Estimating Eastern Larch Beetle (ELB) Mortality in Harvest Scheduling Analyses

Curtis L. VanderSchaaf

Forest Modeler

Resource Assessment Unit
Grand Rapids, MN
(218) 322-2518
curtis.vanderschaaf@state.mn.us

Resource Assessment Unit Forest Biometrics Report Number Eighteen

Minnesota Department of Natural Resources

A tamarack assessment analysis was conducted to help address how the DNR can better market products and resources of this species. A harvest scheduling analysis was conducted to model forward the existing landbase to see how various assumptions about markets and how future infestation of Eastern larch beetle (*Dendroctonus simplex*), further referred to as ELB, will impact future timber yields. As part of this analysis, an initial baseline estimate of mortality prior to the beginning of the landbase projection was needed. Currently infested polygons are determined from aerial flights where tamarack mortality due to the ELB is thought to occur. It is important that future timber supply projections quantify loss of tamarack volume due to ELB mortality.

To account for the spatial location of mortality and particular cover types where mortality is occurring, a CLIP analysis within the Extract tool group of the Analysis Tool package within ArcToolbox was used.

Forest Inventory and Module (FIM) Dataset

The ELB mortality polygons were clipped from an existing Forest Inventory Module (FIM) dataset. The most recent DNR FIM shapefile database (03/08/2012) was queried. Cover type is determined based on internal DNR algorithms, age is based on field measurements, and site quality is based on field measurements and selected site index equations.

There are 188,761 polygons totaling an acreage of 4,827,917 acres. This shapefile reflects updates (alterations to acres) entered through March 1, 2012. This shapefile is not a statewide dataset, rather it only contains land in the SFRMP project areas which excludes Western and Southwestern Minnesota and state lands in the Boundary Waters Canoe Area Wilderness (BWCAW).

This dataset only contains stands that have been inventoried thru the FIM system and under the DNR Administration of Forestry OR Wildlife, Fisheries lands in Lake County, and Trails and Waterways Lands in St. Louis County. This dataset also contains stands designated as Old Growth and No Harvest areas from the DNR administrations listed above.

Scientific and Natural Areas (SNAs), state parks, Camp Ripley Military lands, Board of Water and Soil Resources (BWSR), Metro Greenways, Municipal Forests and other DNR administrations have been excluded. Old Growth stands in these administration types have been excluded as well.

Further description of the FIM dataset used can be found in the harvest scheduling description.

Final FIM Dataset Used in Harvest Scheduling Analysis

The *.dbf created during the CLIP analysis was merged with the FIM *.dbf file, for those FIM polygons containing ELB mortality, the acres were separated into an infested component and an uninfested component, and the revised FIM *.dbf file was subsequently used in the harvest

scheduling analysis. After merging, since there were 9,056 polygons with ELB mortality, the total number of polygons increased from 188,761 to 197,817. The number of polygons probably increased from 8,695 as shown in Table 1 to 9,056 because of "slivers" created during the CLIP analysis (the total number of acres did not change).

Below is an example showing how ELB mortality polygons were removed from the forested FIM polygons. For all cover type acres infested with ELB, mortality of tamarack was assumed to be 95% and that this 5% survival rate would be maintained into the future for these stands, no future regeneration of tamarack WITHIN THE EXISTING STAND was assumed (essentially 5% of the predicted harvested volume of infested stands was calculated). Some may think of this as no ingrowth of tamarack took place WITHIN THE EXISTING STAND.

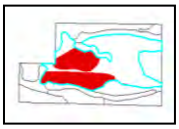
1. Eastern larch beetle (ELB) mortality polygons.

2. A black spruce cover type polygon (highlighted in blue) from FIM – an acreage of 118.1 acres.

3. Overlay of the ELB mortality polygons over the black spruce cover type polygon from FIM, 43.6 acres are intersected.

4. Modified FIM polygons after "clipping" the ELB mortality polygons from the MN DNR FIM polygons.

5. Area of the black spruce cover type polygon where it is assumed that ELB has resulted in 95% mortality of tamarack. In terms of harvestable volume, only the tamarack portion of a stand is assumed to be eliminated, **ALL** woody fiber of other species can still be obtained. The acreage from which **100% of the tamarack species volume can be harvested** of this black spruce polygon will be reduced to 74.5 acres, woody fiber of all other species can still be obtained on the original 118.1 acres.



Assigning ELB Mortality to Cover Types in the Harvest Scheduling Analysis

Based on the total number of acres that have been infested over the past 13 years and the most recent pattern in mortality (Table 1), three scenarios were quantified:

1. Continue the current level of 15,000 acres per year and assign acreage across all cover types,
2. Double the current level (or 30,000 acres per year) and assign acreage across all cover types, and
3. Continue the current level for 5 years and assign acreage across all cover types, then ELB population is assumed to collapse and there will be no **new** mortality.

Table 2 shows the amount of mortality over the past 13 years by cover types on MN DNR lands utilized during harvest scheduling analyses within Remsoft Spatial Planning System Woodstock software. Some individual FIM stands (or polygons) were comprised of more than one ELB mortality polygon, and hence the number of infested stands is less than 9,056 polygons.

Harvest scheduling analyses are conducted using Woodstock software. Currently, when harvests occur, cover type volume is initially estimated based on cover type, site index (base age 50), and age specific yield tables. These volumes are then assigned to particular species based on average percent species compositions calculated using FIA and/or FIM data for a particular cover type. Since the percent of tamarack volume harvested on a per acre basis differs by cover type, it is important to assign the mortality for a particular scenario to the tamarack cover type plus other cover types. The relative percentage of future infestation acres assigned to a particular cover type was calculated using the relative relationships found in Table 2.

Within Woodstock, projection periods are for 5 years, and hence the annual number of infested acres above must be multiplied by 5. Therefore, the scenarios become:

1. Continue the current level of 75,000 acres per five year period and assign acreage across all cover types,
2. Double the current level (or 150,000 acres per year) per five year period and assign acreage across all cover types, and
3. Continue the current level for 5 years and assign acreage across all cover types, then ELB population is assumed to collapse and there will be no **new** mortality.

Table 1. Number of annually newly infested Eastern larch beetle (ELB) infestation polygons and the total number of acreage by year, ACROSS ALL OWNERSHIPS (DNR as well as other ownerships).

Year	Number of Polygons	Acreage
2000	1	54
2001	72	4,561
2002	180	16,505
2003	161	6,240
2004	241	7,908
2005	243	9,418
2006	238	7,267
2007	211	11,450
2008	950	15,908
2009	1,876	13,301
2010	1,649	13,166
2011	1,919	17,358
2012	954	42,275
Total	8,695	165,411

Table 2. Amount of infested Eastern larch beetle (ELB) polygons and total acreage by cover types on MN DNR land and used within the harvest scheduling analyses. Cover Type Percentage represents the NOMINAL relative amounts of each cover type assigned ELB mortality for a particular scenario, thus 34.0% of any assumed ELB mortality acreage rate will be assigned to the Tamarack - Good (72) cover type.

