct: Kennedy's hawthorn (*Crataegus kennedyi*) lost due to forest succession, Robbin's milk-vetch (*Astragalus robbinsii* var. *robbinsii*) lost due to dam construction, smooth-glumed slender crabgrass (*Digitaria filiformis* var. *laeviglumis*) lost due to trampling[98]	3 taxa

*Division 1 = globally rare (usually G1 through G3 or T1 through T3 per NatureServe criteria); Division 2 = regionally rare taxa with 20 or fewer current occurrences observed within the last 20–25 years in New England



Numbers of recorded rare plant populations in New England towns (for 71 species). Darker shades reflect higher numbers of populations; white areas indicate regions that have not yet reported these rare plants and may require more intensive survey.

There are several notable hotspots of rare plant diversity in New England; these are sites in which clusters of specialized plants co-occur on unusual substrates or in uncommon ecological community types. These hotspots include the marble valleys of western New England (CT, MA, VT), Connecticut River Valley (CT, MA, NH, VT), Cape Cod and the Islands (MA), southern Rhode Island, St. John's River Valley (ME), and the Presidential Range (NH).

Several traits are associated with declining species. A disproportionately high percentage of declining species require insect pollination, show localized seed dispersal modes, or reach their northern range boundary in New England.[100] Infrequent species of sandplain grasslands exhibit greater habitat specialization, larger seed size, smaller plant height, less capacity for vegetative (colonial) reproduction, and a tendency toward annual or biennial life history, relative to related common congeners.[101] It is important to note that some rare taxa have always been thus, and have small populations throughout their range regardless of anthropogenic threats; such "sparse" taxa (*sensu* Rabinowitz 1981) can persist stably for many years.[102]

In addition to intrinsic life-history traits that contribute to rarity,[103] there are many external drivers of decline. We compiled a database that scored populations of 81 rare plant species according to the threats identified on existing Natural Heritage field forms.[104] Of the 820 populations for which threats were evaluated, 54 percent had one primary threat, 31 percent faced 2 threats, and 4 percent faced a constellation of 4–5 challenges. Overall, the top four threats to these populations of rare species were succession to a closed canopy, invasive species, trampling, and habitat conversion.

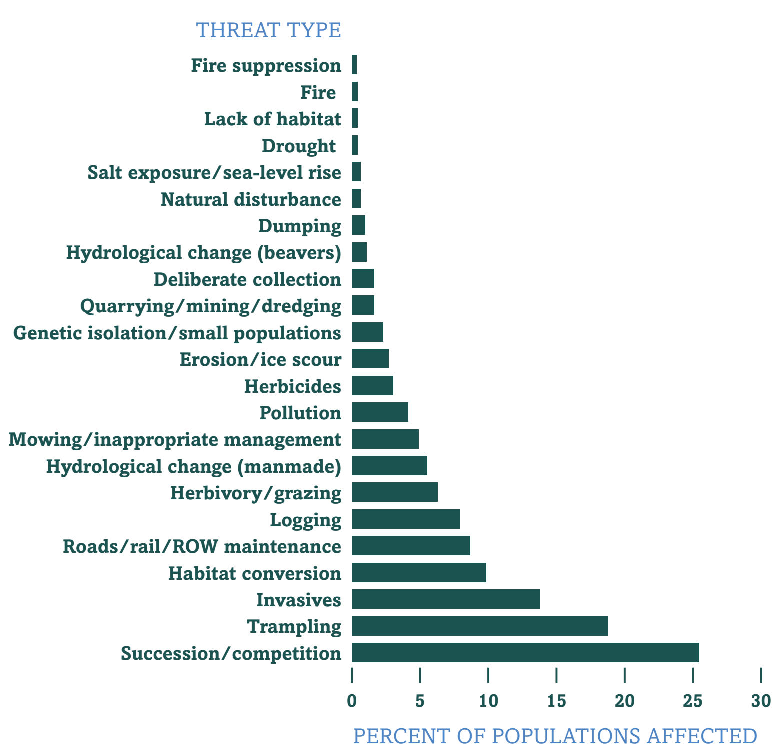
These broad-brush data must be interpreted with caution; observer bias in perceived threats can skew the results, and rarely can a single, unambiguous threat be identified. For example, although invasive species co-occur with rare plants at nearly half of sites, and populations of rare taxa in proximity to invasives show higher (but statistically insignificant) rates of population loss, decline is best explained by the same habitat variables that are associated with invasive species presence, rather than by the presence of invasives alone.[104] Thus, invasive species are both a direct threat and a symptom of larger landscape variables that influence the persistence of rare species.[105] Population decreases are most frequently the product of many stressors acting synergistically.

Threats also vary by the type of habitat in which a species occurs. We classified the rare (*Flora Conservanda* Divisions 1 and 2[44]) plant taxa as belonging to one or more categories of habitat, to explore whether certain habitat types had high frequencies of rare taxa. The habitats with the largest number of rare species were forests (including closed-canopy deciduous and coniferous forests and woodlands), river and pond shorelines, and sites modified by human activity (including roadsides, rights-of-way, fields, clearings, etc.).

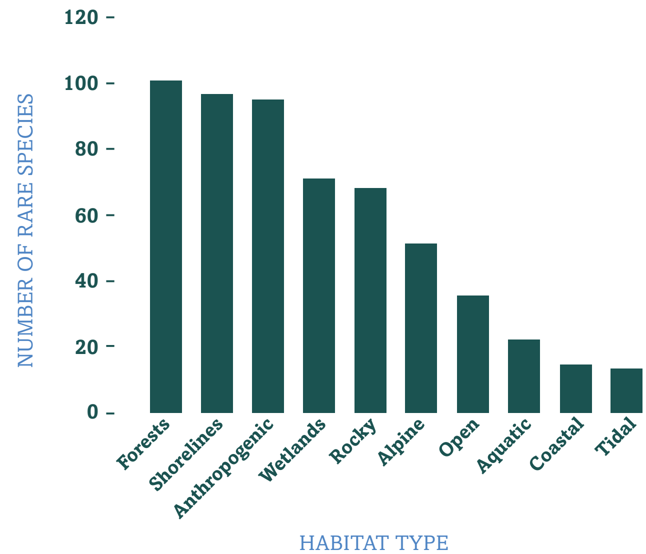
Comparing the 2012 and 1996 *Flora Conservanda* data,[44] we asked whether species showing declines in total numbers of populations were associated with particular habitats. Overall, declining species were most frequently associated with open sites such as meadows and fields; river and pond shores; and rocky habitats such as cliffs, balds, and scree, with trends varying across states.

Many *Flora Conservanda* species showed increases in the number of recorded populations between 1996 and 2012,[44] particularly those of forests and wetlands. These apparent increases likely were due to enhanced survey effort and new discoveries of previously unknown populations in the intervening years, rather than actual range expansions. Many of these "new" populations were discovered via concerted searches recommended by NEPCoP Conservation and Research Plans.[42] Likewise, targeted ecoregional inventories (such as those carried out by the Maine Natural Heritage Program on newly opened public lands) have revealed many previously unrecorded occurrences. However, some species may be exhibiting actual range expansions in New England, with disjunct populations representing new incursions;[106] this may be especially true for species that can readily colonize disturbed sites. Interpreting these apparent increases should be done with caution in the absence of comprehensive presence-absence data.

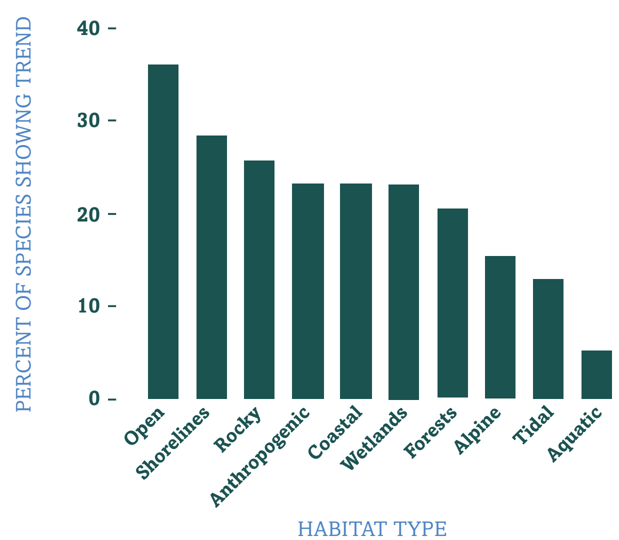
Threats to Rare Plant Populations



Percent of 820 rare plant populations threatened by a given stressor



Number of rare plant species occurring in one or more of ten general habitat types



Percent of rare plant species exhibiting declines in numbers of populations between 1996 and 2012, shown by the habitat type(s) they occupy

>>> Looking Ahead: The Challenge of Climate Change

Despite decades of research, the impacts of all these synergistic climate change factors on plants and habitats are very difficult to predict.

Mounting evidence indicates irrefutably that the globe is undergoing rapid climate change as a result of increasing greenhouse gas emissions due to anthropogenic activities, including fossil fuel production and use, agriculture, industry, transport, and construction.[107] Atmospheric CO_2 concentrations are higher than they have been in 800,000 years[107] (global mean 399.6 ppm) and are increasing by an average of 2.1 ppm/yr.[108] Other greenhouse gases, including CH_4 and N_2O, are also increasing.[107] Global temperatures are tightly correlated with greenhouse gas concentrations; global sea-plus-terrestrial temperatures have risen an average of 0.85°C (1.7°F) from 1983 to 2012,[107] and 2014 saw the warmest year on record since 1880.[109-110] Rates of warming are higher at high latitudes, including the northeastern United States, where mean annual temperatures have been rising at nearly 0.3°C (0.5°F) per decade since 1970, and winter temperatures have risen at a rate of 0.7°C (1.3°F) per decade.[111]

Changes associated with global warming are already occurring in the northeastern United States, including more frequent days with temperatures exceeding 32°C (90°F), a 71 percent increase since 1958 in very heavy precipitation events, more intense but less frequent snowstorms, earlier breakup of winter ice and concomitant earlier spring floods, and rising sea level.[111] These changes are projected to become more extreme if greenhouse gas emissions are not significantly curtailed: increased summer and fall droughts, a halving duration of the winter season, and a sea-level rise of up to 1 meter by 2100 are all predicted outcomes from a business-as-usual scenario (and an unusual 128 mm spike in sea level occurred in 2009-10 along the northeast coast of North America, due to changes in oceanic currents that models predict will become more frequent).[112] These predictions cannot yet account for uncertainty around potential system feedbacks (such as a spiraling increase in methane emissions from melting permafrost) or rapid regime shifts (such as a spike in sea-level rise caused by massive melting of the Greenland or West Antarctic ice sheets),[107] but the possibility exists that unprecedented and seriously damaging changes to human and natural systems could occur within a generation.

Despite decades of research, the impacts of all these synergistic climate change factors on plants and habitats are very difficult to predict. Thousands of experiments have exposed individual plant species to elevated CO_2, artificial warming, or both;[113] and many more open-chamber field studies have documented responses of multiple associated species.[114] Other studies have compared the present-day phenology of plant species to temporal patterns of flowering and fruiting indicated by herbarium specimens, presenting evidence that some plants flower significantly earlier now than in the past, whereas other species are not as responsive.[32]

Although individual and species-level responses to climate change are highly idiosyncratic, several generalities emerge from meta-analyses and reviews of plant functional groups. Since most plants depend on photosynthesis to produce sugars and grow, they are sensitive to the concentration of carbon dioxide in the atmosphere. For example, plants that use different photosynthetic pathways (i.e., C_3, C_4, CAM) will respond differently to elevated CO_2 in terms of growth and water-use efficiency; C_3 species may respond more positively than other species that are not as limited in their ability to process carbon, provided sufficient soil nutrients are available.[116] Species that can fix nitrogen from soils, such as legumes, may show enhanced growth rates (but not necessarily final biomass) in elevated CO_2.[116] Certain non-native species may show enhanced positive responses to elevated CO_2, temperature, and precipitation relative to native species; the effects seen in experiments to date are particularly strong for non-native aquatic species.[117]

Obviously, appropriate caveats must be issued regarding differences in experimental methodology, the tendency of experiments to address only a few interacting factors (i.e., CO_2, temperature, and/or nutrient availability).

But the overall point is that there will be "winners" and "losers" as the climate changes, plants are likely to adapt and/or migrate at different rates, and plant communities will therefore change over time. As the body of scientific literature grows, so does our ability to issue hypotheses about the future composition of New England's flora.

A more general approach considers which natural community types, with suites of characteristic species with common life histories and selection pressures, will be most vulnerable to warming, other climatic changes, and sea-level rise.[16] Several models indicate that forests of the Northeast, for example, will experience disproportionate tree species loss compared to other regions of the country.[118-9] A regional assessment of habitat vulnerability recently evaluated 13 broad northeastern habitat types for their respective vulnerabilities to climate change, considering their position within the regional range (and extent of that range), the degree of cold-adaptation exhibited by dominant species, sensitivity to extreme climatic events and maladaptive human interventions, intrinsic adaptive capacity, dependence on hydrology, sensitivity of foundation or keystone species, likelihood of mitigating climate impacts, and the extent to which climate interacts with other stressors.[120] Among the habitat types considered most susceptible are: Appalachian spruce-fir forest, alpine tundra, montane spruce-fir forest, boreal peatlands (bogs and fens), and the southern reaches of northern hardwoods forest. Considered less vulnerable are: central oak-pine forest, pine barrens, marshes, shrub swamps, and northern Atlantic Coastal Plain Basin swamps.

The aforementioned analysis did not consider coastal or estuarine systems. However, a similar assessment of Maine habitats[121] concluded that a high percentage of threatened and endangered plant species of coastal systems would be moderately or severely imperiled by climate change: fully 95 percent of open water taxa, 90 percent of rocky coastline taxa, and 83 percent of estuarine marsh taxa would be at risk. Ninety-eight percent of already rare alpine taxa and 85 percent of rare riparian species would be similarly affected. More than 90 percent of fungi and lichens and nearly 50 percent of all vascular plants reviewed were deemed highly vulnerable to climate change. The top three reasons for such vulnerability were a high degree of habitat specialization, a highly fragmented range, and barriers to dispersal. An analysis of Massachusetts habitats similarly concluded that brackish marshes, as well as spruce-fir forests, wetlands, and small coldwater lakes, would be highly vulnerable to climate change resulting from either a doubling or tripling of ambient CO_2.[16]

A high percentage of threatened and endangered plant species of coastal systems will be moderately or severely imperiled by climate change

>>> From the Mountains to the Sea: Case Studies of Plants and Habitats

The Natural Heritage programs in New England recognize hundreds of ecological community types,[19-21] broadly distributed between palustrine (wetland), terrestrial (upland), and estuarine environments.[48,122-126] The distinctions among ecological communities can be subtle, reflecting a shift in dominance of only a few plant species. Likewise, communities can grade into each other or overlap in complex ways. It is also important to recognize that these assemblages are not static entities; through processes of succession and disturbance, many communities are continually in flux. Nevertheless, robust classification systems have now been developed for all of North America and much of the rest of the world.[20-21]

In a series of case studies, we focus on five broad habitat types (each supporting numerous ecological communities) that span the New England landscape from the region's highest mountains to the coast. We chose these to capture a range of community types from high to low elevations, wetland and upland, mesic and xeric, and rich to poor soils. In these communities, we also see suites of threats that operate across much of the New England landscape, which suggests that coordinated action would potentially benefit multiple communities at once. Thus, although not an exhaustive survey of all ecological communities, these case studies yield insights into the overall state of the plants and how their prospects can be improved.

ALPINE AND SUBALPINE ZONES

48 rare plant species are associated with alpine areas such as that on Mt. Katahdin (ME). Krummholz in the foreground grades to alpine meadow (mid-slopes) and felsenmeer at the summit. *Photo: Aaron Ellison*

Unlike the mountainous West, New England boasts few mountains tall enough to exhibit a treeline with tundra near the summit.[127] Mount Katahdin (ME), portions of the Presidential Range (NH), and Mounts Mansfield (VT), Abraham (ME), Saddleback (ME), Camel's Hump (VT), and others exceed 1,200 meters in elevation, with wind-exposed, rocky summits subject to frost-heaving and long, harsh winters. Certain smaller mountains, such as Mt. Monadnock (NH), exhibit an artificial treeline created by historical overgrazing and fire, but also contain important occurrences of alpine communities.[128]

In New England, climatic treeline occurs at ca. 1,500 meters. Most often, alpine habitat can be found above this elevation. Subalpine areas (and occasionally alpine tundra) can occur at lower elevations (typically between 900–1,500 meters) as a result of wind exposure, poor soil development, or recent fire history. Subalpine habitat is intermediate between alpine tundra and high-elevation spruce-fir forest and is characterized by open rocky balds and stunted spruce, fir, and birch trees (krummholz). These lower-elevation subalpine areas are generally small and support fewer alpine-restricted species.[129]

Although alpine communities occupy far less than 1 percent of New England's land area, they contain many unique and rare plant species that can withstand challenging climatic conditions. These plants exhibit specialized adaptations, such as cushion or prostrate growth forms, hairy or leathery leaves that resist desiccation, and fast reproductive cycles optimized for the short growing season.

Rare Plants. Alpine habitats are limited in extent in New England, so many of their characteristic plant species are considered regionally rare. Overall, 48 globally or regionally rare plant species occur in alpine and subalpine habitats. At least 60 taxa are listed as rare or historical by one or more New England states.[122] One, Robbins' cinquefoil (*Potentilla robbinsiana*), is a global endemic known only from Mount Washington in New Hampshire. This diminutive member of the Rose family had been documented in only two locations; a 0.5-hectare site contained 95 percent of the total world's population. A popular hiking trail known as the Crawford Path ran directly through this population. Plants were trampled underfoot and hundreds were poached by collectors. In 1996, the plant was listed as Federally Endangered.[130] Staff of the U. S. Fish and Wildlife Service and the White Mountain National Forest and members of the Appalachian Mountain Club constructed a scree wall to shield the population, diverted the trail, and began an intensive public education effort. Meanwhile, New England Wild Flower Society developed protocols for germinating seed and propagating the plants. Transplants were used to augment the two existing populations and to establish satellite subpopulations at four additional sites.[131] Today, more than 14,000 plants inhabit the original site, with 300 others reproducing at a site at Franconia Notch. The species was officially de-listed in 2002. Other notable rare plants with very restricted distributions include mountain avens (*Geum peckii*), known only from the White Mountains and two sites in Nova Scotia; *Nabalus boottii* (Boott's rattlesnake-root); and *Solidago leiocarpa* (Cutler's goldenrod).[127] The alpine zone of New England represents the southern range limit for a number of arctic plants.[127]

Common Plants. Alpine communities grade from felsenmeer (frost-fractured, barren summits that support only lichens) to dwarf shrublands of *Diapensia lapponica* (cushion-plant) and low-growing, ericaceous shrubs in wind-driven zones, to sedge meadows dominated by Bigelow's sedge (*Carex bigelowii*) that intergrade with dwarf heathlands of moss-plant (*Harrimanella hypnoides*), black crowberry (*Empetrum nigrum*), and alpine bilberry (*Vaccinium uliginosum*). Lower alpine elevations are dotted with scattered, gnarly balsam fir (*Abies balsamea*) and black spruce (*Picea mariana*) called krummholz. Ravines may support thickets of mountain alder (*Alnus viridis*).

Other Species Supported by This Habitat. Spruce-fir krummholz is home to the rare Bicknell's thrush (*Catharus bicknelli*) and American pipit (*Anthus rubescens*), as well as other coniferous forest specialists such as spruce grouse and blackpoll warblers.[132] Krummholz also provides protective cover for small mammals such as shrews, rock voles, bog lemmings, and snowshoe hares;[127] and the American marten reaches the southern limit of its range in the Presidentials of New Hampshire.[132] Larger mammals such as black bear, moose, and lynx forage near treeline. Several rare insects occur in areas with Bigelow's sedge, including the White Mountain Arctic (*Oeneis melissa semidea*) and White Mountain fritillary (*Boloria titania montinus*), two butterflies endemic to the Presidential Range.[122]

Threats

Climate change. True alpine habitats span only approximately 34 square kilometers in the Northeast,[133] and their small extent makes their persistence in the New England landscape precarious. As such, a major concern is that changing climate, with predicted lower amounts of precipitation falling as snow, earlier and longer growing seasons, and summer drought,[134] may facilitate recruitment of low-elevation species that will outcompete high-elevation species;[135-6] likewise, alpine specialists may not be able to adapt to changing weather patterns.[133] Although alpine communities have remained relatively stable during the past 9,000 years,[137] there is new evidence that both shrubs and trees are becoming more abundant in alpine zones, while forbs and graminoids are declining slightly in Maine[138] and the Adirondacks.[139]

Air pollution. Increasing aerial transport of ozone, plus nitrogen deposition, may exacerbate the stress of climate change. Many alpine plant species are already at the limits of their physiological tolerances and are strongly nutrient-limited in these environments. Changes in nitrogen input may result in altered allocation between roots and shoots and disrupted mutualisms with mycorrhizae, on which many alpine species are heavily dependent.[140] Acidic precipitation has also been a significant driver of conifer mortality, as it leaches calcium from needles and makes them more susceptible to desiccation.[141]

Reproductive limitation. Changes in phenology in response to climate change may create a temporal mis-match between plants and their pollinators, particularly species with patchy or limited distributions.[142-3] Pollen limitation could reduce plant fitness, erode levels of genetic diversity in isolated popu-

New England Wild Flower Society team monitoring rare alpine plants on Mt. Washington. The Society and partners also restored populations of Robbins' cinquefoil (*Potentilla robbinsiana*) on the mountain, resulting in the first removal of a plant from the Federal Endangered Species List.

