Fundy Model Forest

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Report Title: Extending the Spruce Budworm DSS: Potential Effects of Budworm on Non-Timber Values in the Fundy Model Forest

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Extending the Spruce Budworm DSS: Potential Effects of Budworm on Non-Timber Values in the Fundy Model Forest

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Executive Summary

Eighty percent of the Fundy Model Forest (FMF) is forested and of that area, 80 % is susceptible to varying degrees of attack from eastern spruce budworm (*Choristoneura fumiferana* Clem.). The Protection Planning System (PROPS), a component of the Spruce Budworm Decision Support System (SBWDSS) was implemented on the FMF in 1999. This system forecasts the effects of spruce budworm on the timber supply. Outbreaks of spruce budworm can also affect a variety of non-timber elements in the forest so PROPS was modified to forecast the effects on the non-timber supply.

The non-timber values examined were: deer wintering areas (DWA); Old Spruce-Fir Habitat (OSFH); buffers along watercourses and highways; future forest structure including species composition and diameter distribution; and conservation and unique areas.

The effect of two outbreak scenarios, normal and severe, occurring over a 15-year period from 2001 to 2015, were analyzed in this report.

In Deer Wintering Areas (DWA's), the amount of softwood cover is crucial; within the FMF this level has been set at $\geq$ 50 m^3/ha. In the current DWA's, 15 years after a normal budworm outbreak 44% of the stands will meet that criteria while under a severe budworm outbreak only 7% of the stands will meet that criteria. When the softwood cover criteria is expanded to the entire FMF the number of stands meeting the criteria is greater at 52% and 47% for a normal and severe budworm outbreak, respectively.

Defined levels of Old Spruce-Fir Habitat (OSFH) are set under New Brunswick's forest management regime. Since spruce and fir comprise a large portion of the stand structure in OSFH, a spruce budworm outbreak has the potential to greatly impact the area available in OSFH conditions. With no budworm outbreak, 21 884 ha of the FMF would meet the compositional and successional stage criteria of OSFH. Under a normal or severe spruce budworm outbreak only 9 094 ha or 3 494 ha, respectively, would meet the OSFH criteria. That would represent a 58% loss under a normal budworm outbreak and an 84% loss under a severe budworm outbreak.

Conservation and unique areas are found within the FMF. They represent an important feature for tourist visitors to the area. Under a normal budworm outbreak only 2% of these stands that are susceptible to spruce budworm would lose more than 50% of their volume. This should not present much of a negative visual impact. Under a severe budworm outbreak 48% of the stands that are susceptible to spruce budworm would lose more than 50% of their volume. This could have a very negative visual impact and affect tourist visits to the area.

Buffer areas provide habitat connectivity, protection of waterways and visual aesthetics along provincial highways. There are approximately 34 982 ha of buffer areas in the FMF. Under a normal spruce budworm outbreak 17% of the susceptible stands in a buffer would lose more than 30% of their volume. Under a severe spruce budworm outbreak 42% of the susceptible stands would lose more than 30% of their volume. Under a severe outbreak the function of the buffers could seriously be compromised.

To maintain these various non-timber values within the FMF consideration should be given, where acceptable, to using protection methods such as biological control agents such as *B.t.* or the growth regulator Mimic. Where this is not possible consideration should be given to putting other management options, such as reducing the susceptible spruce/fir content of the stands, into effect now well in advance of a budworm outbreak.

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Introduction

Fundy Model Forest (FMF) is a 422 932 ha landbase located in southern New Brunswick with almost 80% of the area being forested. The forests not only provide the material for various timber industries in the area, they also present cover and structure for a variety of non-industrial uses and functions.

Eighty percent of the forested area or 265 120 ha is composed of stands that contain balsam fir (*Abies balsamea* (L.) Mill.) and spruce (*Picea* sp.) mixtures which render them susceptible to attack from spruce budworm (*Choristoneura fumiferana* Clem.) (Figure 1). The various stand types are colour coded according to the degree of vulnerability to attack from spruce budworm (SBW). Those stands coded in the red range (58 084 ha), are the most vulnerable. Those in the yellow range (74 436 ha) are moderately vulnerable, while those in the green range (138 781 ha) have low vulnerability. The rating of a stand's vulnerability to SBW depends on the percent spruce/fir content of the stand and age of the stand.

Outbreaks of spruce budworm are natural, cyclical disturbance agents within the spruce and balsam fir forests of North America. In the 20th century there have been 3 major spruce budworm outbreaks, beginning about 1910, 1940 and 1970 with each successive outbreak affecting increasingly larger areas (11, 25 and 58 million ha respectively) (Kettela 1983). Spruce budworm is considered one of the most destructive forest pests in Canada causing about 40% of the 81-107 million m^3 of timber volume lost to insects and disease each year (Sterner and Davidson 1982, Power 1991).

Outbreaks of spruce budworm can have a dramatic affect on timber supply and the impact of future spruce budworm outbreaks on the timber supply within the Fundy Model Forest has been well documented (MacLean et al. 1999). Spruce budworm outbreaks affect a variety of non-timber values as well. The resulting growth loss and mortality from a budworm outbreak can affect the availability of specific forest structure types that provide for important forest functions or values other than timber.

The Spruce Budworm Decision Support System that was developed to forecast the effects of SBW on the timber supply was modified to derive the effects on the non-timber values.

The non-timber values that may be affected by a spruce budworm outbreak in the FMF explored in this report include: deer wintering areas (DWA); Old Spruce-Fir Habitat (OSFH); buffers along water courses and highways; future forest structure including species composition and diameter distribution; and conservation and unique areas.

Method

Procedures used to implement the SBWDSS on FMF are detailed in MacLean et al. (1999). This report will summarize those procedures and describe the modifications used to derive SBW effects on selected non-timber values.

Management plan information and forest inventory data were the main data inputs. The data were manipulated and analyzed using Arc/Info version 7.1.2 on a Unix Workstation and a PC running ArcView 3.1. SAS, and Sigma Plot were also used to describe and present results of different budworm outbreak scenarios.

Database Construction

There are two databases that must be constructed to determine volume loss: the stand impact matrix and the stand history file.