MN Cover Type	Number of Polygons	Total Acres	Cover Type Percentage
1	186	881	1.2%
9	17	68	0.1%
12	1,208	7,357	9.8%
13	73	425	0.6%
14	166	1,202	1.6%
20	18	51	0.1%
30	22	61	0.1%
51	6	12	0.0%
52	33	107	0.1%
53	264	1,483	2.0%
61	27	129	0.2%
62	189	1,723	2.3%
71	333	3,133	4.2%
710	274	3,448	4.6%
711	625	6,741	9.0%
72	1,375	25,571	34.0%
721	1,039	16,877	22.5%
73	580	5,365	7.1%
74	24	110	0.1%
521 RP Plantation	64	331	0.4%
611 WS Plantation	26	100	0.1%
Totals	6,549	75,173	100.0%

Table 3. Total number of HARVESTABLE (excludes old growth and other non-harvestable stands) acres by cover type across all DNR ownership, percent of new ELB mortality acreage assigned to a particular cover type, and the total number of acres ON A FIVE-YEAR BASIS assigned ELB mortality for a particular scenario. For the Collapse (Insect Collapse) scenario, mortality will only occur during the first FIVE-YEAR period. Cover Type Percentage represents the NOMINAL relative amounts of each cover type assigned ELB mortality for a particular scenario, thus 34.0% of any assumed ELB mortality acreage rate will be assigned to the Tamarack - Good (72) cover type. No ELB was assigned to Oak – High Slope acreage (301), a total of 19,939 acres – thus total acres for the Oak cover type is 98,488 (30 and 301).

			Acres Assigned ELB Mortality		
MN Cover Type	Total Number of Harvestable Acres	Cover Type Percentage	Current	Double	Collapse
1	122,214	1.17%	879	1,758	879
9	23,554	0.09%	68	136	68
12	1,020,150	9.79%	7,340	14,680	7,340
13	57,973	0.57%	424	849	424
14	39,074	1.60%	1,199	2,398	1,199
20	104,451	0.07%	50	101	50
30	78,549	0.08%	61	123	61
51	15,887	0.02%	12	25	12
52	26,590	0.14%	106	213	106
53	86,669	1.97%	1,480	2,959	1,480
61	13,046	0.17%	128	257	128
62	55,474	2.29%	1,719	3,439	1,719
71	77,514	4.17%	3,125	6,251	3,125
710	141,719	4.59%	3,440	6,880	3,440
711	232,417	8.97%	6,725	13,450	6,725
72	141,019	34.02%	25,512	51,024	25,512
721	218,093	22.45%	16,838	33,676	16,838
73	151,265	7.14%	5,352	10,705	5,352
74	8,364	0.15%	110	220	110
521 RP Plantation	80,726	0.44%	330	660	330
611 WS Plantation	36,270	0.13%	99	199	99
Totals	2,731,018		75,000	150,000	75,000

Description of Harvest Scheduling Analyses

04/10/2013

Woodstock is a software package that allows users to examine how various land uses, management alternatives, and social policies will impact timber supply at a strategic-level, given the existing forest types and stand inventories. Strategic means at a large-scale, and ignores the spatial relationships between/among individual stands.

Within DNR's strategic-level plans the planning horizon is 75 years but only the initial 50 years are analyzed by planners. For this analysis the objective function in Woodstock is to maximize harvested volume. Since Woodstock uses linear programming to find an optimal solution when trying to maximize harvested volume, which is merely a mathematical operation, if no constraints are included most stands will be harvested at year 50 – hence harvested volume is maximized. Of course linear programming has no concept of the future beyond the 50 year planning period. Hence, the additional 25 years helps to provide a more realistic depiction of how stands will be managed near the end of the initial 50 year period. It is felt this is advantageous to placing binding constraints (or constraints that must be met) to avoid illogical behavior 45 and 50 years into the future. For the part of the planning horizon that is analyzed, 10 five-year planning periods were used.

In general, individual stands are not grown throughout a planning horizon when using Woodstock. Rather, stands are grouped into categories and then acres within a category, where the acres are a conglomeration of many stands, receive treatments and are grown throughout the planning horizon. For example, all stands classified as a tamarack cover type (within FIM/CSA coded as 72), could be grouped into site qualities using an interval of 5 feet (e.g. site quality class 50 could encompass all tamarack cover type stands with site qualities ranging from 50 to 54 feet) and then these tamarack cover type stands grouped by site quality class would receive treatments within Woodstock and projected forward as a group. In this case, when treatments are assigned to a category, there is no way to tell what specific stands should be treated within a particular planning period.

As opposed to other optimization techniques, linear programming allows proportions of a landbase to receive treatments. For example, it could be that only 34% of Black Spruce cover type, site index 35 stands receive a clearcut operation in a particular planning period. For other optimization techniques, such as integer programming, activities either occur or don't (either 1 or 0) in a particular planning period.

Forest planning and harvest scheduling does not optimize management objectives of the target forest. Rather, these plans are about developing an optimal activity schedule for the transition of the existing forest to the desired future forest. For many stands, individual stand management may be less than optimal so that statewide/regional/subsection objectives as a whole can be met.

The objective of this current study is to determine how different assumptions about the rate of tamarack mortality caused by the Eastern larch beetle (ELB) and their interaction with varying Desired Future Forest Conditions (DFFC) impact long-term age-class distributions, and acres and volumes harvested. Within Woodstock, the objective function is to maximize total cordwood volume harvested relative to a set of management constraints or goals.

For this analysis, cover type volumes are initially estimated using cover type specific yield tables (see Appendix I for an example), then average cover type species compositions (calculated using FIA/FIM data) are used to determine the amount of individual species harvested volumes.

Basal area, mean stand diameter, and total cordwood volume were estimated for each planning period. Clearcut even-aged systems were modeled using Walters and Ek (1993, Whole Stand Yield and Density Equations for Fourteen Forest Types in Minnesota, Northern Journal of Applied Forestry, 10:75-85). These equations require cover type, site index, and age. After reviewing projections, new yield tables were fit for red pine and white spruce plantations and oak stands using stand-level data from FIM. All red pine and white spruce thinnings generate 10 cords per acre, while all oak thinnings generate 8 cords per acre, regardless of cover type or age.

For all-aged types the Walters and Ek (1993) equations were used for the first entry only. Here, 33% of standing volume was removed; this corresponded to how Subsection Forest Resource Management Planning (SFRMP) plans calculate volume from partial harvests. It was then assumed that the result of this initial stand entry was a regulated diameter distribution. For these regulated stands volumes from Thunderhawk DEIS (H. Hoganson, pers. comm.) and a 20-yr reentry interval were used.

Tables 10, 11, and 12 show what forest management actions can occur on particular cover types and any conditions that must be met. These actions are clearcuts, thinnings, and partial cutting treatments. **FOR PURPOSES OF MODELING, NO EXTENDED ROTATION FORESTRY (ERF) WAS ASSUMED.**

DEVELOPING A GIS ARCMAP SHAPEFILE

To conduct a landscape level harvest scheduling analysis, the landbase must be quantified as to the amount of cover type acres by age and site productivity and potential management restrictions/actions that can occur on those acres. The most recent DNR FIM shapefile database (03/08/2012) was queried. Cover type is determined based on internal DNR algorithms, site index is calculated based on measurement of dominant trees within the field and appropriate equations, and age is based on field measurements.

There are 188,761 polygons totaling an acreage of 4,827,917 acres. This shapefile reflects updates (alterations) entered through March 1, 2012. This shapefile is not a statewide dataset,

rather it only contains land in the Subsection Forest Resource Management Plans (SFRMP) project areas which excludes Western and Southwestern Minnesota. State lands in the BWCAW have been excluded.

The shapefile only contains stands that have been inventoried thru the FIM system and under the DNR Administration of Forestry OR Wildlife, Fisheries lands in Lake County, and Trails and Waterways Lands in St. Louis County. This dataset also contains stands designated as Old Growth and no harvest areas from the DNR administrations listed above.

SNAs, State Parks, Camp Ripley Military lands, BWSR, Metro Greenways, Municipal Forests and other DNR administrations have been excluded. Old Growth stands in these administration types have been excluded as well.

For the purposes of this analysis, all FIM reported ages were updated to the current age using the year 2012.

Some stands are designated as no harvest by law or policy, technically these acres are not timberland and therefore were excluded from the analysis.

Table 4. Harvestable cover type acreages within the FIM dataset. Excludes stands classified as Old Growth or stands with other harvesting restrictions. Insignificant Acreage and Low Productivity acreages include all stands – both harvestable and non-harvestable, FOR THIS ANALYSIS, THERE IS NO HARVESTING OF THESE ACRES.

