Timberland Growing Stock Mortality White Paper

2nd Generation North Central Landscape Plan

MFRC North Central Planning Committee

February 22, 2017

Minnesota Forest Resources Council

North Central Landscape: Timberland Growing Stock Mortality

MFRC staff compiled the following white paper on timberland growing stock mortality to develop a structure for informed dialog during the North Central Landscape Plan revision. This information was used by the Planning Committee when developing the goals and objectives in the revised North Central Landscape Forest Resources Plan.

Data source

The primary source for mortality data is the Forest Inventory and Analysis (FIA) dataset coordinated by the US Forest Service (www.fia.fs.fed.us). FIA is a continuous forest census designed to provide reliable estimates on the type, extent, growth, mortality, and removals of forestland. Results are based on remote sensing and field sample plots. FIA data is often reported for a single year (as we do here); however, the actual data represents a five year running average. For example data reported as 2015 is an annual average over the 2011, 2012, 2013, 2014 and 2015 period. This is important when comparing between consecutive years because four of the years leading to the estimate are the same. In other words the 2013 and 2014 data sets both include data from 2010, 2011, 2012, and 2013. This is done because it takes five years to accumulate one complete set of data; in each of those five years a different set of plots is measured. For this analysis we are focusing on mortality in *Timberlands* (see definitions below).

Forest Inventory and Analysis definitions:

- Timberland. Forest land that is producing or is capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation. (Note: Areas qualifying as timberland are capable of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included, but these likely are a very small number of acres.)
- Growing stock. All live trees of commercial species that meet minimum merchantability standards (at least 5 inches d.b.h.). In general, these trees have at least one solid 8-foot section, are reasonably free from defect on the merchantable bole, and at least 34% or more of the volume is merchantable. Excludes rough or rotten cull trees.
- Net cubic-foot volume. For timber species, this is the net volume of wood in the central stem of a sample tree ≥ 5.0 inches in diameter, from a 1-foot stump to a minimum 4-inch top diameter, or to where the central stem breaks into limbs all of which are <4.0 inches in diameter.
- Average annual net growth**.** The average annual change in the volume of trees during the period between inventories. Components include the change in volume of trees that have met the minimum size requirements over the inventory period, plus the volume of trees reaching the minimum size (≥ 5.0 inches dbh) during the period (ingrowth), minus the volume of trees that died during the period, minus the volume of cull during the period. Mortality removals (trees killed in the harvesting process and left on site) and diversion removals (trees removed from the forest-land base due to a change from forest to non-forest land) are not included.
- Average annual removals of growing stock. Trees that were growing-stock trees on timberland at the time of the previous inventory and were removed from timberland by the time of the current inventory. Removals are cut and utilized trees, trees killed as a result of harvest operations but not utilized and live trees associated with land-use reclassifications.
- Average annual mortality of growing stock. Volume of growing stock trees that were alive at the time of the previous inventory and are dead in the current inventory. Tree death associated with insects, disease, fire, animals, weather, and other factors are included.

- Sampling error percent. Equals 100 multiplied by the square root of the variance divided by the sample estimate. Since sampling error is given in percent of the estimate, a large sampling error indicates that there is considerable uncertainty associated with the estimate.

Data analysis summary

There were 5.27 billion cubic feet (66.7 million cords) of growing stock on timberland in the North Central Landscape in the 2015 FIA survey dataset (Table 1). Average annual net growth in this dataset was 143.6 million cubic feet. Quaking aspen and red pine had both the highest net volumes and average annual net growth rates; together they made up about 32.7% of the total growing stock volume and 46.8% of the total average annual net growth.

The total average annual removals (82.4 million cubic feet) exceeded the total average annual mortality (65.0 million cubic feet) by almost 17.4 million cubic feet. This was not true for all species, particularly those species for which there is little to no market (e.g., white cedar, tamarack, etc). Additionally, for some species average annual removals were greater than their average annual net growth. This was most noticeable with jack pine and paper birch, which experienced average annual removals over twice as large as average annual net growth, ultimately resulting in a negative net change for those species.

Between 2003 and 2015, net volume and annual net growth increased by 2.2% and 13.3%, respectively (Table 2). Annual removals decreased by 24.4% and mortality decreased by 35.8%. Among individual species, paper birch growth decreased by 253%, red pine and black spruce removals increased by 243% and 185% respectively, and white pine mortality increased by 738%.

Overall relative mortality rates increased from 1.0% of growing stock volume in 1977 to 1.2% in 2015 (Table 3) with a six fold increase in paper birch and white pine, although 2015 mortality rates were highest for balsam fir, balsam poplar, and jack pine. Data collection methods changed significantly over this period and we do not know how much those changes may have influenced the estimates.

More recent trends can be detected by comparing FIA data from 2003 to 2015. Relative mortality rates increased between 2003 and 2015 for white pine, tamarack, jack pine, sugar maple, and black ash, decreased for elm, paper birch, white cedar, red maple, white spruce, quaking aspen, basswood, balsam fir, black spruce, green ash, balsam poplar, red pine, and bigtooth aspen, and did not change for bur oak or northern red oak.

Mortality is strongly related to age class structure. Overall, mortality volume is higher in the 41-60 and 61-80 age classes, but relative mortality rates are highest in the 0-20 age class (Table 4). Notable exceptions to this trend include longer lived species (e.g. black ash, white cedar) whose mortality volume is highest in the 81-100, and 101-150 age classes. Other species such as northern red oak, green ash, balsam poplar, and American elm had higher relative mortality rates in older age classes.

Relative mortality rates were generally similar across ownerships (Table 5), although they were particularly high for balsam poplar on private timberlands.

Total relative removal rates were highest from county and state timberlands and lower from private and national forest timberlands (Table 6). The relative removal rate of individual species varied widely across ownerships. The most striking difference was the high removal rates of quaking aspen, bigtooth aspen, and paper birch on county timberlands and jack pine and black spruce on state timberlands.

Over the period from 2004 to 2015, average annual growing stock mortality did not drastically change for most species. Jack pine mortality fell by over 7 million cubic feet from a high of nearly 10 million cubic feet in 2004 to less than 3 million cubic feet in 2015. Furthermore, the relative mortality rate for elm dropped drastically from 16.3% of growing stock volume in 2004 to 2.6% in 2015.

