

Composition, Structure, and Sustainability of Hemlock Ecosystems in Eastern North America

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Abstract

Across its natural range in North America, eastern hemlock (*Tsuga canadensis* (L.) Carriere) is an important resource for people and wildlife, but it is seriously threatened by the hemlock woolly adelgid (HWA) (*Adelges tsugae* Annand). From 10 to 20 percent of the hemlock resource is found in the Canadian provinces of New Brunswick, Nova Scotia, Ontario, Prince Edward Island, and Quebec. In the United States, hemlock is found across a wide range of forest types and stand conditions. There are 2.3 million acres of hemlock-dominated stands, but this species also is a common associate in many other forest types. The total net volume of live hemlock trees in the United States is 8.4 billion cubic feet, or 2 percent of the total inventory in states within its natural range. The existing hemlock resource is in a mature condition dominated by large-sized stands and trees. Young stands of hemlock are uncommon. Currently, hemlock mortality is low compared to other species within its range, but this would change if the HWA continues to expand. Hemlock is growing at a rate three times faster than it is being removed by harvesting and changes in land use. Long-term sustainability will depend heavily on the degree that hemlock is favored in future management practices, the future spread of the HWA, and the ability of forest managers and policymakers to control the HWA.

Background

Eastern hemlock (*Tsuga canadensis* (L.) Carriere) is an important resource for people and wildlife in North America. Around the turn of the century, hemlock was harvested extensively as a source of tannin for the leather industry. Today, hemlock is used primarily in the manufacture of pulp, paper, and sawlogs. Hemlock provides critical winter habitat for moose, white-tailed deer, ruffed grouse, turkey, songbirds, and other wildlife species. Although not as prevalent as some other tree species, hemlock is highly visible because it frequently grows along streams where high-use hiking trails are located. Recently, the hemlock woolly adelgid (HWA) (*Adelges tsugae* Annand) has emerged as a serious pest across much of hemlock's range (USDA Forest Service 1994).

Source Data

For this analysis, we divided the geographic range of hemlock into five regions: Canada (New Brunswick, Nova Scotia, Ontario, Prince Edward Island, and Quebec), New

England (Connecticut, Massachusetts, Maine, New Hampshire, Rhode Island, and Vermont), Lake States (Minnesota, Michigan, and Wisconsin), Mid-Atlantic States (Delaware, Indiana, Maryland, New Jersey, New York, Ohio, Pennsylvania, and West Virginia), and Southern Appalachian States (Alabama, Georgia, Kentucky, North Carolina, South Carolina, Tennessee, and Virginia). Information for Canada is from a recent compendium of national forest statistics (Can. Coun. of For. Minist. 1997). Most of the data for the United States are from the most recent forest inventories conducted by the USDA Forest Service's, Forest Inventory and Analysis (FIA) project (Hansen and others 1992). The Carolina hemlock (*Tsuga caroliniana* Engelm.), a closely related species found on the slopes of the southern Appalachian Mountains, is likely included in the source data. Information on area, volume, and components of inventory change are for hemlock found on "timberland," which is defined as forest land capable of producing merchantable timber crops. This definition excludes public forest land that is reserved from timber harvesting, such as tracts within the Adirondack Park and some unproductive acreage on poor sites.

North America

Hemlock's natural range extends from northeast Minnesota across Wisconsin, northern Michigan, south-central Ontario, extreme southern Quebec, and through New Brunswick and Nova Scotia. This species is found throughout New England, New York, Pennsylvania, and other Mid-Atlantic States; and as far south as northwestern Alabama (Godman and Lancaster 1990). The entire range lies between 33° and 48° N. Hemlock is generally restricted to cool humid climates with adequate moisture. Annual precipitation ranges from 29 inches to more than 50 inches across its natural range.