Stand impact matrix

The stand impact matrix is a large lookup table

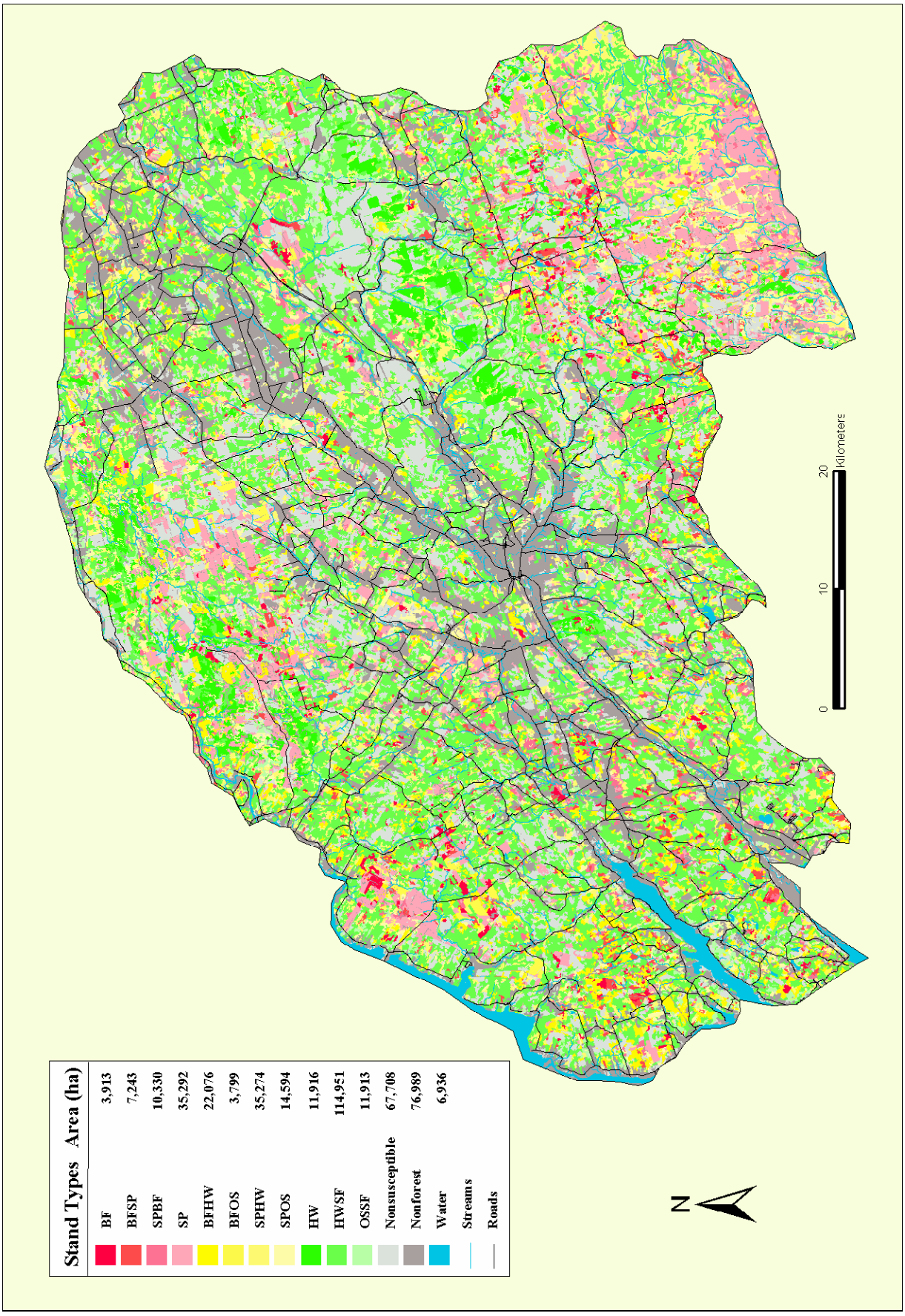

Figure 1. Budworm forest stand types for the Fundy Model Forest in 2000. Nonsusceptible stands contain less than 10% spruce/balsam fir content.

that contains percent volume reductions caused by varying levels of SBW defoliation. These percent reductions are applied to the volume yield curves obtained from the management plan. For the FMF landbase, the yield curves from Crown License 7 were used. The percent reductions were calculated based on STAMAN version 2.4 model runs for each SBW impact class for each 5-year period for all future defoliation conditions over the next 10 years (MacLean et al. 1999).

A total of 54 budworm impact classes that will sustain different losses during a budworm outbreak were defined. Impact classes were delineated based on a combination of four stand factors: percent spruce-fir content, species composition, age class, and silvicultural treatment. The 54 budworm impact classes are listed and defined in Table 1. For the purposes of defining volume loss on non-timber values, treated stands were not differentiated; they were included in the natural stand types based on the above factors.

Generally the highest percent volume losses occur in the older budworm impact classes: fir > 80 years old and spruce > 100 years old. The maximum percent volume loss values for these impact classes can range from 91-95%. These older classes sustain the greatest volume loss because as trees age, their ability to withstand and recover from defoliation decreases. Younger classes (especially < 40 yrs old) do not sustain as high volume loss because the trees are more vigorous, increasing their ability to recover from defoliation.

Both mature (age 41-80 or 41-100 yrs) and overmature (age > 80 or > 100 yrs) stands sustained large losses to budworm.

The impact classes that contain less percent spruce/fir (moving vertically down Table 1) sustain less volume loss than those with greater percent spruce/fir content as there is a smaller proportion of susceptible trees in the stand.

The yield curves were matched to one of the 54 budworm impact classes by species composition and age; for the purposes of this report, treated stands were not differentiated. The percent volume reduction for a given budworm impact class is a function of the reported period of loss (period 3 or 15 years after the start of a budworm outbreak), and the cumulative defoliation levels in period 1 (1-5 years) and period 2 (6-10 years).

Stand History File

The stand history file is the second major database needed when using this system for determining volume loss. This file contains a unique stand identifier, budworm impact class number, harvest period, stand area, and 5 years of past and 10 years of future defoliation information. The detailed procedures undertaken in creating this INFO file called STANDHISTORY and assigning values to its attributes are described in Sections 2.8 - 2.24 of Appendix I of Vanguard Forest Management Services Ltd. (1993). This file also contains budworm-caused absolute volume loss values at specified outbreak levels and specified periods in the future.

Varying Budworm Outbreak Scenarios

Different budworm outbreak conditions were simulated by changing the defoliation conditions in the stand history file, to represent “normal” and “severe” spruce budworm outbreaks starting in 2000. The pattern of defoliation for normal and severe outbreak scenarios is presented in Figure 2. PROPS requires explicit assumptions about future budworm defoliation levels; these assumed defoliation values are based on past outbreak cycles in NB (Royama 1984; Steinman and MacLean 1994).

The normal outbreak scenario (Figure 2 A) shows a 30-year cyclical pattern of defoliation and associated budworm population levels. There is a 12-year outbreak period of moderate-severe

Table 1. The 54 budworm impact classes used in the stand impact matrix.

% SP/BF Content	Stand Type	Species Composition (%)	Age (yrs) 0	20	40	60	80	100	120
	Natural Stands:								
80 - 100	BF	BF ≥ 80	1		2			3	
	BFSP	BF ≥ SP	4		5			6	
	SPBF	BF < SP	7		8			9	
	SP	SP ≥ 80	10		11			12	
	WS	WS ≥ 80	13		14			15	
50 – 79	BFHW	BF ≥ SP and HW ≥ OS	16		17			18	
	BFOS	BF ≥ SP and HW < OS	19		20			21	
	SPHW	BF < SP and HW ≥ OS	22		23			24	
	SPOS	BF < SP and HW < OS	25		26			27	
10 – 49	HW	HW ≥ 80	28		29			30	
	OS	OS ≥ 80	31		32			33	
	HWSF	HW ≥ OS	34		35			36	
	OSSF	HW < OS	37		38			39	
	Treated Stands:								
80 – 100	TNBF	BF ≥ SP	40		41				
	PLBS	BF < SP or BS/RS ≥ 80	42		43				
	PLWS	WS/NS ≥ 80	44		45				
50 – 79	TNFS	BF ≥ SP	46		47				
	TNSF	BF < SP	48		49				
10 – 49	TNHW	HW ≥ OS	50		51				
	TNOS	HW < OS	52		53				
	All Stands:								
0 - 9	NONS	SP/BF < 10	54						

Note:
BF – Balsam fir
SP – All spruce species combined
WS – White spruce
RS – Red spruce
BS – Black spruce
NS – Norway spruce
HW – Hardwood
OS – Other softwood
SF – Spruce-fir
FS – Fir-spruce
TN – Thinning
PL – Plantation
NONS – Nonsusceptible