Implications for forest management

- Is overall mortality too high?
- Is mortality in certain species too high?
- What is an acceptable, desirable, and/or reasonable goal for annual mortality on the landscape?
- What strategies are available to accomplish this goal?
- Would more harvest, or shorter rotation lengths for species with high mortality rates reduce mortality?
- Should reducing mortality be a priority for species with high mortality rates within the wood analysis areas (50 mile radii) around Bemidji, Grand Rapids, Cloquet, and Duluth?
- What policies might be appropriate for other parts of the North Central Landscape more distant from these primary timber markets?

Mortality trends are primarily discussed in terms of increasing or decreasing mortality over time. This is valuable information but the North Central Landscape Planning Committee should work to establish long-term goals regarding mortality rates across the landscape. In other words, even if mortality is declining or staying the same for some species it may have started too high, therefore, stable mortality may not be desirable.

Table 1. Net volume, average annual net growth, average annual removals, and average annual mortality of growing stock trees, in cubic feet, on timberlands in the North Central Landscape, 2015.

Species	Net Volume			Average Annual Net Growth			Average Annual Removals			Average Annual Mortality		
	Volume (ft^3)	Sampling error %	% of total volume	Growth (ft^3)	Sampling error %	% of total growth	Removals (ft^3)	Sampling error %	% of total removals	Mortality (ft^3)	Sampling error %	% of total mortality
Quaking aspen	1,150,172,481	4.4	21.8	47,785,805	6.2	33.3	37,173,611	13.6	45.1	23,856,705	8.0	36.7
Red pine	572,051,568	9.2	10.9	19,453,361	10.5	13.5	9,261,909	22.2	11.2	787,320	39.6	1.2
American basswood	409,174,292	7.9	7.8	7,391,096	12.6	5.1	3,191,258	33.5	3.9	2,057,416	33.7	3.2
Black ash	382,379,902	7.7	7.3	8,819,439	12.2	6.1	1,565,787	33.8	1.9	1,988,310	31.5	3.1
Paper birch	311,996,211	6.0	5.9	2,912,258	24.2	2.0	6,493,128	20.4	7.9	5,906,338	11.2	9.1
Bur oak	308,632,830	7.2	5.9	6,895,566	6.8	4.8	1,291,599	28.9	1.6	787,808	28.3	1.2
Northern red oak	248,750,128	9.2	4.7	5,169,640	15.4	3.6	3,154,028	28.7	3.8	2,555,636	25.1	3.9
Northern white-cedar	216,656,647	14.6	4.1	4,307,932	20.7	3.0	131,639	75.0	0.2	410,516	29.4	0.6
Sugar maple	213,696,420	9.0	4.1	4,733,264	10.4	3.3	1,173,380	28.2	1.4	882,864	27.1	1.4
Tamarack (native)	207,313,901	10.3	3.9	4,377,966	25.7	3.0	1,940,882	59.8	2.4	3,764,248	28.1	5.8
Balsam fir	180,957,762	7.2	3.4	3,282,687	25.2	2.3	3,335,220	30.5	4.0	7,044,573	11.5	10.8
Eastern white pine	157,614,329	14.1	3.0	4,173,335	33.3	2.9	383,215	81.7	0.5	1,954,831	54.9	3.0
Bigtooth aspen	156,983,660	12.9	3.0	5,368,619	19.3	3.7	2,675,124	38.6	3.2	1,868,360	39.6	2.9
Red maple	153,863,439	6.8	2.9	4,774,524	8.2	3.3	2,049,834	27.1	2.5	992,472	20.7	1.5
Green ash	108,231,443	11.3	2.1	3,305,114	11.5	2.3	269,199	38.6	0.3	320,482	40.3	0.5
Balsam poplar	95,806,273	10.8	1.8	1,782,136	38.7	1.2	1,541,532	44.0	1.9	2,875,657	20.3	4.4
Jack pine	93,017,433	13.0	1.8	496,364	117.7	0.3	2,863,935	36.0	3.5	2,732,517	19.9	4.2
Black spruce	92,411,472	12.2	1.8	1,837,990	25.0	1.3	2,522,016	56.0	3.1	1,588,874	20.1	2.4
White spruce	82,973,289	13.5	1.6	2,438,838	21.9	1.7	754,197	54.9	0.9	1,010,927	35.2	1.6
Northern pin oak	42,557,434	19.7	0.8	1,208,436	19.9	0.8	374,598	96.3	0.5	235,469	47.6	0.4
American elm	39,077,613	9.0	0.7	1,724,914	17.2	1.2	202,758	43.7	0.2	985,757	20.8	1.5
Silver maple	26,789,146	50.1	0.5	356,353	60.9	0.2	--	--	--	9,579	101.5	0.0
Yellow birch	6,713,262	23.6	0.1	171,979	29.9	0.1	--	--	--	37,864	51.1	0.1
Eastern cottonwood	4,478,293	87.6	0.1	731,176	97.7	0.5	--	--	--	--	--	--
Boxelder	3,363,984	49.0	0.1	163,292	32.5	0.1	--	--	--	6,609	102.1	0.0
Butternut	2,328,596	71.3	0.0	26,821	178.4	0.0	--	--	--	37,137	101.9	0.1
Black cherry	1,414,956	34.7	0.0	33,225	108.2	0.0	--	--	--	40,947	61.4	0.1
Scotch pine	771,865	101.5	0.0	136,790	101.9	0.1	--	--	--	--	--	--
Bitternut hickory	320,592	84.1	0.0	40,894	77.8	0.0	--	--	--	--	--	--
White oak	318,309	84.9	0.0	-231,258	-104.0	-0.2	58,850	95.7	0.1	251,980	98.4	0.4
Black walnut	294,366	102.4	0.0	23,610	102.1	0.0	--	--	--	--	--	--
Slippery elm	104,249	57.8	0.0	-2,408	-433.9	0.0	--	--	--	17,222	101.9	0.0
Total	**5,271,216,145**	**2.2**	**100.0**	**143,652,725**	**3.7**	**100.0**	**82,407,701**	**10.1**	**100.0**	**65,049,598**	**5.4**	**100.0**

Source: Forest Inventory and Analysis estimates.