Although alpine communities have remained relatively stable during the past 9,000 years, there is new evidence that both shrubs and trees are becoming more abundant in alpine zones, while forbs and graminoids are declining slightly in Maine and the Adirondacks.

lations, and contribute to inbreeding depression. Pollinators themselves, such as the endemic butterflies mentioned above, may be threatened by altered flowering times of their preferred nectar plants. Studies are sorely needed for New England alpine habitats; the few studies documenting plant-insect phenology in other areas indicate that plants and their pollinators (chiefly flies and bees) respond differently to temperature, snow-melt, and day-length cues.[143]

Trampling. A popular destination for recreationists, alpine and subalpine habitats are threatened by trampling on many peaks and ridgelines.[124] Short growing seasons do not allow delicate alpine plants sufficient time to grow following such disturbance; thus, denuded footpaths can take decades to recover.

Large-scale disturbance. Large-scale disturbance can permanently alter community structure in alpine and subalpine zones. Development of ski resorts and construction of wind turbines have reduced cover of privately owned subalpine habitats. Installation of a cog railway from the base to the summit of Mount Washington (1869) and a trench to carry a fiber-optic cable along the same route (2008) disturbed a 5-meter-wide swath of vegetation, which has been slow to recover.[144]

Judicious placement and restriction of trails can steer hikers clear of rare plants and minimize overall trampling of fragile alpine communities. *Photo: Aaron Ellison*

Management Needed to Sustain This Habitat. Climate change poses a serious threat to alpine and subalpine communities, and only national (and international) legislation, initiatives, and incentives to reduce emissions of greenhouse gases and other pollutants will alleviate the problem. On the ground, two strategies are needed: 1) To track the responses of vegetation to climate change and pollutants, permanent transects and plots (such as those already established by the Appalachian Mountain Club) should be expanded along elevational gradients at multiple alpine and subalpine sites.[133] 2) Preserving seed from several populations for restoring populations *in situ* and promoting genetic diversity should inbreeding depression and local extinction occur.[25] Seeds of rare plants are being collected from alpine and subalpine sites by staff and volunteers of New England Wild Flower Society, in collaboration with other organizations.

To address other threats to this community, it is important to carefully route and delineate trails using scree walls, which has proven successful in steering hikers away from fragile plant populations. Many alpine and subalpine habitats are protected from direct anthropogenic disturbance on conservation land, but private landowners and corporate interests with alpine and subalpine holdings should be encouraged to steward their property prudently. Several organizations offer outreach, education, and consulting on habitat management.[145]

MIXED NORTHERN HARDWOODS FOREST

The emblematic forest of New England, these woods—often dominated by sugar maples (*Acer saccharum*)—explode with brilliant fall color. Rich, mesic variants that occur on soils or talus of circumneutral pH or with a deep, moist cover of leaf litter are among the most diverse forests in New England, both in terms of tree composition and understory herbaceous cover. Here, plants benefit from an abundance of water and available nutrients; productivity is high, and older trees can attain prodigious sizes. These rich, mesic forests are most widespread in Vermont[48] but range throughout all six New England states at elevations lower than 800 meters.

Rare Plants. Overall, 48 globally or regionally rare plant species occur in mixed northern hardwoods forests in New England. More than half of the forest-dwelling *Flora Conservanda* Division 1 and 2 taxa are found in rich, mesic forest community variants. With moist, nutrient-rich soils, a sparse subcanopy layer, and deciduous trees that create an early window of blooming time before leaf-out in the spring, these communities have characteristically lush and diverse herbaceous plants on the forest floor. Examples include Alleghany fumitory (*Adlumia fungosa*), black cohosh (*Actaea racemosa*), and Canada sanicle (*Sanicula canadensis*). Ferns such as silvery glade fern (*Deparia acrostichoides*) and Goldie's fern (*Dryopteris goldiana*) may abound. Several state-listed orchid species inhabit this forest, including three-birds orchid (*Triphora trianthophoros*),[146] Hooker's bog-orchid (*Platanthera hookeri*), fall coral-root (*Corallorhiza odontorhiza*), and putty-root (*Aplectrum hyemale*).[147]

Two understory species that have been extensively collected outside New England for their medicinal or culinary value are regarded as imperiled in much of their New England range and beyond: goldenseal (*Hydrastis canadensis*) and American ginseng (*Panax quinquefolius*).[148-9] Harvesting has occurred at several populations of American ginseng in Maine.[150] However, the incidence of over-collecting in all of New England needs further investigation.

Common Plants. The dense canopy of trees is the dominant feature of these forests. Beech (*Fagus grandifolia*), maple, white ash (*Fraxinus americana*) and yellow birch (*Betula alleghaniensis*) are the predominant species, with lesser amounts of basswood (*Tilia americana*) and the uncommon butternut (*Juglans cinerea*). These communities grade into mixed coniferous forests (particularly in the north and in cool, shallow-to-bedrock ravines), but pine and hemlock typically make up only a small percentage of the canopy. In Massachusetts and Rhode Island, these forests may contain higher proportions of oak and hickory species.[123,125] Common understory plants inhabiting mixed northern hardwoods forests include violets (*Viola* spp.), red trillium (*Trillium erectum*), wild sarsaparilla (*Aralia nudicaulis*), starflower (*Lysimachia borealis*), eastern spicy-wintergreen (*Gaultheria procumbens*), partridge-berry (*Mitchella repens*), and bunchberry (*Chamaepericlymenum canadense*). Maidenhair fern (*Adiantum pedatum*), plantain-leaved sedge (*Carex plantaginea*), blue cohosh (*Caulophyllum thalictroides*), bloodroot (*Sanguinaria canadensis*), and wild ginger (*Asarum canadense*) are indicative of richer hardwoods sites. Where trees have been harvested or deer are overabundant, dense swards of hay-scented fern (*Dennstaedtia punctilobula*) or Pennsylvania sedge (*Carex pensylvanica*) can take over the forest understory. Likewise, certain invasive shrubs are increasingly taking the place of the mid-size trees that used to populate the subcanopy (such as flowering dogwood, *Benthamidia florida*, which has declined due to the anthracnose leaf blight[151]). These invasives include winged euonymus (*Euonymus alatus*), Japanese barberry (*Berberis thunbergii*), buckthorns (*Rhamnus* and *Frangula* spp.), and shrubby honeysuckles (*Lonicera* spp.).

Other Species Supported by This Habitat. The expanse of mixed northern hardwoods forest, covering thousands of square kilometers, provides a matrix of habitats for numerous animal species. Many birds depend upon deep interior forests for nesting, including hermit thrush, rose-breasted grosbeak, scarlet tanager, veery, and several warbler species. Mammals with large home ranges—most notably black bears—wander these forests; smaller mammals include shrews, porcupines, flying squirrels, woodland jumping mouse, and red-backed vole. Where vernal pools occur, amphibians such as wood frogs and rare blue-spotted, red-backed, and dusky salamanders are present.[48] The early hairstreak (*Erora laeta*), one of New England's rarest butterflies, is found in northern forests.[124]

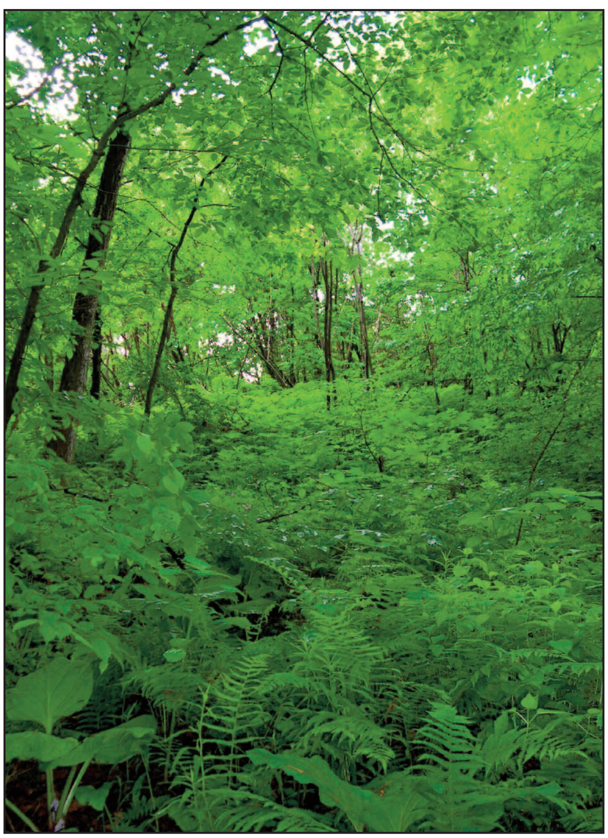
Threats

Clearing. The threats to intact mixed northern hardwoods forests are legion, precisely because their constituent species are of such utility to humans. The soils that sustain these forests are excellent for agriculture and have long been exploited for that purpose. The legacy from a 200-year history of clearing is still reflected in relatively depauperate understories.[88] Today, forests are being cleared again, as markets for timber, biomass fuels, and real estate grow.[15,86] Even where cuts are patchy and small, they can fragment habitat for species that require large, unbroken home ranges, such as forest-interior nesting birds (which are already stressed by reductions in their neotropical wintering grounds)[152] and amphibians dependent on corridors between juvenile and breeding habitats. Cuts can also facilitate the entry and spread of invasive plants, which otherwise would be unable to establish beneath a closed canopy.

Invasive shrubs are increasingly taking the place of the mid-size trees that used to populate the subcanopy.

Three-birds orchid (*Triphora trianthophoros*) is a rare plant of beech-dominated rich forests. *Photo: Arthur Haines*

Forests of all types throughout New England also have been invaded by multiple species of exotic earthworms, which accelerate litter decomposition, disrupt soil fungal webs, and convert forest soils from carbon sinks to carbon sources.



A diverse understory of herbs characterizes this forest on rich soils in Greenfield, MA. *Photo: Elizabeth Farnsworth*

Invasive invertebrates and pathogens. Over the past century, eastern deciduous forests have experienced several invasions by exotic organisms, and dominant species of northern hardwoods continue to be killed in large numbers by invasive insects and pathogens.[153] Dutch Elm disease, chestnut blight, hemlock woolly adelgid, and gypsy moths have decimated tree species and have caused major changes in forest composition. The emerald ash borer, which is expanding eastward rapidly, has killed millions of white ash in the Midwest[154] and is beginning to kill trees in New England. Beech trees are attacked by the *Nectria coccinea* fungus, a pathogen spread by the exotic scale insect *Cryptococcus fagisuga.*[155] Forests of all types throughout New England also have been invaded by multiple species of exotic earthworms, which accelerate litter decomposition, disrupt soil fungal webs, and convert forest soils from carbon sinks to carbon sources.[156] These worms also endanger orchids[157] and other understory plants by physically uprooting plants and by ingesting and burying their seeds, which make nutrients more available to competing species.

Deer. A decline in natural predators and human deer-hunting in the populous Northeast has enabled white-tailed deer to proliferate in the past three decades. Deer densities can reach 15-30 individuals per square kilometer[158] (much higher than the 3-8 per km^2 in colonial times), and deer are exceptionally populous in the rich, mesic forests of western Massachusetts, Connecticut, and Vermont. Deer browse reduces the diversity of understory herbaceous species and hinders tree regeneration;[158-9] some unpalatable species can come to dominate the herb layer.[160] Exclosure experiments reveal that forest diversity recovers slowly after deer are removed, especially if invasive plant species are not simultaneously removed.[161]

Invasive plant species. Although closed-canopy forests would appear to suppress invasions by shade-intolerant shrubs and herbs, recent study has revealed that invasives can penetrate deep into forests[162] or persist for many years following prior disturbance.[89] Invasive species have been intentionally introduced in many areas, have escaped adjacent gardens, and have been spread by frugivorous birds. Invasive plants are particularly prevalent in rich, mesic forests because they exploit the same nutrient-rich soils that support high plant diversity. Many invasive shrubs leaf out early in spring, hampering the ability of spring ephemerals to capture sun and nutrients.[163] Conservation organizations tend to be reluctant to conserve forests in which invasive species are prevalent[164] and may miss opportunities to conserve and restore habitat for rare plant and animal species.[165]

Climate change. Warming, a lengthening of the growing season, and changing patterns of precipitation exert species-specific impacts on native and non-native plants of mixed northern hardwoods forests. Climate-envelope modeling suggests that southern tree species will migrate northward, but these models make somewhat simplistic assumptions regarding the actual habitat affinities and tolerances of species based primarily on where they are currently present (i.e., without systematic data on where they are actually absent)[166-7] and do not account for interspecific interactions.[118] Likewise, more data are needed on the tolerances of other species, such as ants[168] and mycorrhizae, on which plants depend for germination, pollination, seed-dispersal, and nutrient acquisition.

Management Needed to Sustain This Habitat. The ecological integrity of mixed northern hardwoods forests is challenged by synergistic natural and manmade disturbances.[169] Protection of large corridors of matrix forests, along with coordinated management of private and publicly owned woodlots, will help conserve the large-scale resiliency of this system while allowing for continued use of forest products. Recent significant gains in conservation have been made through regional efforts such as the Forest Legacy Program and the Wildlands and Woodlands initiative.[170] Preventing the spread of invasive insects by discouraging the transport of logs, firewood, and other vectors[171] is a high priority, as is the need to identify native parasites or competitors that can reduce populations of invasive insects.[172] Research on forest soil webs is sorely needed to understand earthworm ecology more fully and to mitigate the effects of exotic earthworms.[156] Efforts to cull or reduce fecundity of deer need to be redoubled, and outdated wildlife protection laws (i.e., the Lacey Act of 1900) that prevent deer from being sustainably harvested for food should be updated. Invasive plants are likely to remain permanent members of forests, but their future spread can be reduced by educating the public, encouraging forestry practices that do not promote the invasibility of disturbed understories, and detecting and removing early infestations. Simply removing invasive plants is not sufficient to guarantee recovery of forest communities, however; in some cases, active augmentation of plants such as orchids will be required. It is challenging to predict the future dynamics of trees, shrubs, and herbaceous species of forests in a changing climate, but a better understanding of species' tolerances can be gained by systematically characterizing their actual and realized niches and thoroughly studying their life history.[167] Coordinated work is underway to develop propagation and reintroduction strategies for imperiled species such as orchids[173] and goldenseal.[174]

RIPARIAN SYSTEMS

From tiny seepages to the region's largest waterway (the Connecticut River), streams and rivers course through the New England landscape. Stream banks and river shores foster unique vegetation that is adapted to changing water levels—able to withstand flooding and scour during spring snowmelt and large storms and to endure drier periods that expose plants to desiccation. Riparian communities are divided into two broad groups: river channels, which are dynamic, often high-energy shorelines below the top of the riverbank; and floodplains, which are flat terraces beyond the top of riverbanks.[122] The gradient and sediment size carried by a river or steam are reliable predictors of the vegetation that will predominate. Cobble bars and sandbars of river channels typically support patchy sedges, forbs, and low shrubs that depend on open sites where competing vegetation has been periodically cleared away by floods. Other plants cling not to alluvial sediments but to the faces of river outcrops and cliff gorges in pockets with small amounts of silt or loam.[48] River channel communities themselves can disappear during large disturbance events, only to reappear downstream where new bars form. These plants establish via waterborne seeds or fragments that can lodge and re-root. These ephemeral plant populations form a chain of genetically related subpopulations (demes) that together make up a metapopulation.[175]

Floodplain vegetation, by contrast, tends to be more permanent and lush, often with a canopy of flood-tolerant trees. In northern reaches, balsam fir and balsam poplar (*Populus balsamifera*) can form a semi-open canopy, with dense thickets of speckled alder (*Alnus incana*) or more open understories dominated by ferns.[122] Further south, deciduous trees, often festooned with vines, form the canopy over a carpet of sensitive fern (*Onoclea sensibilis*) and other wetland herbaceous species.[125]

Although we focus on shoreline communities in this report, it is important not to ignore the diverse submerged aquatic vegetation (SAV) that grows beneath the river's surface. River shallows and coves contain rich assemblages of aquatic plants that form the basis of a diverse food web, from algae and diatoms to invertebrates such as snails and juvenile insects, to fish and the birds (and people) that eat them.[176] The composition of SAV beds is heavily influenced by light, substrate, current, temperature, and nutrient availability; thus, SAV is a strong indicator of overall water quality.[177]

Rare Plants. Overall, 44 globally or regionally rare plant species occur in riparian habitats in New England. Two of New England's rarest endemic plants are associated with river shores: Furbish's lousewort (*Pedicularis furbishiae*) and Jesup's milk-vetch (*Astragalus robbinsii* var. *jesupii*). First discovered by botanist-artist Kate Furbish in 1880, Furbish's lousewort was one of the first plants to receive concerted conservation attention in North America, beginning in the 1970s; it is an exemplary case study for understanding the complex phenomena associated with metapopulations. A string of ephemeral demes totaling between 5,000 and 12,000 plants[178] grows along gravelly shores of the St. John River in Maine and New Brunswick. These demes can vary greatly in size from year to year; they persist for a short

Sandbar and cobble bar species such as this willow (*Salix exigua*) require high-energy rivers to eliminate competitors and maintain metapopulations. *Photo: Elizabeth Farnsworth*

Intact floodplains provide flood control and filtering; they also support many rare plant and animal species. *Photo: Elizabeth Farnsworth*

Furbish's lousewort (*Pedicularis furbishiae*, as originally illustrated by Kate Furbish in 1880) is one of New England's rarest riparian species and spurred the first sophisticated genetic studies in conservation biology. *Source: Bowdoin College Furbish Collection*

The edible fiddleheads of ostrich fern (*Matteuccia struthiopteris*) are commonly harvested from floodplains in early spring. *Photo: Elizabeth Farnsworth*

time before ice scouring washes away plants and hurries their seeds downstream, where the plants reestablish and begin the cycle again.[179] In 1987, Furbish's lousewort was one of the first wild plants to be genetically analyzed using then-modern techniques of gel electrophoresis; those pioneering studies revealed that the plant has extremely low levels of genetic variability, reflecting gene flow along with minimal founder effects exhibited by small demes.[180] Further complicating this plant's life history is its dependence on other plants for nutrients during early growth: it is a hemiparasite that must form haustorial connections with host plants to survive.[181] Thus, newly establishing demes must not only settle on appropriate open habitat, but also must associate with other plant symbionts. This requirement, together with extreme habitat specialization and low genetic variability, complicates the prospects for managing or augmenting this rare species. A related species, swamp lousewort (*Pedicularis lanceolata*), shows similar metapopulation dynamics and vulnerability in its more southerly floodplain habitats.[175]

Another rare endemic, Jesup's milk-vetch, clings to outcrops of phyllite schist along the Connecticut River. It is known from only three populations in the world, all in Vermont or New Hampshire, and is listed federally as endangered. Numbers of plants at each population fluctuate from year to year, from only 7 plants at the smallest population to nearly 26,000 at the largest population; actual effective population sizes are likely much smaller.[182] Although a few potential sites with similar habitat have been located and surveyed along the river, none as yet support additional populations.[183] Another rare congener, *Astragalus alpinus* var. *brunetianus*, also inhabits rocky river shores.

Several shrubs pop up on ephemeral river shores, including two willows (*Salix exigua* and *S. myricoides*) and dwarf cherry (*Prunus pumila* var. *depressa*). A globally rare community, poised in a narrow band between the shore of Maine's Saco River and the forested upland, supports an unusual combination of hairy hudsonia (*Hudsonia tomentosa*) and silverling (*Paronychia argyrocoma*); the only other place where this community is known to occur is in West Virginia.[122]

More populations of rare plants may exist in these somewhat inaccessible and under-studied habitats. For example, a concerted search to find a historical occurrence of false mermaid-weed (*Floerkea proserpinacoides*) in 2004 along the Green River floodplain in Franklin County, Massachusetts, led to the discovery or rediscovery of numerous extant occurrences of nine other state-listed plant species (of which seven were new finds for the Green River area), including *Acer nigrum, Carex hitchcockiana, Caulophyllum giganteum, Dryopteris goldiana, Equisetum pratense, Hydrophyllum canadense, Sanicula odorata, Viola rostrata*, and *Geum fragarioides*. Several occurrences consist of multiple subpopulations. Another (unlisted) species, *Carex lacustris*, was documented from Franklin County for the first time. Large, exemplary occurrences were documented of two state-rare (S2) natural community types: high-terrace floodplain forest and cobble bar forest.[184]

Marshes associated with freshwater tidal reaches of rivers are especially productive areas. They are dominated by grasses such as wild rice (*Zizania aquatica*) in high-quality examples and cattails (*Typha* spp.) in lower-quality areas. These communities, considered to be of conservation concern in Connecticut, Maine, and Massachusetts, harbor globally rare species such as Eaton's beggar-ticks (*Bidens eatonii*) and, on flooded flats, tiny Parker's pipewort (*Eriocaulon parkeri*).