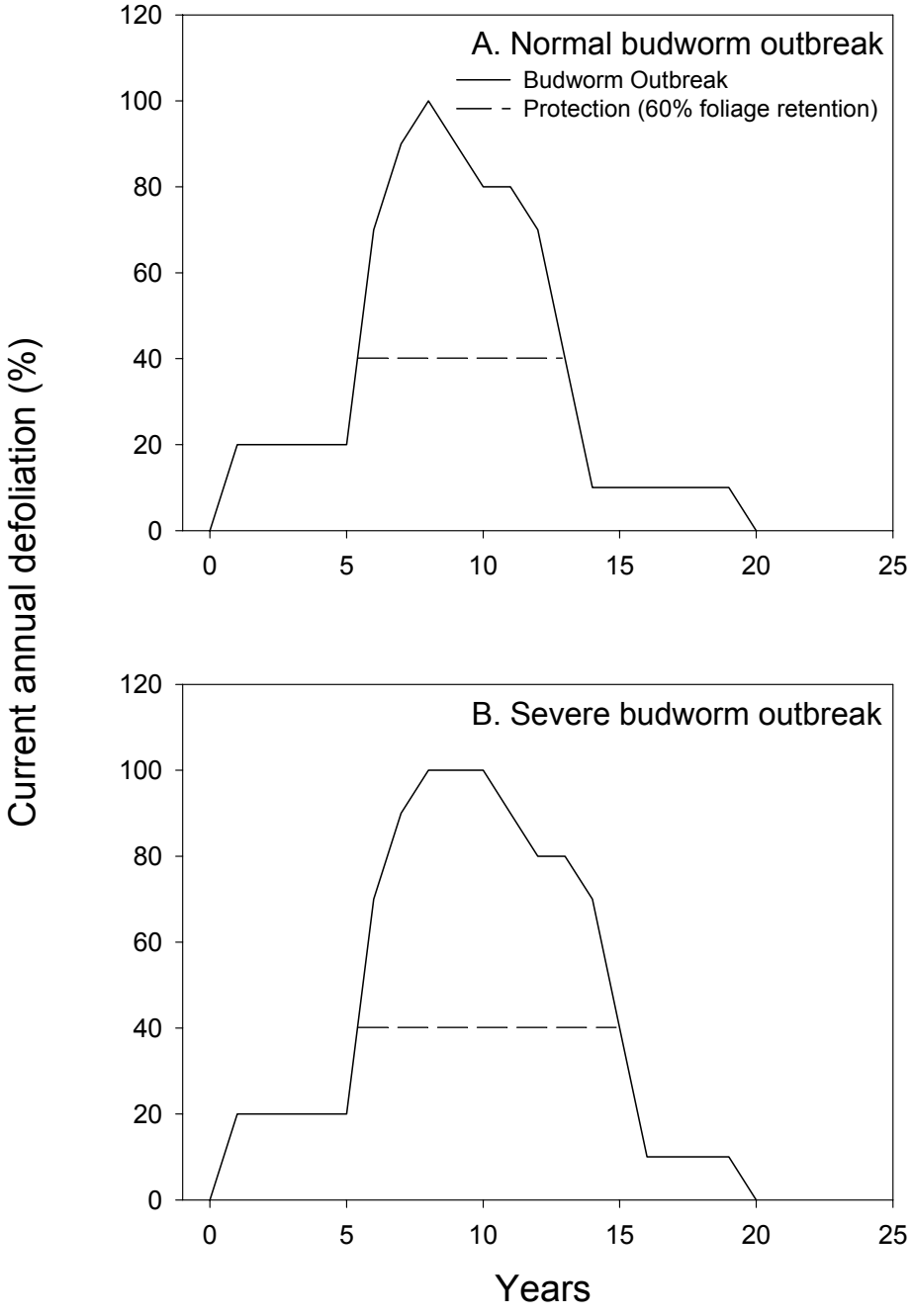

Figure 2. Current annual defoliation sequences for A. normal budworm outbreak, and B. severe budworm outbreak.

defoliation, followed by 18 years of nil-light (≤ 20%) defoliation. This scenario reflects lower defoliation, for a given budworm population level, in the declining phase (years 9-14) of the outbreak than in the increasing phase (years 6-8). This is because of the action of parasitoids and diseases that build up during the outbreak. The broken line shows a target defoliation limit of 40%, which corresponds to the NB Department of Natural Resources and Energy (NB DNRE) current protection strategy for balsam fir. The severe outbreak scenario (Figure 2 B) was developed because analyses indicated that the normal scenario did not result in cumulative defoliation or tree mortality levels as high as past severe outbreaks, such as in northern NB in the 1950's (Baskerville and MacLean 1979) and Cape Breton from 1976-84 (MacLean and Ostaff 1989). Therefore, two more years of 100% defoliation were added at the peak of the outbreak scenario (Figure 2 B). These two scenarios indicate probable future budworm outbreak patterns.

Results and Discussion

The effects of two SBW outbreak scenarios, normal and severe, were analyzed on the following non-timber values: deer winter areas; conservation and unique areas; Old Spruce-Fir Habitat; buffers (roads and waterways); forest stand types and diameter class distribution. These losses are summarized in Table 2.

Deer Wintering Areas

Deer wintering areas are important for maintaining healthy deer populations. The DWA's provide both food and cover for thermal shelter. For the NB DNRE, one of the primary management objectives is to maintain the long-term sustainable supply of deer winter habitat (NB DNRE 2000). For the purposes of DWA

Table 2. Effect of various spruce budworm outbreak scenarios occurring from 2000-2015 on non-timber values in the Fundy Model Forest.

	Area Affected (ha)		
	Protected	**Normal Outbreak**	**Severe Outbreak**
Deer Wintering Areas (designated)			
Stands expected to achieve 50m^3/ha softwood volume	1 657	1 372	265
Stands not expected to achieve 50m^3/ha softwood volume	2 134	2 420	3 526
Total Fundy Model Forest			
Stands expected to achieve 50m^3/ha softwood volume	191 803	177 844	158 628
Stands not expected to achieve 50m^3/ha softwood volume	147 203	161 162	180 378
Conservation and Unique Areas			
0% stand volume lost	922	779	779
1-24% stand volume lost	5 251	3 142	1 635
25-49% stand volume lost	116	2 237	892
50-74% stand volume lost	0	131	2 386
≥70% stand volume lost	0	0	597
Buffer Areas			
Stands expected to lose ≤ 30% volume	34 813	29 850	20 289
Stands expected to lose > 30% volume	169	5 132	14 693

habitat management, NB DNRE divides the province into a Severe Winter Deer Habitat (SWDH) in the north; and a Moderate Winter Deer Habitat (MWDH) in the south. There are different stand structure and spatial requirements for each habitat type. DWA's in the FMF need to meet the MWDH requirements.

One of the criteria of MWDH is that stands contributing to the MWDH are expected to achieve a peak softwood volume of 50 m^3/ha at some point in the life of the stand. For this report we looked at those stands that would reach 50 m^3/ha within a 15-year period after the start of an outbreak. Figure 3 shows the delineation of the current DWA's with the FMF. The DWA's cover a land area of 5 489 ha with 4 425 ha being susceptible to SBW.

Forest structure changes over time, even without a budworm outbreak. Within the DWA's some stands do not contain any softwood volume even 15 years into the future. Of the 5 489 ha in DWA's, 1 697 ha will not contain any softwood volume 15 years in the future; this leaves 3 791 ha that will have softwood volume in the future. With no budworm outbreak, 1 722 ha will achieve 50 m^3/ha of softwood volume in 2015. Fifteen years after the start of a normal outbreak 1 371 ha will achieve 50 m^3/ha softwood volume (Figure 3). This represents a 20% reduction from a no outbreak scenario. Fifteen years after a severe outbreak only 265 ha will achieve 50 m^3/ha softwood volume; this represents an 85% reduction in areas meeting the criteria (Figure 4). Protecting stands during a budworm outbreak will allow 1 657 ha to achieve 50 m^3/ha softwood volume; this represent only a 3% reduction in areas meeting the criteria.

During a budworm outbreak, the areas currently delineated as DWA's potentially could lose a large component of their softwood volume if they are not protected. Not protecting these stands during an outbreak could reduce their ability to function as winter protection for deer.

The location of DWA's change over time as the composition of stands transform through natural succession. When projecting the same criterion of stands reaching a peak softwood volume of 50 m^3/ha in 15 years over the whole FMF, the reduction in softwood volume under the various scenarios is not as extreme. With no defoliation, 195 086 ha would achieve a peak softwood volume of 50 m^3/ha. Under a severe budworm outbreak 158 628 ha would achieve a peak softwood volume of 50 m^3/ha; this represents a 19% reduction from the no outbreak scenario (Figure 5). Under a normal budworm outbreak 177 844 ha would achieve a peak softwood volume of 50 m^3/ha; this represents a 9% reduction from the no outbreak scenario (Figure 6). Protecting stands during a budworm outbreak would result in 191 803 ha reaching a peak softwood volume of 50 m^3/ha which represents only a 2% reduction from the no outbreak scenario.