MN_CTYPE	Cover Type Name	Number of Stands	Harvestable Acres
1	Ash	7,325	122,214
9	Lowland Hardwoods	1,198	23,554
12	Aspen	51,386	1,020,150
13	Birch	3,078	57,973
14	Balm of Gilead	2,644	39,074
20	Northern Hardwoods	4,534	104,451
30	Oak	3,543	78,549
301	Oak - High Slope	699	19,939
51	White Pine	1,314	15,887
52	Red Pine – Natural	2,155	26,590
521	Red Pine Plantation	4,792	80,726
53	Jack Pine	5,697	86,669
61	White Spruce – Natural	832	13,046
611	White Spruce Plantation	2,213	36,270
62	Balsam Fir	3,709	55,474
71	Black Spruce, Lowland – Good	4,204	77,514
710	Black Spruce, Lowland – Poor	5,300	141,719
711	Black Spruce, Lowland – Medium	9,634	232,417
72	Tamarack – Good	5,407	141,019
721	Tamarack – Bad	5,556	218,093
73	NWC	6,802	151,265
74	Black Spruce, Upland	573	8,364
		132,595	2,750,957

Insignificant Acreage - Includes Non-harvestable stands

MN_CTYPE	Cover Type Name	Number of Stands	All Acres
0	No designation	3	34
6	Willow	18	490
15	Cottonwood	56	1,033
17	Hybrid Poplar	2	18
25	Walnut	203	2,245
40	Central Hardwoods	181	2,528
54	Scotch Pine	8	96
55	Ponderosa Pine	1	5
64	Norway Spruce	11	92
70	Upland Larch	5	46
81	Red Cedar	40	358

Low Productivity - Includes Non-harvestable stands

MN_CTYPE	Cover Type Name	Number of Stands	All Acres
75	Stagnant Spruce	5,965	361,450
76	Stagnant Tamarack	1,486	145,052
77	Stagnant Cedar	3,449	128,404
78	Offsite Aspen	214	4,492
79	Offsite Oak	379	8,068

Table 5. For the purposes of modeling, several cover types above have been separated out and in some cases new cover types have been created.

MN_CTYPE	Cover Type Name	Creation	Reasoning
101	Regulated Ash	Created during model	-
109	Regulated Lowland Hardwoods	Created during model	-
120	Regulated Northern Hardwoods	Created during model	-
301	Oak – High Slope	Existing, TOPO = 3	High slope Oak sites not thinned
302	Once Thinned Oak	Created during model	To ensure stands can only be thinned
303	Twice Thinned Oak	Created during model	**UP TO** 2 times prior to age 70
151	Regulated White Pine	Created during model	-
152	Once Thinned Red Pine Natural Stand	Created during model	
252	Twice Thinned Red Pine Natural Stand	Created during model	
352	Three Thinned Red Pine Natural Stand	Created during model	To ensure stands can only be thinned
452	Four Thinned Red Pine Natural Stand	Created during model	**UP TO** 6 times prior to age 100
552	Five Thinned Red Pine Natural Stand	Created during model	
652	Six Thinned Red Pine Natural Stand	Created during model	
521	Red Pine Plantation	Existing, ORIGIN = 2	-
522	Once Thinned Red Pine Plantation	Created during model	
523	Twice Thinned Red Pine Plantation	Created during model	
524	Three Thinned Red Pine Plantation	Created during model	To ensure stands can only be thinned
525	Four Thinned Red Pine Plantation	Created during model	**UP TO** 6 times prior to age 100
526	Five Thinned Red Pine Plantation	Created during model	
527	Six Thinned Red Pine Plantation	Created during model	
71	Black Spruce – Good	Existing, SI >=40	
710	Black Spruce – Poor	Existing, SI 20 to 29	Allows for three different rotation ages
711	Black Spruce – Medium	Existing, SI 30 to 39	
72	Tamarack – Good	Existing, SI >=40	Allows for two different rotation ages
721	Tamarack – Bad	Existing, SI < 40	

161	Regulated White Spruce	Created during model	-
611	White Spruce Plantation	Existing, ORIGIN = 2	-
612	Once Thinned White Spruce Plantation	Created during model	To ensure stands can only be thinned
613	Twice Thinned White Spruce Plantation	Created during model	**UP TO** 2 times prior to clearcut
162	Regulated Balsam Fir	Created during model	-

For the purposes of Eastern larch beetle (ELB) modeling, when ELB was assigned to a particular stand (or amount of cover type acreage), a new cover type was created where the existing cover type numerical code was used but the number 99 was added. Hence, a Red Pine plantation (521) assigned ELB was coded as 52199 and a Tamarack - Bad cover type stand (721) assigned ELB was coded as 72199.

DESIRED FUTURE FOREST CONDITIONS (DFFCs) AND CONSTRAINTS

The following constraints were utilized during this particular analysis (Tables 6 to 8). THERE ARE NO CONVERSIONS of Aspen/BG and Birch cover types to softwood cover types.

Table 6. Normal rotation age (NRA) by cover type. Defined as, for even-aged managed cover types, the rotation age set for non-ERF timberland acres. It is based on the culmination of mean annual increment (MAI), other available data related to forest productivity that also considers wood quality, and local knowledge.

Cover Type	Site Index	Age
Aspen/BG	All	45
Birch	All	55
Jack Pine	All	50
BSL 23-29	All	120
BSL 30-39	All	100
BSL 40+	All	75
Tamarack <40	All	95
Tamarack 40+	All	70
White Spruce	Planted	50
Balsam Fir	All	50
Red Pine	All	110
Oak	All	85

Table 7. Maximum rotation age (MRA) by cover type. Defined as the maximum age at which a forest type will retain its biological ability to regenerate to the same forest type and remain commercially viable as a marketable timber sale.

Cover Type	Site Index	Age
Aspen/BG	All	75
Birch	All	80
Jack Pine	All	70
BSL 23-29	All	170
BSL 30-39	All	135
BSL 40+	All	100
Tamarack <40	All	145
Tamarack 40+	All	110
White Spruce	Planted	70
Balsam Fir	All	65
Red Pine	All	190
Oak	All	113

Table 8. Even-flow percentage by cover type. It should be made clear that even-flows are by cover types, not individual species volumes.

Cover Type	Site Index	Percent
Aspen/BG	All	20%
Birch	All	20%
Jack Pine	All	20%
BSL 23-29	All	20%
BSL 30-39	All	20%
BSL 40+	All	20%
Tamarack <40	All	20%
Tamarack 40+	All	20%
White Spruce	Planted	20%
Balsam Fir	All	20%
Red Pine	All	20%
Oak	All	20%

There is also a 20% even-flow constraint for harvested volume across all cover types.

EVEN FLOWS WERE CALCULATED WITHOUT ANY CONSIDERATION OF ELB INFESTATION RATES. WHEN CALCULATING EVEN FLOWS, NO ATTEMPT WAS MADE TO ADJUST COVER TYPE VOLUMES DUE TO THE LOSS OF TAMARACK SPECIES VOLUME – STATED DIFFERENTLY EVEN FLOWS WERE CALCULATED STILL INCLUDING TAMARACK SPECIES VOLUMES REGARDLESS OF INFESTATION.

Thus, total estimated harvested volumes are essentially constant across the three scenarios (Current, Double, and Collapse) and the fourth scenario of No Future Infestation. The impacts of ELB mortality on harvested volumes are obtained by manually subtracting out estimated tamarack species harvested volumes.