Common Plants. Low river channels that stay moist (but not flooded) year-round support abundant forbs, such as cardinal-flower (*Lobelia cardinalis*) and beggar-ticks (*Bidens* spp.), mixed with grasses, rushes, and sedges. Willows and alder become more common away from the scouring forces of the river. Transitioning from low-elevation river edges to higher river terraces, tall meadows of grasses, goldenrods, sedges, virgin's-bower (*Clematis virginiana*), and ferns flourish in the regularly replenished alluvial soils. Higher floodplain terraces support flood-tolerant trees, such as sycamore (*Platanus occidentalis*), red maple (*Acer rubrum*), silver maple (*Acer saccharinum*), box-elder (*Acer negundo*), and eastern cottonwood (*Populus deltoides*).

Growing on rich soils with abundant moisture, some of these trees can reach prodigious sizes. The largely shrub-free understory is dense with herbaceous species; one of particular economic importance is the edible ostrich fern (*Matteuccia struthiopteris*), whose fiddleheads are wild-harvested from many sites along large rivers in the spring. Where high-terrace floodplain forests grade into uplands, they are colonized by upland herbs that enjoy rich soils, such as bottlebrush grass (*Elymus hystrix*), floodplain avens (*Geum laciniatum*), trout-lily (*Erythronium americanum*), and enchanter's nightshade (*Circaea lutetiana* ssp. *canadensis*). Three common species can make it hard-going for botanists in transitional and high-terrace floodplains: poison ivy (*Toxicodendron radicans*), cutgrasses (*Leersia* spp.), and stinging nettle (*Urtica dioica*).

Invasive plant species gain footholds in areas where flood scour is less frequent or where nutrient loading into waterways encourages their growth. Examples include Japanese knotweed (*Fallopia japonica*), purple loosestrife (*Lythrum salicaria*), reed canary-grass (*Phalaris arundinacea*), and common reed (*Phragmites australis*). Moneywort (*Lysimachia nummularia*), forget-me-not (*Myosotis scorpioides*), and glossy buckthorn (*Frangula alnus*) also colonize transitional floodplain forests.[125]

Other Species Supported by This Habitat. River channels and floodplains are alive with wildlife that uses them for breeding, migrating, and hunting. Land adjacent to waterways is used by 85 percent of Maine's vertebrate species, for example.[185] Many rare species of insects spend their juvenile and adult lives in these habitats, including tiger beetles, dragonflies, and damselflies. In Massachusetts alone, 14 state-listed odonate species are recorded from river corridors.[125] Because many insects deposit their eggs directly in river sediments, they are sensitive to pollution; thus, areas with diverse insects are indicative of high-quality, well-oxygenated water buffered by vegetation. Other invertebrates such as snails, clams, and mussels (including the federally endangered dwarf wedge-mussel, *Alasmidonta heterodon*) inhabit shallow shorelines and mid-streams. Three rare species of turtle (wood, Blanding's, and spotted) use shorelines for egg laying, and three rare salamander species (Jefferson's, blue-spotted, and four-toed) breed in the temporary pools of river swales.[125] Raccoons, minks, and river otters prey upon these shellfish and amphibians, as well as fish.

Large riparian corridors are critical flyways for migrating waterfowl,[186] raptors, and other birds. The Connecticut River watershed, for example, contains twenty Important Bird Areas recognized by the National Audubon Society.[187] More generally, river floodplains provide nesting habitat for numerous rare birds, including cerulean warbler, wood thrush, grasshopper sparrow, American woodcock, prairie warbler, and globally significant populations of saltmarsh sparrow.[187] Great blue herons, egrets, and other wading birds spend significant time foraging in river shallows. Bald eagles and osprey use trees along rivers as roosts and hunting platforms for fish.

Threats

Dams and channelization. The largest threats to riparian communities are dams—more than 10,250 of them in New England's waterways. According to state records, there are 3,070 active dams along New Hampshire's rivers (with 840 classified as dangerous),[188] 2,892 in Massachusetts,[189] 1,168 in Maine,[190] 1,304 in Connecticut,[191] 1,200+ in Vermont,[192] and 618 in Rhode Island.[193]

Dams provide an important source of hydropower and are also used to store water for irrigation, human consumption, and flood control. It is well known, however, that they also fragment fish habitat,[194] with ramifications for the entire food web. Dams are designed to dampen the magnitude and duration of flooding events, particularly the spring freshet, which reduces the periodic scouring that removes competitors of rare riparian plant species.[195] By diminishing river overflow, dams also cut off a river's connection with its floodplain, leading to profound changes in nutrient cycling and plant species composition.[196] They also can prevent rivers from naturally meandering and creating new alluvial features such as sandbars—important habitat for certain organisms. Upstream of dams, impoundments lead to

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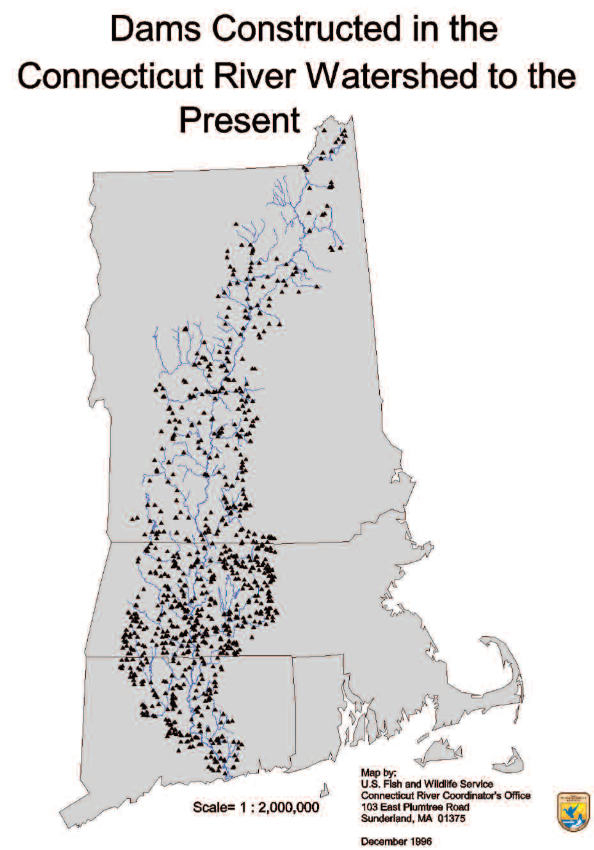

Dams are ubiquitous on the Connecticut River and other New England waterways. *Source: U. S. Fish & Wildlife Service* flooding of low-lying areas, sometimes for extended periods, which can kill upland vegetation. Invasive aquatic plants such as Eurasian water milfoil (*Myriophyllum spicatum*) and Carolina fanwort (*Cabomba caroliniana*) frequently thrive in these sluggish, often eutrophic waters. Lastly, sudden and catastrophic flooding, with destruction of habitat and infrastructure, can occur when aging dams fail.

Related to damming are the (often futile) attempts to stabilize river banks and channelize waterways with the use of riprap and other artificial barriers. By eliminating contact between the river and its shoreline ecotone, these barriers actually increase river speeds and exacerbate flooding downstream.[197] The floodplain ecotone is necessary to slow flows, filter pollution, and trap sediments. A complex shoreline with coarse and fine woody debris creates habitat for fish and other aquatic organisms. De-vegetated shorelines do not offer shade, and water temperatures and algal biomass can increase. Riprap also requires constant monitoring to ensure it does not fail during flood events. In the aftermath of Hurricane Irene in 2011, which brought record floods to the Connecticut River and its tributaries, river shores were bulldozed, riprapped, and channelized, especially in hard-hit areas of the Berkshire foothills and Vermont.[198] Installation of all these impervious surfaces may have the unintended effect of worsening floods in the future.

Clearing. The fertile alluvial soils of floodplains have long been exploited for agriculture. Spring floods continually replenish these soils, making them ideal for moisture-demanding crops. Removal of forests that would ordinarily buffer rivers has increased large-scale nonpoint pollution of rivers by fertilizers and pesticides running off agricultural fields and feedlots. Eroding soil also increases sedimentation and turbidity. Increased housing development on river banks further destabilizes shorelines and contributes pollutants from yards and septic systems. Today, few intact floodplain forests remain in southern New England (more remain in Maine), and many are affected by logging and trail-clearing activities that make them susceptible to invasion by non-native plant species.[125] In New Hampshire, most remaining examples of floodplain forests are smaller than 12 hectares in extent.[122]

Pollution and dumping. Floodplains often become dumping grounds for trash, yard waste, boat ballast, tires, and hazardous materials. Each year, for example, the Connecticut River Watershed Council rallies scores of volunteers for the annual "Source-to-Sea Clean-up" in MA, CT, NH and VT. In 2013, more than 2,200 volunteers pulled over 40 metric tons of trash from 222 kilometers of waterways.[199]

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Our waterways receive the pesticides, fertilizer, oil, gasoline, and other pollutants in the runoff from agricultural fields, golf courses, lawns, and impervious surfaces. Combined sewer overflows (CSOs) in more than 100 New England communities deliver hundreds of millions of liters of bacteria-laden waste into waterways during moderate to severe rain events.[200] These pollutants are, in turn, washed into riparian communities, contributing to declining soil quality and plant and animal mortality.

Likewise, industrial pollution has notoriously fouled New England's waterways with polychlorinated biphenyls (PCBs) and numerous other poisonous chemicals. Although federal legislation through the Clean Water Act has stemmed much of this outright pollution, harmful chemicals such as chromium, PCBs, and mercury are still being detected in fish and other aquatic animals. This contamination results from both new inputs and reworking of old river-bottom sediments that were formerly polluted.[201]

Management Needed to Sustain This Habitat. Recognizing that aging dams pose a danger to water quality, biodiversity, and human life and property, efforts are underway by several agencies to remove those with crumbling infrastructure and to install fish ladders where possible. In 2012 and 2013, two massive dam removals on the Penobscot River in Maine (Great Works and Veasie), fish stocking, and installation of a fish lift brought national attention to the possibilities of restoring thousands of contiguous kilometers of habitat for plants and anadromous fish while still maintaining energy production.[202] Dams also have been removed recently on the Green River (MA), Wells River (VT), Ashuelot River (NH), and Salmon River

(CT).[203] Although natural reestablishment of riparian communities will take years, new projects are underway to actively restore floodplain forests. One such ambitious tree-planting project is being guided by The Trustees of Reservations along the Housatonic and Connecticut rivers in Massachusetts.[204] Likewise, alternative methods of stabilizing banks are being developed, involving bioengineering, hydroseeding to promote rapid revegetation (with native plants), and the construction of "logjams" that naturally trap sediments.[197] Agencies such as the Connecticut River Joint Commissions and Massachusetts Water Resources Authority are working to inventory and fix problem CSOs, resulting in a reduction of pollution by over 1 billion gallons a year.[205] In Maine, more than $430 million has been spent by municipalities to abate CSOs, reducing inputs by 53 percent since 1989.[206] In New Hampshire, the cities of Portsmouth, Manchester, Nashua, Lebanon, Berlin, and Exeter have also significantly reduced CSO pollution.[207] Industrial pollution has declined considerably in New England rivers since the 1970s, and formerly poisonous waters are now deemed clean enough for boating and swimming. Concerted programs to monitor water quality exist throughout New England, many fueled by the energy of citizen-scientists.[208] Volunteer teams continually work to clean polluted river shores, but broader public education and incentives are needed to discourage people from dumping. Ultimately, the best way to sustain riparian habitats for all organisms is to conserve and restore shorelines, establish clear buffers, and protect water quality. Because waterways do not respect state boundaries, this must be a multi-state effort. With respect to conserving rare riparian plants, efforts by New England Wild Flower Society and partners are underway to find suitable habitat for some of New England's rarest riparian species, such as Jesup's milk-vetch, and to establish new populations at these sites while augmenting existing populations.

SANDPLAIN GRASSLANDS AND HEATHLANDS

Leaving the moist environs of riparian habitats, we turn our attention to comparatively dry places: the grasslands and heathlands that grow on New England's sandplains. As the name implies, sandplains are defined by their excessively well-drained sandy soils, which are typically acidic and nutrient poor. Some sandplains are further shaped by small, incised streams that create moist gullies in the otherwise dry, friable soil;[48] these occasionally foster vernal pools and pockets of white pine-oak forest. Generally, however, sandplains support a "barrens" vegetation characterized by sparse, xerophytic trees with tough needles or leaves and a ground layer of drought-resistant grasses, forbs, and shrubs. Much of this vegetation is also adapted to fire, with the ability to resprout following a burn and, in some species, with serotinous fruits that release seeds when stimulated by burning.

New England has two forms of sandplain: inland and maritime. Inland sandplains most commonly occur on deltas and outwash plains that formed during deglaciation. Noteworthy examples include Montague Sandplain (MA)[54] and Waterboro and Shapleigh Barrens (ME).[55] Some also occur on dunes that winds have reworked over the last 13,000 years (an inland dune system occurs near the Connecticut River in Whately, MA, for example, a remnant of the shore of Lake Hitchcock).[54] Maritime sandplains form near coastlines and on glacial outwash at the southern margins of glacial retreat; plants in those closest to the sea may be influenced by salt spray and coastal winds.

Sandplains are rarest in Vermont, where they occur at the confluence of the Lamoille and Winooski rivers with Lake Champlain.[48] They are also infrequent in New Hampshire, where they occur in the vicinity of Ossipee, Concord, and the Merrimack River Valley.[122] Sandplains have been greatly reduced in extent in Connecticut[126] and New Hampshire[129] and occur mostly in remnant patches of 5 ha or less in Rhode Island[123] and Massachusetts.[54]

Rare Plants. Due to their relatively limited extent, primarily along the coastal plain, sandplain habitats contain a disproportionately high number of rare and specialized plant species. Overall, 52 globally or regionally rare

Overall, 52 globally or regionally rare plant species occur in sandplain habitats in New England. Twelve taxa are listed as globally rare (a proportion second only to salt marshes).

New England sandplains support 10 globally rare plant species and many rare insects. *Photo: Elizabeth Farnsworth*

Northern blazing-star (*Liatris novae-angliae*) occurs only in New England sandplains. *Photo: Paul Somers*

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Sandplain gerardia (*Agalinis acuta*) is listed federally as endangered; it is known only from Connecticut, Rhode Island, Massachusetts, Maryland, and New York. Another species, northern blazing-star (*Liatris novae-angliae*), is endemic to New England and New York. Vermont lists 26 species, some with more northerly affinities, and others that reach the northern edge of their range.[48]

Several species share affinities with prairie vegetation, such as purple milkweed (*Asclepias purpurascens*) and short-awned rice-grass (*Piptatherum pungens*).[125] Wild goat's-rue (*Tephrosia virginiana*), bird's-foot violet (*Viola pedata*), butterfly weed (*Asclepias tuberosa*), and wild lupine (*Lupinus perennis*) are other state-listed species of sandplains.

Common Plants. Sandplains support several vegetation communities, ranging from open grasslands to heathlands to open-canopy pine-oak woodlands. Open grasslands are dominated by little bluestem grass (*Schizachyrium scoparium*), Pennsylvania sedge (*Carex pensylvanica*), and poverty grass (*Danthonia spicata*). Forbs include wild yellow indigo (*Baptisia tinctoria*), a legume with the ability to fix nitrogen from otherwise infertile soils. Bracken fern (*Pteridium aquilinum* ssp. *latiusculum*), goldenrods (*Solidago* spp.), American-asters (*Symphyotrichum* ssp.), pinweeds (*Lechea* spp.), bastard-toadflax (*Comandra umbellata*), and white-grained rice grass (*Oryzopsis asperifolia*) are also reliable indicator species of sandplain grasslands, especially where they co-occur. Scattered shrubs may also occur here in patches. Vascular plant richness is highest in early-successional open grasslands relative to more closed-canopy communities.

Heathlands contain higher densities of shrubs, particularly in the "heath" family (Ericaceae), including bearberry (*Arctostaphylos uva-ursi*), lowbush blueberry (*Vaccinium angustifolium*), and black huckleberry (*Gaylussacia baccata*). New Jersey tea (*Ceanothus americanus*), small bayberry (*Morella caroliniensis*), and sweet-fern (*Comptonia peregrina*)—all nitrogen-fixing plants—can also occur here, along with stunted scrub oak (*Quercus ilicifolia*).

Woodlands consist of a patchy canopy of pitch pine (*Pinus rigida*) and tree oaks such as scarlet oak (*Quercus coccinea*), red oak (*Q. rubra*), and black oak (*Q. velutina*).[48] White pine (*Pinus strobus*) and, in northern and more mesic forests, red maple (*Acer rubrum*) can also appear in the mix. The partially shaded understory is dominated by shrubby heaths, wintergreen (*Gaultheria procumbens*), and hazelnuts (*Corylus* spp.); herbaceous plants are typically not as rich here.

Other Species Supported by This Habitat. Sandplain communities are especially notable for the diversity of insect species they support, many of which are rare. Six rare moths and butterflies frequent Massachusetts sandplain grasslands, and two rare beetles occur in heathlands in Massachusetts.[125] Sixteen rare lepidopteran species inhabit a grassland owned by Camp Edwards military base on Cape Cod (MA),[209] and 56 species dependent on grasslands have been listed for southern New England and New York.[210] Fully 364 species of insects (19 state-listed) have been documented from the Waterboro and Shapleigh Barrens in Maine.[211] Wild lupine (*Lupinus perennis*), a characteristic species of these habitats, is an important host plant for the federally endangered Karner blue butterfly (*Lycaeides melissa samuelis*), as well as for the frosted elfin (*Incisalia irus*) and Persius duskywing (*Erynnis persius*). These butterflies have very specialized feeding preferences for legumes found only in these habitats.

Sandplain communities are especially notable for the diversity of insect species they support, many of which are rare.

In addition, several uncommon bird species feed on abundant insects and nest in sandplain environments, including savannah sparrow, horned lark, upland sandpiper, grasshopper sparrow, vesper sparrow, and pine warblers.[48] Birds of prey such as short-eared owls, snowy owls, kestrels, and northern harriers hunt meadow voles, jumping mice, short-tailed shrews, and white-footed mice. Camp Edwards is also home to the rare New England cottontail rabbit.[209] Rare reptiles and amphibians include black racer, Eastern box turtle, and Fowler's toad.[209]

Threats

Habitat conversion. The vast majority of sandplain barrens have been converted to urban and suburban uses throughout New England. Located on well-drained soils, sandplains have been subject to conversion to pastures, hayfields, and other types of cultural grasslands. They have also been used for cemeteries, airports, and military bases. A historical reconstruction of sites along the Connecticut River Valley in west-central Massachusetts, for example, documented the loss of thousands of hectares of pitch pine-scrub oak forests and the urbanization of 47 percent and farming of 14 percent of the total area of xeric outwash soils.[54] Pitch pine was extensively harvested for its fuelwood and timber.[54] Sand-mining, grazing, and charcoal production have also taken their toll.[212]Agricultural activities on sandplains further north were not as widespread, but have involved planting of blueberries and other crops.[54] Wholesale clearing of forests for agriculture also created many new grasslands and heathlands, particularly near the coast; however, these novel communities probably bore little resemblance to pre-colonial grasslands.[85] Tillage farming greatly altered the soil profile, creating a distinct plow layer (A_p horizon) that continues to influence the plants that establish on it.[54] Since agricultural abandonment, plant species that were formerly common in intact pine-oak forests, such as scrub oak and huckleberry, have been slow to recolonize these altered soils. A mixture of pitch pine and white pine has come to predominate.[54]

Lack of fire. Fire has long been identified as the major natural disturbance that maintains sandplains in an early-successional phase. The leaves of many sandplain shrubs contain highly flammable volatile compounds, and other species, such as pitch pine, require fire to open their cones or are adapted to readily resprout following a burn. Evidence from inland barrens suggests that spontaneous fires may have been widespread in the pre-colonial era, with some fires severe enough to remove the organic soil layer (O horizon).[54-55] Other analyses from coastal areas suggest that open grasslands were not widespread and that natural fire did not play a significant role in originally structuring these communities. Rather, burning practiced by colonial settlers in the 1600s to mid-1800s may have driven sandplain forests to shift to open grasslands and shrublands.[85]

Although the sandplain assemblages we see today are likely quite different from ancient communities, they still support some of the highest concentrations of rare plant and animal species in the Northeast and are the focus of major conservation concern.[213] Due to fire-suppression policies instituted since the mid-1900s, these communities are transitioning to forest. Such succession may eliminate the conditions needed to sustain sun-demanding plants such as wild lupine, and the organisms, such as the Karner blue butterfly, that depend upon them. Encroachment of trees has reduced heathland cover on Cape Cod by 63 percent since 1962, for example.[214] Hence, prescribed burns are recommended and used for these areas, but this management tool is difficult to implement in densely populated areas.

Invasive species. Many invasive plant species are well adapted to colonize disturbed areas, so they readily invade open grasslands and some woodland understories. Scotch broom (*Cytisus scoparius*), cypress spurge (*Euphorbia cyparissias*), spotted knapweed (*Centaurea stoebe*), Japanese knotweed (*Fallopia japonica*), and Oriental bittersweet (*Celastrus orbiculatus*) regularly occur in sandplain areas.[215] Weedy, cool-season grasses that are remnants of the agricultural past, such as sweet vernal grass (*Anthoxanthum odorata*), sheep fescue (*Festuca ovina*), velvet-grass (*Holcus lanatus*), and Kentucky bluegrass (*Poa pratensis*), change the physiognomy and phenology of sandplain grasslands.[125] A recent survey of coastal southern New England revealed that open grasslands and heathlands, especially those with calcium-influenced and post-agricultural soils, harbor significantly larger cover and richness of invasive species than closed forests on poorer soils (i.e., outwash, not fine-textured, lacustrine soils).[215] The ability of these species to competitively exclude native and rare sandplain species has not been explicitly quantified, but each invasive is known to alter community composition in other contexts.