A greater proportion of stands will reach a peak volume of 50 m^3/ha in the whole FMF compared with the current DWA's. This would indicate that due to the species composition and age of the current DWA's they would be more susceptible to a budworm attack than would the FMF forest land base as a whole. This may indicate that there could be abundant, suitable habitat elsewhere in the FMF 15 years after a budworm outbreak; however, this projection is based on budworm as the only disturbance factor; harvesting, fire, other insect outbreaks, and conversion of forest stands have not been incorporated into this projection.

Conservation and Unique Areas

Conservation and unique areas are defined as areas of high or unique ecological, historical, cultural or scenic value (NB DNRE, 2000). The

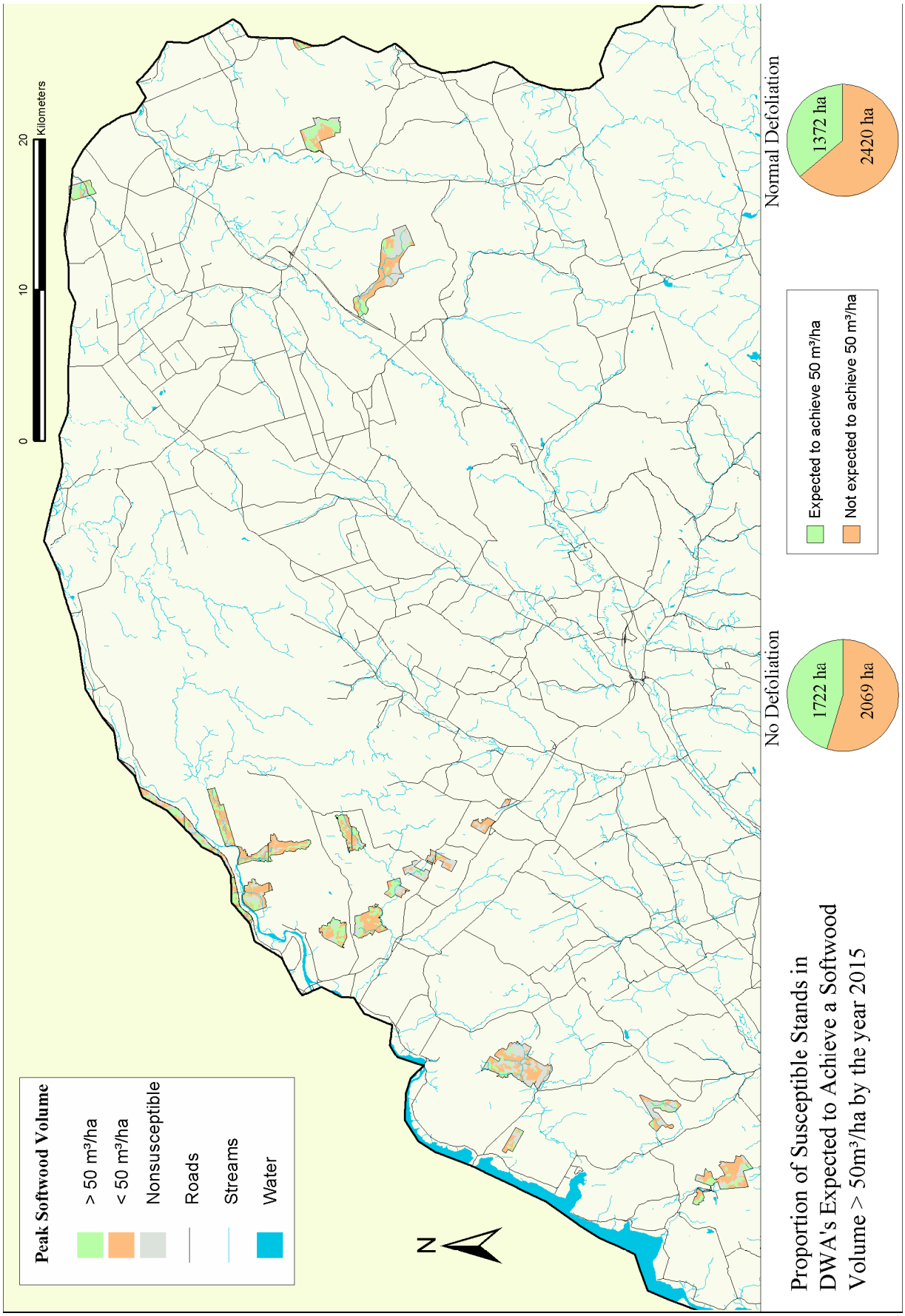

Figure 3. Proportion of susceptible stands in deer wintering areas expected to achieve a softwood volume > 50 m^3/ha by the year 2015 after a normal spruce budworm outbreak.

