Estimated Impacts of Emerald Ash Borer (EAB) on Ash Timber Supply in Minnesota

Curtis L. VanderSchaaf
Forest Modeler
Resource Assessment Unit
Grand Rapids, MN 55744
(218) 327-4449 Ext 247
curtis.vanderschaaf@state.mn.us

and

Keith Jacobson
Forest Products Utilization and Marketing Program Supervisor
500 Lafayette Road
St. Paul, MN 55155

September, 2011

Minnesota Department of Natural Resources

DNR Division of Forestry Centennial 1911 2011 Minnesota

TABLE OF CONTENTS

Many useful comments were received from DNR Division of Forestry staff including Anna Dirkswager (Biomass Program Consultant) and Steve Vongroven (Utilization & Marketing), Mark Lindquist (Biofuels Program Manager), and Val Cervenka (Forest Health Program Coordinator). Cover photographs were taken by Curtis VanderSchaaf and Eric R. Day, Virginia Tech University, Bugwood.org.

Executive Summary

Purpose

This analysis was done to inform development and execution of ash utilization strategies. These strategies will be an important management and mitigation tool as Emerald Ash Borer (EAB) spreads. Utilization strategies will be very different depending on potential volumes, and period of time wood may be available to the marketplace.

It is important to note that this analysis focused on biological potential, and that market and site operability factors will result in actual harvest levels below biological potential.

Background

The emerald ash borer (*Agrilus planipennis* Fairmaire), commonly referred to as EAB, was introduced to the United States from Asia and first detected in southeast Michigan during 2002. Since then, it has spread to a number of additional states, including the detection of several small infection centers in Minnesota over the last 2 years.

Recent observations revealed no natural ash resistance to EAB, reinforcing the thought that it is likely that virtually all trees of these species will eventually be killed.

Ash is a significant component of rural forests, as well as urban areas. Three species of ash are found in Minnesota. In relative order of total volume they are black, green and white ash.

A relatively straightforward analysis was conducted to determine how much volume might be harvested annually under various management regimes and assumptions of EAB spread. This analysis is basic, initial work that should be expanded upon and adjusted as more is learned about EAB spread and utilization over time.

Findings

Currently there are 18.1 million cords of ash (black, green, and white) in rural areas and 0.7 million cords in urban areas. According to the inventory data, methods, and assumptions used for this analysis, the maximum annual rural ash harvest levels are 458,000, 485,000, and 495,000 cords when assuming the ash resource is depleted over a 25, 50, or 75 year period, respectively. The minimum annual harvest levels for the three ash resource depletion periods range from 24,000 to 26,000 cords. On average, annual harvest levels range from 275,000 to 281,000 cords over the three ash resource depletion periods.

For the urban resource, the maximum annual ash harvest levels range from 16,100 to 16,600 cords when assuming the ash resource is depleted over a 10, 15, or 20 year period. The minimum annual harvest levels are 3,000, 1,400, and 1,100 cords over a 10, 15, or 20 year period, respectively. On average, the annual harvest levels are 12,500, 10,500, and 9,800 cords over the 10, 15, or 20 year periods, respectively.

It is estimated that EAB could annually cause up to 1.8 million cords of mortality in rural areas and up to 126,500 cords of mortality in urban areas, depending on the depletion rate of ash.

Estimated Impacts of Emerald Ash Borer (EAB) on Ash Timber Supply in Minnesota

Purpose

This analysis was done to inform development and execution of ash utilization strategies. These strategies will be an important management and mitigation tool as Emerald Ash Borer (EAB) spreads. Utilization strategies will be very different depending on potential volumes, and period of time wood may be available to the marketplace.

This analysis is basic, initial work that should be expanded upon and adjusted as more is learned about EAB spread and utilization over time.

It is important to note that this analysis focused on biological potential, and that market and site operability factors will result in actual harvest levels below biological potential.

Background

The emerald ash borer (*Agrilus planipennis* Fairmaire), commonly referred to as EAB, was introduced to the United States from Asia and first detected in southeast Michigan during 2002. It is thought the beetle existed in Michigan for years prior to its discovery, perhaps introduced as early as the first half of the 1990's. EAB has since been detected in Minnesota and many other states, including Wisconsin as well as in Ontario[1]. It was first detected in Minnesota in May 2009. Currently there are two known infestations - one is in the Twin Cities metropolitan area and the other is in Houston County near the Wisconsin border[2]. This wood-boring beetle has a low rate of spread naturally but can be transported to new areas in infested firewood, unprocessed logs, and nursery stock. New infestations can be difficult to detect as symptoms may not be readily apparent for up to three years.

All North American ash (*Fraxinus*) species appear susceptible, even healthy trees, regardless of whether they are located in an urban or rural setting. Within Minnesota, the three common ash species are black (*Fraxinus nigra* Marsh.), green (*Fraxinus pennsylvanica* Marsh.), and white (*Fraxinus americana* L.). Recent observations revealed no natural ash resistance to EAB, reinforcing the thought that it is likely that virtually all trees of these species will eventually be killed. Rates of annual natural spread of EAB have been reported to be ½ mile. Thus, if infested areas can be isolated by quarantine, there may be time to develop treatments[3] to reduce or eliminate or at least slow and mitigate the impacts of these insects in both urban areas and forests. In addition, with time, some natural resistance by ash trees may be identified allowing for genetic modification of trees.

A relatively straightforward analysis was conducted to determine how much volume might be harvested annually under various management regimes and assumptions of EAB spread. Ash trees may be harvested and utilized in areas with no known EAB infestation to capture resources

[1] http://www.emeraldashborer.info/files/MultiState_EABpos.pdf
[2] http://www.emeraldashborer.info/files/MN_June_2009_Statewide_EAB_map.pdf
[3] http://www.mda.state.mn.us/plants/pestmanagement/eab/biocontrolinsemn.aspx

that would otherwise eventually be wasted due to mortality and decay and to begin the process of ash species replacement in some stands. Market-based utilization is likely to be a key forest management strategy, as it can greatly reduce costs of accomplishing management and mitigation to transition forest stands to their desired post-EAB condition. Also, as part of controlling EAB spread by eliminating its breeding substrate, it has been proposed that eliminating the ash resource around known infestations will reduce or eliminate the spread of that infestation (of course the insect can still be transported through the actions of humans).

The Ash Resource in Minnesota

Rural Forests

Ash trees are a major component of lowland hardwood forests in Minnesota. They comprise 8% of the total all live volume on Minnesota's forest land, and are well distributed across Minnesota[4]. Ash trees constitute at least 25 percent of the stand volume on 1.7 million acres of forest land.

Urban Areas

According to a recent inventory of urban areas, there are around 2.91 million ash trees with a diameter of at least one inch in residential and commercial areas (this estimate does not include areas such as city parks and city forests).

Estimation of EAB Related Ash Mortality and Annual Potential Harvest Levels

Since the ash resource is located in both urban and rural areas, where each area has different growing conditions and likely utilization opportunities, separate analyses were conducted. For each area, a cord of stacked wood and bark is assumed to consist of 79 cubic feet of wood.

Rural Forests

USDA Forest Service Forest Inventory and Analysis (FIA) data were used to determine the existing resource and net growth rates. See Appendix I for more details about the modeling process. The existing total rural forest volume for ash is 18.1 million cords. The majority being black (69%), followed by green (30%), while white ash comprises less than 1%. Projections are needed to determine how potential conditions in the future might impact the amount of ash volume. To project growth of the existing resource forward, the amount of estimated net growth (gross volume growth minus volume mortality) as obtained from FIA was assumed to be 2.8297% of the standing inventory.

$$\frac{\text{Average annual net growth in cords}}{\text{Standing inventory at time present}} = \frac{511{,}365 \text{ cords}}{18{,}071{,}399 \text{ cords}} = 2.897\%$$

[4] http://nrs.fs.fed.us/pubs/38095 - Minnesota's Forests 2008.

Based on rates of spread found in other states, both human-related and natural, three projection periods (25, 50, and 75 years) were chosen that assume varying rates of elimination of the rural ash resource across Minnesota.

Assumed Mortality Rates Over Time Due to EAB for Projections

Currently, mortality rates due to EAB in Minnesota forests are very low. There are only a handful of known infection centers. Since the insect is expected to spread, the amount of volume/biomass lost due to EAB related mortality is almost certain to increase over time. It is likely that the biggest unknown is the *rate* of spread. Eventually, as the ash resource continues to decrease due largely to EAB related mortality and stand conversion work, the amount of volume/biomass lost due to EAB will decrease. To model this, the normal distribution was used to depict annual mortality rates (Figure 1). The amount of volume/biomass lost due to EAB related mortality is obtained by multiplying the Percent Annual Mortality rate by the amount of volume at year 0 (or the present time). Therefore, for a particular projection period, mortality was assumed to be greatest at the midpoint. The standard deviation (determining the spread of the curve) for a particular projection period was selected such that reasonable mortality rates were obtained.