Since agricultural abandonment, plant species that were formerly common in intact pine-oak forests, such as scrub oak and huckleberry, have been slow to recolonize these altered soils. A mixture of pitch pine and white pine has come to predominate.

Management Needed to Sustain This Habitat. The best way to conserve these communities is to protect and manage the remaining large examples to the extent possible. High-quality sandplain communities consist of mostly native plants, including rare forbs, graminoids, shrubs, and a patchy canopy of native trees. Some of the best remaining examples of sandplain communities are protected on large military bases. For example, the sandplain of Fort Devens in eastern Massachusetts has been noted as unusually rich in plant species (857 taxa) growing on 2,700 ha,[216] and the 5,800-ha Camp Edwards complex on Cape Cod contains 11 rare plant species.[209] Camp Edwards in particular is working to foster open grasslands by creating types of disturbances, such as mowing and controlled burning, which sustain these early-successional communities. In New Hampshire, The Nature Conservancy has used a combination of controlled burning and mechanical treatments since 2005 to manage the Ossipee Pine Barrens.[217-8] Biologists from the Rhode Island Department of Environmental Management are successfully working to establish populations of *Agalinis acuta* in restored sandplain on RI Audubon land and other properties.[219] And in Maine, The Nature Conservancy is using fire rotations, mowing, and thinning to reduce duff and open canopies in the Waterboro Barrens Preserve.[220]

Not all management strategies are created equal, however, and rare plant species differ in their affinities for fire lanes, plowed areas, and intact forest.[221] Certain rare species exhibit traits, such as limited seed dispersal, that impede their ability to recolonize a site following management.[221] Likewise, artificial disturbance can open large areas that can be invaded by nonnative species before the native vegetation recovers.[215] In areas suitable for prescribed burns, the timing of fire application is important. Fires conducted during the dormant season or in early spring (when moisture is abundant and fires easier to control) are generally less effective at clearing existing vegetation and improving soil conditions that certain rare species require. Although summer burns can better expose mineral soil, they are logistically difficult to conduct and extinguish. In populous areas where controlled burning is not an option, a combination of tree-clearing followed by active reseeding has successfully restored sandplain grasslands and shrublands.[222-3] Mowing and grazing have also been employed with some success.[224] In general, it may be necessary to employ multiple management methods, on a rotational basis, to maintain a rich mosaic of communities in varying stages of succession.

Another approach is to create *new* sandplain communities in habitats with appropriate edaphic conditions. Recent modeling has identified many areas on Martha's Vineyard (MA) with features conducive to supporting new grasslands and heathlands.[225] Establishing new communities adjacent to existing communities can buffer them and create corridors between isolated patches. Since many sandplain assemblages are already manmade formations, it is reasonable to consider actively creating new ones.

Estuarine marshes are home to plants specialized for saline and hypersaline conditions. Changing hydrology and nutrient loading create opportunities for species like Phragmites (tall grass, left) to invade. *Photo: Elizabeth Farnsworth*

ESTUARINE MARSHES

At the interface between land and the sea lie some of the most productive ecosystems in the world: estuarine marshes.[226] Globally, estuarine marshes are most abundant on the eastern seaboard of North America, extending from the Gulf of Mexico to the Gulf of St. Lawrence, reaching their northerly limit in Labrador.[227] They occupy low-lying zones at river mouths and behind spits and barrier beaches that are protected from high-energy wave action. These systems perform critical ecosystem functions, including fixing carbon at high rates, trapping and building sediments, filtering pollutants, buffering uplands from storms and tidal surges, contributing nutrients to marine communities, and providing habitat for economically important fish, shellfish, and many other animals.[228]

Marshes form amidst a complex interplay of tides, river currents, sea-level fluctuations, and storms. In New England, the majority of marshes have been aged at about 3,000 to 4,000 years;[226] it is thought that they accreted during a post-glacial period of relatively slow rates of sea-level rise (that rate being a balance between glacial melt, which caused sea level to rise, with isostatic rebound of the land recovering from the weight of glaciers). The capacity of estuarine marshes to keep pace with predicted future sea-level rise is, thus, of great concern.

Estuarine marshes are a diverse matrix of low marsh, which floods twice daily with tides, and high marsh, which floods infrequently and has embedded salt pannes and pools. At their seaward edge, they grade into mudflats and subtidal eelgrass beds.[125] All plants must cope with at least intermittent flooding and show adaptations for aerating their porous rhizomes during periods of soil anoxia, sequestering or excluding salt, and conserving fresh water in their leaves.[227] As a result, many plants of estuaries, particularly those found at lower intertidal zones, are highly specialized and found only in these habitats. Some of these species also inhabit freshwater tidal zones.

The capacity of estuarine marshes to keep pace with predicted future sea-level rise is of great concern.

Rare Plants. Overall, 21 globally or regionally rare plant species occur in estuarine habitats in New England. All coastal New England states list several plant species that occur in brackish and saline marsh communities, including mudwort (*Limosella australis*), eastern grasswort (*Lilaeopsis chinensis*), saltpond pennywort (*Hydrocotyle verticillata*), American sea-blite (*Suaeda calceoliformis*), estuary arrowhead (*Sagittaria montevidensis*), and river arrowhead (*Sagittaria subulata*).[125] The diminutive estuary arrowhead is one example of the types of rare plants that inhabit these changeable habitats. In its sandy shore and mudflat habitats, it is often completely submerged at high tide and exposed at low tide; changes in hydrology and increased sedimentation can kill plants.[229] Attaining heights of only 4-18 cm, this annual plant can be overtopped by other vegetation, especially where invasive species colonize the marsh. The species is restricted to a narrow coastal band from North Carolina to New Brunswick, where it reaches a northern range limit.

Overall, 21 globally or regionally rare plant species occur in estuarine habitats in New England.

Common Plants. Estuarine marshes are physically structured by their component plant species, whose roots stabilize substrate and whose dead tissues contribute to peat accumulation over time. These habitats thus tend to show characteristic zones of vegetation. At the upper reaches of estuarine marshes, where salinity is lower (oligohaline zones), shrubs such as maritime marsh-elder (*Iva frutescens*) and forbs such as Carolina sea-lavender (*Limonium carolinianum*) gain a foothold on older deposits of peat, topped by soil transported from the upland. To seaward, salt-tolerant grasses, such as saltmarsh hay (*Spartina patens*) and smooth cordgrass (*Spartina alterniflora*), capture sediments amidst a tangle of root and stem fibers, which form layers of peat that accumulate over time. Saltmarsh hay thrives best in a belt between the forb-dominated oligohaline zone and the salinity-stressed lower marsh.[230] Dominating the lower marsh, *Spartina alterniflora* has a very plastic growth form depending on its position relative to tidal inundation: a tall (1.5-2.5m) form in lower reaches of the marsh and a short (0.5-1m) form in shallow, wet pannes on the high salt marsh.[231] Where sea-level rise is not rapid enough to destabilize growing vegetation, phalanxes of *Spartina* spp. gradually grow outward, colonizing sand, mudflats, and rocky outwash to seaward.

High and low salt marshes exhibit patch dynamics.[230] Tides, especially those driven by storms or abetted by ice rafts in winter, heft quantities of wrack onto the marsh. Existing plants smother under the weight and shade of these pockets of dead plant material, and bare mud is exposed when the tide takes away the debris. Evaporation proceeds rapidly in these bare areas, and the soil quickly becomes hypersaline relative to the rest of the marsh. However, new ruderal plants, capable of subsisting on the hypersaline substrate, will establish here: the grass *Distichlis spicata* and the halophytic succulents, common glasswort (*Salicornia depressa*) and orache (*Atriplex acadiensis*), are typical new recruits in these areas. The seeds of the latter two are often transported in the wrack itself. These species ameliorate soil conditions by shading, reducing evaporation, and taking up and processing salt. In turn, they facilitate the later colonization of these areas by other forbs such as seaside goldenrod (*Solidago sempervirens*) and graminoids such as saltmarsh rush (*Juncus gerardii*). Thus, an estuarine marsh is a diverse and changeable mosaic of species. Increasingly in the past three decades, however, another colonial grass has come on the scene, altering marsh dynamics: the very tall (4m) and invasive common reed (*Phragmites australis*).[232]

Submerged aquatic vegetation also grows in high marsh deep water pools and beds of wider creeks, and is stranded on mudflats exposed at low tide. Species with an affinity for upper estuaries with more freshwater input include horned pondweed (*Zannichellia palustris*), Sago pondweed (*Stuckenia pectinata*), and tapegrass (*Vallisneria americana*). In deeper, saltier waters, eel grass (*Zostera marina*) and widgeon grass (*Ruppia maritima*) may form dense beds growing alongside macroalgae (seaweeds). *Zostera marina* (eelgrass) is an important primary producer in near-shore ecosystems such as the Gulf of Maine, providing both habitat and nutrients for a variety of organisms including crustaceans, polychaetes, gastropods, and fish.[233]

Ditching, poor culverting, and impoundments alter tidal flow and hamper flushing of estuarine marshes.
Photo: Elizabeth Farnsworth

Other Species Supported by This Habitat. Plants are not the only important organisms in estuarine marshes. It was long thought that so-called "bottom-up" drivers such as nutrient inputs (these are highly nutrient-limited systems) and hydrology were the primary influences on marsh structure.[226-7] Although nutrient availability does profoundly shape marsh plant composition, recent studies of plant-animal interactions reveal that top-down, consumer-driven processes also exert important and complicated pressures on the flora. Periwinkle snail species (*Littorina* and *Littoraria* spp.)[234] can attain prodigious densities, particularly in the low marsh zone. Some of these snails forage on algae, combing rocks and other hard substrates and preventing soil buildup in the rocky intertidal zone, and thus precluding pockets of marsh grasses from establishing. Others forage on *Spartina* stems, using their radulas to wound the grass and introduce a fungus (*Phaeosphaeria spartinicola*) on which they feed (the only known example aside from arthropods of an invertebrate "farming" a fungus).[236] This behavior causes injury or death of *Spartina* stems and undermines the stability of the grass along creeks. Other marine animals, such as fiddler crabs, however, can directly facilitate *Spartina* growth, preying on herbivorous snails and digging burrows in the mud, aerating it much as earthworms do in forest soils.[236]

Indeed, estuarine marshes support numerous species of invertebrates, including mussels, crabs, and both common and rare snails (the latter such as New England siltsnail [*Cincinnatia winkleyi*] and the coastal marsh snail [*Littoridinops tenuipes*]).[125] The crabs and fish that prey on these species form the basis of a critical coastal fishery; 75 percent of commercial fish, shellfish, and crab species in Rhode Island depend on estuaries for their primary habitat, spawning grounds, and nursery areas.[237] Mammals also make forays into estuarine marshes, seeking mussels and other invertebrates. White-footed mice and meadow voles forage on marsh grasses, including the invasive common reed.[238]

Many birds, including osprey, northern harrier, short-eared and snowy owls, snowy egret, American oystercatcher, black-crowned night-heron, least bittern, laughing gull, least tern, and glossy ibis use the open expanses of salt marshes as hunting grounds for insects, fish, and mammals. Willets, seaside sparrows and salt-marsh sharp-tailed sparrows also nest in these habitats.[125,132] Snow geese, whose populations have expanded markedly during past decades, congregate in northern marshes and can cause significant mortality as they grub among the grasses.[239]

An estimated 37 percent of estuarine marshes across New England have been lost; in Rhode Island, 53 percent of coastal marshes have been filled to enable development.

Threats

Historical conversion and manipulation. Ever since pilgrims landed on the New England coast, the region's salt marshes have been extensively exploited for fodder (salt marsh hay), converted to agriculture, and lost to port development and urbanization. An estimated 37 percent of estuarine marshes across New England have been lost; in Rhode Island, 53 percent of coastal marshes have been filled to enable development.[240] Past efforts to control marsh hydrology have involved diking, culverting, draining, and ditching. Such manipulations deprive marshes of the tidal flushing that would normally help to control mosquitoes (by favoring their primary predator, killifish) and encourage the expansion of oligohaline invasive species such as common reed.[232] One-fifth of the marsh area of the Gulf of Maine (stretching from Cape Sable, Nova Scotia to Cape Cod) exhibits restricted tidal flow, and the majority of marshes have been ditched.[241]

Die-back. In the mid-1970s, salt marshes began to decline on Cape Cod (MA) and die-back has since spread to Narragansett Bay (RI), Long Island Sound (CT, NY), and the southeastern United States.[243] More than 80 percent of Cape Cod's marshes have already been affected, and the annual rate of die-off expansion there is nearly 3 percent.[243] Such die-back is due to the loss of the cordgrass foundation species, leading to erosion of peat and subsidence of substantial amounts of marsh area. Cordgrass mortality results from a complex trophic cascade involving the population explosion of *Sesarma reticulatum*, an herbivorous crab that creates extensive burrows in ditched areas. Activities such as overfishing and dumping (which affects water quality) are depleting populations of the predatory fish that would normally keep *Sesarma* numbers in check. *Sesarma* feeds heavily on cordgrass roots, undermining their already tenuous hold and destabilizing banks. *Sesarma*-caused die-back is particularly prevalent around marinas, dredged boat channels, and other areas where recreational fishing is popular. A study of 24 southern New England marshes showed that areas lacking docks and other fishing infrastructure supported twice the biomass of natural *Sesarma* predators, much lower densities of crabs, and significantly less die-back.[242] As southern New England marshes are increasingly impacted by overfishing and pollution, the rate of die-back is predicted to accelerate.[242] This and other runaway herbivore effects on coastal plants threaten not only estuarine marshes, but also seagrass beds and rocky shorelines across the western Atlantic.[243]

Nutrient loading. Estuarine marshes are inherently nutrient-limited systems, and constituent plants respond quickly and dramatically to exogenous inputs of nitrogen and phosphorus. Eutrophication is linked to upland development adjacent to marshes, which increases sewage loads and run-off from impervious surfaces. The capacity of marshes to store nitrogen protects estuaries from damaging algal blooms and hypoxia.[244] Marsh plants receiving high levels of nutrients are more vulnerable to herbivory.[244] They also tend to allocate more biomass above-ground and thus contribute less root matter to the buildup of peat.[243]

Eutrophication also favors invasion of common reed, which efficiently capitalizes on nutrients, exhibits an extended growth phenology,[245] and quickly outcompetes shorter-statured marsh plants.[232] Although *Phragmites* has been present in coastal marshes for three millennia or more, an invasive haplotype (*Phragmites australis*) has invaded both freshwater and brackish marshes throughout North America, largely replacing the native haplotype (*Phragmites americanus*).[246] Its spread has also been facilitated by activities that have contributed to the decline of *Spartina* spp. and by hydrological diversions that disrupt tidal flooding and allow more freshwater to influence the marsh. In addition to reducing plant diversity, common reed changes marsh geomorphology—accumulating litter, elevating the marsh above the water table, and accelerating freshwater evaporation through transpiration.[247]

Climate change. Global ambient carbon dioxide concentrations have risen 1.5 percent since 2010 and are continually increasing.[248] Global climate change is already manifesting itself in rising air and water temperatures[134] and rising sea levels (rates have doubled in the 20th century relative to the past five centuries, and an unusual rise of 128 mm was noted in 2009-10 in the Northeast).[111-2] Data on coastal storm frequency and severity have not demonstrated clear trends in the past century; however, strong storm surges are exacerbated by rising sea level.[249] All of these factors will exert complex influences on estuarine marshes.

A recent analysis of habitat vulnerability to climate change used data on sea-level rise to predict that, although salt marshes may increase in certain coastal areas, high marshes are expected to disappear as they are overtaken by more halophytic vegetation.[16] It is unknown how well or how rapidly marshes can keep up with sea-level rise by expanding inland, however. As that report acknowledges, coastal geomorphology and sediment accretion rates vary widely among sites; and in many areas, estuarine marshes are constrained from expanding into already developed uplands, even in regions that are sparsely populated.[244] Thus, both high and low marshes may be imperiled by sea-level rise.

An in-depth analysis that mapped and surveyed more than 9,000 ha of Maine estuarine marshes calculated that 11 percent of the land area en-

One-fifth of the marsh area of the Gulf of Maine exhibits restricted tidal flow, and the majority of marshes have been ditched.

More than 80 percent of Cape Cod's marshes have already been affected, and the annual rate of die-off expansion there is nearly 3 percent.

countered by marshes "migrating" inland to keep pace with simulated sea-level rise of 1.0 meter is developed land (i.e., buildings, impervious surfaces, roads). This infrastructure would impede the establishment of new marsh area (even assuming upland migration could keep pace with the rate of sea-level rise). At the simulated rise of 1.0 m, it would take more than 2,360 hectares of land to fully accommodate expanding and migrating marsh area.[250] The majority of non-tidal lands needed by migrating marshes is not currently protected from development.

A recent analysis of habitat vulnerability to climate change used data on sea-level rise to predict that, although salt marshes may increase in certain coastal areas, high marshes are expected to disappear as they are overtaken by more halophytic vegetation.

Rising air temperatures, together with an extended growing season, may promote the productivity of certain species of estuarine plants while challenging others. Experimental warming treatments in Rhode Island and Maine salt marshes, for example, stimulated a significant increase in plant productivity.[251] However, higher temperatures worsened the already stressful, hypersaline conditions of salt pannes, which resulted in local extirpation of specialized salt panne species such as *Triglochin maritima*, reducing overall marsh diversity. Although elevated carbon dioxide can also spur plant productivity in both the short and medium terms[252] (including increasing the productivity of invasive common reed[253]), only long-term experimental work that examines synergistic effects of rising sea level, elevated greenhouse gas concentrations, and disturbance regimes will yield reliable predictions of long-term responses of marsh systems to multiple stressors.

The effects of warming waters on estuarine communities are, so far, little studied. However, recent reports of a substantial increase in sea-surface temperatures in the Gulf of Maine[254] highlight the urgent need to better understand influences on water temperature and the implications of a sustained temperature rise on algal blooms, red tide, and the growth and survivorship of marsh plants and animals (particularly fish and invertebrates).

Damage to estuarine marshes can also result in feedbacks that could hasten climate change. Salt marsh die-back is releasing carbon that had been sequestered in these systems for more than two centuries.[255] Disturbances like trophic cascades, eutrophication, and oil spills can convert marshes from carbon sinks to carbon sources.[251]

Management Needed to Sustain This Habitat. Once a complex habitat is damaged, it is very difficult to restore original functioning. All five coastal New England states have estuarine marsh restoration programs, and new techniques for restoring eelgrass beds are also being developed.[256] Many attempts have been made to restore degraded marshes, with mixed outcomes. The least ambitious marsh projects involve digging new channels or expanding culverts to increase the tidal flushing of upper marshes. In some cases, such as Little Mussachuck Creek (Barrington, RI), volunteers have teamed up with professionals at conservation organizations to perform this arduous work; they have successfully restored hydrology and have observed a recovery of native marsh vegetation.[237] In other cases, such as at Sachuest Salt Marsh (Middletown, RI), the restoration required the Army Corps of Engineers using massive equipment to install large culverts. To address large-scale damage to marshes from hurricanes or sediment-dumping, a multi-year effort is needed.[237] More controversial methods aim to mitigate salt marsh subsidence by spraying a fine layer of dredged sediments onto the marsh surface.[257] Surveys of some restored marshes in Rhode Island have demonstrated recovery of killifish and other indicator species.[258] A review of 20 years of salt marsh restoration in Connecticut found that recovery was most rapid in areas with lower elevations, greater hydroperiods, and higher soil water tables. However, recovery of associated birds, fish, and invertebrates was far slower than that of the vegetation.[259]

Once a complex habitat is damaged, it is very difficult to restore original functioning.

Although hydrological processes can eventually recover following such projects, biological processes can take years to rebound.[241] Consistent use of metrics and methods for data-gathering, plus widespread accessibility of such data sets, are necessary to understand whether these projects are successfully restoring degraded habitats. Anecdotes and research articles abound, but meta-analyses are lacking because techniques vary so widely among projects and studies. Ultimately, it remains problematic to define what is meant by "success" in restoration unless baseline conditions are well established and precise goals can be articulated.[260]

Likewise, removing invasive species such as common reed takes more than simply cutting vegetation; frequently, repeated removal and active replanting of native species are necessary.[261-2] A meta-analysis of 40 years of *Phragmites* management in North America revealed that few projects consistently monitor or assist vegetation recovery; the majority of such projects take place at small scales and do not consider the landscape-scale drivers of invasion, such as nutrient loading.[263] Controlling nutrient inputs to estuarine marshes is best accomplished by buffering and reducing the upland sources of these pollutants at large scales.[244]

Salt marsh die-back is a more difficult issue to address. Research indicates that declines in the populations of normal fish predators of *Sesarma* crabs has enabled the crabs' populations to explode.[242] Reversing this decline will entail imposing limits on recreational fishing and pollution in proximity to marshes, an almost impossible policy to enforce. Public education should be enhanced by incorporating information on the ramifications of overfishing into recreational fishing guides.[264] It is also imperative to better understand the dynamics of predators that control *Sesarma* populations and conditions that limit crab herbivory on cordgrass.