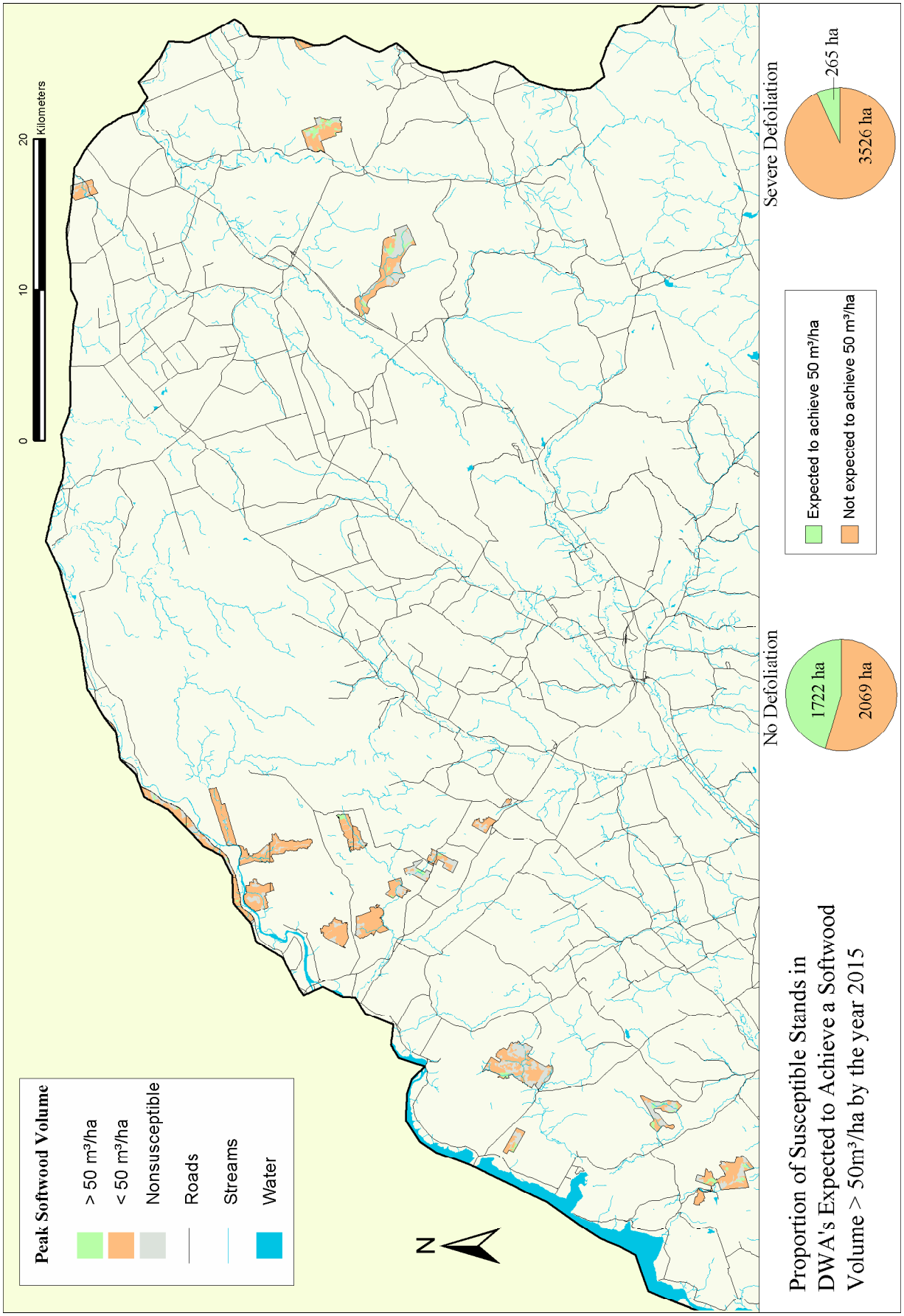

Figure 4. Proportion of susceptible stands in deer wintering areas expected to achieve a softwood volume > 50 m^3/ha by the year 20015 after a severe spruce budworm outbreak.

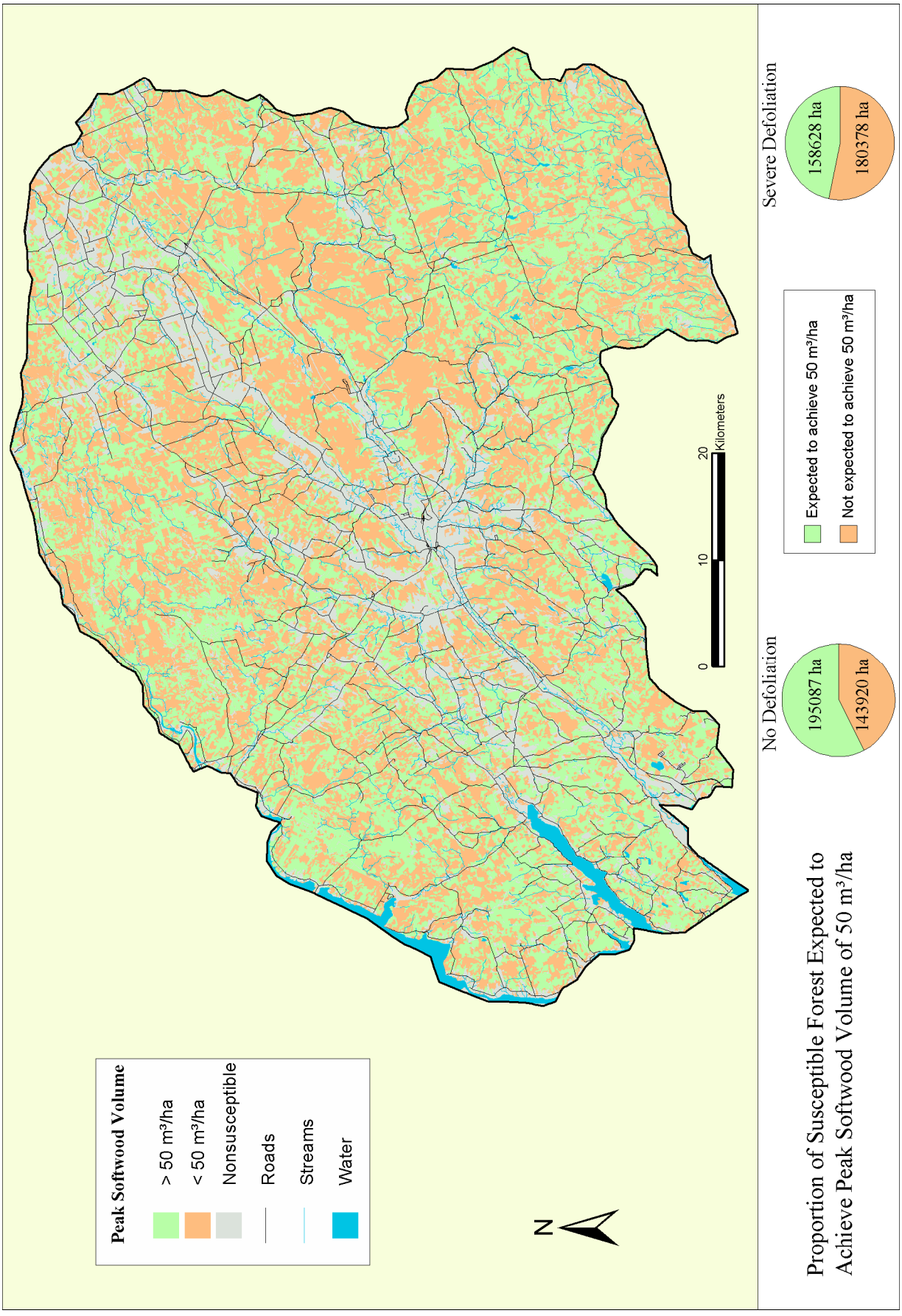

Figure 5. Proportion of susceptible forest expected to achieve a softwood volume > 50 m^3/ha by the year 2015 after a severe spruce budworm outbreak.