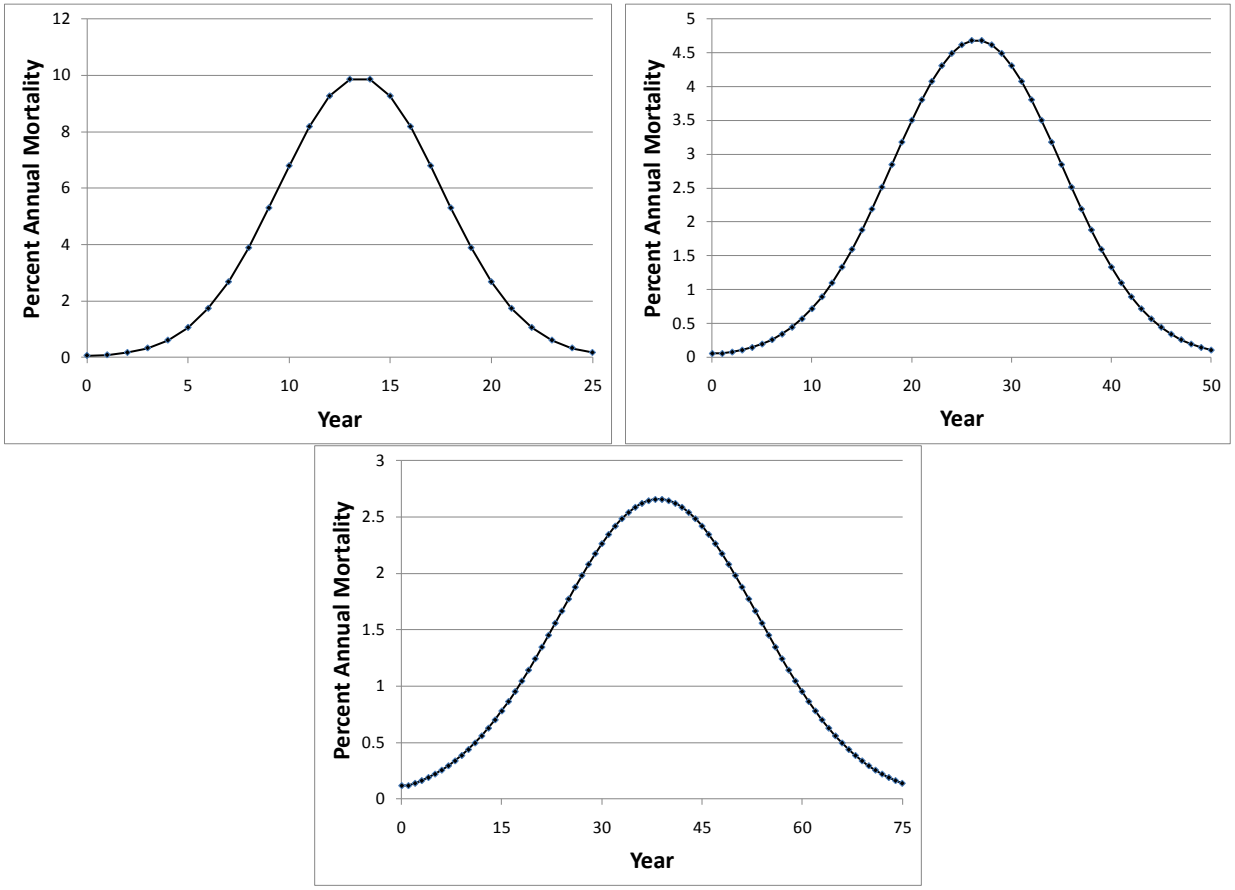

Figure 1. Depiction of normal distribution curves used to model mortality rates for the three projection periods (25, 50, and 75 years). For the 25-year projection, the mean was 13 years and the standard deviation was 4.0, for the 50-year projection, the mean was 26 years and the standard deviation was 8.5, and for the 75-year projection the mean was 38 years and the standard deviation was 15.

Minimum Ash Inventory Volumes

There may be some natural resistance of ash trees to EAB and with time economically feasible controls may be developed such that a minimum level of ash volume will be retained. For each projection period in this analysis, the amount of ash volume is not allowed to be less than 5% of the existing inventory, or 903,570 cords.

Estimated Potential Harvest Removals

Based on rates of spread found in other states, both human-related and natural, three projection periods were chosen that assume different rates of reduction to reach the point of minimum inventory. For each projection period, 25, 50, or 75 years, a constant proportional rate of harvested material was assumed across all years. This results in the maximum amount of harvesting occurring when the standing inventory is greatest (Figure 2, Tables 1-3). For a particular projection, the rate was selected such that the minimum ash inventory (903,570 cords) would be reached in the final projected year and that no harvesting would occur in the last year, given the amount of net growth and mortality due to EAB. Hence, for the 25-year, 50-year, and 75-year projection periods, harvest rates of 2.5203%, 2.6714%, and 2.7398% of total volume were used, respectively.

For simplicity, an estimate of oven-dry top and limb biomass for trees (all woody stem and branch biomass (includes wood and bark) above a 4-inch top DOB for trees, regardless of form, with diameters at breast height of 5 inches or greater) and sapling biomass (all living aboveground portions of live trees with diameters less than 5 inches) was obtained by multiplying harvested volumes by 0.7879 (Tables 1-3). This value was obtained from the ratio presented below, data from FIA.

$$\frac{\text{Oven-dry tons of all live top and limb and living sapling biomass At time present}}{\text{Merchantable cords at time present}} = \frac{14{,}237{,}621 \text{ tons}}{18{,}071{,}621 \text{ cords}} = 0.7879$$

Reminder: This analysis focused on biological potential. Market and site operability factors will result in actual harvest levels below biological potential.

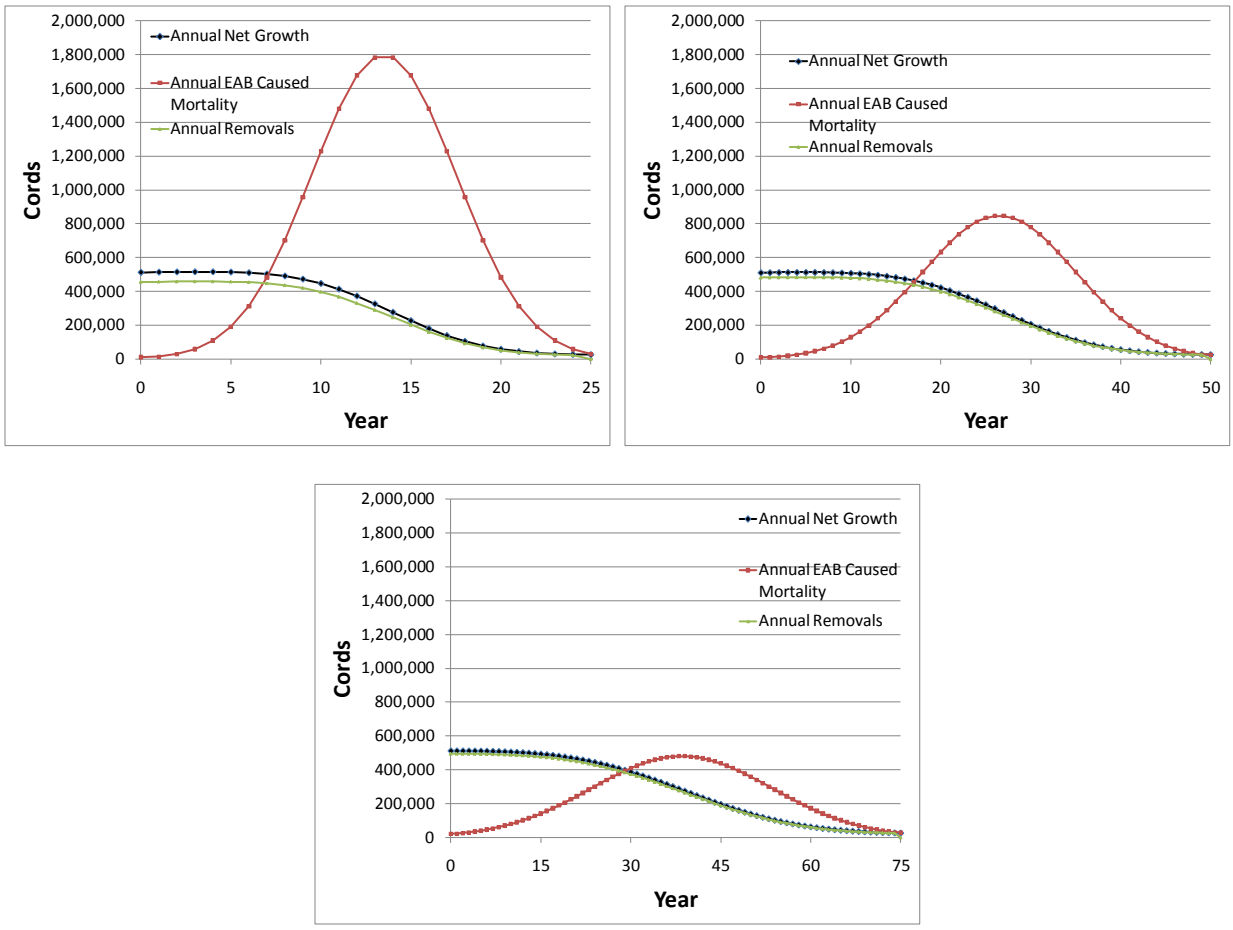

Figure 2. Annual net growth, annual removals, and annual loss due to EAB for the three projection periods (25, 50, and 75 years).