CONCLUSION: STATUS OF HABITATS IN NEW ENGLAND

We have highlighted five broad ecological communities and the conservation challenges they face. There are, of course, dozens of habitats in the region that harbor many ecological communities and unique and rare plant and animal species that merit conservation attention, including bogs, coastal plain ponds, fens, rocky balds, glades, and submerged aquatic systems. However, our analysis of five focal terrestrial and wetland habitats captured 213 of the plant taxa categorized as globally rare, regionally rare, or regionally declining in the *Flora Conservanda* 2012 update (see full list for each state in Appendix 3). We used data from NatureServe Explorer to count the total number of North American states and provinces in which each taxon occurs and the number in which it is listed as of conservation concern; from these numbers, we could estimate the percentage of jurisdictions in which a taxon is listed—an index of its overall rarity. A summary of these taxa reveals several patterns and calls attention to the habitats and constituent plant species that are most threatened in the region and throughout their range (Table 3).

Table 3. Distribution of rare plants among habitats and their rarity status outside New England

Habitat type	Total number of globally or regionally rare plant taxa*	Number (%) globally rare, Division 1	Mean number (mean % of total) states/provinces outside New England in which species are ranked S1-S3, SH, or SX, followed by the mean number of states outside New England in which species occur
Alpine and Subalpine Zones	48	4 (8.3%)	3.4 (31.6%) of 13.9
Mixed Northern Hardwoods Forest	48	5 (10.4%)	7.8 (33.5%) of 24.8
Riparian Systems	44	9 (20.5%)	7.6 (45.4%) of 21.5
Sandplain Grasslands and Heathlands	52	12 (23.1%)	6.7 (42.9%) of 20.1
Estuarine Marshes	21	6 (28.6%)	5.6 (39.2%) of 19.1
TOTAL	**213**	**36 (16.9%)**	**6.2 (38.5%) of 19.9**

**Flora Conservanda* 2012 Divisions 1, 2, and 3a (declining throughout New England range)

All rare species in these habitats are listed in at least one other state or province and on average are listed in more than one-third of the states and provinces in which they occur outside New England.

Habitats are in trouble. Sandplain grassland and heathland habitats show the largest absolute number of both regionally and globally rare taxa. Estuarine marshes have the fewest number of rare taxa overall (reflecting lower species richness in general in these stressful habitats), but a high percentage of these (28.6 percent) are globally rare. Riparian species are imperiled in the highest percentage of the states and provinces outside New England in which they occur (45.4 percent), followed closely by sandplain grassland and heathland species. Alpine and subalpine taxa generally show the smallest overall average range sizes (13.9 states/provinces), and are imperiled throughout one-third (31.6 percent) of their extra-New England ranges.

Plants are not just rare in New England. All rare species in these habitats are listed in at least one other state or province (mean = 6.2 jurisdictions) and on average are listed in more than one-third (38.5 percent) of the states and provinces in which they occur outside New England. Thus, their rarity in New England is indicative of their somewhat precarious status throughout their range. The fact that these species are imperiled across a considerable swath of their ranges points to widespread challenges to their continued survival.

Each New England state has dozens of rare and declining plant species in these habitats. Massachusetts has the largest number of state-listed species, followed by Maine and New Hampshire (Table 4). By taking a broad ecological approach to protecting, sustaining, and restoring these and other habitats, it may be possible to conserve many species simultaneously.

Table 4. Number of plant taxa in each state in Flora Conservanda Divisions 1-3a, across the five habitat types

State	Division 1: Globally rare	Division 2: Regionally rare	Division 3a: Declining	Total
CT	13	58	4	75
MA	18	78	4	100
ME	18	70	1	89
NH	16	65	1	82
RI	13	51	3	67
VT	14	64	1	79

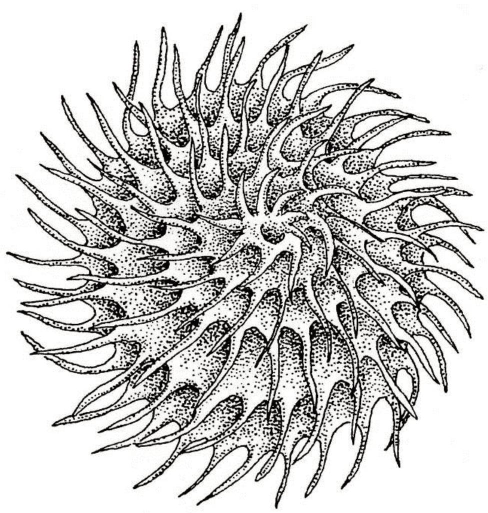
Certain plant families are at special risk. Among the plant families with large numbers of rare taxa are the Cyperaceae (32 species), Poaceae (26), and Asteraceae (22). This finding accords with other botanical inventories[34-37] and in part reflects the fact that these families are generally speciose (Cyperaceae [195 total taxa in New England], Poaceae [315], and Asteraceae [388][45]). Other plant families, however, show disproportionately high percentages of rare or declining taxa, including the Ophioglossaceae (60 percent of all known New England taxa in the family), Orobanchaceae (41 percent), Saxifragaceae (43 percent), Orchidaceae (36 percent), and Gentianaceae (32 percent).

Multiple threats impinge on habitats. These threats include: development (habitat conversion); altered hydrology; invasive species (and exploding native species such as deer); nutrient loading and other pollution; lack of necessary ecological disturbances such as fire or water fluctuations; and disrupted mutualisms between plants and their associated pollinators, mycorrhizae, and seed dispersers. Indeed, most of these threats influence *all* of these communities and many more ecological systems, often working synergistically to impair ecosystem functioning and induce trophic cascades. Strategies for addressing most of these threats are well known, albeit at times politically difficult and expensive to implement. Nonetheless, mitigating identified threats in advance of significant impacts from a changing climate will help restore or ensure resilience and biological diversity.

Climate change affects many habitats. Looming over all these issues is the impact of global climate change, including a warming climate, sea-level rise, and altered weather patterns. Humans are on the cusp of major and largely unpredictable planetary shifts; the evidence that such changes are underway is everywhere and undeniable.[134] Intensive research, proactive management, protection of resilient habitats, and vigorous regional and global policy steps will all be necessary to address and mitigate threats; actions taken to stem large-scale problems can positively affect multiple community types simultaneously.

Other plants must be proactively considered. Although *Flora Conservanda* has yielded comprehensive information on globally and regionally rare vascular plant taxa, there are many more species that are listed as rare or declining in portions of New England (Appendix 3) and elsewhere in their range (Division 3a per *Flora Conservanda*[11]). These declining taxa should be taken into account when planning management and conservation of their habitats.

Not just vascular plants are affected. Non-vascular plants (mosses, liverworts, and hornworts) play important roles in habitat formation and maintenance; consider, for example, the *Sphagnum* moss species that are foundations of bogs and fens, creating substrate and microenvironments for establishment of other plants and habitats and nest materials for insects[265] and other animals. These non-vascular, photosynthetic organisms contribute significantly to carbon sequestration[266] and biodiversity, yet have received little attention in global conservation efforts. Although some 2,400 taxa have received conservation ranks nationwide at NatureServe, only New Hampshire and Vermont as yet have developed these ranks for any bryophyte taxa. Vermont's Bryophyte List and Atlas, developed by botanist Dorothy Allard for the Vermont Natural Heritage Inventory, is unique in its comprehensive coverage of the non-vascular plants of the state.[267] It not only provides a checklist of species, but also assigns conservation ranks to these taxa.



Not just vascular plants are affected. Non-vascular plants (mosses, liverworts, and hornworts) play important roles in habitat formation and maintenance.

Recommendations

Although plants are the cornerstones of terrestrial ecosystems on earth, their status and fate receive far less attention (and research funding) than those of animals. Recent global status reports have been issued for hundreds of species of birds,[268] thousands of mammals, birds, reptiles, amphibians,[269] and fish,[270] and hundreds of insect pollinator species.[271] Some of these reports take a habitat-based approach to predicting rates of extinction for animals; for example, the 2013 assessment of breeding birds in Massachusetts identifies "winner" and "loser" species associated with forests, agricultural lands, shrublands, wetlands, etc.[272] It is imperative to recognize that conservation of all these species will be possible only by conserving the plant communities and their constituent species, landscape features, and ecological processes, which together comprise these "habitats."

It is imperative to recognize that conservation of all these species will be possible only by conserving the plant communities and their constituent species, landscape features, and ecological processes, which together comprise these "habitats."

However, global or even regional compendia of rarity and extinction statistics for plants are comparatively few,[273] and the few that exist are sobering. For example, a global analysis based on models of species-area relationships for vascular plants predicted that reduction of plant habitat by year 2050 (largely due to agricultural expansion to feed a burgeoning human population) will result in a loss of global vascular plant diversity ranging from 7 to 24 percent relative to 1995.[274] This means a loss of 25,000–85,000 species worldwide, assuming a global total of species at ~350,000.[275] With continued levels of botanical discovery and taxonomic effort, an estimated additional 10-15 percent of species remain to be discovered; however, recent patterns suggest that discoveries are overwhelmingly likely to be of rare taxa with small ranges concentrated in highly imperiled ecosystems throughout the world.[275]

To address biodiversity loss, the Convention on Biological Diversity has developed a Global Strategy for Plant Conservation, with goals to be achieved by 2020.[276] Ironically, the United States is one of only three nations worldwide that have *not* signed on to the Convention.[277] However, in an encouraging development, the latest (2012) National Fish, Wildlife, and Plants Climate Adaptation Strategy[278] is the first to explicitly include plants. Its recommendations dovetail with those of the Global Strategy, and both provide frameworks for conservation action in New England.

We offer four primary recommendations for conserving plants and habitats in New England.

1. Research, document, and understand New England's plant diversity

Recent research, publications, and collaborative efforts provide robust documentation of the plant diversity of New England and take important steps toward meeting two of the three targets of the Global Strategy in this area: an online flora and an assessment of the conservation status of known plant species. The publication of New England Wild Flower Society's *Flora Novae Angliae* (2011)[45] and its development of Go Botany,[46] an online identification key and infrastructure for continually updating the *Flora,* together fulfill the important goal of understanding the current distributions of the region's 3,514 plant taxa. The Society, Natural Heritage programs, and other members of the NEPCoP network have assembled some of the best current data in North America on the distribution of rare plants in New England. *Flora Conservanda: New England* (2012)[11] stands as the region's most comprehensive and current assessment of the status of 593 regionally and globally rare plants. However, the report also makes it clear what we do not know: there are 53 taxa that are presumed rare but for which we have insufficient information to know for sure (Appendix 4). Of these, 19 are subspecific taxa (subspecies or varieties) with possibly uncertain taxonomy or that may be overlooked in the field due to their close resemblance to related taxa. We should thoroughly search for these taxa to ascertain their true status on the landscape.

The United States is one of only three nations worldwide that have not *signed on to the Convention on Biological Diversity.*

In general, more research on rare plants and ecological communities is sorely needed. Basic autecology and life history information is lacking for the majority of rare species in New England, let alone the thousands of common species.

Research needed includes:

- plant-pollinator relationships
- plant symbionts such as mycorrhizae and host plants
- limits to reproductive output
- genetic diversity within and among populations
- seed dispersal mechanisms
- protocols for successfully storing seeds, taking into account dormancy and germination dynamics
- competitive and facilitative interactions with other plants
- plant-herbivore interactions
- minimum viable population sizes and means of estimating population viability
- threats to individuals and populations
- methods for restoring and managing populations
- searches for historical populations of rare plants (those not seen for at least 20-25 years)
- genomic studies to determine physiological stress responses and adaptability in plants[115]

These topics alone provide fodder for hundreds of potential theses and doctoral dissertations, not to mention field studies by professionals and dedicated independent botanists. Students can collaborate with conservation agencies, delivering valuable data while gaining professional experience.[279] Simple field observation can yield much knowledge, but the scope of research needed to inform conservation and management decisions will take significant funding.

Efforts to manage plant populations also need to be structured as controlled experiments whenever possible in order to yield meaningful data on their success or failure, with consistent methods of objectively characterizing the results.[258] Too often, monitoring of outcomes of activities such as invasive species removal continues for one growing season or less[263] (although notable exceptions exist[261]). These outcomes also need to be publicly available—published in peer-reviewed, open-access formats or online forums—to enable others to learn efficiently and to build a body of field-tested techniques. Many reports on management trials languish in filing cabinets.

There is little comprehensive information about how much area of particular habitats has been lost in New England, except in distinct zones such as estuarine marshes that can be readily traced in aerial photographs.[240] The area of "natural" habitat (with little direct human influence) in the temperate zone is projected to remain relatively stable over the coming 50–100 years, although the range of temperate deciduous forests is predicted to decline due to increased land conversion and the effects of climate change, with concomitant declines in plant diversity.[280] Forest area has increased in the past century (although regional declines are noted since 1950), but these novel forests are not comparable in plant diversity to their predecessors. To reverse an old maxim, forests must be seen for their trees to fully understand whether they are truly functional and resilient. Only long-term, careful on-the-ground monitoring[281] will elucidate how forest recovery is truly faring.

Basic information on the local adaptations and ecology of plants is also required before devising plans for reintroduction of plants or assisted migration in the face of climate change. Conservation organizations are beginning to ponder the efficacy of moving plants to new ranges where they will be apparently less vulnerable to warming temperatures and pathogens and can overcome barriers to natural migration.[282] These measures appear proactive, but are controversial[284] because of the unknown ramifications of scrambling ecological communities and introducing new species outside their current range (possibly even fostering invasions).[284] Current predictions of the responses of plant species to climate change are based on imperfect models of their current climate envelopes and tolerances.[167] A look back into the Holocene record shows that certain species colonized quickly after deglaciation, whereas others did not (oaks did not take over Vermont during the Hypsithermal, for example);[62] modern-day responses are likely to be as

Simple field studies have revealed new information about the reproduction, herbivores, and population dynamics of rare plants such as *Calystegia spithamaea*. *Photo: Elizabeth Farnsworth*

The scope of research needed to inform conservation and management decisions will take significant funding.

Only long-term, careful on-the-ground monitoring will elucidate how forest recovery is truly faring.

The actual climatic tolerances and limits to dispersal of plant species need to be assessed scientifically before decisions to move them are finalized.

species-specific as in the past. The actual climatic tolerances and limits to dispersal of plant species need to be assessed scientifically before decisions to move them are finalized. Assisted gene flow (rather than translocation) may be a more viable strategy, provided that outbreeding depression is avoided and the mechanisms of local adaptation and diversification are understood.[285]

2. Urgently conserve plant diversity

The Global Strategy for Plant Conservation articulates several targets relevant to New England: protecting at least 75 percent of threatened species *in situ* and *ex situ*; conserving, effectively managing, and/or restoring 15 percent of "ecological regions or vegetation types"; managing and preventing biological invasions; and ensuring that 75 percent of production lands (agriculture, forestry) are managed sustainably.

Save threatened species. Clearly the highest priority for rare plants is ensuring their survival on the landscape, through management of threats and, where appropriate, augmentation or restoration of populations. As noted earlier, coordinated actions by NEPCoP partners have resulted in the delisting of the endangered species *Potentilla robbinsiana*,[24] and efforts to manage habitat for an endangered orchid, *Isotria medeoloides*, have helped one of its largest populations rebound substantially.[286] Hundreds of management and monitoring actions prescribed by the Society's Conservation and Research Plans[42] have enabled many plant populations to recover from stresses such as competition with invasive species.

That said, global and national initiatives to collect and store seeds from both rare and common plants are critical to conserving plant diversity in the long term. The botanical community has collaborated on developing systematic protocols for seed collection and storage, with goals of capturing as large a proportion of the flora as possible while avoiding risks to the reproductive potential of rare plant populations.[283] New England Wild Flower Society has a two-pronged, region-wide seed banking effort: collecting and banking genetically diverse seeds of 100 percent of the region's rare and endangered plants by 2020 (a $5 million initiative), and banking seeds of common plants for habitat restoration projects and to produce genetically diverse, local provenance plants for horticultural purposes. These efforts dovetail with large-scale, coordinated seed-banking programs like the Millennium Seed Bank Partnership[288] (Royal Botanic Gardens, Kew) and Seeds of Success[289] (U. S. Bureau of Land Management), in which the Society is a partner.

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Protect, manage, and/or restore sufficient land to ensure plant diversity. A recent global survey of 109,000 plant species indicates that it is theoretically possible to protect the full range of 67 percent of known plant species (and part of the ranges of 81 percent) by conserving approximately 17 percent of terrestrial land area, particularly if protection efforts are focused on biodiverse regions like the tropics.[290] A species accumulation curve indicates that achieving 25 percent protection would capture nearly 100 percent of plant species, but that effort entails protecting 1.2 billion km^2 across the globe. Today, approximately 12.7 percent of global terrestrial land area is under some form of conservation protection, but the effectiveness of this protection in actually sustaining species varies widely among regions.[290]

The situation in New England is somewhat encouraging. To date, the concerted work of land trusts and government agencies has succeeded in protecting more than 3.4 million hectares in the region, comprising 12 percent of the area's total land mass.[291] All six New England states have initiatives to conserve and restore plants and their habitat [see box]. Ecologically "resilient" sites are being mapped and prioritized for future conservation by The Nature Conservancy.[280] The New England Governors' Conference elevated the importance of both conservation and a coordinated approach by convening a panel of experts, who produced "building blocks for a regional conservation strategy" focused on forests, coasts, and farms.[292] Extending the vision to conservation across a mosaic of physical landforms would enhance the long-term preservation of biodiversity because geomorphological diversity—which creates a range of microenvironments that support different assemblages of specialized taxa—is correlated with species diversity.[293-4] The creation of habitat corridors would also enable plants to move, ex-change genes, and evolve in response to climate change. Land protection efforts, coupled with active management, mitigation, and reversal of the full range of anthropogenic threats, can achieve the long-term goal of resiliency, grounded in keeping common plants common and preventing more plants from joining the ranks of imperiled species.

Control or stop biological invasions. Roughly one-third of the flora of New England is not native to the region. Although relatively few non-native species are considered invasive, they, along with other invasive pests and diseases, present a significant threat to the region's plants and habitats. The threat is likely to increase with climate change, as aggressive species from warmer climes, such as kudzu (*Pueraria montana*), invade a warming New England. Proactive steps are needed to reduce or prevent the negative effects of such invasions on native plant communities.

Assess species for threats. We should assess which species are invasive, at both regional and state levels, so that management of these species in designated critical areas can proceed.

Early detection and rapid response. A system of early detection and rapid response to new invasive (and potentially invasive) species is being gradually instituted on state and regional scales. The national EDDMapS program (including the Invasive Plant Atlas of New England), for example, trains people to recognize and report invasive species occurrences and thus to contribute to a better understanding of invasive species distributions and rates of spread.[97]

Select critical areas for management. Although eradication of existing invasive species in New England will probably not be possible, we must select critical natural areas as targets of coordinated management efforts. We must expect that management of these resources will be needed indefinitely, so management efforts must be focused on those areas where management is feasible and can be successful.

Establish broad private and public partnerships. Establish and support a centralized means within government for interagency coordination on invasive species management, in partnership with public and private sector interests. Institute best forestry and agricultural practices to limit the spread of current invasives and prevent new ones from being introduced.

Educate people about invasive species. Increase outreach and education to raise awareness of the extent of the invasive plant problem and of each property owner's role in preventing and controlling invasive species. Public education should focus on those vectors of spread most likely to introduce invasive plants into critical areas.

Increase the amount of productive lands managed sustainably. In New England, 10 percent of the land is in cultivation and 1.3 billion hectares (~ 70 percent of land area) is forested, with the majority of that area managed for harvesting forest products, affording recreation, and other uses. The report from the Governors' Conference, as well as reports from the Wildlands and Woodlands Initiative, New England Forestry Foundation, and others, focus on sustainable forestry and/or sustainable agriculture, with an emphasis on sustaining the resource for its economic value. Thus, their definitions may not fully address biological diversity as a goal of sustainability. To ensure the long-term health of New England's plants and habitats, we should aim to achieve the goal in the Global Strategy for Plant Conservation of having 75 percent of production lands managed sustainably, which means managing impacts on soils, water, plants, habitats, and air quality.

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Examples of Innovative State Initiatives in New England

New England States are national leaders in efforts to coordinate conservation, to provide accurate information needed for wise decision-making, and to manage and restore habitats. The following are brief snapshots of only a few of the many activities that are underway.

Connecticut. The state's Department of Energy and Environmental Protection has undertaken numerous projects to "restore and enhance instream fish and riparian habitats that have been altered or degraded by human activities," to identify areas suitable for supporting warm-season grasslands, and to help the Housatonic River recover from decades of PCB pollution. The latest state Wildlife Action Plan, due out in 2015, includes several new categories of habitat targeted for conservation, including shrub swamps, red maple swamps, and algal beds. 295

Maine. Maine's Beginning with Habitat (BwH) program is a collaboration among federal, state, and local agencies and nongovernmental organizations to offer a habitat-based approach to conserving wildlife and plant communities on a landscape scale. The program compiles maps of rare species and critical habitats and provides tools to implement conservation. Since its launch in 2000, more than 140 cities and towns, and 35 land trusts and regional planning commissions, have incorporated BwH information into their strategic approaches to conservation.296

Massachusetts. The Commonwealth and land trusts have permanently protected nearly 506,000 hectares (> 25 percent of land area). Another 1.1 million hectares (53 percent of land area) are neither developed nor protected, with 607,000 of those hectares identified as having high conservation value.15 Massachusetts has also developed a thorough picture of its natural resources, through such projects as BioMap I,297 BioMap 2,298 Living Waters,299 and the 2006 Comprehensive Wildlife Conservation Strategy,300 which stressed the need to protect 22 habitat types in the state. The next iteration of the Wildlife Conservation Strategy will directly address plant species.301

New Hampshire. The state's Natural Heritage Bureau (NHB) developed an online DataCheck Tool that enables landowners to quickly learn if rare plants, animals, and other species on a parcel of interest will affect intended development projects.302 The tool also streamlines the permitting process; if there are no NHB records in the vicinity of the project area, landowners can immediately receive an official letter to that effect. If there are NHB records, staff assess potential impacts of the project before sending the official letter to be used in permit applications.