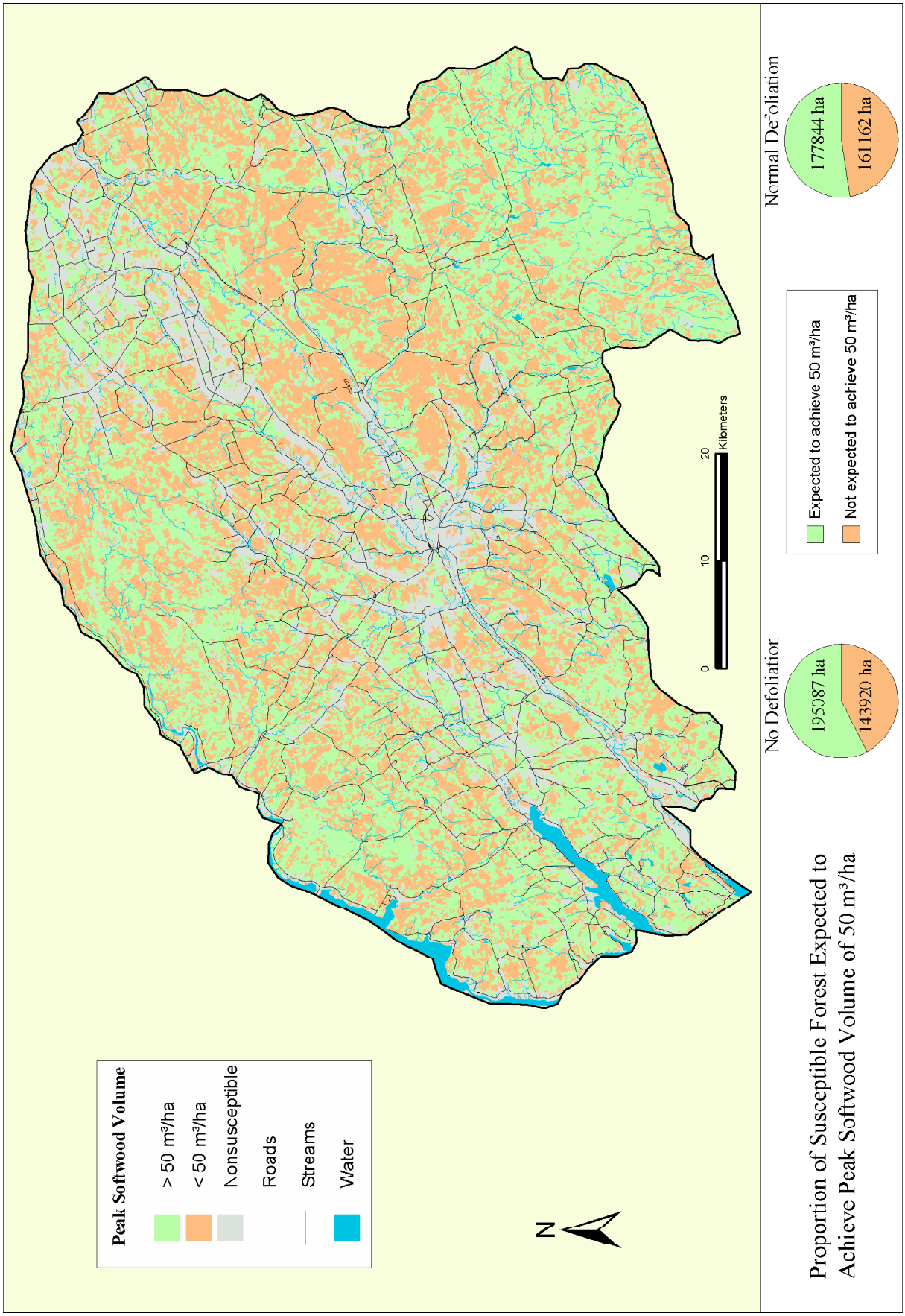

Figure 6. Proportion of susceptible forest expected to achieve a softwood volume > 50 m^3/ha by the year 2015 after a normal spruce budworm outbreak.

portion of the FMF that is designated as conservation or unique areas total 9 772 ha, with 6 289 ha of the area being susceptible to spruce budworm (Figure 7). While discoloured, defoliated or dying trees may not reduce the value of areas that are designated cultural or historical, it may greatly alter an essential element in those areas that are designated as highly or uniquely ecologically significant. It may also reduce the desirability of scenic areas as a tourist stop.

In this report, for the section on conservation and unique areas, volume loss is related to discolouration, defoliation and mortality of susceptible trees.

Fifteen years after the start of a severe budworm outbreak it is projected that 12% of the susceptible stands would not sustain volume loss (Figure 7). Twenty-six percent of the stands would lose 1-24% of their volume, which may cause the trees to discolour and begin to appear defoliated. Fourteen percent of the stands would lose between 25 and 49% of their volume; at this level, defoliated and dead trees may become noticeable. Thirty-eight percent of the stands would lose between 50 and 74% of their volume. At this level dying and dead trees may be prominent in the stands. Ten percent of the stands would lose between 75-100% of their volume; dead and dying trees would dominate these stands. After a severe outbreak, over 45% of the susceptible stands would lose over one-half of their volume. This would have a definite visual impact in these areas.

Fifteen years after the start of a normal spruce budworm outbreak it is projected that 12% of the susceptible stands will not lose any volume (Figure 8). Fifty percent of the stands would lose between 1 and 24% volume, while 36% of the stands would lose between 25 and 49% volume. Two percent of the stands would lose between 50 and 74% volume. No stands would lose over 74 % of their volume.

Protecting the stands during a spruce budworm outbreak would reduce the volume loss and hence reduce the negative visual impact associated with the outbreak. Under a protection strategy, 15% of the susceptible stands would not incur any volume loss. Eighty-three percent of the susceptible stands would lose 1-24% of their volume, which may result in some discolouration and the appearance of thinning foliage. Only 2% of the stands would lose between 25 and 49% of their volume. With protection, no stands should lose more than half their volume; accordingly, the visual impact of a spruce budworm outbreak should be minimal.

Old Spruce-Fir Habitat

From the document "A Vision for New Brunswick Forests" (NB DNRE 2000), old spruce-fir habitat (OSFH) is defined as: stands within the vegetation communities of any of spruce (SP), balsam fir (BF), black spruce (BS) or eastern cedar (EC) in the old or large successional stage and expected to achieve a peak total volume of $\geq$ 70 m^3/ha. Vegetation communities are defined by the composition of the overstory tree species. The compositional criteria of the vegetation communities require that softwood content of the stands be $\geq$ 50% and the specific vegetation community species is $\geq$ 35%. For example, for a stand to be assigned to the BF vegetation community the softwood content would need to be $\geq$ 50% and the BF content would need to be $\geq$ 35%. The old and large successional stages are based on age. The approximate minimum ages for old successional stages are 80, 80, 90 and 60 years for CE, BS, SP and BF, respectively. Only SP has an approximate minimum age for the large successional stage; it is 110 years.

For the purposes of this report, all of the criteria that define OSFH were used to delineate OSFH and assess the effect of spruce budworm outbreaks on them, except for the peak total

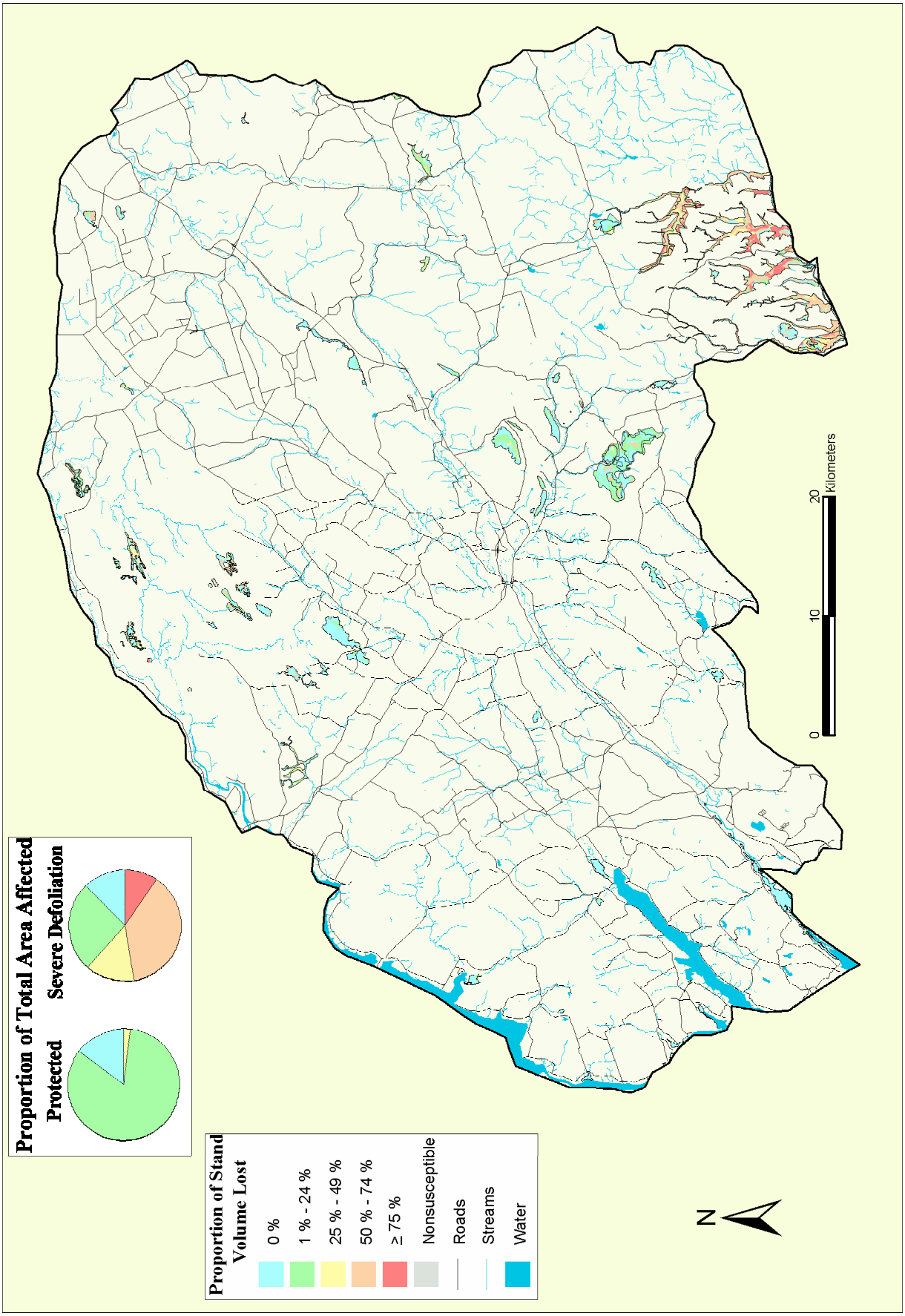

Figure 7. Proportion of stand volume lost in susceptible forest of conservation and unique areas by the year 2015 after a severe spruce budworm outbreak.