Within the North American forest mosaic, hemlock occupies a variety of sites, soil types, and climatic conditions. This species is most common at elevations up to 2,400 feet in Canada, New England, and the Lake States, from 1,000 to 3,000 feet in the Mid-Atlantic States, and from 2,000 to 5,000 feet in the southern Appalachians (Fowells 1965). Hemlock prefers moist to very moist soils, but is commonly found growing on drier soils on talus slopes and ridgetops (Braun 1950; Godman and Lancaster 1990). The species is noted as being long-lived, extremely tolerant of shade, and is considered to be a principal cohort of pre-settlement (late successional) forests (Foster 1997). Hemlock's association with other species ranges from occasional membership in diverse broadleaf deciduous systems to a codominant role with a number of northern coniferous species, to a dominant role in relatively pure stands. Although the national inventory data for Canada and the United States are a coarse representation of hemlock's diversity within the regional forest mosaic, they do aid in summarizing composition, structure, and sustainability of the hemlock ecosystem.

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Table 1.—Gross volume of merchantable wood (million cubic feet) on stocked, timber-productive, nonreserved forest land for Canadian provinces within the natural range of eastern hemlock, by province and species group, 1991

Species group	All provinces	Nova Scotia	New Brunswick	Quebec	Ontario
Softwoods					
Spruce	122,965	3,072	7,416	62,189	50,288
Pine	32,737	530	918	9,747	21,542
Fir	38,705	1,519	4,944	25,921	6,321
Hemlock	2,048	212	247	989	600
Other	8,829	71	1,801	3,779	3,178
Total softwoods	205,284	5,404	15,326	102,625	81,929
Hardwoods					
Aspen	36,727	247	1,554	11,371	23,555
Birch	35,738	848	2,048	20,341	12,501
Maple	23,413	2,084	3,108	11,053	7,169
Other	6,851	388	777	2,860	2,825
Total hardwoods	102,729	3,567	7,487	45,625	46,050
All species	308,013	8,971	22,813	148,250	127,979

Canada

In Canada, the national inventory data include estimates of gross merchantable volume for major tree-species groups. Hemlock is found entirely in the provinces of New Brunswick, Nova Scotia, Ontario, Prince Edward Island, and Quebec. Forests in this region are two-thirds coniferous and one-third deciduous (Table 1). The most common species groups are spruce (*Picea* spp. A. Dietr.), fir (*Abies balsamea* (L.) Mill.), aspen (*Populus grandidentata* Michx. and *P. tremuloides* Michx.), birch (*Betula* spp. L.), and assorted pines (mostly jack pine (*Pinus banksiana* Lamb.), red pine (*P. resinosa* Ait.), and white pine (*P. strobus* L.)).

The gross volume of hemlock in Canada is 2.0 billion cubic feet. Differences in compilation procedures and estimation techniques preclude direct comparisons of inventory volume between Canada and the United States; however, Canada likely contributes from 10-20 percent of the hemlock inventory in North America; hemlock volume is less than 1 percent of Canada's total inventory. About half of the hemlock in the five-province region is found along the southern boundary of Quebec. Ontario has 29 percent of the hemlock inventory, nearly all of which is located in the southeast. New Brunswick has 12 percent of Canada's hemlock, or about 1 percent of the total volume. Prince Edward Island contains scant amounts of hemlock (not recorded in Table 2). Nova Scotia contains the rest of Canada's hemlock, or 2 percent of that province's total volume.

United States

Forests of eastern North America support a diverse mix of species and stand structures. One useful measure of

composition is FIA's "forest type" variable, which is a classification of timberland based on predominate species. For reporting, it is convenient to combine specific forest types into groups. Oak and maple-beech-birch are the dominant forest-type groups in states within eastern hemlock's natural range, accounting for just over half of the timberland (Table 2). Other important forest-type groups in areas where hemlock is common are aspen-birch, spruce-fir, and white-red-jack pine.

Hemlock is a major component of four forest cover types, a common member of seven types, and a minor species in 18 other types (Godman and Lancaster 1990). The hemlock forest type includes stands where at least half of the stocking is composed of hemlock. The hemlock forest type is included in the white-red-jack pine forest-type group. In states within hemlock's natural range, the hemlock forest type totals 2.4 million acres, or less than 1 percent of the total area of timberland. Hemlock-dominated stands are divided between New England (with 54 percent of the acreage), the Mid-Atlantic States (44 percent), and Southern Appalachian States (2 percent). It should be noted that hemlock-dominated stands are found in the Lake States, but are lumped into the white-red-jack pine group by the North Central FIA project. In the white pine-hemlock forest type, hemlock shares dominance with white pine in varying degrees. There are 0.7 million acres of white pine-hemlock forests in states within hemlock's natural range.