Projected Ash Standing Volumes and Biomass

For the 25- and 50-year projections, supply slightly increases over the initial five or so years and then steadily declines to the retained amount of 903,570 cords (Figure 3, Tables 1 and 2). The 75-year projection steadily declines across time (Figure 3, Table 3). As expected for comparative years (e.g. the first 25 or 50 years of the 75-year projection) for the 75-year projection, the amount of annual harvests is greater relative to the 25- and 50-year projections.

It is difficult to predict the rate of spread of EAB over the next 25 to 75 years. If infested areas can be quickly quarantined and residents and visitors are diligent in their attempts to reduce spread, then the 75-year projection period may be most appropriate. If the 50-year and 75-year projection periods mimic reality, then it is possible that economically feasible and highly effective control agents may be identified. Perhaps even under the 25-year scenario economically feasible and effective control agents may be identified. Alternatively, natural resistance by ash may be identified and these trees can then be used in genetic programs to develop resistant strains of ash trees.

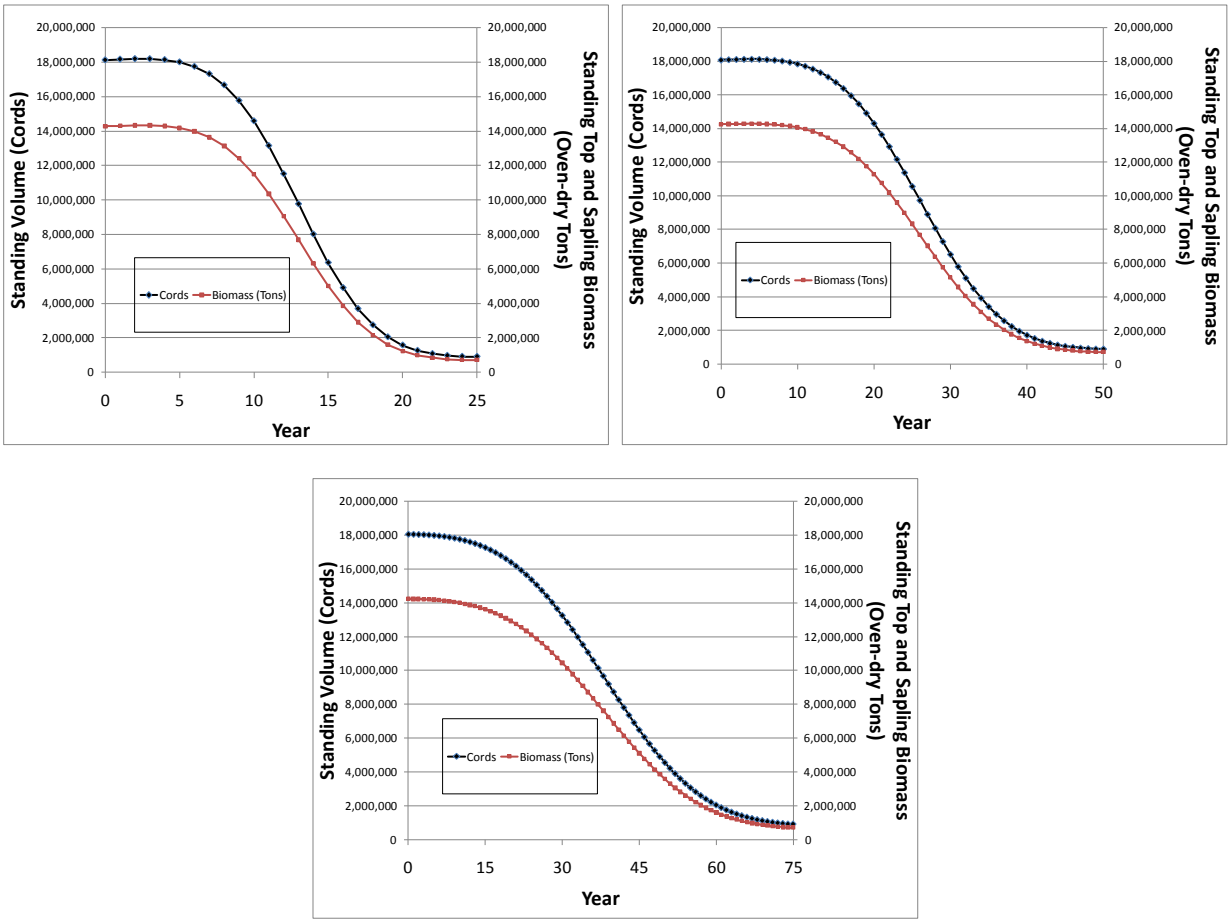

Figure 3. Ending rural forest inventory of ash volume and biomass (tops, limbs, and saplings) for the three projection periods (25, 50, and 75 years).

Table 1. Estimated rural forest ash volumes and biomass (tops, limbs, and saplings – oven-dry tons) for the 25-year projection period.

Year	Beginning Inventory (cords)	Net Growth (cords)	Annual EAB Caused Mortality (cords)	Estimated Potential Harvest Removals (cords)	Estimated Potential Harvest Removals (Biomass - tons)	Ending Inventory (cords)	Ending Inventory (Biomass - tons)
Present	18,071,399	511,365	10,428	455,451	358,829	18,116,885	14,273,458
1	18,116,885	512,652	13,967	456,598	359,732	18,158,973	14,306,617
2	18,158,973	513,843	29,454	457,658	360,568	18,185,705	14,327,677
3	18,185,705	514,600	58,369	458,332	361,099	18,183,604	14,326,022
4	18,183,604	514,540	108,696	458,279	361,057	18,131,169	14,284,711
5	18,131,169	513,057	190,213	456,958	360,016	17,997,055	14,179,049
6	17,997,055	509,262	312,798	453,577	357,353	17,739,940	13,976,480
7	17,739,940	501,986	483,375	447,097	352,247	17,311,455	13,638,896
8	17,311,455	489,861	701,940	436,298	343,739	16,663,078	13,128,070
9	16,663,078	471,514	957,883	419,957	330,865	15,756,751	12,414,017
10	15,756,751	445,868	1,228,351	397,115	312,869	14,577,153	11,484,666
11	14,577,153	412,489	1,480,232	367,386	289,447	13,142,024	10,353,994
12	13,142,024	371,879	1,676,233	331,217	260,950	11,506,453	9,065,403
13	11,506,453	325,597	1,783,761	289,996	228,474	9,758,294	7,688,109
14	9,758,294	276,130	1,783,761	245,937	193,762	8,004,725	6,306,553
15	8,004,725	226,509	1,676,233	201,742	158,943	6,353,259	5,005,440
16	6,353,259	179,778	1,480,232	160,120	126,151	4,892,685	3,854,721
17	4,892,685	138,448	1,228,351	123,310	97,150	3,679,472	2,898,886
18	3,679,472	104,118	957,883	92,733	73,060	2,732,974	2,153,184
19	2,732,974	77,335	701,940	68,879	54,266	2,039,490	1,606,820
20	2,039,490	57,711	483,375	51,401	40,496	1,562,426	1,230,963
21	1,562,426	44,212	312,798	39,378	31,024	1,254,462	988,333
22	1,254,462	35,497	190,213	31,616	24,909	1,068,130	841,530
23	1,068,130	30,225	108,696	26,920	21,209	962,739	758,497
24	962,739	27,243	58,369	24,264	19,116	907,349	714,858
25	907,349	25,675	29,454	0	0	903,570	711,881

Reminder: This analysis focused on biological potential. Market and site operability factors will result in actual harvest levels below biological potential.

Table 2. Estimated rural forest ash volumes and biomass (tops, limbs, and saplings – oven-dry tons) for the 50-year projection period.