UNDER DEVELOPMENT STANDS

At the time of the shapefile creation, many stands were scheduled to receive some type of treatment, or these stands were specified as "Under Development" within FIM. Unfortunately the exact treatment is not specified within FIM. To account for changes to the landbase from these treatments, for cover types that are normally clearcut, ages were reset to 1. However, for red pine and white spruce stands including and younger in age than 100 and 49, it was assumed these treatments are thinnings and hence age was not reset. Additionally, thinnings were assumed to occur for oak stands younger in age than 80, on Level (TOPO = 1) or Rolling (TOPO = 2) land, and with site indexes of 60 feet or greater, and hence for these stands age was also not reset.

Table 9. Range of ages considered to be thinning treatments for White Spruce, Red Pine, and Oak cover type stands specified as "Under Development" within FIM.

Cover Type	Site Index	Age Range of Thinnings
White Spruce	Planted	<= 49 years
Red Pine (both natural and plantation)	All	<= 100 years
Oak (TOPO = 1 or TOPO = 2)	>= 60	<= 79 years

For cover types normally receiving partial cuttings (e.g. group and regulated harvests), age was also not reset.

BRIEF DESCRIPTION OF MODELING DESIRED FUTURE FOREST CONDITIONS

Even-flows

Even-flows by cover type provide a target relative range of harvested volume over the next 75 years and represents the stability of harvested volumes. Quantifying the average amount of harvested volume and the likely variation about that average over the next 75 years provides industry some idea of the amount of fiber available for the production of primary wood products (e.g. pulpwood for oriented strand board and paper/pulp production and sawlogs for lumber, pallet, and veneer production) and even the production of secondary wood products.

Factors such as rotation ages and yield tables (predicted volumes) all play an important part in estimating even-flows and their variation about the average harvested volume. A greater percent even-flow allows for more flexibility as to the timing of harvests across the landscape and will likely result in slightly greater average harvested volumes. However, the greater average harvested volumes across time may result in periods of excessive supply and demand that could negatively impact the forest industry.

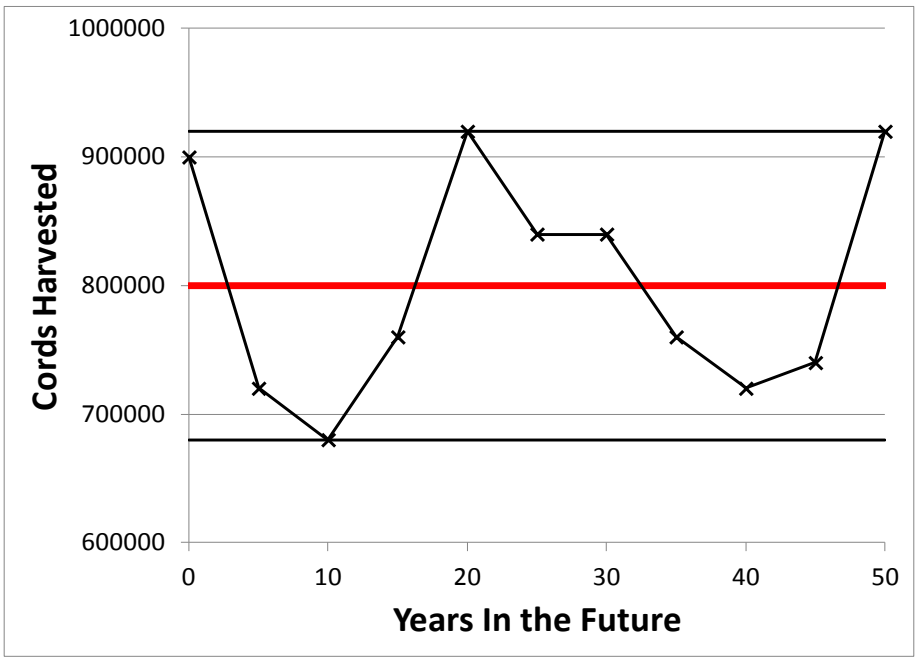


Figure 1. Depiction of an even-flow constraint on harvested volume. The average amount of cords harvested over the next 50 years is 800,000 cords. An even-flow constraint of 15% was utilized. Hence, in any one year, the amount of harvested volume could deviate +/- 15% from the average harvest of 800,000 cords.

Greater percent even-flows allow for more flexibility in choosing stands to harvest across time to meet Desired Future Forest Conditions (DFFCs), this will generally result in a greater average harvested volume. However, greater percent even-flows result in more variation in the amount of harvested volumes from year to year which could negatively impact the forest industry.

Effective and Prescribed ERF
FOR PURPOSES OF MODELING, NO EXTENDED ROTATION FORESTRY (ERF) WAS ASSUMED.

POTENTIAL MANAGEMENT ACTIONS

Given the current amount of acres by cover type, site quality, and age, and desired future forest conditions and management objectives, and potential management actions that can occur, Woodstock will find the optimal mathematical management scheme of all stands. For any acre, there are many potential management actions that could occur and the timing of those actions can vary. It is important that potential management actions within Woodstock reflect possible operational management options and the conditions that could impact choosing one alternative over another.

For instance, operationally, aspen stands are generally clearcut, and these clearcut operations do not occur until a stand reaches age 45. There are many options for a particular stand, for instance it could be harvested at age 45 or it could be harvested at age 55. The timing of a specific operation depends on the projected yields and the desired future forest conditions. It could be that for a particular aspen stand, based on its site index, volume is maximized at age 46. However, because of age-class distribution constraints at the landscape level, the optimal time to harvest this stand is at age 54. Thus, in order to optimize landscape level management objectives, some stand-level harvested volume would be sacrificed.

For this analysis, THERE ARE NO CONVERSIONS OF Aspen, Balm of Gilead (Balsam Poplar), and Birch cover types to softwood cover types.

Table 10. Potential clearcut operations by cover type.

Cover Type	Cover Type Code	Site Index (base age 50)	Ages
Aspen	12	All site qualities	> = 45
Balm of Gilead	14	All site qualities	> = 45
Birch	13	All site qualities	> = 55
Red Pine (both natural and plantation)	52, 521	All site qualities	> = 110
Jack Pine/Upland Black Spruce	53	All site qualities	> = 50
White Spruce Plantation	611	All site qualities	> = 50
Balsam Fir	62	All site qualities	> = 50
Black Spruce – Poor	710	<= 29 ft	> = 120
Black Spruce – Medium	711	>= 30 ft and <= 39 ft	> = 100
Black Spruce – Good	71	>= 40 ft	> = 75
Tamarack – Bad	721	<= 39 ft	> = 95
Tamarack – Good	72	>= 40 ft	> = 70
Oak	30, 301	All site qualities	> = 85

For red pine, white spruce, and oak thinnings, at least 10, 15, and 15 years must pass before another thinning can occur, respectively. For red pine, up to 6 thinnings can occur before or up to age 100, for oak up to 2 thinnings can occur up to or before age 70, and for white spruce up to 2 thinnings can occur before the final harvest.

Table 11. Potential thinning operations by cover type.

Cover Type	Cover Type Code	Site Index (base age 50)	Ages
Red Pine (both natural and plantation)	52, 521	>= 45	>= 25 years and <= 100 years
White Spruce Plantation	611	All site qualities	>= 25 years
Oak	30	>= 60	>= 30 years and <= 70 years

For any partial cutting (whether GROUP or REGULATED), at least 20 years must pass before another cutting can occur.

Table 12a. Potential uneven-aged (partial cutting) GROUP harvesting operations by cover type.

Cover Type	Cover Type Code	Site Index (base age 50)	Ages	Basal Area Per Acre	Cords Per Acre
Ash	1	>= 45	All	>= 120	>= 21
Lowland Hardwoods	9	>= 45	All	>= 120	>= 21
Northern Hardwoods - Young	20	All site qualities	>= 30 years and <= 55 years	>= 100	-
Northern Hardwoods - Old	20	All site qualities	>= 60 years	>= 100	-
White Pine	51	All site qualities	>= 125 years	-	-
White Spruce	61	All site qualities	>= 80 years	-	-
Balsam Fir	62	All site qualities	>= 50 years	-	-

Table 12b. Potential uneven-aged (partial cutting) REGULATED harvesting operations by cover type.