Note: Sampling error is based on one standard error, that is, the chances are two in three that the results would have been within the limits indicated had a 100-percent inventory been conducted using these methods.

Table 2. Net volume, average annual net growth, average annual removals, and average annual mortality of growing stock trees, in cubic feet, on timberlands in the North Central Landscape, 2003.

Species	Net Volume			Average Annual Net Growth			Average Annual Removals			Average Annual Mortality		
	Volume (ft^3)	Sampling error %	% of total volume	Growth (ft^3)	Sampling error %	% of total growth	Removals (ft^3)	Sampling error %	% of total removals	Mortality (ft^3)	Sampling error %	% of total mortality
Quaking aspen	1,160,456,796	5.1	22.5	32,650,759	15.3	25.8	54,096,015	11.6	49.6	33,889,740	9.3	33.4
Paper birch	420,863,037	5.6	8.2	-1,903,587	-110.2	-1.5	8,181,779	19.8	7.5	19,172,017	11.2	18.9
Red pine	406,285,904	11.0	7.9	12,586,465	22.4	9.9	2,770,767	29.8	2.5	1,259,681	37.3	1.2
American basswood	359,490,541	8.3	7.0	9,570,574	17.8	7.6	3,022,825	34.4	2.8	3,895,330	25.9	3.8
Black ash	340,156,370	8.3	6.6	11,407,267	12.8	9.0	2,546,617	30.2	2.3	1,210,579	45.5	1.2
Northern red oak	320,495,879	8.1	6.2	6,288,684	20.9	5.0	4,309,239	30.5	4.0	3,159,660	23.2	3.1
Bur oak	262,737,393	7.6	5.1	11,913,963	23.5	9.4	832,419	32.2	0.8	847,232	37.0	0.8
Sugar maple	213,767,565	8.8	4.1	5,941,820	19.3	4.7	1,062,772	54.9	1.0	684,053	35.0	0.7
Northern white-cedar	206,023,150	13.5	4.0	4,886,445	59.8	3.9	941,945	77.1	0.9	2,807,644	47.9	2.8
Balsam fir	195,001,227	7.8	3.8	3,891,462	40.1	3.1	6,279,084	22.3	5.8	8,408,895	15.4	8.3
Jack pine	192,308,549	11.4	3.7	2,375,303	70.4	1.9	9,884,028	24.8	9.1	4,923,710	29.1	4.9
Tamarack (native)	190,141,806	10.8	3.7	4,902,551	27.3	3.9	1,632,598	50.0	1.5	3,143,818	32.4	3.1
Bigtooth aspen	163,660,093	14.9	3.2	2,934,103	45.1	2.3	2,891,418	37.7	2.7	2,192,249	34.8	2.2
Red maple	162,435,570	7.8	3.1	7,228,960	19.3	5.7	1,194,752	37.5	1.1	2,767,355	27.4	2.7
Balsam poplar	136,811,448	11.6	2.7	1,860,020	81.0	1.5	4,126,184	27.4	3.8	4,914,332	19.5	4.8
Eastern white pine	109,539,592	15.7	2.1	3,462,806	27.9	2.7	1,553,572	60.7	1.4	233,221	51.1	0.2
Black spruce	91,642,406	13.1	1.8	2,133,429	47.3	1.7	884,763	48.9	0.8	2,536,744	22.8	2.5
Green ash	76,891,801	13.3	1.5	1,956,868	32.9	1.5	505,201	49.0	0.5	333,365	45.3	0.3
White spruce	55,895,863	15.5	1.1	1,807,741	65.9	1.4	1,492,471	42.4	1.4	1,254,939	39.7	1.2
American elm	33,785,280	10.7	0.7	-446,649	-181.0	-0.4	443,313	50.3	0.4	2,939,574	25.1	2.9
Silver maple	31,065,366	50.6	0.6	1,009,092	98.1	0.8	--	--	--	--	--	--
White oak	11,093,991	34.6	0.2	56,754	110.4	0.0	--	--	--	--	--	--
Yellow birch	6,208,326	25.9	0.1	12,818	714.6	0.0	86,448	100.1	0.1	99,300	71.4	0.1
Boxelder	4,959,049	44.5	0.1	2,291	5006.9	0.0	--	--	--	--	--	--
Northern pin oak	3,537,153	40.3	0.1	237,880	75.9	0.2	--	--	--	--	--	--
Butternut	863,752	81.3	0.0	-287,578	-112.8	-0.2	218,023	100.2	0.2	401,077	99.7	0.4
Black cherry	583,850	45.2	0.0	45,841	574.6	0.0	--	--	--	284,294	59.7	0.3
Black oak	410,954	76.2	0.0	71,351	97.0	0.1	--	--	--	--	--	--
Rock elm	220,684	93.2	0.0	86,274	98.6	0.1	--	--	--	--	--	--
Slippery elm	200,887	59.7	0.0	--	--	--	--	--	--	--	--	--
Eastern cottonwood	44,944	102.2	0.0	--	--	--	--	--	--	--	--	--
Siberian elm	34,473	106.2	0.0	--	--	--	--	--	--	--	--	--
Other	33,827	103.0	0.0	--	--	--	--	--	--	--	--	--
Total	**5,157,647,523**	**2.4**	**100.0**	**126,741,128**	**7.9**	**100.0**	**108,956,233**	**8.9**	**100.0**	**101,358,810**	**5.9**	**100.0**

Source: Forest Inventory and Analysis estimates.

Note: Sampling error is based on one standard error, that is, the chances are two in three that the results would have been within the limits indicated had a 100-percent inventory been conducted using these methods.

Table 3. Average annual growing stock mortality, in percent of growing stock volume, on timberlands in the North Central Landscape, 1977, 1990, 2003, and 2015.