Year	Beginning Inventory (cords)	Net Growth (cords)	Annual EAB Caused Mortality (cords)	Estimated Potential Harvest Removals (cords)	Estimated Potential Harvest Removals (Biomass - tons)	Ending Inventory (cords)	Ending Inventory (Biomass - tons)
Present	18,071,399	511,365	9,466	482,759	380,344	18,090,539	14,252,701
1	18,090,539	511,907	9,466	483,271	380,747	18,109,709	14,267,804
2	18,109,709	512,449	13,374	483,783	381,150	18,125,002	14,279,853
3	18,125,002	512,882	18,636	484,191	381,472	18,135,057	14,287,774
4	18,135,057	513,167	25,612	484,460	381,684	18,138,151	14,290,212
5	18,138,151	513,254	34,717	484,543	381,749	18,132,146	14,285,481
6	18,132,146	513,084	46,412	484,382	381,622	18,114,436	14,271,528
7	18,114,436	512,583	61,194	483,909	381,250	18,081,916	14,245,907
8	18,081,916	511,663	79,577	483,040	380,565	18,030,962	14,205,763
9	18,030,962	510,221	102,061	481,679	379,493	17,957,444	14,147,841
10	17,957,444	508,141	129,101	479,715	377,945	17,856,768	14,068,524
11	17,856,768	505,292	161,062	477,026	375,827	17,723,972	13,963,900
12	17,723,972	501,534	198,178	473,478	373,032	17,553,851	13,829,869
13	17,553,851	496,720	240,498	468,934	369,451	17,341,139	13,662,283
14	17,341,139	490,701	287,849	463,251	364,974	17,080,741	13,457,127
15	17,080,741	483,333	339,792	456,295	359,494	16,767,986	13,210,722
16	16,767,986	474,483	395,602	447,940	352,911	16,398,927	12,919,958
17	16,398,927	464,040	454,254	438,081	345,144	15,970,631	12,582,523
18	15,970,631	451,920	514,441	426,639	336,130	15,481,471	12,197,136
19	15,481,471	438,078	574,603	413,572	325,834	14,931,374	11,763,740
20	14,931,374	422,512	632,990	398,877	314,257	14,322,020	11,283,658
21	14,322,020	405,269	687,735	382,598	301,432	13,656,956	10,759,685
22	13,656,956	386,450	736,956	364,832	287,434	12,941,619	10,196,104
23	12,941,619	366,208	778,857	345,722	272,379	12,183,248	9,598,619
24	12,183,248	344,749	811,839	325,463	256,417	11,390,694	8,974,202
25	11,390,694	322,322	834,599	304,291	239,737	10,574,126	8,330,866
26	10,574,126	299,215	846,217	282,477	222,551	9,744,647	7,677,357
27	9,744,647	275,744	846,217	260,318	205,093	8,913,854	7,022,814
28	8,913,854	252,235	834,599	238,125	187,607	8,093,365	6,376,389
29	8,093,365	229,018	811,839	216,206	170,339	7,294,338	5,746,872
30	7,294,338	206,407	778,857	194,861	153,522	6,527,028	5,142,344
31	6,527,028	184,695	736,956	174,363	137,373	5,800,404	4,569,871
32	5,800,404	164,134	687,735	154,952	122,080	5,121,851	4,035,270
33	5,121,851	144,933	632,990	136,825	107,798	4,496,969	3,542,954
34	4,496,969	127,250	574,603	120,132	94,646	3,929,484	3,095,859
35	3,929,484	111,192	514,441	104,972	82,703	3,421,263	2,695,455
36	3,421,263	96,811	454,254	91,396	72,006	2,972,425	2,341,836
37	2,972,425	84,111	395,602	79,405	62,560	2,581,528	2,033,867
38	2,581,528	73,049	339,792	68,963	54,333	2,245,822	1,769,380
39	2,245,822	63,550	287,849	59,995	47,267	1,961,528	1,545,397
40	1,961,528	55,505	240,498	52,400	41,284	1,724,135	1,358,366
41	1,724,135	48,788	198,178	46,059	36,287	1,528,686	1,204,382
42	1,528,686	43,257	161,062	40,837	32,174	1,370,044	1,079,394
43	1,370,044	38,768	129,101	36,599	28,835	1,243,112	979,391
44	1,243,112	35,176	102,061	33,208	26,163	1,143,019	900,532
45	1,143,019	32,344	79,577	30,535	24,057	1,065,252	839,263
46	1,065,252	30,143	61,194	28,457	22,420	1,005,744	792,379
47	1,005,744	28,459	46,412	26,867	21,168	960,924	757,068
48	960,924	27,191	34,717	25,670	20,224	927,728	730,914
49	927,728	26,252	25,612	24,783	19,526	903,584	711,892
50	903,584	25,569	25,583	0	0	903,570	711,881

Reminder: This analysis focused on biological potential. Market and site operability factors will result in actual harvest levels below biological potential.

Table 3. Estimated rural forest ash volumes and biomass (tops, limbs, and saplings – oven-dry tons) for the 75-year projection period.

Year	Beginning Inventory (cords)	Net Growth (cords)	Annual EAB Caused Mortality (cords)	Estimated Potential Harvest Removals (cords)	Estimated Potential Harvest Removals (Biomass - tons)	Ending Inventory (cords)	Ending Inventory (Biomass - tons)
Present	18,071,399	511,365	21,138	495,120	390,082	18,066,506	14,233,766
1	18,066,506	511,227	21,138	494,986	389,977	18,061,609	14,229,908
2	18,061,609	511,088	24,915	494,852	389,871	18,052,931	14,223,071
3	18,052,931	510,843	29,236	494,614	389,684	18,039,923	14,212,823
4	18,039,923	510,475	34,154	494,258	389,403	18,021,986	14,198,691
5	18,021,986	509,967	39,724	493,766	389,016	17,998,463	14,180,158
6	17,998,463	509,301	45,996	493,122	388,508	17,968,646	14,156,667
7	17,968,646	508,458	53,023	492,305	387,864	17,931,776	14,127,619
8	17,931,776	507,414	60,853	491,295	387,068	17,887,043	14,092,376
9	17,887,043	506,149	69,529	490,069	386,103	17,833,594	14,050,266
10	17,833,594	504,636	79,090	488,605	384,949	17,770,536	14,000,585
11	17,770,536	502,852	89,566	486,877	383,588	17,696,944	13,942,606
12	17,696,944	500,769	100,981	484,861	382,000	17,611,872	13,875,581
13	17,611,872	498,362	113,346	482,530	380,163	17,514,358	13,798,754
14	17,514,358	495,603	126,661	479,858	378,058	17,403,441	13,711,368
15	17,403,441	492,464	140,913	476,819	375,664	17,278,172	13,612,674
16	17,278,172	488,919	156,074	473,387	372,960	17,137,631	13,501,948
17	17,137,631	484,943	172,099	469,537	369,926	16,980,937	13,378,497
18	16,980,937	480,509	188,929	465,244	366,544	16,807,274	13,241,675
19	16,807,274	475,594	206,484	460,486	362,795	16,615,898	13,090,899
20	16,615,898	470,179	224,671	455,242	358,664	16,406,164	12,925,659
21	16,406,164	464,244	243,376	449,496	354,137	16,177,536	12,745,534
22	16,177,536	457,775	262,470	443,232	349,202	15,929,609	12,550,203
23	15,929,609	450,759	281,807	436,439	343,850	15,662,122	12,339,463
24	15,662,122	443,190	301,227	429,111	338,077	15,374,975	12,113,233
25	15,374,975	435,065	320,558	421,244	331,878	15,068,238	11,871,570
26	15,068,238	426,385	339,617	412,840	325,257	14,742,167	11,614,673
27	14,742,167	417,158	358,214	403,906	318,219	14,397,205	11,342,893
28	14,397,205	407,397	376,155	394,455	310,773	14,033,992	11,056,734
29	14,033,992	397,119	393,244	384,503	302,932	13,653,363	10,756,855
30	13,653,363	386,348	409,287	374,075	294,716	13,256,350	10,444,067
31	13,256,350	375,114	424,095	363,197	286,147	12,844,172	10,119,330
32	12,844,172	363,451	437,492	351,905	277,249	12,418,226	9,783,747
33	12,418,226	351,398	449,311	340,235	268,055	11,980,079	9,438,551
34	11,980,079	339,000	459,403	328,230	258,597	11,531,445	9,085,093
35	11,531,445	326,305	467,640	315,939	248,913	11,074,171	8,724,828
36	11,074,171	313,365	473,915	303,410	239,043	10,610,211	8,359,295
37	10,610,211	300,237	478,145	290,699	229,028	10,141,604	7,990,101
38	10,141,604	286,976	480,274	277,860	218,913	9,670,447	7,618,898
39	9,670,447	273,644	480,274	264,951	208,743	9,198,866	7,247,362
40	9,198,866	260,300	478,145	252,031	198,563	8,728,990	6,877,168
41	8,728,990	247,004	473,915	239,157	188,421	8,262,922	6,509,975
42	8,262,922	233,815	467,640	226,388	178,360	7,802,709	6,147,395
43	7,802,709	220,793	459,403	213,779	168,426	7,350,320	5,790,978
44	7,350,320	207,992	449,311	201,384	158,661	6,907,617	5,442,193
45	6,907,617	195,464	437,492	189,255	149,105	6,476,335	5,102,405
46	6,476,335	183,260	424,095	177,439	139,796	6,058,062	4,772,867
47	6,058,062	171,425	409,287	165,979	130,767	5,654,221	4,454,700
48	5,654,221	159,997	393,244	154,914	122,050	5,266,059	4,148,885
49	5,266,059	149,013	376,155	144,279	113,671	4,894,638	3,856,259
50	4,894,638	138,503	358,214	134,103	105,654	4,540,823	3,577,505
51	4,540,823	128,491	339,617	124,409	98,016	4,205,288	3,313,153
52	4,205,288	118,997	320,558	115,216	90,774	3,888,511	3,063,579
53	3,888,511	110,033	301,227	106,537	83,936	3,590,780	2,829,010
54	3,590,780	101,608	281,807	98,380	77,509	3,312,202	2,609,531
55	3,312,202	93,725	262,470	90,748	71,496	3,052,709	2,405,089
56	3,052,709	86,382	243,376	83,638	65,895	2,812,077	2,215,506
57	2,812,077	79,573	224,671	77,045	60,700	2,589,934	2,040,490
58	2,589,934	73,287	206,484	70,959	55,905	2,385,778	1,879,644
59	2,385,778	67,510	188,929	65,366	51,498	2,198,994	1,732,486
60	2,198,994	62,225	172,099	60,248	47,467	2,028,872	1,598,454
61	2,028,872	57,411	156,074	55,587	43,794	1,874,622	1,476,928
62	1,874,622	53,046	140,913	51,361	40,465	1,735,394	1,367,237
63	1,735,394	49,106	126,661	47,546	37,460	1,610,293	1,268,675
64	1,610,293	45,566	113,346	44,119	34,759	1,498,394	1,180,515
65	1,498,394	42,400	100,981	41,053	32,344	1,398,760	1,102,018
66	1,398,760	39,581	89,566	38,323	30,193	1,310,451	1,032,444
67	1,310,451	37,082	79,090	35,904	28,287	1,232,539	971,061
68	1,232,539	34,877	69,529	33,769	26,605	1,164,119	917,155
69	1,164,119	32,941	60,853	31,895	25,128	1,104,313	870,037
70	1,104,313	31,249	53,023	30,256	23,837	1,052,282	829,045
71	1,052,282	29,776	45,996	28,830	22,714	1,007,232	793,552
72	1,007,232	28,502	39,724	27,596	21,742	968,414	762,968
73	968,414	27,403	34,154	26,533	20,904	935,130	736,746
74	935,130	26,461	29,236	25,621	20,185	906,735	714,374
75	906,735	25,658	28,823	0	0	903,570	711,881