Cover Type	Cover Type Code	Site Index (base age 50)	Ages
Ash	101	All site qualities	All
Lowland Hardwoods	109	All site qualities	All
Northern Hardwoods	120	All site qualities	All
White Pine	151	All site qualities	All
White Spruce	161	All site qualities	All

Because of ecological concerns, we assumed no harvesting of northern white cedar stands. Due to low acreages, there are no management actions in willow, cottonwood, hybrid poplar, walnut, Central hardwoods, Scotch pine, ponderosa pine, Norway spruce, upland larch, and red cedar cover type stands. Due to low productivity and therefore relatively high logging costs per unit harvested, stagnant spruce, stagnant tamarack, stagnant cedar, offsite aspen, and offsite oak have no management actions.

Volumes of individual species shown in Table 13 are quantified within the analysis, volumes of other species are not calculated.

STUMPAGE REVENUES

Stumpage Prices Per Species

Revenues per cord of harvested wood are presented in Table 13. For several species a blended pulpwood/bolt/sawtimber price was used. This was obtained by multiplying the per cord stumpage revenues associated with pulpwood exclusively, bolts/pulpwood, and sawtimber times their reported cords to produce a weighted-average cord revenue.

Red Pine

Because of the economic significance, and its importance to several sawmills throughout the region, more sophisticated stumpage revenues were developed for red pine stumpage on red pine cover types (Table 14).

HARVESTED TAMARACK COVER TYPE AND SPECIES MODELING APPROACH

Decreases in estimated harvested tamarack species volume assume that harvest practices and relative rates of harvesting among cover types remains essentially constant in the future. As opposed to quantifying the potential maximum amount of harvestable tamarack species volume over the next 50 years, or maximum amount of sustainable harvestable tamarack species volume over the next 50 years, this analysis attempts to quantify the decrease in tamarack species volume assuming harvesting practices basically remain constant. If accelerated harvesting occurred on tamarack cover type or for tamarack species, then the predicted harvestable volumes would likely be greater than those reported in this document, but the sustainable harvest of tamarack may decrease at some point in the future because additional harvested acres combined with additional ELB infested acres will likely greatly limit tamarack supply at some point in the future. Essentially then, we are assuming no change in management associated with ELB infestation.

Table 13. Prices per cord of harvested wood. Applies to all scenarios.

Minnesota DNR weighted average stumpage prices.

Species	Price per Cord Pulpwood	Price per Cord Pulp/Bolts /Sawtimber	Real Price Adjustment (1)
Aspen	-	$28.00	-
Balm of Gilead	$18.00	-	-
Paper Birch	-	$10.00	-
Basswood	-	$16.00	-
Red Oak (2)	-	$40.00	Y
White Oak (3)	-	$30.00	Y
Maple (4)	-	$10.00	-
Ash (5)	-	$6.50	-
Elm (6)	-	$15.00	-
Balsam Fir	$17.00	-	-
Black Spruce	$19.00	-	-
Jack Pine	-	$28.00	Y
Red Pine (Non-Red pine Cover Type) (7)	-	$45.00	Y
Tamarack	$5.00	-	-
White Pine	-	$35.00	Y
White Spruce (8)	-	$26.00	Y
Cedar (9)	$5.00	-	-

Table Notes:

(1) For planning purposes, designated species increase in real terms at 0.5% per year.
(2) Includes black oak.
(3) Includes bur oak.
(4) Sugar and red maple.
(5) Black, green, and white ash.
(6) Includes American elm, red elm, black cherry, butternut, pin oak, hackberry, hickory, silver maple, cottonwood, willow, and misc.
(7) For red pine cover type, use red pine price table by age and silvicultural treatment (Table 11).
(8) Pulp/bolts only; use $50 per cord for white spruce sawtimber (final harvest >= age 60).
(9) Includes northern white and eastern red cedar.

Table 14. Prices per cord of red pine harvested wood ON RED PINE COVER TYPES. Applies to all scenarios.

Age	Stumpage Price Per Cord	
	Thinning	Clearcut
30	$16.00	-
40	$26.00	-
50	$32.00	$50.00
60	$40.00	$65.00
70	$45.00	$70.00
80	$50.00	$75.00
90	$50.00	$75.00
100	$50.00	$75.00
110	-	$75.00
120	-	$75.00
130	-	$75.00
140	-	$75.00
150	-	$75.00

These prices reflect that a thinning at age 30 will generally only contain pulpwood, but with age the percent bolts (or small sawlogs) will likely increase and at older ages thinnings may even remove smaller sawlogs. For clearcuts, as age increases, the percent bolts and sawlogs will increase, but at some point a percentage of the tree diameters will become too large for current mill specifications, thereby eliminating the potential to sell that timber.

EASTERN LARCH BEETLE (ELB) INFESTATION RATES

As previously mentioned, in stands currently infested **(see Final FIM Dataset Used in Harvest Scheduling Analysis** section), 95% mortality of all tamarack was assumed and no regeneration WITHIN THE EXISTING STAND (or no tamarack ingrowth) was assumed to occur over the next 75 years. This reduced the harvestable land base from 2,750,957 acres (see Table 4) to 2,675,784 acres (2,750,957 – 75,173, where 75,173 can be seen in Table 2) at time 0. Beginning in the first 5 year period, ELB mortality amounts were assigned by cover type as reported in Table 3, for a particular mortality scenario (Figure 2). Remember, for the 75,173 acres, 5% of the predicted tamarack species volume was still harvestable.

Initially, mortality amounts were setup as goals within Woodstock. However, for Tamarack – Good (72) and Tamarack – Bad (721) cover types in the Current scenario, and for Tamarack – Good (72), Tamarack – Bad (721), Black Spruce – Good (71), and Northern White Cedar (73) cover types in the Double scenario, for many periods the nominal mortality amounts were not

achieved. Therefore, in some instances, the desired mortality rates were setup as binding constraints (must be met in order to obtain a feasible solution). In some cases, likely due to even-flow constraints, desired mortality rates could not be obtained across all planning periods and in some cases a combination of goals and binding constraints were used to produce the greatest amount of mortality acreage. For the Collapse (Insect Collapse) scenario, all nominal mortality acreages were obtained during the first period.

Similar to existing acreage with ELB infestation, regardless of cover type, only 95% of the tamarack trees on a future (or infestation assigned during the projection) infested acre were assumed to die; the remaining 5% was assumed to produce woody fiber. On all infested acres, no tamarack regeneration **WITHIN THE EXISTING STAND** was assumed. **However, for the subsequent stand following harvesting, 5% of the tamarack was assumed to be regenerated.** In some cases, this low regeneration rate may actually produce a change in the cover type (e.g. tamarack cover type), but for simplicity we assumed the same cover type and hence the same yield tables and percent species compositions if an acre/stand was harvested a second time during the projection. **With that said, given the projection period is only 75 years and given the relative length of rotations associated with cover types most impacted by ELB and the lack of tamarack regeneration, the lack of changes in cover types for subsequent harvests is not likely an issue (e.g. given a rotation age of 70 years for Tamarack-Good cover type, an acre would likely only be harvested once in the 75-year projection).** Because of the potential of acres infested with ELB of certain cover types to be harvested more than once during the projection period, e.g. ABg, Balsam Fir, Birch, Jack Pine, White Spruce Plantations, percent regeneration of tamarack within subsequent stands can be an issue because perhaps different yield tables or percent species compositions should be used. However, the potential of harvesting acres more than once during the projection is only an issue for stands that will likely maintain their cover types despite the low regeneration rates of tamarack, e.g. ABg, Balsam Fir, Birch, Jack Pine, White Spruce Plantations, etc.