A more complete description of hemlock's role in the composition of eastern forests is gained by examining the volume of hemlock inventory and its distribution by region and forest-type group. The total forest inventory in states within hemlock's range is 382.5 billion cubic feet; this includes the merchantable volume of all live trees at least 5

Table 2.—Area of timberland (thousand acres) by forest-type group, specific forest types within the white-red-jack pine type, and U.S. region, 1999

Forest-type group	All states	New England	Lake States	Mid-Atlantic	Southern Appalachian
White-red-jack pine:					
White pine	4,416.7	2,191.3	488.9	1,319.8	416.7
White pine-hemlock	683.2	224.8	...	273.1	185.3
Hemlock	2,358.2	1,271.5	...	1,046.6	40.1
Other pine	4,132.7	72.6	3,567.2	483.2	9.7
Total	11,590.8	3,760.2	4,056.1	3,122.7	651.8
Spruce-fir	15,640.6	7,363.4	7,570.4	693.7	13.1
Southern pine	36,867.4	178.8	...	1,554.2	35,134.4
Oak	106,851.8	4,122.0	6,033.2	28,819.4	67,877.2
Lowland hardwood	21,801.5	827.9	4,444.9	3,607.0	12,921.7
Maple-beech-birch	48,068.8	12,349.5	13,854.2	20,714.4	1,150.7
Aspen-birch	16,676.5	2,694.1	12,881.8	1,100.6	...
Nontyped	379.5	26.5	199.3	103.9	49.8
Total	257,876.9	31,322.4	49,039.9	59,715.9	117,798.7

Table 3.—Net volume of live hemlock trees (million cubic feet) by forest-type group, specific forest types within the white-red-jack pine type, and U.S. region, 1999

Forest-type group	All states	New England	Lake States	Mid-Atlantic	Southern Appalachian
White-red-jack pine					
White pine	153.7	95.6	6.6	43.9	7.6
White pine-hemlock	387.1	137.4	...	170.0	79.7
Hemlock	2,843.7	1,431.9	...	1,355.5	56.3
Other pine	2.5	...	2.5
Total	3,387.0	1,664.9	9.1	1,569.4	143.6
Spruce-fir	320.9	245.1	51.2	23.7	0.9
Southern pine	8.7	0.4	8.3
Oak	1,137.0	230.0	4.1	460.3	442.6
Lowland hardwood	59.6	5.6	43.4	10.0	0.6
Maple-beech-birch	3,439.8	961.3	1,007.0	1,427.6	43.9
Aspen-birch	65.2	33.2	27.9	4.1	...
Total	8,418.2	3,140.1	1,142.7	3,495.5	639.9

inches in diameter. The hemlock inventory is 8.4 billion cubic feet or 2 percent of the volume of all species (Table 3). The Mid-Atlantic States contain 42 percent of the hemlock inventory, followed by New England (37 percent), the Lake States (14 percent), and the Southern Appalachian States (8 percent).

Maple-beech-birch forests contain most of the hemlock volume with 3.4 billion cubic feet or 41 percent of the total. Hemlock is a minor associate in maple-beech-birch forests, but its volume accumulates over vast areas of the type group commonly found in the Lake, Mid-Atlantic, and Southern Appalachian States.

White-red-jack pine contributes 40 percent of the hemlock inventory. The hemlock forest type has 84 percent of the hemlock volume in this type group. The white pine-hemlock and white pine forest types contain nearly all of the remaining hemlock inventory in this group.

The other forest-type group with significant hemlock inventory is the oak group, which is comprised of oak-pine and oak-hickory forests (10 percent). Most of the oak stands containing hemlock are in the Mid-Atlantic and Southern Appalachian States. Hemlock plays a minor role in the other groups, but it is interesting to note that hemlock is found in all the forest-type groups common in the various regions.