Reminder: This analysis focused on biological potential. Market and site operability factors will result in actual harvest levels below biological potential.

Urban Areas

Data used to project ash supply in urban areas were collected by the Minnesota Department of Natural Resources, Division of Forestry's Resource Assessment Unit during the late spring, summer, and early fall of 2010. This inventory is referred to as the Community Tree Inventory. City limits of 699 communities were reduced to areas that were primarily residential neighborhoods and main business corridors (referred to as Business/Residential Areas). Hence, the primary focus of sampling was street and yard trees in these areas, rather than woodlot trees in zones of low urban population densities (e.g. city parks and forests). Estimates of trees within city parks and forests is part of the rural estimate obtained from FIA (Rural Forests section). The Business/Residential Areas were further separated into Maintained and Non-maintained acres.

Maintained areas are those that are periodically mowed or fall within an artificial surface, such as a parking lot. Non-maintained areas are those areas where trees are essentially free to grow without periodic maintenance. Within Maintained areas, the number of ash trees by species and diameter class were counted during the field inventory and all ash species were collectively grouped. Diameter classes were Small (1 – 4.9 in. dbh), Medium (5 – 11.9 in. dbh), Large (12 – 20.9 in. dbh), and Super (21+ in. dbh). In Non-maintained areas, during the field inventory, only the percent of species existing was quantified and actual numbers of trees were not obtained. For example, a specific Non-maintained area may have been made up of 20% ash, 50% elm (*Ulmus* spp.), and 30% boxelder (*Acer* spp.).

Included within the 699 communities are all communities contained within the Twin Cities, Rochester, Duluth, and St. Cloud metropolitan areas. In terms of number of trees, these metropolitan areas contain a large majority. For example, within Maintained areas in the Twin Cities metropolitan area (Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington counties), there are 11,277,353 trees of which 1,549,679 are ash. Across all Maintained areas within the state, trees within these seven counties comprise 64.3% and 58.5% of all trees and of ash trees, respectively.

Based on rates of spread found in other states, both human-related and natural, three projection periods (10, 15, and 20 years) were chosen that assume varying rates of reduction of the urban ash resource across Minnesota. For the urban areas, projections were conducted for 10, 15, and 20 years because it is expected that a greater amount of the urban ash resource will be removed in the short term as compared to the rural ash resource. To project the amount of urban ash resource forward, the same net growth rate (from FIA data; mortality is already accounted for) as described for rural forests was used, 2.8297%.

$$\frac{\text{Average annual net growth in cords}}{\text{Standing inventory at time present}} = \frac{511{,}365 \text{ cords}}{18{,}071{,}399 \text{ cords}} = 2.897\%$$

Number of Ash Trees Within Maintained Areas of Business/Residential Areas

Across all species, there were 17,526,402 trees (both living and dead) estimated within Business/Residential Areas. Of the living and dead trees estimated within Business/Residential

Areas, 2,650,289 trees were ash. The total number of Maintained acres across the state was 773,466. Hence, on average across all species, there were 22.7 trees per acre.
For ash within the Maintained areas, there are estimated to be: 436,334 (16.5%) Small diameter (1 – 4.9 in. dbh) trees, 962,659 (36.3%) Medium diameter (5 – 11.9 in. dbh) trees, 986,717 (37.2%) Large diameter (12 – 20.9 in. dbh) trees, and 264,580 (10.0%) Super diameter (21+ in. dbh) trees.

Number of Ash Trees Within Non-maintained Areas of Business/Residential Areas

There are estimated to be 30,130 Non-maintained acres across all communities. On average, of the trees within a Non-maintained acre, 8.4% are ash, but many communities contained no ash trees in these areas. As mentioned above, the number of trees was not quantified in these areas, only the relative percents of species. Based on personal field experience, on average, there is a greater number of ash trees found on Non-maintained acres relative to Maintained acres. Therefore, to estimate tree numbers, the average number of trees per acre within Maintained areas was tripled (3 x 22.7 = 68.0 trees per acre). This number was then multiplied by 8.4%, producing an estimate of 5.7 ash trees per acre in Non-maintained areas.

The estimated number of ash trees per acre in Non-maintained areas was multiplied by 30,130 acres to arrive at an estimate of 172,244 ash trees in Non-maintained areas. Using the relative diameter class ratios from the Maintained areas, it is estimated that there are 28,358 Small diameter trees, 62,564 Medium diameter trees, 64,127 Large diameter trees, and 17,195 Super diameter trees.

See Appendix II for more details about tree estimation in Non-maintained areas.

Calculating Volume and Biomass of Ash Trees Within Maintained and Non-maintained Areas

To estimate volumes, the biomass of tops and limbs of trees greater in diameter at breast height than 5 inches, and the biomass of saplings, ash trees within the FIA rural database were separated into the same diameter classes as used during the Community Tree Inventory to determine the average volume and biomass per tree by diameter class (Table 4).

Table 4. Estimated ash volumes, biomass in tons (tops, limbs, and saplings), and number of trees by Community Tree Inventory diameter class. Cords and Biomass in Tons is the average amount of cord volume per tree (each cord is comprised of 79 cubic feet of wood) and biomass per tree as obtained from FIA, respectively.

Maintained Areas					
Diameter Class	Cords	Biomass in Tons (Tops/Saplings)	Number of Trees	Total Cords	Total Biomass (Tons)
Small (1 - 4.9 in.)	0.00	0.0014	436,334	0	603
Medium (5 - 11.9 in.)	0.06	0.0308	962,659	62,230	29,638
Large (12 - 20.9 in.)	0.31	0.1017	986,717	303,072	100,318
Super (21 + in.)	0.96	0.2764	264,580	255,042	73,135
Total			2,650,289	620,344	203,694

Non-Maintained Areas					
Diameter Class	Cords	Biomass in Tons (Tops/Saplings)	Number of Trees	Total Cords	Total Biomass (Tons)
Small (1 - 4.9 in.)	0.00	0.0014	28,358	0	39
Medium (5 - 11.9 in.)	0.06	0.0308	62,564	4,044	1,926
Large (12 - 20.9 in.)	0.31	0.1017	64,127	19,697	6,520
Super (21 + in.)	0.96	0.2764	17,195	16,575	4,753
Total			172,244	40,317	13,238

Assumed Mortality Rates Over Time Due to EAB for Projections

Currently, EAB related mortality in Minnesota urban areas is relatively low. Since the insect is expected to spread the amount of volume/biomass lost due to EAB related mortality will increase. Eventually, as the ash resource continues to decrease due to EAB related mortality and harvesting, the amount of volume/biomass lost due to EAB will likely decrease. To model this, the normal distribution was used to model annual mortality rates (Figure 4). The amount of volume/biomass lost due to EAB related mortality is obtained by multiplying the Percent Annual Mortality rate by the amount of volume at year 0 (or the present time). Therefore, for a particular projection period, mortality was assumed to be greatest at the midpoint. The standard deviation (determining the spread of the curve) for a particular projection period was selected such that reasonable mortality rates were obtained.