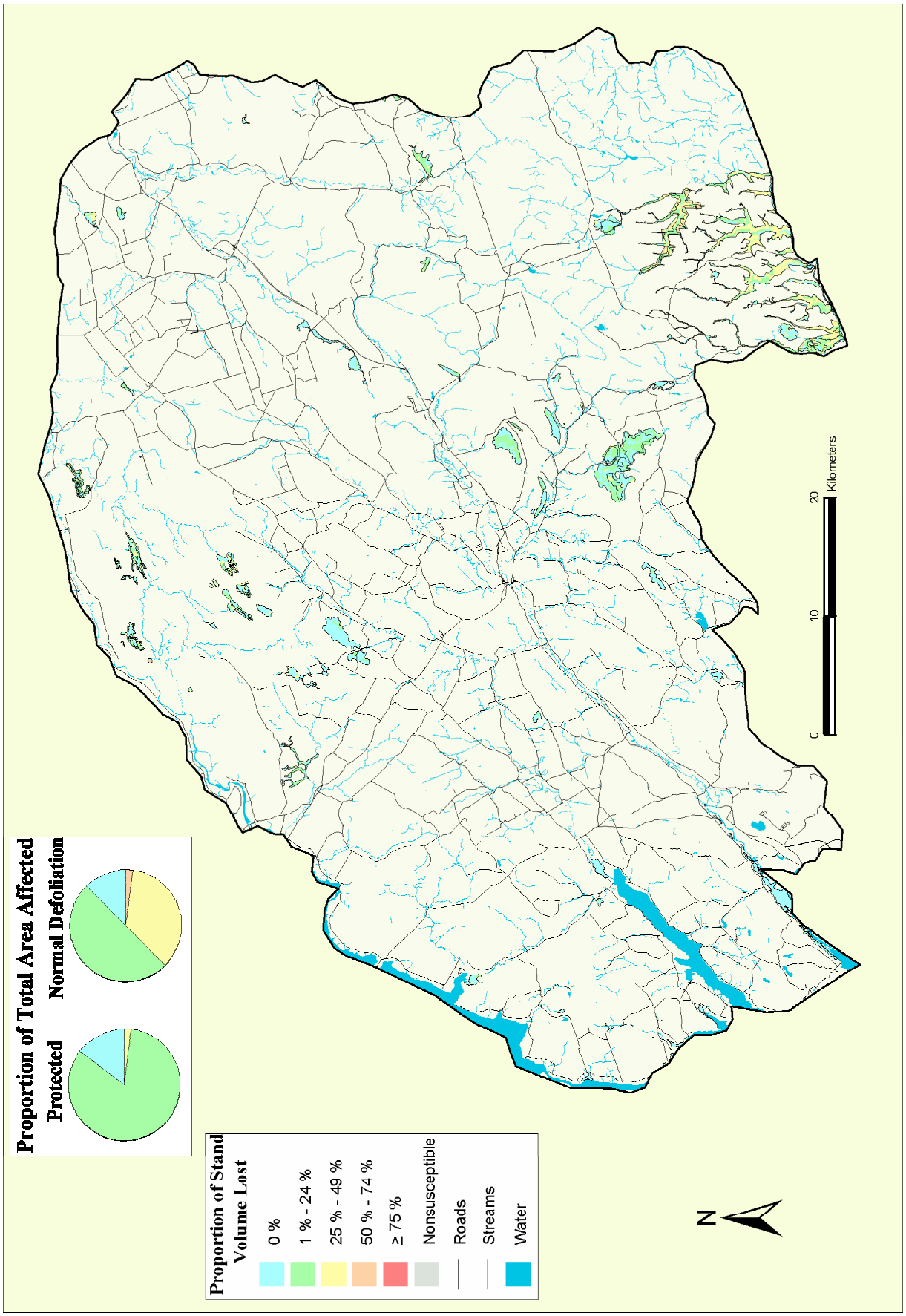

Figure 8. Proportion of stand volume lost in susceptible forest of conservation and unique areas by the year 2015 after a normal spruce budworm outbreak.

volume criteria. Within the FMF approximately 21 880 ha will meet the OSFH compositional and successional stage criteria in 2015 with no budworm outbreak (Figure 9). After 15 years of a normal spruce budworm outbreak, approximately 9 090 ha will meet the criteria. After 15 years of a severe spruce budworm outbreak, the area of stands meeting the OSFH criteria is reduced to approximately 3 490 ha. This comprises only 15 % of the original area of stands meeting the OSFH criteria.

The importance of OSFH forest types is stressed in the NB DNRE Vision document. The report indicates that these stand types are currently at risk due to human activity. As can be seen from the projections, a spruce budworm outbreak could seriously compromise the extent of OSFH forest types, and by inference, those plant and animal species that are dependant on these forest types could also be compromised.

Buffer Areas

Buffers of varying widths are maintained on watercourses to protect water quality and aquatic habitat. Aesthetic buffers are also maintained along provincial highways that are adjacent to crown land. Using the buffer guidelines presented in "A Vision for New Brunswick Forests" (NB DNRE 2000) the following buffer widths were used for the purposes for this report: streams—60 m; rivers—85 m; lakes and ponds > 4 ha—100m; lakes and ponds ≤ 4 ha—60m; and provincial highways—30 m.

Using these guidelines 68 603 ha of land could be applied as buffer areas within the FMF, with 34 982 ha of this area being susceptible to spruce budworm. Harvesting is permitted within buffer areas as long as it does not compromise the function of the buffer. Guidelines in New Brunswick's Clean Water Act (NB 1990) stipulate that no more than 30 % of the volume in a water course buffer can be removed in any 5 year period. For the purposes of this report, susceptible buffer areas were classified into 2 categories, those that would lose ≤ 30 % volume and those that would lose > 30% volume 15 years after the various outbreak scenarios.

Under a normal budworm outbreak scenario, 5 132 or 15% of the susceptible buffer areas would lose more than 30% of its volume 15 years after the start of an outbreak (Figure 10). Under a severe outbreak 14 693 ha or 42% of the susceptible areas in buffers would lose more than 30 % of its volume (Figure 11).

Applying a protection strategy would greatly reduce the volume loss in buffers as only 169 ha or < 0.5% of the susceptible stands would lose > 30 % of their volume.

Future Stand Composition

Species Composition

The species composition of forest stands change over time regardless of whether or not they are subjected to any disturbance agent. When large budworm populations progress through a forest, those stands that contain a large spruce/fir component and have older trees are more vulnerable to attack and suffer greater mortality than those stands with lower spruce/fir content and are in a younger age group.

To look at the change in stand composition over a 15 year time period, we ran 3 scenarios: no budworm outbreak; normal budworm outbreak; and severe budworm outbreak. The results are shown in Figures 12, 13 and 14, respectively.

With no outbreak, the most vulnerable stands, those containing 80-100% spruce/fir (coded in red), will occupy 58 084 ha or 17% of the forested land base. After a normal outbreak these stands will occupy 17 351 or 5% of the forested land base; and after a severe outbreak, none of these stand types will be present.