The "other private" owner group controls nearly three-fourths of the hemlock inventory in states within its natural range (Table 4). This is roughly equivalent to this group's share of the total inventory for all species. The other private owners are a diverse group, ranging from individuals owning small forest tracts to corporations (other than forest industry) with large tracts. Objectives for owning timberland vary from purely aesthetic to economic, making it difficult to predict future management trends for hemlock. Forest industry owns 10 percent of the hemlock resource. Forest industry owners are defined as individuals or companies that operate a primary wood-using plant. Public owners control the remaining 16 percent of the hemlock inventory. This share is split in roughly equal parts between federal National Forests and other state, county, and municipal owners. The Southern Appalachian states and the Lake States have the largest concentrations of publicly owned hemlock with 35 and 30 percent, respectively. In the Southern Appalachian States, about 90 percent of the publicly owned hemlock is located in National Forests.

Stand structure is a general term describing numbers of trees, tree size, degree of site occupancy, and other vegetative measures. FIA's stand-size variable offers a coarse but useful proxy of stand structure as well as stage of stand development. Stand-size class is assigned to FIA sample locations according to the predominance of stems by size class: seedling-sapling, poletimber, and sawtimber. The limitation of characterizing hemlock using stand-size class is that the species occurs in so many different forest types and type groups that it is most useful for highlighting the hemlock forest type. With this in mind though, the distribution of hemlock-dominated forests by stand-size class has implications for large-scale management and policy issues.

Two dominant trends are apparent in New England and the Mid-Atlantic states where most of the hemlock forest type is found. First, the inventory of hemlock is heavily concentrated in sawtimber-size stands (75 percent) (Table 5). The build-up of hemlock in larger stands is relatively constant across owner groups. Second, there is a general lack of young stands containing hemlock. Only 4 percent of the hemlock inventory is in seedling-sapling stands, primarily in the Mid-Atlantic States, compared to 17 percent of the area of all forest types in New England and the Mid-Atlantic States in seedling-sapling stands.

In the Lake States, the two most recent inventories of Michigan and Wisconsin indicate that the number of small hemlock trees is decreasing (Schmidt and McWilliams 1995). Deer browsing, lack of active management, and damage by forest pests were cited as possible explanations. Inventory data for Mid-Atlantic and New England states does not indicate a shortage of small hemlock trees. Recent inventories of New York, Maine, and New Hampshire show increases in small-diameter hemlock.

Because the health and sustainability of the hemlock resource depends on a wide array of interrelated factors, it is difficult to make blanket statements about hemlock's long-term stability within the eastern forest mosaic. In addition to

the composition and structure information, the FIA project's data on mortality, net growth, and removals provide some simple but insightful measures of health and sustainability.

The FIA mortality estimates are expressed on an annual basis to provide information that can be compared among regions and species. The mortality estimates in Table 6 are indexed as a percentage of growing-stock volume. The overall rate of hemlock mortality across its natural range is 0.26 percent. Hemlock's mortality rate is among the lowest of tree species in states within hemlock's natural range. Species with high mortality rates tend to be associated with well-established stressors, such as spruce budworm, *Choristoneura fumiferana* (Clemens), and its impact on spruce and fir (mortality rate of 1.90). The rate for all species combined is 0.86. Thus, it would seem that hemlock is relatively healthy. Rates of hemlock mortality were highest in the Lake and Southern Appalachian States, particularly on publicly owned timberland. Mortality rates were below average in New England and average in Mid-Atlantic States. The current distribution of the HWA extends along the eastern fringe of hemlock's range from northwestern North Carolina to the northern border of Massachusetts (Souto and Shields 1999). Although the HWA has been known to occur in the eastern U.S. since 1951 (Gouger 1971), its impact was not well publicized until it invaded Connecticut in 1985 (McClure 1987). The effects of the HWA on the hemlock resource will likely increase if the pest spreads to the west. Also, it is expected that the HWA will develop sufficient cold-hardiness to expand its distribution northward (McClure 1996). Monitoring mortality rates as conditions develop will provide a gauge for policies and programs directed at slowing the spread of the HWA.