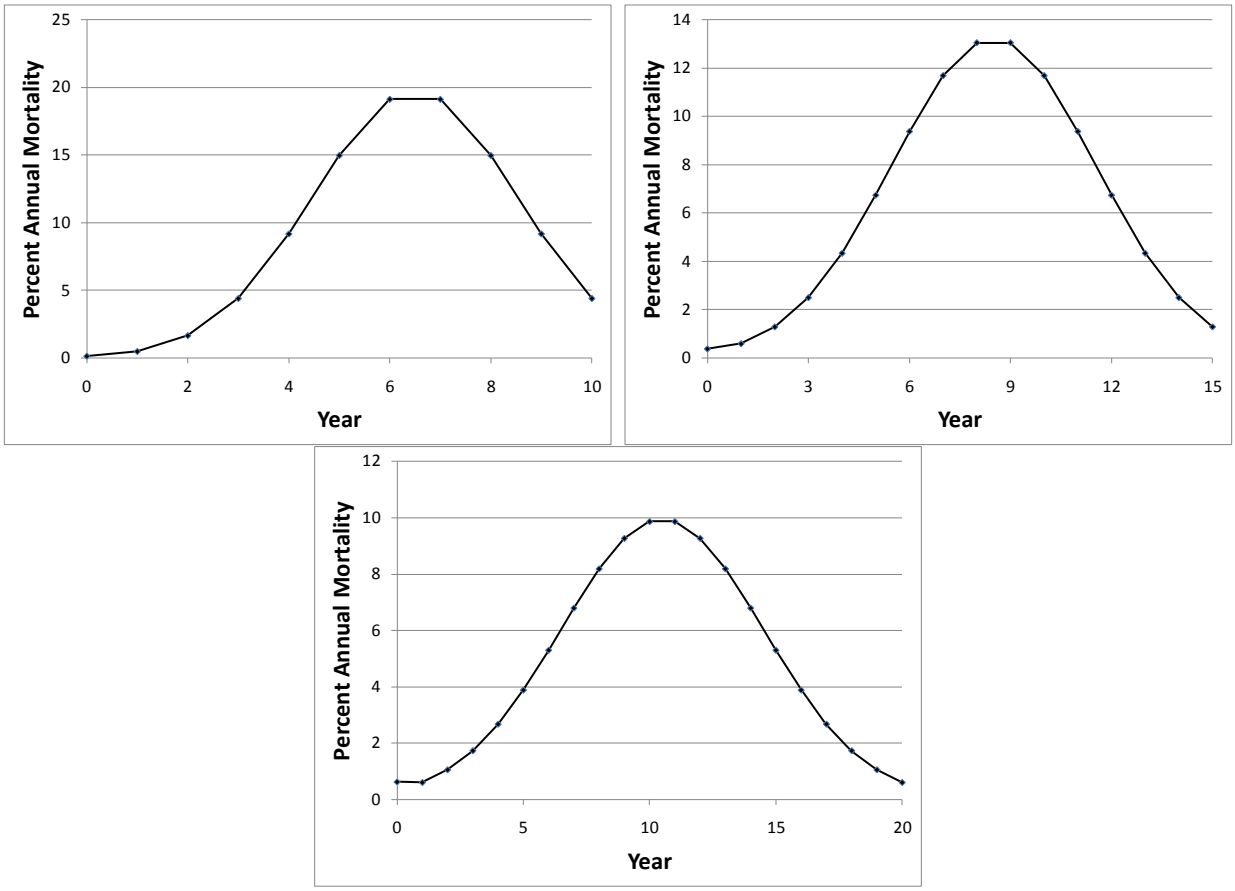

Figure 4. Depiction of normal distribution curves used to model mortality rates for the three projection periods (10, 15, and 20 years). For the 10-year projection, the mean was 6 years and the standard deviation was 2.0, for the 15-year projection, the mean was 8 years and the standard deviation was 3, and for the 20-year projection the mean was 10 years and the standard deviation was 4.

Minimum Ash Inventory Volumes

There may be some natural resistance to EAB by ash trees and with time economically feasible controls may be developed such that a minimum level of ash volume will be retained. For each projection period in this analysis, the amount of ash volume is not allowed to be less than 5% of the existing inventory, or 33,033 cords.

Estimated Potential Harvest Removals

For each projection period, 10, 15, or 20 years, a constant proportional rate of harvested material was assumed across all years. This results in the maximum amount of harvesting occurring when the standing inventory is greatest (Figure 5). For a particular projection, the rate was selected such that the minimum ash inventory (33,033 cords) would be reached in the final projected year and that no harvesting would occur in the last year, given the amount of net growth and mortality due to EAB. Hence, for the 10-year, 15-year, and 20-year projection periods, harvest rates of 2.5026%, 2.4379%, and 2.4783% of total volume were used, respectively.

For simplicity, an estimate of oven-dry top and limb biomass for trees (all woody stem and branch biomass (includes wood and bark) above a 4-inch top DOB for trees, regardless of form, with diameters at breast height of 5 inches or greater) and sapling biomass (all living aboveground portions of live trees with diameters less than 5 inches) was obtained by multiplying harvested volumes by 0.3284 (Tables 5-7). This value was obtained from the ratio presented below (see Table 4).

$$\frac{\text{Oven-dry tons of all live top and limb and living sapling biomass at time present}}{\text{Merchantable cords at time present}} = \frac{261{,}932 \text{ tons}}{660{,}661 \text{ cords}} = 0.3284$$

Reminder: This analysis focused on biological potential, and that market and site operability factors will result in actual harvest levels below biological potential.

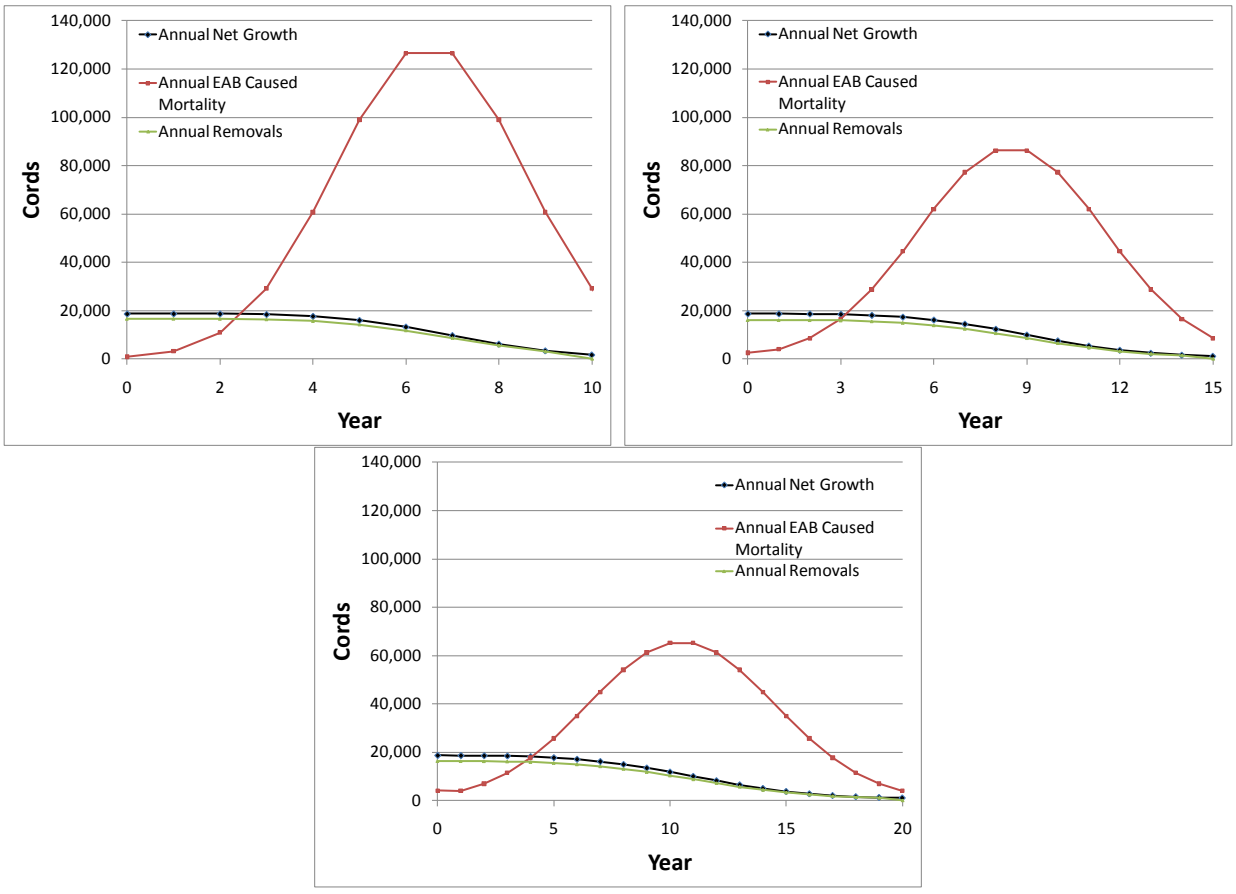

Figure 5. Annual urban ash net growth, annual removals, and annual loss due to EAB for the three projection periods (10, 15, and 20 years).