Tree species	1977		1990		2003		2015	
	% of volume	Sampling error %	% of volume	Sampling error %	% of volume	Sampling error %	% of volume	Sampling error %
Balsam fir	1.0	9.5	3.1	5.4	4.4	15.0	3.9	10.3
Balsam poplar	1.8	1.7	2.7	5.6	3.3	22.8	3.0	20.0
Jack pine	0.6	12.6	1.7	6.4	2.8	30.2	3.0	17.7
American elm	0.5	4.2	7.6	7.6	8.1	28.6	2.6	21.9
Quaking aspen	1.9	1.0	1.8	2.3	2.9	9.6	2.1	7.3
Paper birch	0.3	8.6	1.4	3.8	4.7	11.2	1.9	11.2
Tamarack (native)	2.3	3.5	1.1	11.3	1.5	33.1	1.8	27.0
Black spruce	0.7	11.8	2.0	7.7	2.2	23.9	1.7	19.7
White spruce	0.5	24.1	0.8	14.5	2.3	45.7	1.3	35.7
Bigtooth aspen	1.4	1.6	0.8	10.6	1.3	30.8	1.2	39.0
Eastern white pine	0.2	17.6	0.3	19.3	0.2	51.9	1.2	55.3
Northern red oak	0.5	1.3	0.7	7.3	1.0	23.3	1.0	24.9
Red maple	0.2	3.7	0.7	10.8	1.7	27.4	0.6	20.5
American basswood	0.3	2.3	0.4	7.4	1.1	26.9	0.5	32.2
Black ash	1.0	10.0	0.5	8.4	0.4	45.4	0.5	30.9
Sugar maple	0.4	2.8	0.3	10.9	0.3	31.4	0.4	27.1
Bur oak	0.3	3.3	0.1	18.2	0.3	37.7	0.3	28.2
Green ash	0.8	3.2	0.3	25.8	0.6	47.4	0.3	39.6
Northern white-cedar	0.4	11.9	0.2	12.6	1.5	50.5	0.2	25.7
Red pine	0.1	83.0	0.1	20.0	0.3	38.1	0.1	39.4
Total	**1.0**	**1.5**	**1.4**	**1.7**	**2.0**	**5.9**	**1.2**	**5.3**

Source: Forest Inventory and Analysis.

Note: Sampling error is based on one standard error, that is, the chances are two in three that the results would have been within the limits indicated had a 100-percent inventory been conducted using these methods.

Note: Estimates are based on the plot area that was timberland at both the beginning and end of the remeasurement period. This provides a more realistic estimate of the actual change component (growth, removals, mortality) that has occurred on lands that remain in the timberland base.

Note: Data collection procedures and plot design have changed over the course of the Forest Inventory Analysis program history which may lead to issues comparing between years. FIA data collected in 1977 and 1990 (*) were collected as a periodic survey while 2003 and 2015 are part of the annual survey (5 year running average). Comparisons between similarly collected survey data are stronger than between the two methods.

Table 4. Average annual growing stock mortality by age class on timberlands in the North Central Landscape, 2015.

Stand age class	All species				Quaking aspen				Red pine			
	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %
0 to 20 years	261,759,153	6,497,825	2.5	26.2	35,762,163	2,392,323	6.7	25.6	31,679,152	99,416	0.3	88.3
21 to 40 years	764,820,670	7,684,467	1.0	10.2	339,266,241	4,896,759	1.4	10.8	139,291,272	28,553	0.0	68.4
41 to 60 years	1,059,172,940	14,290,189	1.3	10.8	370,700,107	7,203,249	1.9	13.5	142,424,323	277,375	0.2	79.7
61 to 80 years	1,598,138,385	21,286,507	1.3	8.8	291,867,417	6,977,505	2.4	14.7	117,747,001	30,867	0.0	70.1
81 to 100 years	1,127,437,966	11,211,475	1.0	11.0	91,910,630	2,083,485	2.3	25.2	101,415,041	318,384	0.3	62.5
101 to 150 years	398,122,996	3,523,682	0.9	19.2	7,595,866	220,960	2.9	105.3	42,648,782	32,726	0.1	80.3
151 to 200 years	23,642,775	122,947	0.5	25.4	--	--	--	--	--	--	--	--
Not collected	--	432,506	--	--	--	82,424	--	--	--	--	--	--
Total	**5,233,094,886**	**65,049,598**	**1.2**	**5.3**	**1,137,102,423**	**23,856,705**	**2.1**	**7.3**	**575,205,571**	**787,320**	**0.1**	**39.4**

Stand age class	American basswood				Black ash				Paper birch			
	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %
0 to 20 years	35,912,122	488,571	1.4	89.7	13,661,159	200,791	1.5	74.6	18,706,704	317,730	1.7	42.4
21 to 40 years	17,152,728	--	--	--	19,005,574	8,614	0.0	99.6	22,048,708	419,141	1.9	34.4
41 to 60 years	39,138,978	74,177	0.2	58.3	33,282,712	28,404	0.1	97.1	51,244,539	1,052,229	2.1	26.3
61 to 80 years	152,770,429	469,715	0.3	30.4	116,178,274	231,060	0.2	39.2	133,584,214	2,222,869	1.7	18.7
81 to 100 years	131,083,279	902,800	0.7	50.0	118,750,934	963,574	0.8	51.0	73,951,015	1,415,675	1.9	20.9
101 to 150 years	30,889,276	122,154	0.4	83.3	70,870,494	555,867	0.8	58.5	13,144,608	235,911	1.8	43.1
151 to 200 years	--	--	--	--	39,277	--	--	--	1,700,328	--	--	--
Not collected	--	--	--	--	--	--	--	--	--	242,783	--	--
Total	**406,946,812**	**2,057,416**	**0.5**	**32.2**	**371,788,425**	**1,988,310**	**0.5**	**30.9**	**314,380,117**	**5,906,338**	**1.9**	**11.2**

Stand age class	Bur oak				Northern red oak				Northern white-cedar			
	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %
0 to 20 years	31,072,598	78,161	0.3	92.5	14,713,928	67,308	0.5	67.3	2,464,227	--	--	--
21 to 40 years	21,406,704	84,568	0.4	79.8	9,804,089	181,450	1.9	87.3	1,259,767	--	--	--
41 to 60 years	56,097,799	82,764	0.1	59.9	27,156,580	8,544	0.0	100.7	8,961,593	7,190	0.1	97.3
61 to 80 years	88,627,094	334,443	0.4	42.6	99,302,510	1,482,221	1.5	39.2	26,353,508	12,019	0.0	74.0
81 to 100 years	84,685,294	166,007	0.2	77.8	90,956,396	762,247	0.8	26.2	63,907,930	134,025	0.2	41.9
101 to 150 years	22,195,729	41,865	0.2	45.7	5,706,146	53,865	0.9	90.8	95,802,371	185,564	0.2	43.7
151 to 200 years	--	--	--	--	--	--	--	--	20,493,904	71,719	0.3	23.2
Not collected	--	--	--	--	--	--	--	--	--	--	--	--
Total	**304,085,217**	**787,808**	**0.3**	**28.2**	**247,639,648**	**2,555,636**	**1.0**	**24.9**	**219,243,299**	**410,516**	**0.2**	**25.7**

Table 4. Continued.