Rhode Island. The Rhode Island Natural History Survey's Rhody Native™ program "aims to build the state's capacity to produce genetically diverse and genetically local native plants for landscape design and restoration."303 Seeded in 2010 with a federal grant, the program now makes 36 native plant species available at ten retail locations in Rhode Island, three in Massachusetts, and select wholesale outlets. As in other states, the 2015 revised suite of Rhode Island Wildlife Action Plans will consider plants when planning management in key habitats that support animal species of greatest conservation need.

Vermont. The Vermont Fish and Wildlife Department and Agency of Natural Resources has also produced a comprehensive manual for cities and towns to use in developing effective conservation plans.304 Filled with information on Vermont's natural heritage and on tools available for analysis and conservation, the manual emphasizes identifying and protecting lands with "enduring features": the parts of the landscape, such as bedrock, topography, and glacial deposits, that are the foundation of natural communities.

3. Promote botanical education and awareness of the importance of native plant diversity

The need has never been greater for a scientifically literate populace and one that recognizes the fundamental importance of plants to human well-being and the future of the planet. Yet the number of botanists able to conduct research that will meet this need is shrinking, as older botanists retire and are not replaced, and younger students are not being enticed to learn about plants. The decline of university-level courses in botany was noted with alarm some 20 years ago.[305] In 1988, 72 percent of the nation's top 50 universities offered advanced degree programs in botany; as of 2009, more than half these universities had eliminated their botany programs and related courses.[306] Statistics from the U.S. Department of Education show that undergraduate degrees earned in botany have declined 50 percent and advanced degrees earned in botany are down 41 percent.[307] Plant research continues apace, but increasingly focuses on the physiology and molecular biology of model laboratory species, without addressing the roles of longer-lived, more complex plants in functioning ecosystems. And yet, the Bureau of Labor Statistics projects that jobs requiring botanical experience will grow by 16 percent in coming years, outpacing jobs related to zoology.[10]

High school curricula also neglect plants. As of 2004, less than 20 percent of high school biology courses addressed plants in their syllabi, and most best-selling textbooks barely mentioned plants.[305] Students report finding plants "boring" and do not often cite a fascination with plants as a reason for majoring in biology. Generations of students who are not engaged with plants grow up to be the teachers of the next generation, and teachers who have not studied plants will be hard-pressed to teach about them with confidence or enthusiasm. With little early exposure to plants, students have neither the incentive nor the opportunity to study them. This lack of interest also results from a phenomenon termed "plant-blindness": an inability to notice plants on the landscape.[308] Human visual senses have evolved to respond primarily to moving objects and animals (potential predators); stationary plants, by contrast, simply dissolve into a static green background.

Fostering a basic fascination with plants inside and outside the traditional classroom will attract and train the next generation of plant scientists. *Photo: Jim Sirch*

Increasingly, botanical gardens, environmental centers, science museums, and other "informal" science education venues are stepping in to fill the educational void. A recent survey[10] of 1,500 professional botanists in the United States to assess the nation's current capacity to educate a new generation about plants, conduct research, and conserve and manage plants concluded that:

> Non-profit organizations play an increasingly critical role in filling gaps in botanical education and training. They contribute to course development and classroom education while providing amplification and practical experience…Because [employment] demand will likely only increase in this area, non-profit organizations should take strategic steps to increase their ability to fill this gap in capacity in this area. ***Leadership to recognize, support and sustain the ability of non-profit organizations to fill this role is needed from private foundations as well as academic and government sectors.***

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In New England, a range of organizations offer botanical and horticultural courses, field trips, and workshops for K-12 students, professionals, and general audiences. Some offer structured certificate programs and formal internships, and most provide in-depth volunteer experiences that enhance the capacity of these institutions to meet their missions of education and conservation.

Technology will also be increasingly important in making botanical education accessible to a large, diverse audience.[309] The National Science Foundation funded the development of New England Wild Flower Society's Go Botany website and the Smithsonian's Leaf Snap application precisely because it wanted to know if botany and an appreciation for the natural world could be taught via technology, especially to media-savvy young learners.[310] Currently, there are very few courses in botany and horticulture online, and only minimal seed money for their development. New England Wild Flower Society, Longwood Gardens, Mt. Cuba Botanical Garden, and

However, no technology can replace the simple, time-honored activity of exploring plants in the field with a mentor.

The overall infrastructure for research, conservation, and—importantly—management of habitats must also be strengthened through increased funding at private, foundation, state, and federal levels.

There is no technological or economic reason for a plant to go extinct.

some Master Gardener programs are engaged in developing online programs and models for disseminating botanical content and, equally importantly, financially sustaining them.

However, no technology can replace the simple, time-honored activity of exploring plants in the field with a mentor. It is essential to get outside to interact with real plants, and the desire to do so must be instilled in young people by educators, family members, and other role models.

4. Fully fund efforts to conserve plant diversity

In 2009, President Obama and the National Research Council identified a suite of "grand challenges" facing the nation, which should drive the agendas in critical scientific research and development involving plants, including sustainable food production, development of non-fossil fuel alternatives, climate stabilization, urban planning, and protection and restoration of biodiversity and the ecosystem services that species provide.

Meeting those "grand challenges" will require three resources: research (and the education that makes it possible), money, and political will. Organizations concerned with conservation must cooperate to develop strategies, communicate a common vision to the broader public, and advocate vigorously for policies and legislation to reverse and, better, prevent the root causes of species loss. Such teamwork should bridge the academic-agency divide,[279] enabling conservation organizations to communicate their research needs to faculty and students and ensuring that new research discoveries are made available outside the ivory tower. To that end, academic botanical societies such as the Botanical Society of America are becoming more vocal at the national level, touting the importance of botanical research and education, and making the science more understandable and relevant to policy.

The overall infrastructure for research, conservation, and—importantly—management of habitats must also be strengthened through increased funding at private, foundation, state, and federal levels. Though many gains have been made in protecting large areas of land in New England, at least on paper, it is not sufficient to merely lock away land and assume that nature will take care of itself, especially as the planet undergoes sweeping climatic changes and reorganization of the flora. To actively manage and restore habitats, so that they continue to support biodiversity and provide ecosystem services, will demand a large monetary investment and much hard work on the ground.[311]

There is no technological or economic reason for a plant to go extinct. Recent global analyses have estimated costs of downlisting a species (i.e., recovering a species sufficiently to move it from a high-risk IUCN red-list category to the next lowest). Examining birds (global data on plants are notably sparse), a 2012 study estimated the total costs of downlisting 1,115 globally threatened species as ranging from $0.975 to $1.56 billion annually over the next decade.[311] However, compared to other taxa, birds are expensive. Based on estimates of decadal averages of expenditures in the United States, the annual costs of 'recovery' for 37 bird species listed under the Endangered Species Act were 8.6 times higher than the collective spending on 371 non-bird vertebrate, invertebrate, and plant species.[311] In the United Kingdom, the costs of conserving vertebrates generally were fully 8.9 times larger than those for plants.[312] Worldwide, the estimated cost per species was estimated at less than $3 million annually for 95 percent of species (< U.S. $1 million annually for 50 percent). Thus, the cost of downlisting all "known threatened species" as called for by the targets of the Convention on Biological Diversity may range from $3.4 billion to $4.7 billion. By comparison, the U. S. annual gross domestic product is $16.8 trillion; this expenditure represents 1/3,500th of U. S. GDP.[313]

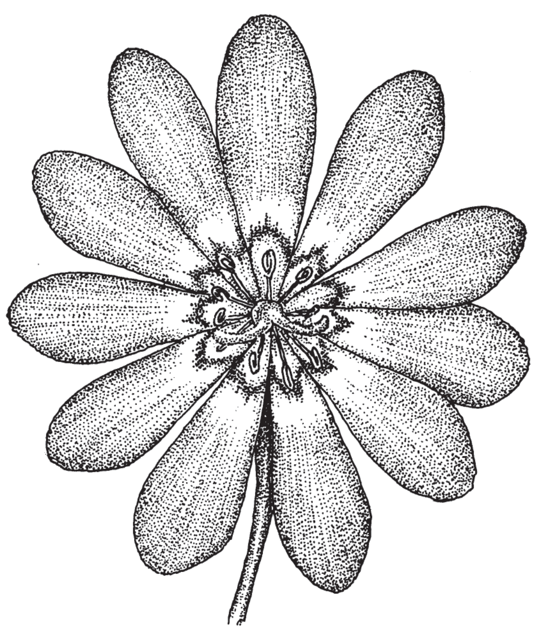
Importantly, the 2012 study estimated that an additional $71 billion would be needed to protect and effectively manage habitats worldwide for the 37 target bird species (reflecting the actual labor-intensive costs of land stewardship), bringing the total annual price tag to approximately $76 billion.[311] In contrast, the total *actual* annual expenditure on global biodiversity was estimated at approximately $21.5 billion for the period 2001–8, of which

$14.5 billion represented domestic spending in individual countries.[314] The United States alone contributed an average $7.4 billion annually to worldwide conservation during this time.

These economic statistics illustrate that the (as yet unmet) costs of recovering rare plants and their habitats is cheap compared to the economic productivity of the United States. Where do some of these funds come from? A 2013 study estimated that $1.5 billion for conservation was contributed by philanthropic sources worldwide, with about half being spent on U. S. domestic projects.[314]

Federal funding also supports species-recovery efforts,[315] even in fluctuating political climates, and these funds are well spent. Looking at expenditures under the U. S. Endangered Species Act, a 2002 study[316] revealed that in cases in which a higher proportion of the estimated funds to recover a species were spent, these were associated with success: namely, a higher proportion of "stable" and "recovering" species relative to uncertain or declining taxa. Success was more likely when funds were targeted at more tractable threats (such as those that could be addressed with regulations on extractive industries on federal lands, hunting, and development). Species facing more complex threats from invasive species, dams, and altered disturbance regimes did not fare as well, indicating that more expenditures and strategic planning would be needed to address these issues. Nonetheless, these systematic analyses yield evidence that species and habitat recovery *is* possible, given adequate funds, an understanding of the constellation of threats facing rare taxa, and a cogent strategy.

That strategy must first and foremost focus on plants as the basis of habitat for all species, including our own.



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>>> # Appendix 1

Definitions of Conservation Status Ranks per NatureServe (2014)[95]

The conservation rank of an element known or assumed to exist within a jurisdiction is designated by a whole number from 1 to 5, preceded by a G (Global), N (National), or S (Subnational) as appropriate. The numbers have the following meaning:

1 = critically imperiled

2 = imperiled

3 = vulnerable to extirpation or extinction

4 = apparently secure

5 = demonstrably widespread, abundant, and secure.

G1, for example, indicates critical imperilment on a range-wide basis—that is, a great risk of extinction. S1 indicates critical imperilment within a particular state, province, or other subnational jurisdiction—i.e., a great risk of extirpation of the element from that subnation, regardless of its status elsewhere. Species known in an area only from historical records are ranked as either H (possibly extirpated/possibly extinct; not having been observed for the past 20–25 years) or X (presumed extirpated/presumed extinct). Certain other codes, rank variants, and qualifiers are also allowed in order to add information about the element or indicate uncertainty.

Elements that are imperiled or vulnerable everywhere they occur will have a global rank of G1, G2, or G3 and equally high or higher national and subnational ranks (the lower the number, the "higher" the rank, and therefore the conservation priority). On the other hand, it is possible for an element to be rarer or more vulnerable in a given nation or subnation than it is range-wide. In that case, it might be ranked N1, N2, or N3, or S1, S2, or S3 even though its global rank is G4 or G5. The three levels of the ranking system give a more complete picture of the conservation status of a species or community than either a range-wide or local rank by itself. They also make it easier to set appropriate conservation priorities in different places and at different geographic levels. In an effort to balance global and local conservation concerns, global as well as national and subnational (provincial or state) ranks are used to select the elements that should receive priority for research and conservation in a jurisdiction.

Use of standard ranking criteria and definitions makes Natural Heritage ranks comparable across element groups; thus, G1 has the same basic meaning whether applied to a salamander, a moss, or a forest community. Standardization also makes ranks comparable across jurisdictions, which in turn allows scientists to use the national and subnational ranks assigned by local data centers to determine and refine or reaffirm global ranks.

Ranking is a qualitative process: it takes into account several factors, including total number, range, and condition of element occurrences, population size, range extent and area of occupancy, short- and long-term trends in the foregoing factors, threats, environmental specificity, and fragility. These factors function as guidelines rather than arithmetic rules, and the relative weight given to the factors may differ among taxa. In some states, the taxon may receive a rank of SR (where the element is reported but has not yet been reviewed locally) or SRF (where a false, erroneous report exists and persists in the literature). A rank of S? denotes an uncertain or inexact numeric rank for the taxon at the state level.

Within states, individual occurrences of a taxon are sometimes assigned element occurrence ranks. Element occurrence (EO) ranks, which are an average of four separate evaluations of quality (size and productivity), condition, viability, and defensibility, are included in site descriptions to provide a general indication of site quality. Ranks range from: A (excellent) to D (poor); a rank of E is provided for element occurrences that are extant, but for which information is inadequate to provide a qualitative score. An EO rank of H is provided for sites for which no observations have made for more than 20 years. An X rank is utilized for sites that are known to be extirpated. Not all EOs have received such ranks in all states, and ranks are not necessarily consistent among states as yet.

>>> # Appendix 2

Explanation of *Flora Conservanda: New England*[11] Ranks

Division 1: Globally Rare Taxa Occurring in New England

Taxa included in this division have a global conservation status rank (GRank) of G1 through G3 or T1 through T3; they are critically imperiled, imperiled, or vulnerable (per NatureServe 2014). Usually, only a few occurrences of these taxa exist within our region, but for some species, such as *Carex oronensis* or *Sabatia kennedyana*, the majority of occurrences of these highly ranked taxa occur in New England. GRanks for taxa in this division appear under each relevant taxon in the list.

Division 2: Regionally Rare Taxa

Within New England, these taxa have 20 or fewer current (observed within the last 20–25 years) occurrences. This division includes taxa that are rare or uncommon throughout their entire range as well as taxa that reach the edge of their distributional range in our region. It is important to conserve these edge-of-range occurrences as part of New England's natural heritage as well as to avoid shrinkage of these species' ranges. All taxa in Division 2 have GRanks of G4 or G5 (apparently secure to secure globally). A taxon with slightly more than 20 occurrences in New England might also be included in Division 2 if it is vulnerable to extirpation due to other important factors (population size and trends, area of occupancy, overall viability, geographic distribution, habitat rarity and integrity, and/or degree of protection). These taxa are denoted as 2(a) in the *Flora Conservanda*, but for the purposes of this report, Divisions 2 and 2(a) are combined.

Division 3: Locally Rare Taxa

These taxa may be declining in a significant part of their range in New England, or may have one or more occurrences of biological, ecological, or possible genetic significance. Division 3(a) taxa are those taxa that have documented decline in a substantial portion of their range in New England, e.g., southern New England. Each state in the declining portion of the range will be listed following the division designation in the List (e.g. MA, NH).

Division 3(b) taxa are those that, based on their biology and geography within New England, have populations that are disjunct to such a degree that genetic isolation is suspected. For example, *Lathyrus japonicus* is not rare in New England, but is highly disjunct in Vermont. Occurrences in adjacent states in the US and provinces of Canada are considered when determining disjunction. Each state with one or more disjunct occurrence will be noted following the division designation in the list, and the county of each disjunct occurrence will be listed in the notes under the taxon. For Division 3(b), only selected occurrences in a particular state are of conservation concern for the purposes of the *Flora Conservanda* list, not all occurrences of the taxon throughout New England. A taxon may be listed as Division 3 in one or more states (designated by an * following the state data), but is not considered to be regionally rare.

Division 4: Historic Taxa

This division consists of taxa that once existed in New England, but have not been observed in natural occurrences on the landscape in the last 20–25 years (depending upon each Natural Heritage Program'smethodology). The purposes of this division are to generate interest in re-locating these taxa if they still exist and to illustrate the level at which species have been lost from the region.

Division Indeterminate (IND.): Indeterminate Taxa

These taxa are under review for inclusion in one of the above divisions, but due to issues of taxonomy (at least for New England occurrences) or nomenclature, or because their status in the wild is not confidently understood, they cannot yet be designated to a particular division. The purpose of this division is to stimulate interest in taxonomic research and/or field surveys for these taxa to bolster our knowledge and understanding.

>>> # Appendix 3

State-by-State Rare Species Summary

CONNECTICUT

Number of Division 1 (Globally rare) taxa: 13
Number of Division 2 (Regionally rare) taxa: 58
Number of Division 3a (Declining) taxa: 4
Total: 75

Connecticut Rare Taxa in the Five Habitat Types

Habitat type	Rare taxa	Family	Flora Conservanda Division
Brackish and Salt Marshes	*Cardamine longii*	Brassicaceae	1
Mixed Northern Hardwoods Forest	*Panax quinquefolius*	Apiaceae	1
Mixed Northern Hardwoods Forest	*Pycnanthemum torrei*	Lamiaceae	1
Mixed Northern Hardwoods Forest	*Cypripedium arietinum*	Orchidaceae	1
Mixed Northern Hardwoods Forest	*Isotria medeoloides*	Orchidaceae	1
Mixed Northern Hardwoods Forest	*Triphora trianthophoros* ssp. *trianthophoros*	Orchidaceae	1
Riparian Communities	*Bidens eatonii*	Asteraceae	1
Riparian Communities	*Eriocaulon parkeri*	Eriocaulaceae	1
Riparian Communities	*Hypericum adpressum*	Hypericaceae	1
Sandplain Communities	*Pityopsis falcata*	Asteraceae	1
Sandplain Communities	*Botrychium rugulosum*	Ophioglossaceae	1
Sandplain Communities	*Agalinis acuta*	Orobranchaceae	1
Sandplain Communities	*Amelanchier nantucketensis*	Rosaceae	1
Brackish and Salt Marshes	*Sagittaria subulata*	Alismataceae	2
Brackish and Salt Marshes	*Hydrocotyle verticillata*	Apiaceae	2
Brackish and Salt Marshes	*Cuscuta coryli*	Convolvulaceae	2
Brackish and Salt Marshes	*Bolboschoenus novae-angliae*	Cyperaceae	2
Brackish and Salt Marshes	*Sabatia stellaris*	Gentianaceae	2
Brackish and Salt Marshes	*Myriophyllum pinnatum*	Haloragaceae	2
Brackish and Salt Marshes	*Leptochloa fusca* ssp. *fascicularis*	Poaceae	2
Mixed Northern Hardwoods Forest	*Viburnum prunifolium*	Adoxaceae	2
Mixed Northern Hardwoods Forest	*Endodeca serpentaria*	Aristolochiaceae	2
Mixed Northern Hardwoods Forest	*Polymnia canadensis*	Asteraceae	2
Mixed Northern Hardwoods Forest	*Cynoglossum virginianum* ssp. *boreale*	Boraginaceae	2
Mixed Northern Hardwoods Forest	*Carex davisii*	Cyperaceae	2
Mixed Northern Hardwoods Forest	*Carex oligocarpa*	Cyperaceae	2
Mixed Northern Hardwoods Forest	*Ribes rotundifolium*	Grossulariaceae	2
Mixed Northern Hardwoods Forest	*Blephilia ciliata*	Lamiaceae	2
Mixed Northern Hardwoods Forest	*Blephilia hirsuta* var. *hirsuta*	Lamiaceae	2
Mixed Northern Hardwoods Forest	*Chamaelirium luteum*	Melanthiaceae	2
Mixed Northern Hardwoods Forest	*Aplectrum hyemale*	Orchidaceae	2
Mixed Northern Hardwoods Forest	*Liparis liliifolia*	Orchidaceae	2
Mixed Northern Hardwoods Forest	*Oxalis montana*	Oxalidaceae	2
Mixed Northern Hardwoods Forest	*Oxalis violacea*	Oxalidaceae	2
Mixed Northern Hardwoods Forest	*Sphenopholis pensylvanica*	Poaceae	2