For example, if an ABg stand infested prior to conducting the projection, was harvested at year 5, it could be harvested again beginning in projection year 50. A second example is where ELB infestation is randomly assigned to a stand in year 5, then it is harvested in year 10. This ABg stand could be harvested again at year 55. Although we are not interested directly in what occurs in years 55 to 75 (remember our concern is the initial 50 years), these projection periods are important because of factors such as even-flow that can impact the timing of harvests at all projection periods.

Impacts of Eastern Larch Beetle on Future Overall Woody Fiber and Tamarack Species Volume Supply

Future ELB infestation will have a dramatic impact on the amount of ANNUALLY harvested tamarack species volumes across all cover types (Figure 3). Assuming infestation ceases

sometime during the next five years (Insect Collapse scenario), impacts on ANNUALLY harvested volume will be minimal. However, if infestation rates increase (e.g. Double scenario), ANNUALLY harvested volume could decrease by close to 42,000 cords 50 years into the future when compared to the No Future Infestation scenario. If infestation rates remain constant, ANNUALLY harvested tamarack species volume will still decrease substantially (35,843 cords) by 50 years into the future.

Overall (all species) ANNUALLY harvested volume is also affected by scenario, particularly with the progression of time (Figure 4). Across all 50 years, average ANNUAL harvested volume for the Double, Current, Insect Collapse, and No Future Infestation scenarios are 758,471 cords, 768,083 cords, 784,781 cords, and 788,109 cords. As expected, if future infestation ceases after the next 5 years, the impacts will be relatively minimal. However, if infestation continues at its current rate then AVERAGE annual harvests could decrease by 20,000 cords and if infestation rates double they could decrease by 30,000 cords. It appears that mortality rates beyond the current rate will still produce relatively lower harvest amounts (e.g. Double), but at a lessening rate.

To some 20,000 or 30,000 cords ANNUALLY may not seem substantial, however, this reduction will make it increasingly difficult when trying to meet harvest target goals. When combined, for example, with the impacts of Emerald Ash Borer (EAB) on ash and spruce budworm on balsam fir, losses in volume can be become meaningful. At the current time though, species such as ash, balsam fir, and in most particularly tamarack for this study, comprise a relatively small amount of annual DNR harvested volume. In fact, many MN DNR tamarack cover type timber sales go unsold.

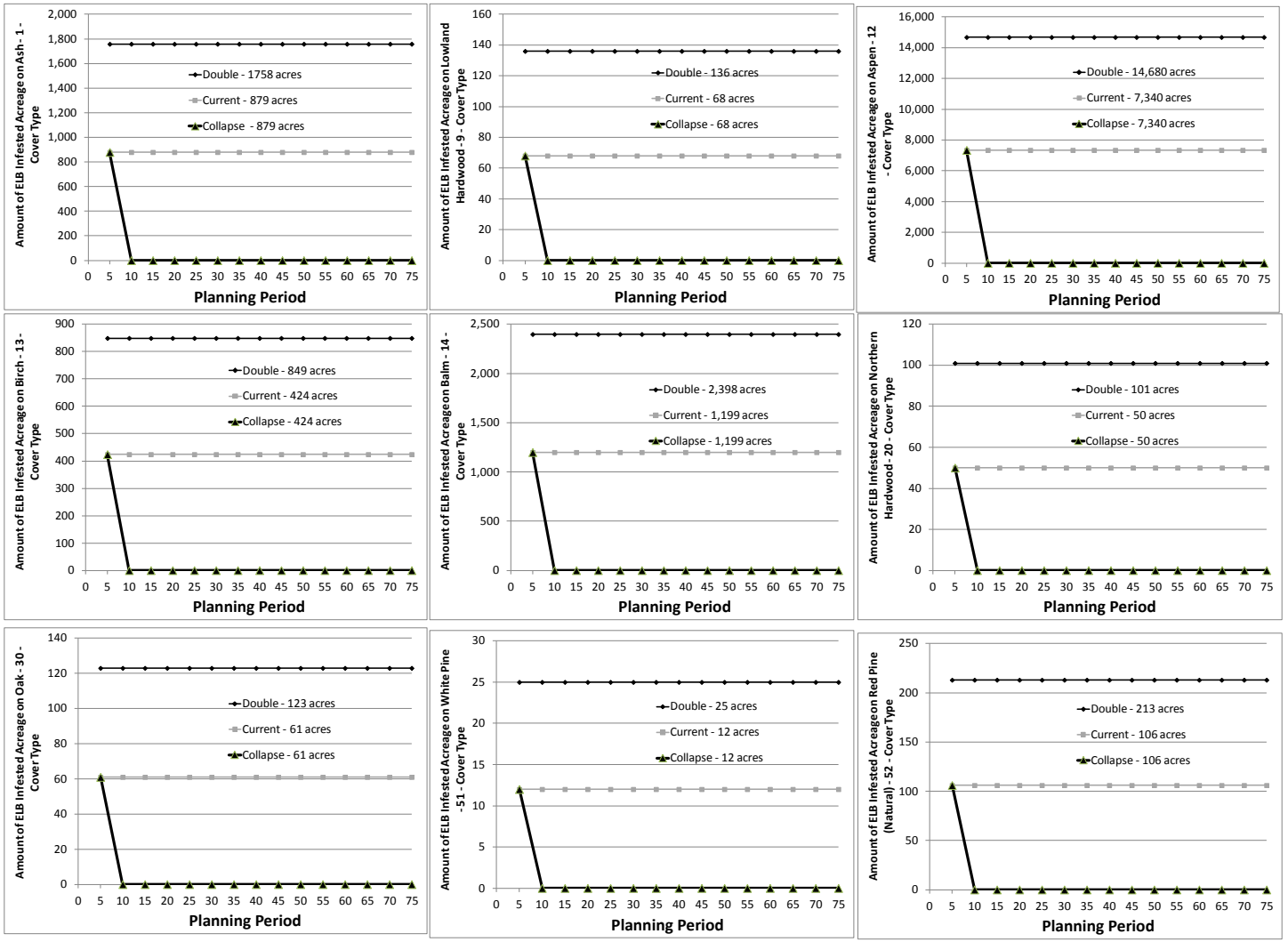


Figure 2. <u>Nominal</u> and <u>Actual</u> number of acres PER 5-year period by cover type and scenario (Double, Current, and Collapse – also referred to as Insect Collapse) infested by Eastern larch beetle (ELB) over the 75-year projection period. In some cases, the nominal acres were not achieved.