Stand age class	Tamarack (native)				Sugar maple				Balsam fir			
	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %
0 to 20 years	5,687,448	256,166	4.5	89.0	12,086,132	80,901	0.7	67.6	10,140,634	715,467	7.1	39.8
21 to 40 years	8,331,179	--	--	--	5,146,001	--	--	--	30,474,390	761,967	2.5	30.0
41 to 60 years	31,582,561	1,182,061	3.7	63.0	8,331,261	8,523	0.1	84.1	42,002,718	1,317,987	3.1	21.1
61 to 80 years	64,590,051	620,283	1.0	37.3	91,545,304	314,042	0.3	34.9	55,470,985	2,809,006	5.1	16.6
81 to 100 years	58,340,038	804,744	1.4	54.2	82,542,068	337,312	0.4	46.9	27,201,392	757,608	2.8	26.3
101 to 150 years	36,125,727	866,773	2.4	45.7	14,596,112	142,086	1.0	88.6	12,800,490	628,545	4.9	28.9
151 to 200 years	823,194	27,092	3.3	0.0	--	--	--	--	415,919	11,006	2.6	75.0
Not collected	--	7,129	--	--	--	--	--	--	--	42,987	--	--
Total	**205,480,198**	**3,764,248**	**1.8**	**27.0**	**214,246,876**	**882,864**	**0.4**	**27.1**	**178,506,529**	**7,044,573**	**3.9**	**10.3**

Stand age class	Bigtooth aspen				Red maple				Eastern white pine			
	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %
0 to 20 years	3,167,128	523,531	16.5	77.5	9,667,327	111,639	1.2	54.5	9,923,121	851,899	8.6	93.1
21 to 40 years	27,893,804	193,315	0.7	81.8	6,940,045	36,820	0.5	96.2	16,979,930	--	--	--
41 to 60 years	35,365,597	145,371	0.4	74.2	34,084,139	224,088	0.7	44.4	33,265,188	61,784	0.2	75.6
61 to 80 years	53,459,978	726,128	1.4	62.3	66,183,212	394,659	0.6	34.6	53,387,588	792,853	1.5	90.6
81 to 100 years	34,174,907	280,015	0.8	56.8	31,547,394	215,959	0.7	41.9	38,784,427	248,296	0.6	77.4
101 to 150 years	3,851,415	--	--	--	4,424,371	--	--	--	5,607,315	--	--	--
151 to 200 years	--	--	--	--	--	--	--	--	--	--	--	--
Not collected	--	--	--	--	--	9,306	--	--	--	--	--	--
Total	**157,912,830**	**1,868,360**	**1.2**	**39.0**	**152,846,487**	**992,472**	**0.6**	**20.5**	**157,947,568**	**1,954,831**	**1.2**	**55.3**

Stand age class	Green ash				Balsam poplar				Jack pine			
	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %
0 to 20 years	6,449,757	27,011	0.4	98.5	3,206,602	66,140	2.1	73.3	2,536,958	102,280	4.0	109.3
21 to 40 years	5,836,965	32,913	0.6	65.2	32,542,502	463,157	1.4	51.1	25,549,884	354,785	1.4	36.8
41 to 60 years	24,297,865	--	--	--	26,680,559	1,142,215	4.3	25.1	30,518,750	612,385	2.0	31.3
61 to 80 years	33,941,735	78,107	0.2	59.7	18,865,719	865,170	4.6	44.3	25,009,039	1,264,003	5.1	31.5
81 to 100 years	30,741,837	101,633	0.3	90.0	11,332,347	227,741	2.0	61.0	7,055,811	344,710	4.9	35.3
101 to 150 years	3,610,137	80,817	2.2	76.0	2,275,673	111,234	4.9	89.6	1,610,001	54,353	3.4	28.6
151 to 200 years	--	--	--	--	--	--	--	--	--	--	--	--
Not collected	--	--	--	--	--	--	--	--	--	--	--	--
Total	**104,878,297**	**320,482**	**0.3**	**39.6**	**94,903,402**	**2,875,657**	**3.0**	**20.0**	**92,280,443**	**2,732,517**	**3.0**	**17.7**

Table 4. Continued.

Stand age class	Black spruce				White spruce				American elm			
	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error %
0 to 20 years	1,386,083	75,150	5.4	93.1	5,502,327	--	--	--	3,662,980	43,342	1.2	60.7
21 to 40 years	3,011,592	--	--	--	21,188,038	--	--	--	5,577,604	213,408	3.8	55.7
41 to 60 years	15,791,950	87,301	0.6	34.9	23,762,717	427,121	1.8	64.0	8,467,174	231,859	2.7	49.7
61 to 80 years	44,971,716	804,965	1.8	30.6	16,529,885	243,618	1.5	56.1	13,776,213	328,899	2.4	36.1
81 to 100 years	18,536,924	516,878	2.8	31.9	7,369,116	267,208	3.6	82.3	4,744,881	110,192	2.3	51.7
101 to 150 years	9,547,292	91,450	1.0	46.0	6,289,570	72,981	1.2	50.4	1,921,519	10,181	0.5	101.6
151 to 200 years	--	13,131	--	--	--	--	--	--	170,152	--	--	--
Not collected	--	--	--	--	--	--	--	--	--	47,876	--	--
Total	**93,245,557**	**1,588,874**	**1.7**	**19.7**	**80,641,654**	**1,010,927**	**1.3**	**35.7**	**38,320,523**	**985,757**	**2.6**	**21.9**

Source: Forest Inventory and Analysis.

Note: Sampling error is based on one standard error, that is, the chances are two in three that the results would have been within the limits indicated had a 100-percent inventory been conducted using these methods.