Habitat type	Rare taxa	Family	Flora Conservanda Division
Mixed Northern Hardwoods Forest	*Hydrastis canadensis*	Ranunculaceae	2
Mixed Northern Hardwoods Forest	*Hybanthus concolor*	Violaceae	2
Riparian Communities	*Taenidia integerrima*	Apiaceae	2
Riparian Communities	*Zizia aptera*	Apiaceae	2
Riparian Communities	*Senecio suaveolens*	Asteraceae	2
Riparian Communities	*Carex alopecoidea*	Cyperaceae	2
Riparian Communities	*Carex crawei*	Cyperaceae	2
Riparian Communities	*Rhynchospora capillacea*	Cyperaceae	2
Riparian Communities	*Lythrum alatum* ssp. *alatum*	Lythraceae	2
Riparian Communities	*Ludwigia polycarpa*	Onagraceae	2
Riparian Communities	*Ludwigia sphaerocarpa*	Onagraceae	2
Riparian Communities	*Cypripedium parviflorum* var. *makasin*	Orchidaceae	2
Riparian Communities	*Pedicularis lanceolata*	Orobranchaceae	2
Riparian Communities	*Mimulus alatus*	Phrymaceae	2
Riparian Communities	*Paspalum laeve*	Poaceae	2
Riparian Communities	*Saururus cernuus*	Saururaceae	2
Sandplain Communities	*Asclepias purpurascens*	Apocynaceae	2
Sandplain Communities	*Asclepias viridiflora*	Apocynaceae	2
Sandplain Communities	*Cirsium horridulum*	Asteraceae	2
Sandplain Communities	*Krigia biflora* var. *biflora*	Asteraceae	2
Sandplain Communities	*Oligoneuron rigidum* var. *rigidum*	Asteraceae	2
Sandplain Communities	*Draba reptans*	Brassicaceae	2
Sandplain Communities	*Calystegia spithamaea* ssp. *spithamea*	Convolvulaceae	2
Sandplain Communities	*Carex bicknellii*	Cyperaceae	2
Sandplain Communities	*Carex bushii*	Cyperaceae	2
Sandplain Communities	*Scleria pauciflora* var. *caroliniana*	Cyperaceae	2
Sandplain Communities	*Scleria triglomerata*	Cyperaceae	2
Sandplain Communities	*Diospyros virginiana*	Ebenaceae	2
Sandplain Communities	*Desmodium sessilifolium*	Fabaceae	2
Sandplain Communities	*Linum sulcatum* var. *sulcatum*	Linaceae	2
Sandplain Communities	*Platanthera ciliaris*	Orchidaceae	2
Sandplain Communities	*Aristida purpurascens* var. *purpurascens*	Poaceae	2
Sandplain Communities	*Aristida tuberculosa*	Poaceae	2
Sandplain Communities	*Bouteloua curtipendula* var. *curtipendula*	Poaceae	2
Sandplain Communities	*Dichanthelium scabriusculum*	Poaceae	2
Sandplain Communities	*Paspalum setaceum* var. *psammophilum*	Poaceae	2
Mixed Northern Hardwoods Forest	*Cypripedium reginae*	Orchidaceae	3a
Mixed Northern Hardwoods Forest	*Galearis spectabilis*	Orchidaceae	3a
Riparian Communities	*Ophioglossum pusillum*	Ophioglossaceae	3a
Sandplain Communities	*Lupinus perennis*	Fabaceae	3a

MAINE

Number of Division 1 (Globally rare) taxa: 18
Number of Division 2 (Regionally rare) taxa: 70
Number of Division 3a (Declining) taxa: 1
Total: 89

Maine Rare Taxa in the Five Habitat Types

Habitat type	Rare taxa	Family	Flora Conservanda Division
Alpine/Subalpine	*Nabalus boottii*	Asteraceae	1
Alpine/Subalpine	*Poa laxa* ssp. *fernaldiana*	Poaceae	1
Brackish and Salt Marshes	*Cardamine longii*	Brassicaceae	1
Brackish and Salt Marshes	*Eleocharis aestuum*	Cyperaceae	1
Brackish and Salt Marshes	*Triglochin gaspensis*	Juncaginaceae	1
Brackish and Salt Marshes	*Mimulus ringens* var. *colpophilus*	Phrymaceae	1
Mixed Northern Hardwoods Forest	*Panax quinquefolius*	Apiaceae	1
Mixed Northern Hardwoods Forest	*Cypripedium arietinum*	Orchidaceae	1
Mixed Northern Hardwoods Forest	*Isotria medeoloides*	Orchidaceae	1
Mixed Northern Hardwoods Forest	*Triphora trianthophoros* ssp. *trianthophoros*	Orchidaceae	1
Riparian Communities	*Bidens eatonii*	Asteraceae	1
Riparian Communities	*Symphyotrichum anticostense*	Asteraceae	1
Riparian Communities	*Eriocaulon parkeri*	Eriocaulaceae	1
Riparian Communities	*Neottia auriculata*	Orchidaceae	1
Riparian Communities	*Pedicularis furbishiae*	Orobranchaceae	1
Sandplain Communities	*Liatris novae-angliae* var. *novae-angliae*	Asteraceae	1
Sandplain Communities	*Botrychium pallidum*	Ophioglossaceae	1
Sandplain Communities	*Amelanchier nantucketensis*	Rosaceae	1
Alpine/Subalpine	*Arnica lanceolata* ssp. *lanceolata*	Asteraceae	2
Alpine/Subalpine	*Omalotheca supina*	Asteraceae	2
Alpine/Subalpine	*Solidago leiocarpa*	Asteraceae	2
Alpine/Subalpine	*Betula glandulosa*	Betulaceae	2
Alpine/Subalpine	*Betula minor*	Betulaceae	2
Alpine/Subalpine	*Cardamine bellidifolia* var. *bellidifolia*	Brassicaceae	2
Alpine/Subalpine	*Silene acaulis*	Caryophyllaceae	2
Alpine/Subalpine	*Carex atratiformis*	Cyperaceae	2
Alpine/Subalpine	*Carex capillaris* ssp. *fuscidula*	Cyperaceae	2
Alpine/Subalpine	*Carex scirpoidea*	Cyperaceae	2
Alpine/Subalpine	*Arctous alpine*	Ericaceae	2
Alpine/Subalpine	*Harrimanella hypnoides*	Ericaceae	2
Alpine/Subalpine	*Kalmia procumbens*	Ericaceae	2
Alpine/Subalpine	*Phyllodoce caerulea*	Ericaceae	2
Alpine/Subalpine	*Rhododendron lapponicum*	Ericaceae	2
Alpine/Subalpine	*Luzula confusa*	Juncaceae	2
Alpine/Subalpine	*Luzula spicata*	Juncaceae	2
Alpine/Subalpine	*Diphasiastrum sitchense*	Lycopodiaceae	2
Alpine/Subalpine	*Epilobium anagallidifolium*	Onagraceae	2
Alpine/Subalpine	*Epilobium hornemannii* var. *hornemaniii*	Onagraceae	2
Alpine/Subalpine	*Castilleja septentrionalis*	Orobranchaceae	2
Alpine/Subalpine	*Euphrasia oakesii*	Orobranchaceae	2
Alpine/Subalpine	*Veronica wormskjoldii* var. *wormskjoldii*	Plantaginaceae	2
Alpine/Subalpine	*Anthoxanthum monticola*	Poaceae	2

Habitat type	Rare taxa	Family	Flora Conservanda Division
Alpine/Subalpine	*Festuca prolifera*	Poaceae	2
Alpine/Subalpine	*Phleum alpinum*	Poaceae	2
Alpine/Subalpine	*Vahlodea atropurpurea*	Poaceae	2
Alpine/Subalpine	*Bistorta vivipara*	Polygonaceae	2
Alpine/Subalpine	*Salix arctophila*	Salicaceae	2
Alpine/Subalpine	*Salix argyrocarpa*	Salicaceae	2
Alpine/Subalpine	*Salix herbacea*	Salicaceae	2
Alpine/Subalpine	*Salix planifolia* ssp. *planifolia*	Salicaceae	2
Alpine/Subalpine	*Salix uva-ursi*	Salicaceae	2
Alpine/Subalpine	*Micranthes foliolosa*	Saxifragaceae	2
Brackish and Salt Marshes	*Suaeda calceoliformis*	Amaranthaceae	2
Brackish and Salt Marshes	*Bolboschoenus novae-angliae*	Cyperaceae	2
Brackish and Salt Marshes	*Eleocharis rostellata*	Cyperaceae	2
Brackish and Salt Marshes	*Agalinis neoscotica*	Orobranchaceae	2
Brackish and Salt Marshes	*Montia fontana*	Portulacaceae	2
Mixed Northern Hardwoods Forest	*Cynoglossum virginianum* ssp. *boreale*	Boraginaceae	2
Mixed Northern Hardwoods Forest	*Hackelia deflexa* ssp. *americana*	Boraginaceae	2
Mixed Northern Hardwoods Forest	*Dryopteris filix-mas*	Dryopteridaceae	2
Mixed Northern Hardwoods Forest	*Huperzia selago*	Huperziaceae	2
Mixed Northern Hardwoods Forest	*Botrychium lunaria*	Ophioglossaceae	2
Mixed Northern Hardwoods Forest	*Goodyera oblongifolia*	Orchidaceae	2
Mixed Northern Hardwoods Forest	*Elymus macgregorii*	Poaceae	2
Riparian Communities	*Tanacetum bipinnatum* ssp. *huronense*	Asteraceae	2
Riparian Communities	*Paronychia argyrocoma*	Caryophyllaceae	2
Riparian Communities	*Carex alopecoidea*	Cyperaceae	2
Riparian Communities	*Carex crawei*	Cyperaceae	2
Riparian Communities	*Carex garberi*	Cyperaceae	2
Riparian Communities	*Carex rostrata*	Cyperaceae	2
Riparian Communities	*Rhynchospora capillacea*	Cyperaceae	2
Riparian Communities	*Trichophorum clintonii*	Cyperaceae	2
Riparian Communities	*Oxytropis campestris*	Fabaceae	2
Riparian Communities	*Gentianella amarella* ssp. *acuta*	Gentianaceae	2
Riparian Communities	*Juncus torreyi*	Juncaceae	2
Riparian Communities	*Sphenopholis obtusata*	Poaceae	2
Riparian Communities	*Anemone multifida*	Ranunculaceae	2
Riparian Communities	*Thalictrum venulosum*	Ranunculaceae	2
Riparian Communities	*Amelanchier gaspensis*	Rosaceae	2
Riparian Communities	*Salix myricoides*	Salicaceae	2
Riparian Communities	*Selaginella selaginoides*	Selaginellaceae	2
Riparian Communities	*Viola novae-angliae*	Violaceae	2
Sandplain Communities	*Artemisia campestris* ssp. *canadensis*	Asteraceae	2
Sandplain Communities	*Calystegia spithamaea* ssp. *spithamea*	Convolvulaceae	2
Sandplain Communities	*Carex adusta*	Cyperaceae	2
Sandplain Communities	*Carex bicknellii*	Cyperaceae	2
Sandplain Communities	*Carex bushii*	Cyperaceae	2
Sandplain Communities	*Piptatheropsis canadensis*	Poaceae	2
Riparian Communities	*Ophioglossum pusillum*	Ophioglossaceae	3a

MASSACHUSETTS

Number of Division 1 (Globally rare) taxa: 18
Number of Division 2 (Regionally rare) taxa: 78
Number of Division 3a (Declining) taxa: 4
Total: 100

Massachusetts Rare Taxa in the Five Habitat Types

Habitat type	Rare taxa	Family	Flora Conservanda Division
Brackish and Salt Marshes	*Suaeda maritima* ssp. *richii*	Amaranthaceae	1
Brackish and Salt Marshes	*Cardamine longii*	Brassicaceae	1
Mixed Northern Hardwoods Forest	*Panax quinquefolius*	Apiaceae	1
Mixed Northern Hardwoods Forest	*Cypripedium arietinum*	Orchidaceae	1
Mixed Northern Hardwoods Forest	*Isotria medeoloides*	Orchidaceae	1
Mixed Northern Hardwoods Forest	*Triphora trianthophoros* ssp. *trianthophoros*	Orchidaceae	1
Riparian Communities	*Bidens eatonii*	Asteraceae	1
Riparian Communities	*Eleocharis diandra*	Cyperaceae	1
Riparian Communities	*Eriocaulon parkeri*	Eriocaulaceae	1
Riparian Communities	*Hypericum adpressum*	Hypericaceae	1
Sandplain Communities	*Coreopsis rosea*	Asteraceae	1
Sandplain Communities	*Eupatorium novae-angliae*	Asteraceae	1
Sandplain Communities	*Liatris novae-angliae* var. *novae-angliae*	Asteraceae	1
Sandplain Communities	*Pityopsis falcata*	Asteraceae	1
Sandplain Communities	*Crocanthemum dumosum*	Cistaceae	1
Sandplain Communities	*Sabatia kennedyana*	Gentianaceae	1
Sandplain Communities	*Agalinis acuta*	Orobranchaceae	1
Sandplain Communities	*Amelanchier nantucketensis*	Rosaceae	1
Brackish and Salt Marshes	*Sagittaria subulata*	Alismataceae	2
Brackish and Salt Marshes	*Suaeda calceoliformis*	Amaranthaceae	2
Brackish and Salt Marshes	*Hydrocotyle verticillata*	Apiaceae	2
Brackish and Salt Marshes	*Cuscuta coryli*	Convolvulaceae	2
Brackish and Salt Marshes	*Cuscuta indecora* var. *indecora*	Convolvulaceae	2
Brackish and Salt Marshes	*Bolboschoenus novae-angliae*	Cyperaceae	2
Brackish and Salt Marshes	*Eleocharis rostellata*	Cyperaceae	2
Brackish and Salt Marshes	*Sabatia stellaris*	Gentianaceae	2
Brackish and Salt Marshes	*Myriophyllum pinnatum*	Haloragaceae	2
Brackish and Salt Marshes	*Leptochloa fusca* ssp. *fascicularis*	Poaceae	2
Brackish and Salt Marshes	*Spartina cynosuroides*	Poaceae	2
Mixed Northern Hardwoods Forest	*Ilex montana*	Aquifoliaceae	2
Mixed Northern Hardwoods Forest	*Doellingeria infirma*	Asteraceae	2
Mixed Northern Hardwoods Forest	*Cynoglossum virginianum* ssp. *boreale*	Boraginaceae	2
Mixed Northern Hardwoods Forest	*Hydrophyllum canadense*	Boraginaceae	2
Mixed Northern Hardwoods Forest	*Lonicera hirsuta*	Caprifoliaceae	2
Mixed Northern Hardwoods Forest	*Cerastium nutans*	Caryophyllaceae	2
Mixed Northern Hardwoods Forest	*Carex davisii*	Cyperaceae	2
Mixed Northern Hardwoods Forest	*Carex gracilescens*	Cyperaceae	2
Mixed Northern Hardwoods Forest	*Carex oligocarpa*	Cyperaceae	2
Mixed Northern Hardwoods Forest	*Ribes rotundifolium*	Grossulariaceae	2
Mixed Northern Hardwoods Forest	*Huperzia selago*	Huperziaceae	2
Mixed Northern Hardwoods Forest	*Blephilia ciliata*	Lamiaceae	2

Habitat type	Rare taxa	Family	Flora Conservanda Division
Mixed Northern Hardwoods Forest	*Blephilia hirsuta* var. *hirsuta*	Lamiaceae	2
Mixed Northern Hardwoods Forest	*Chamaelirium luteum*	Melanthiaceae	2
Mixed Northern Hardwoods Forest	*Aplectrum hyemale*	Orchidaceae	2
Mixed Northern Hardwoods Forest	*Liparis liliifolia*	Orchidaceae	2
Mixed Northern Hardwoods Forest	*Oxalis violacea*	Oxalidaceae	2
Mixed Northern Hardwoods Forest	*Elymus macgregorii*	Poaceae	2
Mixed Northern Hardwoods Forest	*Poa saltuensis* ssp. *languida*	Poaceae	2
Mixed Northern Hardwoods Forest	*Sphenopholis pensylvanica*	Poaceae	2
Mixed Northern Hardwoods Forest	*Claytonia virginica*	Portulacaceae	2
Mixed Northern Hardwoods Forest	*Hydrastis canadensis*	Ranunculaceae	2
Mixed Northern Hardwoods Forest	*Ranunculus micranthus*	Ranunculaceae	2
Mixed Northern Hardwoods Forest	*Athyrium asplenioides*	Woodsiaceae	2
Riparian Communities	*Paronychia argyrocoma*	Caryophyllaceae	2
Riparian Communities	*Carex alopecoidea*	Cyperaceae	2
Riparian Communities	*Rhynchospora capillacea*	Cyperaceae	2
Riparian Communities	*Lycopus rubellus*	Lamiaceae	2
Riparian Communities	*Lythrum alatum* ssp. *alatum*	Lythraceae	2
Riparian Communities	*Ludwigia polycarpa*	Onagraceae	2
Riparian Communities	*Ludwigia sphaerocarpa*	Onagraceae	2
Riparian Communities	*Cypripedium parviflorum* var. *makasin*	Orchidaceae	2
Riparian Communities	*Pedicularis lanceolata*	Orobranchaceae	2
Riparian Communities	*Mimulus alatus*	Phrymaceae	2
Riparian Communities	*Paspalum laeve*	Poaceae	2
Riparian Communities	*Agrimonia parviflora*	Rosaceae	2
Riparian Communities	*Saururus cernuus*	Saururaceae	2
Sandplain Communities	*Asclepias purpurascens*	Apocynaceae	2
Sandplain Communities	*Asclepias viridiflora*	Apocynaceae	2
Sandplain Communities	*Cirsium horridulum*	Asteraceae	2
Sandplain Communities	*Nabalus serpentarius*	Asteraceae	2
Sandplain Communities	*Symphyotrichum concolor* ssp. *concolor*	Asteraceae	2
Sandplain Communities	*Draba reptans*	Brassicaceae	2
Sandplain Communities	*Calystegia spithamaea* ssp. *spithamea*	Convolvulaceae	2
Sandplain Communities	*Carex bicknellii*	Cyperaceae	2
Sandplain Communities	*Carex bushii*	Cyperaceae	2
Sandplain Communities	*Cyperus houghtonii*	Cyperaceae	2
Sandplain Communities	*Cyperus retrorsus*	Cyperaceae	2
Sandplain Communities	*Rhynchospora inundata*	Cyperaceae	2
Sandplain Communities	*Rhynchospora nitens*	Cyperaceae	2
Sandplain Communities	*Rhynchospora torreyana*	Cyperaceae	2
Sandplain Communities	*Scleria triglomerata*	Cyperaceae	2
Sandplain Communities	*Diospyros virginiana*	Ebenaceae	2
Sandplain Communities	*Desmodium sessilifolium*	Fabaceae	2
Sandplain Communities	*Sabatia campanulata*	Gentianaceae	2
Sandplain Communities	*Hypericum stragulum*	Hypericaceae	2
Sandplain Communities	*Linum sulcatum* var. *sulcatum*	Linaceae	2
Sandplain Communities	*Rhexia mariana* var. *mariana*	Melastomataceae	2

Habitat type	Rare taxa	Family	Flora Conservanda Division
Sandplain Communities	*Platanthera ciliaris*	Orchidaceae	2
Sandplain Communities	*Tipularia discolor*	Orchidaceae	2
Sandplain Communities	*Amphicarpum amphicarpon*	Poaceae	2
Sandplain Communities	*Aristida purpurascens* var. *purpurascens*	Poaceae	2
Sandplain Communities	*Aristida tuberculosa*	Poaceae	2
Sandplain Communities	*Dichanthelium dichotomum* ssp. *mattamuskeetense*	Poaceae	2
Sandplain Communities	*Dichanthelium ovale* ssp. *pseudopubescens*	Poaceae	2
Sandplain Communities	*Dichanthelium scabriusculum*	Poaceae	2
Sandplain Communities	*Paspalum setaceum* var. *psammophilum*	Poaceae	2
Mixed Northern Hardwoods Forest	*Cypripedium reginae*	Orchidaceae	3a
Mixed Northern Hardwoods Forest	*Galearis spectabilis*	Orchidaceae	3a
Riparian Communities	*Ophioglossum pusillum*	Ophioglossaceae	3a
Sandplain Communities	*Lupinus perennis*	Fabaceae	3a

NEW HAMPSHIRE

Number of Division 1 (Globally rare) taxa: 16
Number of Division 2 (Regionally rare) taxa: 65
Number of Division 3a (Declining) taxa: 1
Total: 82