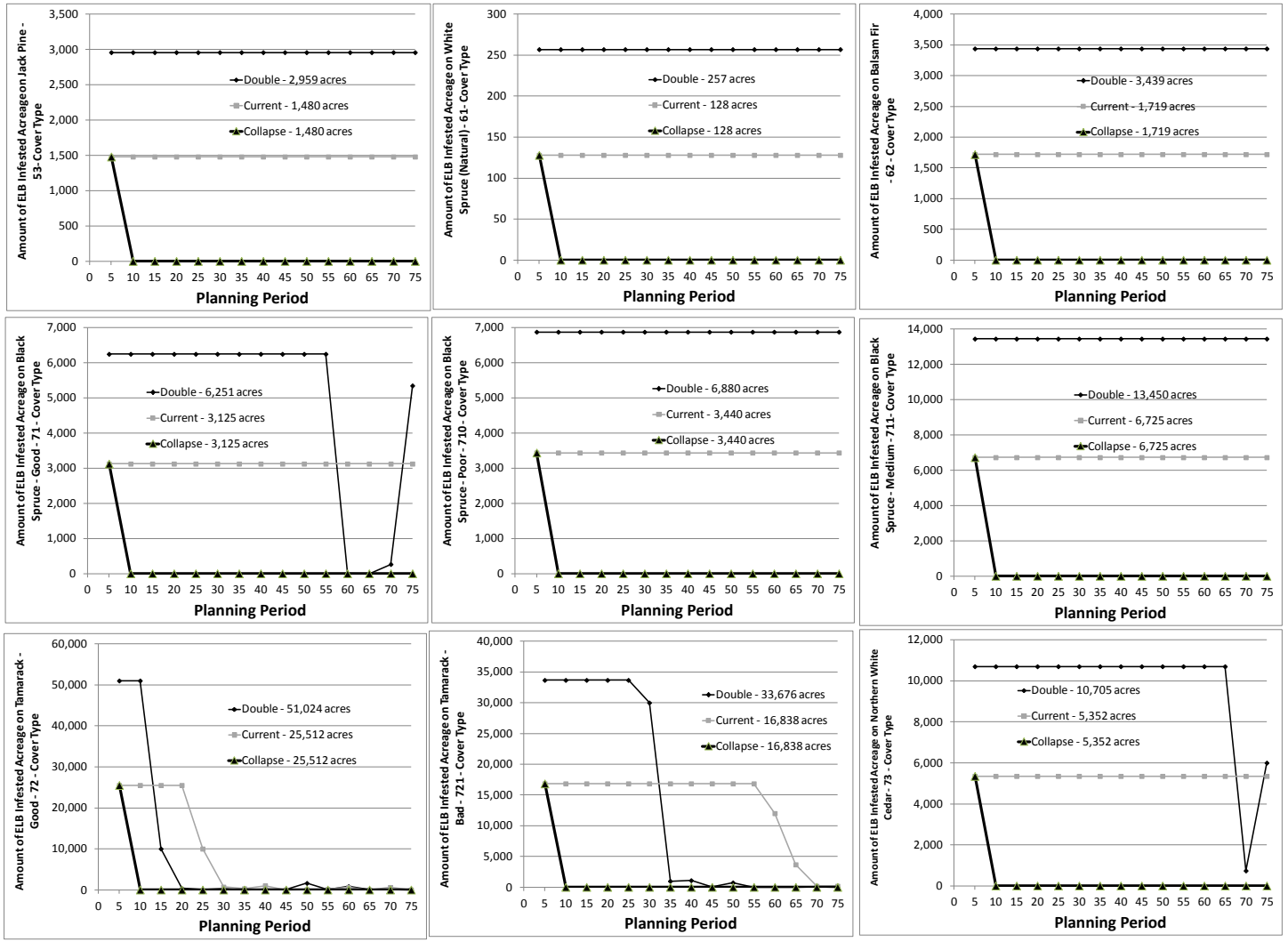


Figure 2. (cont.)

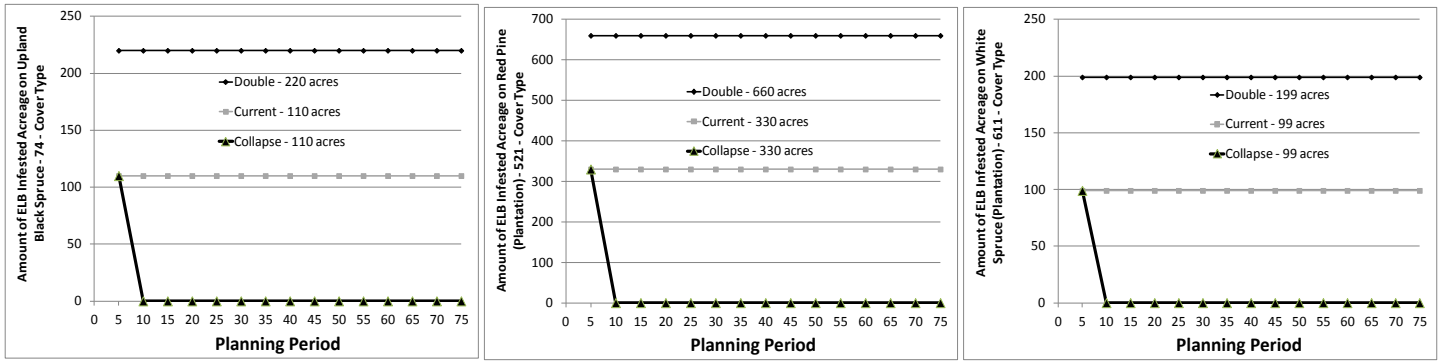


Figure 2. (cont.)

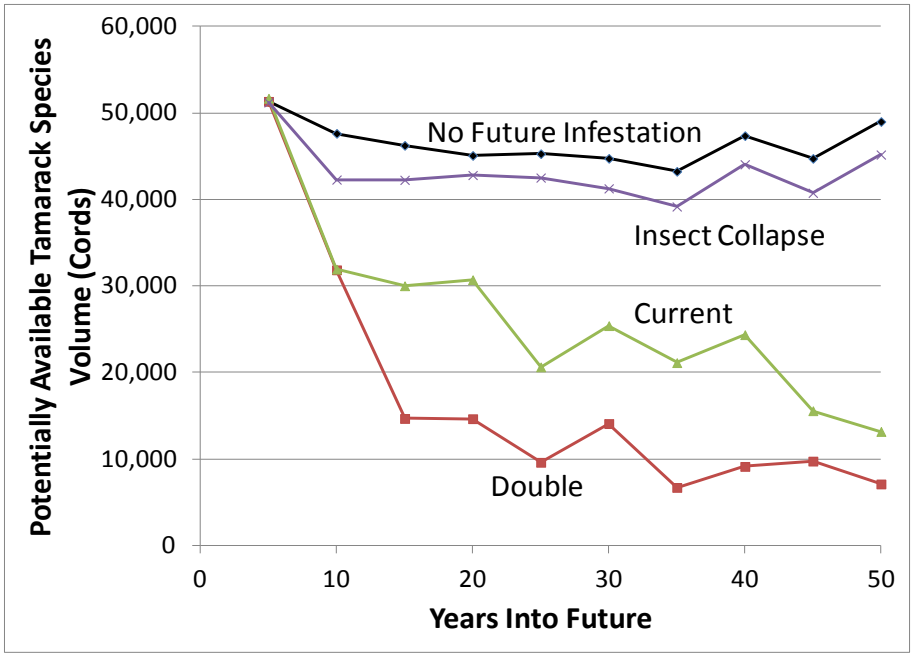


Figure 3. Estimated harvested tamarack species volume <u>across all cover types</u> over the next 50 years by scenario. The Insect Collapse scenario only has future Eastern larch beetle (ELB) infestation during the first period (or first 5 years).