Note: Estimates are based on the plot area that was timberland at both the beginning and end of the remeasurement period. This provides a more realistic estimate of the actual change component (growth, removals, mortality) that has occurred on lands that remain in the timberland base.

Table 5. Average annual growing stock mortality by timberland ownership in the North Central Landscape, 2015.

Species	National Forest				State			
	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error (%)	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error (%)
Quaking aspen	211,432,823	3,485,346	1.6	17.5	150,649,685	3,404,168	2.3	16.0
Red pine	204,445,233	276,041	0.1	68.6	56,675,612	152,900	0.3	57.9
American basswood	70,023,900	686,706	1.0	67.0	41,311,936	69,417	0.2	65.5
Black ash	45,389,410	47,548	0.1	50.0	67,163,174	350,190	0.5	57.3
Paper birch	61,169,773	788,390	1.3	33.4	30,674,640	608,576	2.0	28.6
Bur oak	20,685,076	203,504	1.0	64.6	32,019,099	5,967	0.0	97.0
Northern red oak	12,890,270	--	--	--	35,598,831	197,335	0.6	42.0
Northern white-cedar	59,516,815	107,492	0.2	44.8	46,373,862	151,268	0.3	43.9
Tamarack (native)	30,563,434	663,670	2.2	65.2	80,599,297	1,153,002	1.4	35.3
Sugar maple	26,736,517	217,852	0.8	51.3	24,515,225	54,918	0.2	88.7
Balsam fir	27,085,829	886,178	3.3	23.2	21,785,629	734,739	3.4	24.1
Bigtooth aspen	23,867,936	732,356	3.1	75.0	21,138,740	167,515	0.8	67.8
Red maple	15,088,674	242,885	1.6	39.2	23,987,665	85,421	0.4	58.4
Eastern white pine	43,204,929	1,027,349	2.4	78.9	11,201,799	60,055	0.5	88.4
Green ash	4,653,771	--	--	--	9,290,114	25,409	0.3	82.4
Balsam poplar	13,076,603	217,312	1.7	53.8	20,672,073	597,417	2.9	34.7
Jack pine	9,573,871	304,369	3.2	38.8	7,676,243	322,853	4.2	40.7
Black spruce	15,698,883	321,159	2.0	52.2	32,018,685	440,117	1.4	28.5
White spruce	9,578,633	23,775	0.2	91.1	10,843,165	253,023	2.3	103.4
American elm	2,924,104	20,721	0.7	103.1	4,347,257	140,324	3.2	48.1
Total	**911,336,883**	**10,511,797**	**1.2**	**18.4**	**732,097,482**	**8,999,334**	**1.2**	**10.7**

Table 5. Continued.

Species	County and Municipal				Private			
	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error (%)	Volume (ft^3)	Mortality (ft^3)	% of volume	Sampling error (%)
Quaking aspen	252,983,458	5,561,509	2.2	16.4	522,036,457	11,323,258	2.2	10.6
Red pine	94,376,061	82,276	0.1	81.3	219,708,665	276,103	0.1	79.3
American basswood	69,807,053	120,602	0.2	46.6	225,803,923	1,180,691	0.5	40.7
Black ash	76,672,450	255,588	0.3	58.5	182,563,390	1,334,984	0.7	38.8
Paper birch	70,719,691	1,483,642	2.1	19.4	151,816,013	2,782,948	1.8	15.4
Bur oak	44,086,598	197,353	0.4	41.9	207,294,443	380,984	0.2	43.1
Northern red oak	60,530,462	217,276	0.4	75.5	138,620,085	2,141,025	1.5	28.6
Northern white-cedar	52,341,110	30,034	0.1	71.9	61,011,512	121,722	0.2	45.9
Tamarack (native)	40,649,771	330,610	0.8	66.8	53,667,697	1,609,836	3.0	48.9
Sugar maple	41,700,587	95,328	0.2	39.4	121,294,547	514,766	0.4	39.7
Balsam fir	44,827,353	1,872,043	4.2	21.9	84,807,718	3,508,626	4.1	15.4
Bigtooth aspen	27,209,765	438,052	1.6	94.8	85,696,388	530,437	0.6	44.6
Red maple	38,911,500	242,635	0.6	40.3	74,858,648	412,224	0.6	34.5
Eastern white pine	37,437,825	--	--	--	66,103,015	867,427	1.3	83.4
Green ash	18,856,812	62,737	0.3	60.6	72,077,600	232,335	0.3	51.4
Balsam poplar	20,105,818	283,431	1.4	32.9	41,048,909	1,777,497	4.3	29.3
Jack pine	20,451,699	616,095	3.0	47.5	54,578,630	1,489,200	2.7	22.6
Black spruce	20,965,969	407,116	1.9	47.0	24,562,021	420,482	1.7	33.1
White spruce	15,869,321	194,072	1.2	62.5	44,350,535	540,058	1.2	42.2
American elm	9,211,051	159,061	1.7	54.3	21,838,111	617,776	2.8	29.2
Total	**1,074,614,755**	**12,736,781**	**1.2**	**10.5**	**2,515,045,766**	**32,369,181**	**1.3**	**7.0**

Source: Forest Inventory and Analysis.

Note: Sampling error is based on one standard error, that is, the chances are two in three that the results would have been within the limits indicated had a 100-percent inventory been conducted using these methods.

Note: Estimates are based on the plot area that was timberland at both the beginning and end of the remeasurement period. This provides a more realistic estimate of the actual change component (growth, removals, mortality) that has occurred on lands that remain in the timberland base.

Table 6. Average annual growing stock removals by timberland ownership in the North Central Landscape, 2015.