New Hampshire Rare Taxa in the Five Habitat Types

Habitat type	Rare taxa	Family	Flora Conservanda Division
Alpine/Subalpine	*Nabalus boottii*	Asteraceae	1
Alpine/Subalpine	*Poa laxa* ssp. *fernaldiana*	Poaceae	1
Alpine/Subalpine	*Geum peckii*	Rosaceae	1
Alpine/Subalpine	*Potentilla robbinsiana*	Rosaceae	1
Brackish and Salt Marshes	*Suaeda maritima* ssp. *richii*	Amaranthaceae	1
Brackish and Salt Marshes	*Cardamine longii*	Brassicaceae	1
Mixed Northern Hardwoods Forest	*Panax quinquefolius*	Apiaceae	1
Mixed Northern Hardwoods Forest	*Pycnanthemum torrei*	Lamiaceae	1
Mixed Northern Hardwoods Forest	*Cypripedium arietinum*	Orchidaceae	1
Mixed Northern Hardwoods Forest	*Isotria medeoloides*	Orchidaceae	1
Mixed Northern Hardwoods Forest	*Triphora trianthophoros* ssp. *trianthophoros*	Orchidaceae	1
Riparian Communities	*Eleocharis diandra*	Cyperaceae	1
Riparian Communities	*Astragalus alpinus* var. *brunetianus**	Fabaceae	1
Riparian Communities	*Astragalus robbinsii* var. *jesupii**	Fabaceae	1
Riparian Communities	*Neottia auriculata*	Orchidaceae	1
Sandplain Communities	*Liatris novae-angliae* var. *novae-angliae*	Asteraceae	1
Alpine/Subalpine	*Arnica lanceolata* ssp. *lanceolata*	Asteraceae	2
Alpine/Subalpine	*Omalotheca supina*	Asteraceae	2
Alpine/Subalpine	*Solidago leiocarpa*	Asteraceae	2
Alpine/Subalpine	*Betula glandulosa*	Betulaceae	2
Alpine/Subalpine	*Betula minor*	Betulaceae	2
Alpine/Subalpine	*Cardamine bellidifolia* var. *bellidifolia*	Brassicaceae	2
Alpine/Subalpine	*Silene acaulis*	Caryophyllaceae	2
Alpine/Subalpine	*Carex arctogena*	Cyperaceae	2
Alpine/Subalpine	*Carex atratiformis*	Cyperaceae	2
Alpine/Subalpine	*Carex scirpoidea*	Cyperaceae	2
Alpine/Subalpine	*Arctous alpina*	Ericaceae	2
Alpine/Subalpine	*Harrimanella hypnoides*	Ericaceae	2
Alpine/Subalpine	*Kalmia procumbens*	Ericaceae	2
Alpine/Subalpine	*Phyllodoce caerulea*	Ericaceae	2
Alpine/Subalpine	*Rhododendron lapponicum*	Ericaceae	2
Alpine/Subalpine	*Luzula confusa*	Juncaceae	2
Alpine/Subalpine	*Luzula spicata*	Juncaceae	2
Alpine/Subalpine	*Diphasiastrum sitchense*	Lycopodiaceae	2
Alpine/Subalpine	*Epilobium anagallidifolium*	Onagraceae	2
Alpine/Subalpine	*Epilobium hornemannii* var. *hornemaniii*	Onagraceae	2
Alpine/Subalpine	*Castilleja septentrionalis*	Orobranchaceae	2
Alpine/Subalpine	*Euphrasia oakesii*	Orobranchaceae	2
Alpine/Subalpine	*Rhinanthus minor* ssp. *groenlandicus*	Orobranchaceae	2
Alpine/Subalpine	*Veronica wormskjoldii* var. *wormskjoldii*	Plantaginaceae	2
Alpine/Subalpine	*Anthoxanthum monticola*	Poaceae	2

Habitat type	Rare taxa	Family	Flora Conservanda Division
Alpine/Subalpine	*Calamagrostis canadensis* var. *langsdorfii*	Poaceae	2
Alpine/Subalpine	*Festuca prolifera*	Poaceae	2
Alpine/Subalpine	*Phleum alpinum*	Poaceae	2
Alpine/Subalpine	*Poa pratensis* ssp. *alpigena*	Poaceae	2
Alpine/Subalpine	*Vahlodea atropurpurea*	Poaceae	2
Alpine/Subalpine	*Bistorta vivipara*	Polygonaceae	2
Alpine/Subalpine	*Oxyria digyna*	Polygonaceae	2
Alpine/Subalpine	*Sibbaldia procumbens*	Rosaceae	2
Alpine/Subalpine	*Salix argyrocarpa*	Salicaceae	2
Alpine/Subalpine	*Salix herbacea*	Salicaceae	2
Alpine/Subalpine	*Salix planifolia* ssp. *planifolia*	Salicaceae	2
Alpine/Subalpine	*Salix uva-ursi*	Salicaceae	2
Alpine/Subalpine	*Saxifraga cernua*	Saxifragaceae	2
Alpine/Subalpine	*Saxifraga rivularis* ssp. *rivularis*	Saxifragaceae	2
Brackish and Salt Marshes	*Suaeda calceoliformis*	Amaranthaceae	2
Brackish and Salt Marshes	*Leptochloa fusca* ssp. *fascicularis*	Poaceae	2
Mixed Northern Hardwoods Forest	*Hieracium umbellatum*	Asteraceae	2
Mixed Northern Hardwoods Forest	*Cynoglossum virginianum* ssp. *boreale*	Boraginaceae	2
Mixed Northern Hardwoods Forest	*Hackelia deflexa* ssp. *americana*	Boraginaceae	2
Mixed Northern Hardwoods Forest	*Dryopteris filix-mas*	Dryopteridaceae	2
Mixed Northern Hardwoods Forest	*Pterospora andromedea*	Ericaceae	2
Mixed Northern Hardwoods Forest	*Huperzia selago*	Huperziaceae	2
Mixed Northern Hardwoods Forest	*Elymus macgregorii*	Poaceae	2
Riparian Communities	*Paronychia argyrocoma*	Caryophyllaceae	2
Riparian Communities	*Carex garberi*	Cyperaceae	2
Riparian Communities	*Carex rostrata*	Cyperaceae	2
Riparian Communities	*Rhynchospora capillacea*	Cyperaceae	2
Riparian Communities	*Cypripedium parviflorum* var. *makasin*	Orchidaceae	2
Riparian Communities	*Coleataenia longifolia* ssp. *longifolia*	Poaceae	2
Riparian Communities	*Sphenopholis obtusata*	Poaceae	2
Sandplain Communities	*Asclepias purpurascens*	Apocynaceae	2
Sandplain Communities	*Artemisia campestris* ssp. *canadensis*	Asteraceae	2
Sandplain Communities	*Nabalus serpentarius*	Asteraceae	2
Sandplain Communities	*Calystegia spithamaea* ssp. *spithamea*	Convolvulaceae	2
Sandplain Communities	*Carex adusta*	Cyperaceae	2
Sandplain Communities	*Cyperus houghtonii*	Cyperaceae	2
Sandplain Communities	*Scleria pauciflora* var. *pauciflora*	Cyperaceae	2
Sandplain Communities	*Linum sulcatum* var. *sulcatum*	Linaceae	2
Sandplain Communities	*Aristida tuberculosa*	Poaceae	2
Sandplain Communities	*Piptatheropsis canadensis*	Poaceae	2
Sandplain Communities	*Lupinus perennis*	Fabaceae	3a

* Global ranks for these taxa are G5T1 and G5T3, respectively; *Astragalus robbinsii* var. *jesupii* is listed as Federally Endangered

RHODE ISLAND

Number of Division 1 (Globally rare) taxa: 13
Number of Division 2 (Regionally rare) taxa: 51
Number of Division 3a (Declining) taxa: 3
Total: 67

Rhode Island Rare Taxa in the Five Habitat Types

Habitat type	Rare taxa	Family	Flora Conservanda Division
Brackish and Salt Marshes	*Suaeda maritima* ssp. *richii*	Amaranthaceae	1
Brackish and Salt Marshes	*Schoenoplectus etuberculatus*	Cyperaceae	1
Mixed Northern Hardwoods Forest	*Panax quinquefolius*	Apiaceae	1
Mixed Northern Hardwoods Forest	*Isotria medeoloides*	Orchidaceae	1
Riparian Communities	*Hypericum adpressum*	Hypericaceae	1
Sandplain Communities	*Coreopsis rosea*	Asteraceae	1
Sandplain Communities	*Eupatorium novae-angliae*	Asteraceae	1
Sandplain Communities	*Liatris novae-angliae* var. *novae-angliae*	Asteraceae	1
Sandplain Communities	*Pityopsis falcata*	Asteraceae	1
Sandplain Communities	*Crocanthemum dumosum*	Cistaceae	1
Sandplain Communities	*Sabatia kennedyana*	Gentianaceae	1
Sandplain Communities	*Agalinis acuta*	Orobranchaceae	1
Sandplain Communities	*Amelanchier nantucketensis*	Rosaceae	1
Brackish and Salt Marshes	*Sesuvium maritimum*	Aizoaceae	2
Brackish and Salt Marshes	*Sagittaria subulata*	Alismataceae	2
Brackish and Salt Marshes	*Chenopodium berlandieri* var. *bushianum*	Amaranthaceae	2
Brackish and Salt Marshes	*Hydrocotyle verticillata*	Apiaceae	2
Brackish and Salt Marshes	*Cuscuta coryli*	Convolvulaceae	2
Brackish and Salt Marshes	*Cuscuta indecora* var. *indecora*	Convolvulaceae	2
Brackish and Salt Marshes	*Bolboschoenus novae-angliae*	Cyperaceae	2
Brackish and Salt Marshes	*Eleocharis rostellata*	Cyperaceae	2
Brackish and Salt Marshes	*Sabatia stellaris*	Gentianaceae	2
Brackish and Salt Marshes	*Myriophyllum pinnatum*	Haloragaceae	2
Brackish and Salt Marshes	*Leptochloa fusca* ssp. *fascicularis*	Poaceae	2
Brackish and Salt Marshes	*Spartina cynosuroides*	Poaceae	2
Mixed Northern Hardwoods Forest	*Doellingeria infirma*	Asteraceae	2
Mixed Northern Hardwoods Forest	*Lonicera sempervirens* var. *sempervirens*	Caprifoliaceae	2
Mixed Northern Hardwoods Forest	*Carex debilis* var. *debilis*	Cyperaceae	2
Mixed Northern Hardwoods Forest	*Carex styloflexa*	Cyperaceae	2
Mixed Northern Hardwoods Forest	*Oxalis violacea*	Oxalidaceae	2
Mixed Northern Hardwoods Forest	*Elymus macgregorii*	Poaceae	2
Mixed Northern Hardwoods Forest	*Poa saltuensis* ssp. *languida*	Poaceae	2
Mixed Northern Hardwoods Forest	*Sphenopholis pensylvanica*	Poaceae	2
Mixed Northern Hardwoods Forest	*Claytonia virginica*	Portulacaceae	2
Mixed Northern Hardwoods Forest	*Ranunculus micranthus*	Ranunculaceae	2
Mixed Northern Hardwoods Forest	*Athyrium asplenioides*	Woodsiaceae	2
Riparian Communities	*Helanthium tenellum*	Alismataceae	2
Riparian Communities	*Taenidia integerrima*	Apiaceae	2
Riparian Communities	*Zizia aptera*	Apiaceae	2
Riparian Communities	*Senecio suaveolens*	Asteraceae	2
Riparian Communities	*Lycopus rubellus*	Lamiaceae	2

Habitat type	Rare taxa	Family	Flora Conservanda Division
Riparian Communities	*Lythrum alatum* ssp. *alatum*	Lythraceae	2
Riparian Communities	*Ludwigia sphaerocarpa*	Onagraceae	2
Riparian Communities	*Sphenopholis obtusata*	Poaceae	2
Riparian Communities	*Saururus cernuus*	Saururaceae	2
Sandplain Communities	*Asclepias purpurascens*	Apocynaceae	2
Sandplain Communities	*Artemisia campestris* ssp. *canadensis*	Asteraceae	2
Sandplain Communities	*Chrysopsis mariana*	Asteraceae	2
Sandplain Communities	*Cirsium horridulum*	Asteraceae	2
Sandplain Communities	*Oligoneuron rigidum* var. *rigidum*	Asteraceae	2
Sandplain Communities	*Symphyotrichum concolor* ssp. *concolor*	Asteraceae	2
Sandplain Communities	*Draba reptans*	Brassicaceae	2
Sandplain Communities	*Rhynchospora inundata*	Cyperaceae	2
Sandplain Communities	*Rhynchospora torreyana*	Cyperaceae	2
Sandplain Communities	*Scleria pauciflora* var. *caroliniana*	Cyperaceae	2
Sandplain Communities	*Scleria triglomerata*	Cyperaceae	2
Sandplain Communities	*Desmodium sessilifolium*	Fabaceae	2
Sandplain Communities	*Strophostyles umbellata*	Fabaceae	2
Sandplain Communities	*Linum sulcatum* var. *sulcatum*	Linaceae	2
Sandplain Communities	*Platanthera ciliaris*	Orchidaceae	2
Sandplain Communities	*Aristida purpurascens* var. *purpurascens*	Poaceae	2
Sandplain Communities	*Dichanthelium dichotomum* ssp. *mattamuskeetense*	Poaceae	2
Sandplain Communities	*Dichanthelium scabriusculum*	Poaceae	2
Sandplain Communities	*Paspalum setaceum* var. *psammophilum*	Poaceae	2
Mixed Northern Hardwoods Forest	*Galearis spectabilis*	Orchidaceae	3a
Riparian Communities	*Ophioglossum pusillum*	Ophioglossaceae	3a
Sandplain Communities	*Lupinus perennis*	Fabaceae	3a

VERMONT

Number of Division 1 (Globally rare) taxa: 14
Number of Division 2 (Regionally rare) taxa: 64
Number of Division 3a (Declining) taxa: 1
Total: 79

Vermont Rare Taxa in the Five Habitat Types

Habitat type	Rare taxa	Family	Flora Conservanda Division
Alpine/Subalpine	*Nabalus boottii*	Asteraceae	1
Alpine/Subalpine	*Poa laxa* ssp. *fernaldiana*	Poaceae	1
Brackish and Salt Marshes	*Eleocharis aestuum*	Cyperaceae	1
Mixed Northern Hardwoods Forest	*Panax quinquefolius*	Apiaceae	1
Mixed Northern Hardwoods Forest	*Cypripedium arietinum*	Orchidaceae	1
Mixed Northern Hardwoods Forest	*Isotria medeoloides*	Orchidaceae	1
Mixed Northern Hardwoods Forest	*Triphora trianthophoros* ssp. *trianthophoros*	Orchidaceae	1
Riparian Communities	*Eleocharis diandra*	Cyperaceae	1
Riparian Communities	*Astragalus alpinus* var. *brunetianus*	Fabaceae	1
Riparian Communities	*Astragalus robbinsii* var. *jesupii*	Fabaceae	1
Riparian Communities	*Neottia auriculata*	Orchidaceae	1
Sandplain Communities	*Botrychium ascendens*	Ophioglossaceae	1
Sandplain Communities	*Botrychium campestre*	Ophioglossaceae	1
Sandplain Communities	*Botrychium rugulosum*	Ophioglossaceae	1
Alpine/Subalpine	*Arnica lanceolata* ssp. *lanceolata*	Asteraceae	2
Alpine/Subalpine	*Solidago leiocarpa*	Asteraceae	2
Alpine/Subalpine	*Betula minor*	Betulaceae	2
Alpine/Subalpine	*Carex atratiformis*	Cyperaceae	2
Alpine/Subalpine	*Carex capillaris* ssp. *fuscidula*	Cyperaceae	2
Alpine/Subalpine	*Carex scirpoidea*	Cyperaceae	2
Alpine/Subalpine	*Luzula spicata*	Juncaceae	2
Alpine/Subalpine	*Castilleja septentrionalis*	Orobranchaceae	2
Alpine/Subalpine	*Anthoxanthum monticola*	Poaceae	2
Alpine/Subalpine	*Calamagrostis canadensis* var. *langsdorfii*	Poaceae	2
Alpine/Subalpine	*Festuca brachyphylla* ssp. *brachyphylla*	Poaceae	2
Alpine/Subalpine	*Vahlodea atropurpurea*	Poaceae	2
Alpine/Subalpine	*Bistorta vivipara*	Polygonaceae	2
Alpine/Subalpine	*Salix planifolia* ssp. *planifolia*	Salicaceae	2
Alpine/Subalpine	*Salix uva-ursi*	Salicaceae	2
Alpine/Subalpine	*Viola palustris* var. *palustris*	Violaceae	2
Brackish and Salt Marshes	*Chenopodium berlandieri* var. *bushianum*	Amaranthaceae	2
Mixed Northern Hardwoods Forest	*Polymnia canadensis*	Asteraceae	2
Mixed Northern Hardwoods Forest	*Podophyllum peltatum*	Berberidaceae	2
Mixed Northern Hardwoods Forest	*Cynoglossum virginianum* ssp. *boreale*	Boraginaceae	2
Mixed Northern Hardwoods Forest	*Hackelia deflexa* ssp. *americana*	Boraginaceae	2
Mixed Northern Hardwoods Forest	*Hydrophyllum canadense*	Boraginaceae	2
Mixed Northern Hardwoods Forest	*Lonicera hirsute*	Caprifoliaceae	2
Mixed Northern Hardwoods Forest	*Cerastium nutans*	Caryophyllaceae	2
Mixed Northern Hardwoods Forest	*Carex davisii*	Cyperaceae	2
Mixed Northern Hardwoods Forest	*Carex gracilescens*	Cyperaceae	2
Mixed Northern Hardwoods Forest	*Carex oligocarpa*	Cyperaceae	2

Habitat type	**Rare taxa**	**Family**	**Flora Conservanda Division**
Mixed Northern Hardwoods Forest	*Carex richardsonii*	Cyperaceae	2
Mixed Northern Hardwoods Forest	*Dryopteris filix-mas*	Dryopteridaceae	2
Mixed Northern Hardwoods Forest	*Pterospora andromedea*	Ericaceae	2
Mixed Northern Hardwoods Forest	*Huperzia selago*	Huperziaceae	2
Mixed Northern Hardwoods Forest	*Blephilia ciliate*	Lamiaceae	2
Mixed Northern Hardwoods Forest	*Blephilia hirsuta* var. *hirsuta*	Lamiaceae	2
Mixed Northern Hardwoods Forest	*Botrychium lunaria*	Ophioglossaceae	2
Mixed Northern Hardwoods Forest	*Aplectrum hyemale*	Orchidaceae	2
Mixed Northern Hardwoods Forest	*Goodyera oblongifolia*	Orchidaceae	2
Mixed Northern Hardwoods Forest	*Liparis liliifolia*	Orchidaceae	2
Mixed Northern Hardwoods Forest	*Oxalis violacea*	Oxalidaceae	2
Mixed Northern Hardwoods Forest	*Elymus macgregorii*	Poaceae	2
Mixed Northern Hardwoods Forest	*Poa saltuensis* ssp. *languida*	Poaceae	2
Mixed Northern Hardwoods Forest	*Claytonia virginica*	Portulacaceae	2
Mixed Northern Hardwoods Forest	*Hydrastis canadensis*	Ranunculaceae	2
Mixed Northern Hardwoods Forest	*Ulmus thomasi*	Ulmaceae	2
Mixed Northern Hardwoods Forest	*Hybanthus concolor*	Violaceae	2
Riparian Communities	*Amaranthus tuberculatus*	Amaranthaceae	2
Riparian Communities	*Taenidia integerrima*	Apiaceae	2
Riparian Communities	*Carex alopecoidea*	Cyperaceae	2
Riparian Communities	*Carex garberi*	Cyperaceae	2
Riparian Communities	*Rhynchospora capillacea*	Cyperaceae	2
Riparian Communities	*Gentianella amarella* ssp. *acuta*	Gentianaceae	2
Riparian Communities	*Juncus torreyi*	Juncaceae	2
Riparian Communities	*Lythrum alatum* ssp. *alatum*	Lythraceae	2
Riparian Communities	*Ludwigia polycarpa*	Onagraceae	2
Riparian Communities	*Cypripedium parviflorum* var. *makasin*	Orchidaceae	2
Riparian Communities	*Coleataenia longifolia* ssp. *longifolia*	Poaceae	2
Riparian Communities	*Sphenopholis obtusata*	Poaceae	2
Riparian Communities	*Anemone multifida*	Ranunculaceae	2
Riparian Communities	*Thalictrum venulosum*	Ranunculaceae	2
Sandplain Communities	*Artemisia campestris* ssp. *canadensis*	Asteraceae	2
Sandplain Communities	*Calystegia silvatica* ssp. *fraterniflora*	Convolvulaceae	2
Sandplain Communities	*Calystegia spithamaea* ssp. *spithamaea*	Convolvulaceae	2
Sandplain Communities	*Carex bicknellii*	Cyperaceae	2
Sandplain Communities	*Cyperus houghtonii*	Cyperaceae	2
Sandplain Communities	*Linum sulcatum* var. *sulcatum*	Linaceae	2
Sandplain Communities	*Lupinus perennis*	Fabaceae	3a

>>> APPENDIX 4

Species Needing More Data on New England Status
(*Flora Conservanda: New England 2012,* Division "Indeterminate")

Actaea racemosa
Atriplex subspicata
Bartonia iodandra
Bartonia paniculata
Betula nigra
Botrychium tenebrosum
Calamagrostis canadensis var. *macouniana*
Cardamine incisa
Carex mesochorea
Celastrus scandens
Cuscuta gronovii var. *latiflora*
Cypripedium parviflorum var. *parviflorum*
Dichanthelium acuminatum ssp. *acuminatum*
Eleocharis ovata
Elymus villosus var. *arkansanus*
Elymus villosus var. *villosus*
Eupatorium torreyanum
Euphorbia glyptosperma
Euphorbia nutans
Galium pilosum var. *puncticulosum*
Huperzia appressa
Hypopitys lanuginosa
Lactuca hirsuta
Lechea minor
Lemna perpusilla
Lemna turionifera
Lemna valdiviana
Lespedeza stuevei
Lobelia spicata var. *hirtella*
Oenothera fruticosa ssp. *fruticosa*
Oenothera fruticosa ssp. *glauca*
Panicum philadelphicum var. *campestre*
Phragmites americanus
Pilea fontana
Platanthera huronensis
Polygonum erectum
Ranunculus hispidus
Rosa blanda var. *glabra*
Rudbeckia hirta var. *hirta*
Sagina decumbens ssp. *decumbens*
Salicornia maritima
Scirpus georgianus
Scutellaria parvula var. *missouriensis*
Solidago simplex ssp. *randii* var. *racemosa*
Sparganium androcladum
Stachys hispida
Symphyotrichum lanceolatum ssp. *lanceolatum* var. *interior*
Taxus canadensis var. *minor*
Veronicastrum virginicum
Viola subsinuata
Vulpia octoflora var. *octoflora*
Wolffiella gladiata