Projected Ash Standing Volumes and Biomass

For all projection lengths, standing volumes essentially steadily decline to the retained amount of 33,033 cords (Figure 6, Tables 5-7). After the initial few years, a greater amount of wood can be consistently harvested every year for the 20-year projection relative to the 10-year and 15-year projections.

It is difficult to predict the rate of spread of EAB over the next 10 to 20 years. If infested areas can be quickly quarantined and residents and visitors are diligent in their attempts to reduce spread, then the 20-year projection period may be most appropriate. If the 15-year and 20-year projection periods mimic reality, then it is possible that economically feasible and highly effective control agents may be identified. Perhaps even under the 10-year scenario economically feasible and effective control agents may be identified. Alternatively, natural resistance by ash may be identified and these trees can then be used in genetic programs to develop resistant strains of ash trees.

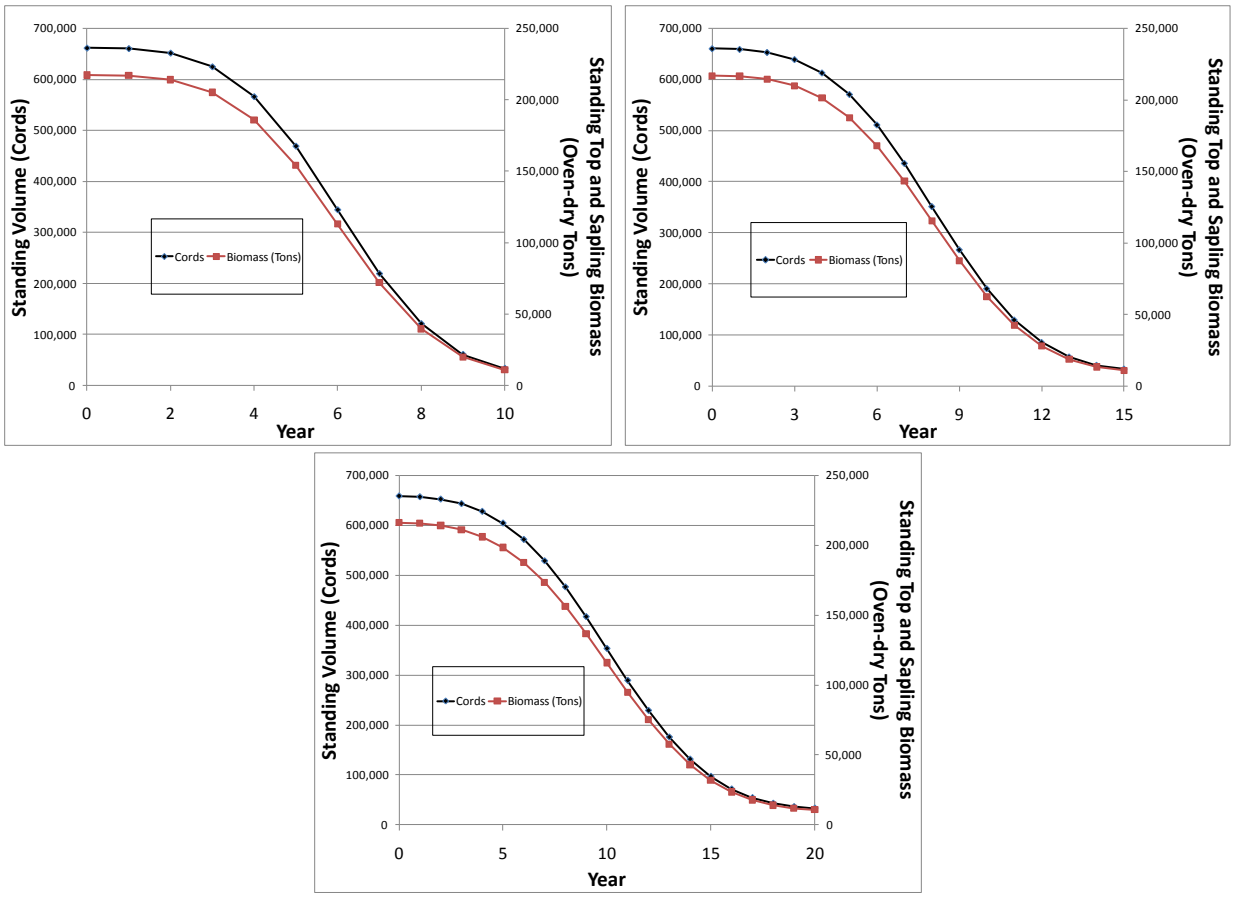

Figure 6. Ending inventory of ash volume and biomass (tops, limbs, and saplings) for the three projection periods (10, 15, and 20 years).

Table 5. Estimated urban ash volumes and biomass (tops, limbs, and saplings – oven-dry tons) for the 10-year projection period.

Year	Beginning Inventory (cords)	Net Growth (cords)	Annual EAB Caused Mortality (cords)	Estimated Potential Harvest Removals (cords)	Estimated Potential Harvest Removals (Biomass - tons)	Ending Inventory (cords)	Ending Inventory (Biomass - tons)
Present	660,661	18,695	892	16,534	5,429	661,930	217,349
1	661,930	18,731	3,211	16,565	5,439	660,885	217,006
2	660,885	18,701	10,928	16,539	5,431	652,119	214,128
3	652,119	18,453	29,107	16,320	5,359	625,146	205,271
4	625,146	17,690	60,680	15,645	5,137	566,510	186,017
5	566,510	16,031	99,021	14,177	4,655	469,342	154,112
6	469,342	13,281	126,492	11,746	3,857	344,386	113,081
7	344,386	9,745	126,492	8,618	2,830	219,021	71,917
8	219,021	6,198	99,021	5,481	1,800	120,716	39,638
9	120,716	3,416	60,680	3,021	992	60,430	19,843
10	60,430	1,710	29,107	0	0	33,033	10,847

Reminder: This analysis focused on biological potential. Market and site operability factors will result in actual harvest levels below biological potential.

Table 6. Estimated urban ash volumes and biomass (tops, limbs, and saplings – oven-dry tons) for the 15-year projection period.

Year	Beginning Inventory (cords)	Net Growth (cords)	Annual EAB Caused Mortality (cords)	Estimated Potential Harvest Removals (cords)	Estimated Potential Harvest Removals (Biomass - tons)	Ending Inventory (cords)	Ending Inventory (Biomass - tons)
Present	660,661	18,695	2,531	16,107	5,289	660,719	216,951
1	660,719	18,696	3,954	16,108	5,289	659,353	216,503
2	659,353	18,658	8,546	16,075	5,278	653,391	214,545
3	653,391	18,489	16,543	15,929	5,230	639,407	209,953
4	639,407	18,093	28,686	15,588	5,119	613,226	201,357
5	613,226	17,352	44,558	14,950	4,909	571,070	187,515
6	571,070	16,160	61,995	13,922	4,571	511,313	167,893
7	511,313	14,469	77,264	12,465	4,093	436,052	143,181
8	436,052	12,339	86,255	10,631	3,491	351,506	115,419
9	351,506	9,947	86,255	8,569	2,814	266,628	87,549
10	266,628	7,545	77,264	6,500	2,134	190,409	62,522
11	190,409	5,388	61,995	4,642	1,524	129,160	42,410
12	129,160	3,655	44,558	3,149	1,034	85,108	27,946
13	85,108	2,408	28,686	2,075	681	56,755	18,636
14	56,755	1,606	16,543	1,384	454	40,434	13,277
15	40,434	1,144	8,546	0	0	33,033	10,847

Reminder: This analysis focused on biological potential. Market and site operability factors will result in actual harvest levels below biological potential.

Table 7. Estimated urban ash volumes and biomass (tops, limbs, and saplings – oven-dry tons) for the 20-year projection period.