Species	National Forest				State			
	Volume (ft^3)	Removals (ft^3)	% of volume	Sampling error %	Volume (ft^3)	Removals (ft^3)	% of volume	Sampling error %
Quaking aspen	211,432,823	2,604,771	1.2	47.6	150,649,685	3,978,818	2.6	49.1
Red pine	204,445,233	2,651,196	1.3	48.8	56,675,612	1,480,319	2.6	38.5
American basswood	70,023,900	120,872	0.2	75.1	41,311,936	809,784	2.0	85
Black ash	45,389,410	--	--	--	67,163,174	155,187	0.2	73.3
Paper birch	61,169,773	70,534	0.1	100.3	30,674,640	1,035,405	3.4	56.5
Bur oak	20,685,076	--	--	--	32,019,099	7,232	0.0	95.9
Northern red oak	12,890,270	7,086	0.1	104.4	35,598,831	618,817	1.7	74.4
Northern white-cedar	59,516,815	--	--	--	46,373,862	--	--	--
Tamarack (native)	30,563,434	--	--	--	80,599,297	833,287	1.0	75
Sugar maple	26,736,517	--	--	--	24,515,225	430,570	1.8	59.2
Balsam fir	27,085,829	96,463	0.4	94.2	21,785,629	232,305	1.1	58.6
Bigtooth aspen	23,867,936	54,271	0.2	107.3	21,138,740	318,040	1.5	77.2
Red maple	15,088,674	--	--	--	23,987,665	673,049	2.8	47.9
Eastern white pine	43,204,929	--	--	--	11,201,799	--	--	--
Green ash	4,653,771	--	--	--	9,290,114	19,447	0.2	105.3
Balsam poplar	13,076,603	--	--	--	20,672,073	7,426	0.0	100.7
Jack pine	9,573,871	--	--	--	7,676,243	488,738	6.4	64
Black spruce	15,698,883	--	--	--	32,018,685	1,774,174	5.5	73.1
White spruce	9,578,633	13,918	0.1	95.7	10,843,165	181,337	1.7	80.5
American elm	2,924,104	--	--	--	4,347,257	38,174	0.9	94.5
Total	**911,336,883**	**5,619,111**	**0.6**	**33.4**	**732,097,482**	**13,082,110**	**1.8**	**25.2**

Table 6. Continued.

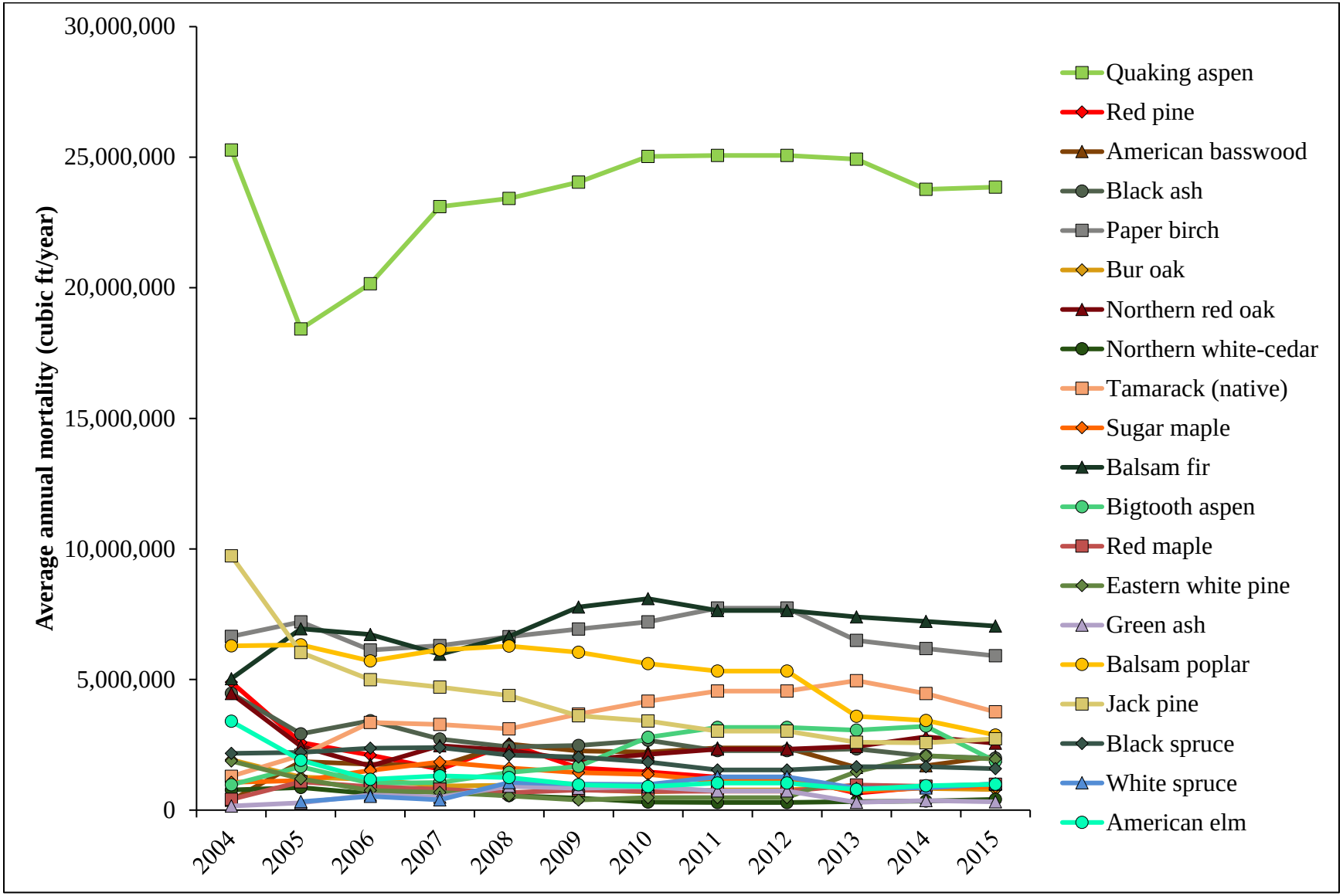
Species	County and Municipal				Private			
	Volume (ft^3)	Removals (ft^3)	% of volume	Sampling error %	Volume (ft^3)	Removals (ft^3)	% of volume	Sampling error %
Quaking aspen	252,983,458	15,897,787	6.3	23.1	522,036,457	14,144,133	2.7	22
Red pine	94,376,061	778,274	0.8	72.7	219,708,665	3,233,492	1.5	33.5
American basswood	69,807,053	707,048	1.0	43	225,803,923	1,197,192	0.5	60
Black ash	76,672,450	604,488	0.8	61.2	182,563,390	681,418	0.4	54
Paper birch	70,719,691	2,883,554	4.1	29.5	151,816,013	1,184,459	0.8	44.2
Bur oak	44,086,598	410,656	0.9	50.7	207,294,443	389,800	0.2	51.4
Northern red oak	60,530,462	1,466,339	2.4	44.4	138,620,085	381,076	0.3	75.7
Northern white-cedar	52,341,110	--	--	--	61,011,512	95,930	0.2	98.2
Tamarack (native)	40,649,771	1,099,869	2.7	92.4	53,667,697	--	--	--
Sugar maple	41,700,587	444,608	1.1	43.1	121,294,547	291,592	0.2	43.9
Balsam fir	44,827,353	1,538,283	3.4	54.8	84,807,718	825,371	1.0	51.7
Bigtooth aspen	27,209,765	1,811,596	6.7	58	85,696,388	491,217	0.6	67.3
Red maple	38,911,500	1,085,226	2.8	40.5	74,858,648	291,559	0.4	72.9
Eastern white pine	37,437,825	15,312	0.0	105.1	66,103,015	68,623	0.1	104.5
Green ash	18,856,812	71,935	0.4	65.2	72,077,600	81,397	0.1	77.5
Balsam poplar	20,105,818	123,236	0.6	102.6	41,048,909	1,130,843	2.8	58
Jack pine	20,451,699	102,885	0.5	75.9	54,578,630	1,976,648	3.6	49.5
Black spruce	20,965,969	747,842	3.6	88.8	24,562,021	--	--	--
White spruce	15,869,321	112,895	0.7	57.7	44,350,535	446,047	1.0	88.3
American elm	9,211,051	7,057	0.1	98.3	21,838,111	87,245	0.4	50.9
Total	**1,074,614,755**	**30,263,463**	**2.8**	**19**	**2,515,045,766**	**27,018,066**	**1.1**	**16.7**