One measure of hemlock sustainability is the ability of the existing resource to expand in volume. The relationship between FIA's estimates of net growth and removals addresses this question. Table 7 shows average annual net growth-to-removals ratios by owner and region. A ratio of 1.00 indicates a balance between growth and removals. Ratios less than 1.00 indicate overcutting and ratios greater than 1.00 indicate resource expansion. For all owners and regions, the net growth-to-removals ratio is 3.22, which means the hemlock inventory is expanding more than three times faster than it is being harvested or removed by other land uses. The relationships are tightest on forest industry land, particularly in New England. The ratio of 1.03 for New England is driven by conditions in Maine, which accounts for 80 percent of the net growth and 89 percent of the removals of hemlock in this region. Recent outbreaks of spruce budworm and increased demand for fiber during the 1980's and early 1990's had a strong impact as hemlock often was included in the mix of harvested species (McWilliams 1997).

Elsewhere in hemlock's natural range, growth-to-removals ratios are highly favorable for increases in inventory volume. Outside of New England, nearly all the ratios are greater than 2.00. Ratios are highest on publicly owned timberland (4.88 for all owners) and within the Mid-Atlantic States (4.06). The primary reason for high ratios is a relatively low demand for hemlock compared to more valuable species

Table 4.—Net volume of live hemlock trees (million cubic feet) by owner group and U.S. region, 1999

Owner group	All states	New England	Lake States	Mid-Atlantic	Southern Appalachian
Public	1,339.6	306.8	342.0	469.5	221.3
Forest industry	847.8	477.8	204.5	139.5	26.0
Other private	6,230.8	2,355.5	596.2	2,886.5	392.6
All owners	8,418.2	3,140.1	1,142.7	3,495.5	639.9

Table 5.—Area of timberland classified as hemlock forest type (thousand acres) by stand-size class and U.S. region, 1999

Stand-size class	All states	New England	Lake States	Mid-Atlantic	Southern Appalachian
Seedling-sapling	96.9	35.4	...	61.5	...
Poletimber	386.4	254.2	...	132.2	...
Sawtimber	1,874.9	981.9	...	852.9	40.1
Total	2,358.2	1,271.5	...	1,046.6	40.1

Table 6.—Average annual mortality of hemlock growing stock expressed as a percent of inventory volume by owner group and U.S. region, 1999

Owner group	All states	New England	Lake States	Mid-Atlantic	Southern Appalachian
Public	0.33	0.10	0.45	0.33	0.46
Forest industry	0.36	0.32	0.41	0.37	0.39
Other private	0.24	0.15	0.36	0.26	0.34
All owners	0.26	0.18	0.40	0.28	0.38

Table 7.—Ratio of average net growth-to-removals of hemlock growing stock by owner group and U.S. region, 1999

Owner group	All states	New England	Lake States	Mid-Atlantic	Southern Appalachian
Public	4.88	2.67	7.67	6.00	3.81
Forest industry	1.02	0.75	1.16	2.18	...
Other private	2.39	1.08	3.15	4.06	3.00
Total	2.28	1.03	2.66	4.14	3.40

such as white pine, spruce, oak (*Quercus* L.), and aspen. Stumpage prices for hemlock sawtimber are among the lowest for any species. Currently, the hemlock product mix is skewed toward pulp and paper products. Of the total volume of hemlock that is used, 60 percent is used for pulp and paper, and 40 percent is used for lumber. With respect to

total timber products output in states within its natural range, hemlock makes up 2 percent of the pulpwood harvest and 1 percent of the sawlog harvest. Hemlock utilization is highest in New England where it accounts for 12 percent of the pulpwood and 7 percent of the sawlog harvest.

Summary

The hemlock resource is in good condition and is increasing in volume across most of its natural range. However, it is important to understand the character of this resource in light of the potential threat posed by the HWA, particularly in the eastern portion of hemlock's range. While the volume of hemlock is increasing, it is doubtful that the area of forest containing this species will expand because sources of new hemlock forests are rare. The existing hemlock resource is in a mature condition dominated by large stands and trees. The short-term expectation for increases in hemlock volume is supported by highly favorable growth-to-removals ratios across most of hemlock's range. The overcutting that developed in Maine during the 1980's and early 1990's has likely subsided. Long-term sustainability will depend heavily on the degree that hemlock is favored in future management practices, the future spread of the HWA, and the ability of forest managers and policymakers to control the HWA.

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