Year	Beginning Inventory (cords)	Net Growth (cords)	Annual EAB Caused Mortality (cords)	Estimated Potential Harvest Removals (cords)	Estimated Potential Harvest Removals (Biomass - tons)	Ending Inventory (cords)	Ending Inventory (Biomass - tons)
Present	660,661	18,695	4,102	16,373	5,376	658,880	216,348
1	658,880	18,644	3,974	16,329	5,362	657,222	215,803
2	657,222	18,597	6,954	16,288	5,348	652,578	214,278
3	652,578	18,466	11,435	16,173	5,310	643,436	211,276
4	643,436	18,207	17,671	15,946	5,236	628,025	206,216
5	628,025	17,771	25,662	15,564	5,111	604,571	198,515
6	604,571	17,108	35,019	14,983	4,920	571,677	187,714
7	571,677	16,177	44,907	14,168	4,652	528,779	173,628
8	528,779	14,963	54,115	13,105	4,303	476,523	156,469
9	476,523	13,484	61,280	11,810	3,878	416,917	136,897
10	416,917	11,797	65,211	10,332	3,393	353,171	115,966
11	353,171	9,994	65,211	8,753	2,874	289,200	94,961
12	289,200	8,183	61,280	7,167	2,353	228,936	75,173
13	228,936	6,478	54,115	5,674	1,863	175,626	57,668
14	175,626	4,970	44,907	4,352	1,429	131,337	43,125
15	131,337	3,716	35,019	3,255	1,069	96,779	31,778
16	96,779	2,739	25,662	2,398	788	71,458	23,464
17	71,458	2,022	17,671	1,771	581	54,037	17,744
18	54,037	1,529	11,435	1,339	440	42,792	14,051
19	42,792	1,211	6,954	1,061	348	35,988	11,817
20	35,988	1,018	3,974	0	0	33,033	10,847

Reminder: This analysis focused on biological potential. Market and site operability factors will result in actual harvest levels below biological potential.

APPENDIX I. Projections for Rural Forests

Black, green, and white ash all live volume on forestland (obtained from 2005, 2006, 2007, 2008, 2009 USDA Forest Service Forest Inventory and Analysis (FIA) measurement panels)

Section One

$\mathbf{Vol_{Ending}} = \mathbf{Vol_{Beginning}} + \mathbf{NG} - \mathbf{AM} - \mathbf{R}$

Where:
$\mathbf{Vol_{Ending}}$ -- all live total volume at time 2, Ending Inventory in Tables 1, 2, and 3,
$\mathbf{Vol_{Beginning}}$ -- all live total volume at time 1, Beginning Inventory in Tables 1, 2, and 3,
NG -- net growth, which is equal to growth minus mortality (equal to 2.8297% of Beginning Inventory volume every year, but net volume growth will change over time),
AM -- annual mortality due to EAB, is equal to the projected annual mortality rate times the Beginning Inventory (or 18,071,399 cords) at the Present time (the rate and VOLUME changes over time based on the normal distribution, see Figure 1),
R -- potential harvest removal, this is equal to the Estimated Potential Harvest Removal rate times the Beginning Inventory volume every year (equal to 2.5203%, 2.6714%, and 2.7398% for projection periods of 25, 50, and 75 years, respectively, but actual removals change over time).

Section Two

For example, when projecting for 25 years from ages 16 to 17,

$\mathbf{Vol_{Ending}} = \mathbf{Vol_{Beginning}} + \mathbf{NG} - \mathbf{AM} - \mathbf{R}$ = 6,353,259 cords + 179,778 cords – 1,480,232 cords – 160,120 cords = 4,892,685 cords

Where:
NG -- 0.028297 * 6,353,259 cords = 179,778 cords,
AM -- 0.0819 * 18,071,399 cords = 1,480,232 cords, and
R -- 0.025203 * 6,353,259 cords = 160,120 cords.

Over time NG will change because the Beginning Inventory will change with time (but the percent net growth will always be 2.8297%). The percent annual mortality due to EAB changes over time depending on the normal distribution used to quantify this percent with time. The actual volume of AM will change with time. Over time R will also change because the Beginning Inventory will change over time (but the percent removal will always be 2.5203% for the 25-year projection period).

Section Three

The value of 2.8297% is obtained by dividing the average annual net growth (FIA data) from the past five years by the standing inventory at time present (FIA data):

511,365 cords/ 18,071,399 cords = 2.8297%

Section Four

To obtain top and sapling biomass, a constant multiplicative factor of 0.7879 was used. This was obtained from the ratio between standing tree cord volume (greater in diameter than 5 inches) and standing top and sapling biomass obtained from FIA:

(7,651,380 oven-dry tons of all live top and limb biomass + 6,586,241 oven-dry tons of living sapling biomass)/ 18,071,399 cords = (14,237,621 oven-dry tons/18,071,399 cords) = 0.7879

APPENDIX II. Projections for Urban Forests

Ash all live volume in Maintained and Non-maintained areas

Section One

$\mathbf{Vol_{Ending}} = \mathbf{Vol_{Beginning}} + \mathbf{NG} - \mathbf{AM} - \mathbf{R}$

Where:
$\mathbf{Vol_{Ending}}$ -- all live total volume at time 2, Ending Inventory in Tables 5, 6, and 7,
$\mathbf{Vol_{Beginning}}$ -- all live total volume at time 1, Beginning Inventory in Tables 5, 6, and 7,
NG -- net growth, which is equal to growth minus mortality (equal to 2.8297% of Beginning Inventory volume every year, but net volume growth will change over time),
AM -- annual mortality due to EAB, is equal to the projected annual mortality rate times the Beginning Inventory (or 660,661 cords) at the Present time (the rate and VOLUME changes over time based on the normal distribution, see Figure 4),
R -- potential harvest removal, this is equal to the Estimated Potential Harvest Removal rate times the Beginning Inventory volume every year (equal to 2.5026%, 2.4379%, and 2.4783% for projection periods of 10, 15, and 20 years, but actual removals change over time).

Section Two

For example, when projecting for 15 years from ages 8 to 9,

$\mathbf{Vol_{Ending}} = \mathbf{Vol_{Beginning}} + \mathbf{NG} - \mathbf{AM} - \mathbf{R}$ = 436,052 cords + 12,339 cords –86,255 cords – 10,631 cords = 351,506 cords

Where:
NG -- 0.028297 * 436,052 cords = 12,339 cords,
AM -- 0.1306 * 660,661 cords = 86,255 cords, and
R -- 0.024379 * 436,052 cords = 10,631 cords.

Over time NG will change because the Beginning Inventory will change with time (but the percent net growth will always be 2.8297%). The percent annual mortality due to EAB changes over time depending on the normal distribution used to quantify this percent with time. The actual volume of AM will change with time. Over time R will also change because the Beginning Inventory will change over time (but the percent removal will always be 2.4379% for the 15-year projection period).

Section Three

The value of 2.8297% is obtained by dividing the average annual net growth (FIA data) from the past five years by the standing inventory at time present (FIA data):

511,365 cords/ 18,071,399 cords = 2.8297%

Section Four

To obtain top and sapling biomass, a constant multiplicative factor of 0.3284 was used. This was obtained from the ratio between standing tree cord volume (greater in diameter than 5 inches) and standing top and sapling biomass (see Table 4):

(216,290 oven-dry tons of all live top and limb biomass + 642 oven-dry tons of living sapling biomass)/ 660,661 cords = (216,932 oven-dry tons/660,661 cords) = 0.3284

Number of Ash Trees Within Maintained and Non-Maintained Areas of Business/Residential Areas

Section One

Based on the Community Tree survey, total number of trees across all species in Maintained areas is 17,526,402.

Based on the Community Tree survey, there were 2,650,289 ash trees in Maintained areas where 16.5% were Small diameter trees (1 – 4.9 in. dbh), 36.3% were Medium diameter trees (5 – 11.9 in. dbh), 37.2% were Large diameter trees (12 – 20.9 in. dbh), and 10.0% were Super diameter trees (21+ in. dbh).

Based on the Community Tree survey, total number of Maintained acres across the state was 773,466.

Based on the Community Tree survey, there is an average of 22.7 trees per acre within Maintained areas of Business/Residential areas.

Section Two

Based on personal experience, the number of trees per acre within Maintained areas was multiplied by 3 to estimate the number of trees per acre within Non-maintained areas, 68.0.

Based on the Community Tree survey, total number of Non-maintained acres across the state was 30,130.

Within Non-maintained areas the actual number of trees was not quantified, rather the relative percent of species numbers within an area. Across all 30,130 Non-maintained acres, on average, 8.4% of the trees within these areas are considered ash.

Thus, on average, the number of ash trees per acre in Non-maintained areas is equal to 5.7. Obtained by multiplying 68.0 **x** 8.4%.

Across all 30,130 Non-maintained acres in Business/Residential areas, there is a total of 172,244 ash trees. Obtained by multiplying 5.7 ash trees per acre **x** 30,130 Non-maintained acres.

Of the 172,244 ash trees in Non-maintained areas, 28,358 are Small diameter trees (16.5% of 172,244), 62,564 are Medium diameter trees (36.3% of 172,244), 64,127 are Large diameter trees (37.2% of 172,244), and 17,195 are Large diameter trees (10.0% of 172,244).