Source: Forest Inventory and Analysis.

Note: Sampling error is based on one standard error, that is, the chances are two in three that the results would have been within the limits indicated had a 100-percent inventory been conducted using these methods.

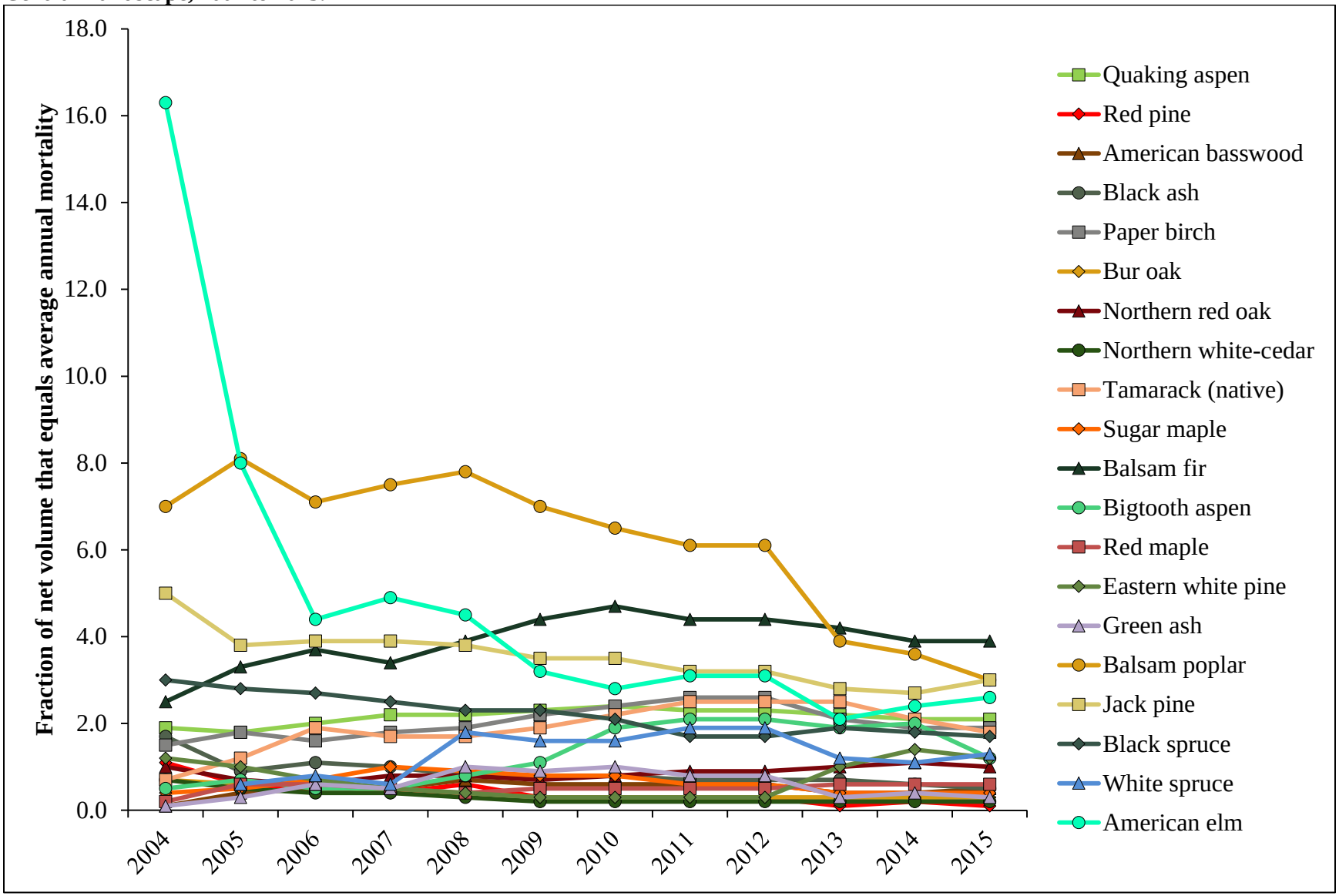
Note: Estimates are based on the plot area that was timberland at both the beginning and end of the remeasurement period. This provides a more realistic estimate of the actual change component (growth, removals, mortality) that has occurred on lands that remain in the timberland base.

Figure 1. Average annual growing stock mortality volume estimate of selected species on timberland in the North Central Landscape, 2004 to 2015.



Source: Forest Inventroy Analysis.

Figure 2. Average annual growing stock mortality, in percent of growing stock volume, of selected species on timberland in the North Central Landscape, 2004 to 2015.



Source: Forest Inventroy Analysis.