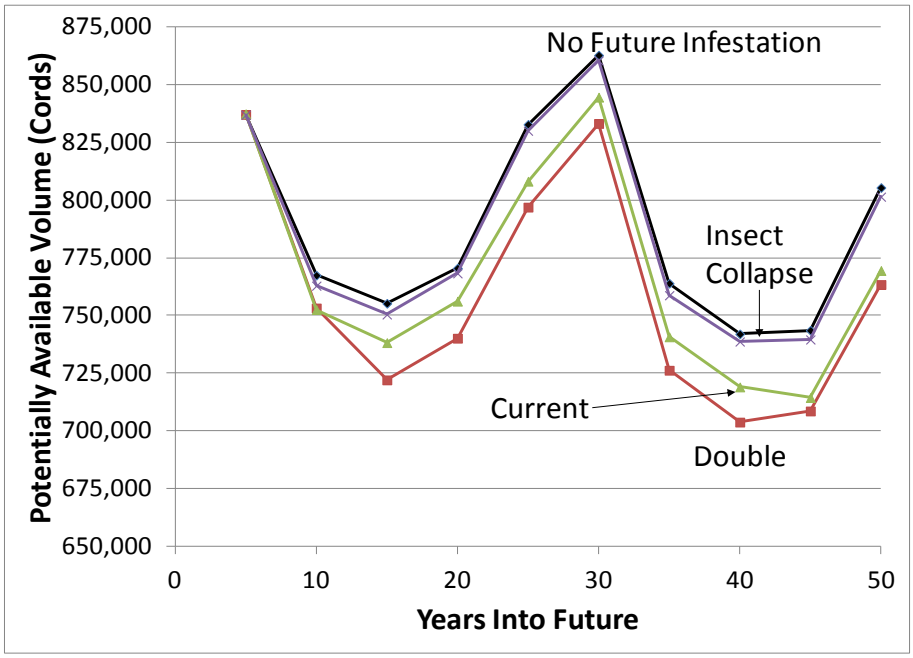


Figure 4. Estimated harvested volume of ALL SPECIES <u>across all cover types</u> over the next 50 years by scenario. The Insect Collapse scenario only has future Eastern larch beetle (ELB) infestation during the first period (or first 5 years). Average ANNUAL harvested volume from the Double scenario is 758,471 cords (red line) while for the No Future Infestation scenario average ANNUAL harvested volume is 788,109 cords.

Appendix I. An example of cover type specific yield tables for red pine plantations. Cover Type is 521 and site indexes are 55 feet and 60 feet (base age 50).

*Y 521	55 ? ?	
_AGE	Basal	Cords
5	46.41	1.44
10	60.61	3.75
15	70.84	6.42
20	79.14	9.28
25	86.24	12.23
30	92.50	15.20
35	98.16	18.15
40	103.34	21.04
45	108.13	23.87
50	112.60	26.61
55	116.81	29.26
60	120.79	31.82
65	124.57	34.28
70	128.17	36.64
75	131.62	38.91
80	134.94	41.08
85	138.12	43.16
90	141.19	45.15
95	144.16	47.05
100	147.04	48.88
105	149.82	50.62
110	152.53	52.30
115	155.16	53.90
120	157.73	55.44
125	160.22	56.91
130	162.66	58.33
135	165.04	59.69
140	167.37	61.01
145	169.64	62.27
150	171.87	63.48
155	174.06	64.66
160	176.20	65.79
165	178.30	66.89
170	180.36	67.95
175	182.38	68.97
180	184.37	69.97
185	182.38	68.97
190	180.36	67.95
195	178.30	66.89
200	176.20	65.79
205	174.06	64.66
210	171.87	63.48
215	169.64	62.27
220	167.37	61.01
225	165.04	59.69

*Y 521 60 ? ?		
_AGE	Basal	Cords
5	48.82	1.62
10	63.75	4.22
15	74.51	7.23
20	83.24	10.45
25	90.70	13.76
30	97.30	17.10
35	103.25	20.42
40	108.69	23.68
45	113.73	26.86
50	118.44	29.95
55	122.86	32.93
60	127.05	35.81
65	131.02	38.58
70	134.82	41.23
75	138.44	43.78
80	141.93	46.23
85	145.28	48.57
90	148.51	50.80
95	151.63	52.95
100	154.66	55.00
105	157.59	56.97
110	160.43	58.85
115	163.20	60.66
120	165.90	62.39
125	168.53	64.05
130	171.09	65.64
135	173.59	67.18
140	176.04	68.65
145	178.43	70.07
150	180.78	71.44
155	183.07	72.76
160	185.32	74.04
165	187.53	75.27
170	189.70	76.46
175	191.83	77.62
180	193.92	78.74
185	191.83	77.62
190	189.70	76.46
195	187.53	75.27
200	185.32	74.04
205	183.07	72.76
210	180.78	71.44
215	178.43	70.07
220	176.04	68.65
225	173.59	67.18

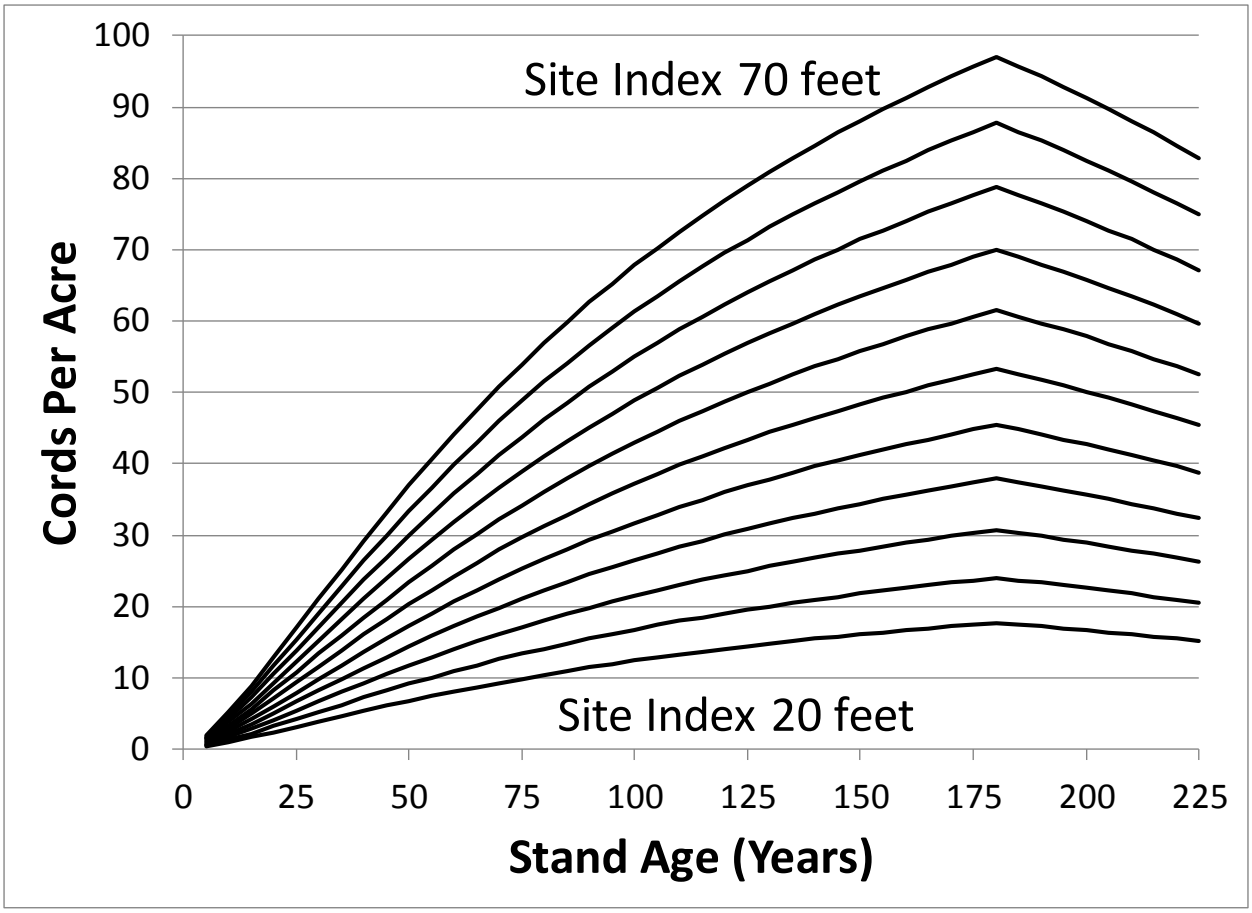


Figure 1. Estimated yields of red pine plantations (Cover Type = 521) by 5 foot site index increments. Yields begin to decrease at age 180, assumed to be due to stand disintegration.

Yield tables show, for a particular cover type and site index, the progressive development of the stand at periodic intervals covering the greater part of that stand's merchantable life.