The moderately vulnerable stands, which contain

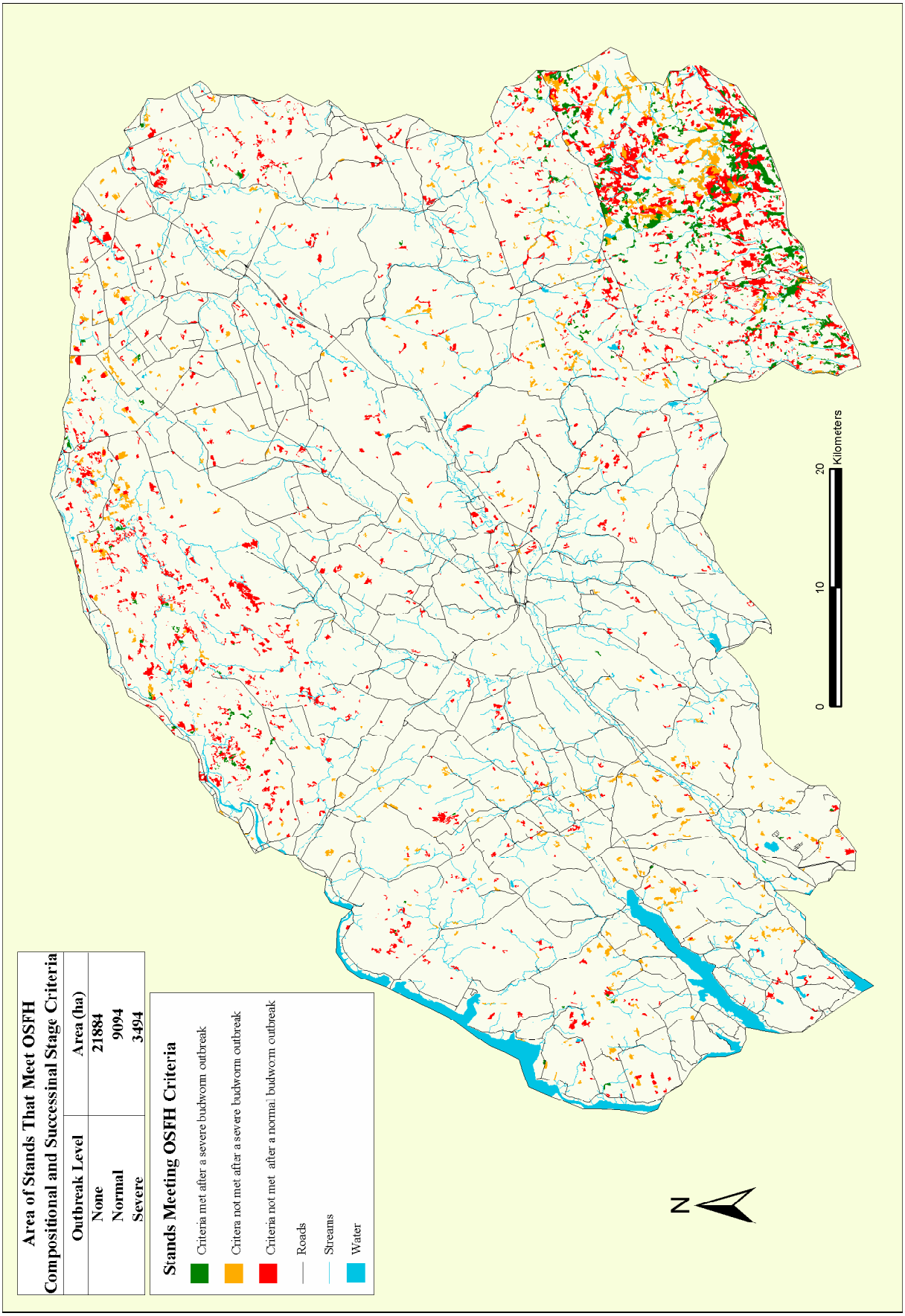

Figure 9. Projection of stands meeting the old spruce-fir habitat (OSFH) compositional and successional stage criteria after a budworm outbreak lasting from 2000-2015.

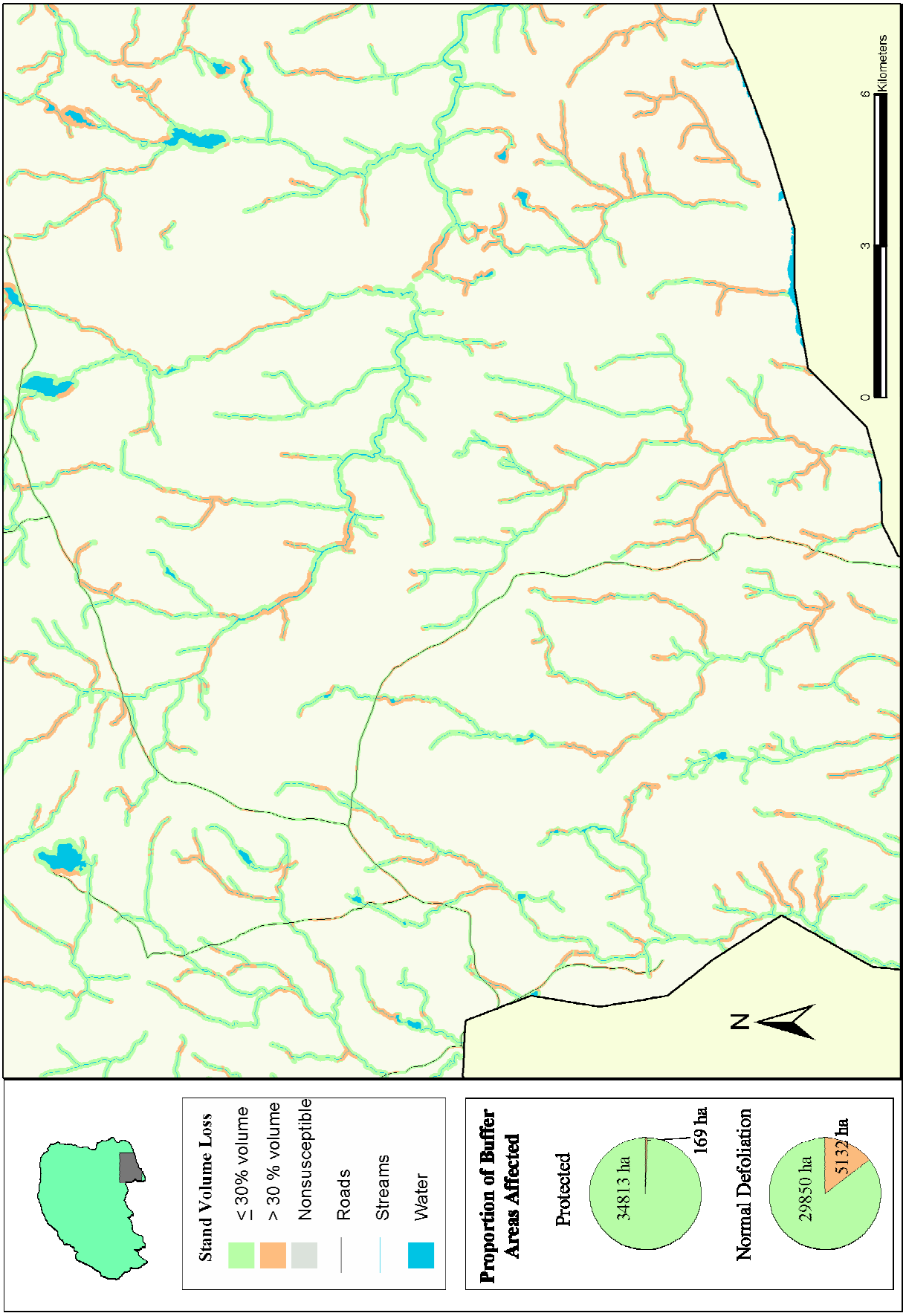

Figure 10. Projection of volume loss in buffer areas for a portion of the Fundy Model Forest in 2015 after a normal spruce budworm outbreak.

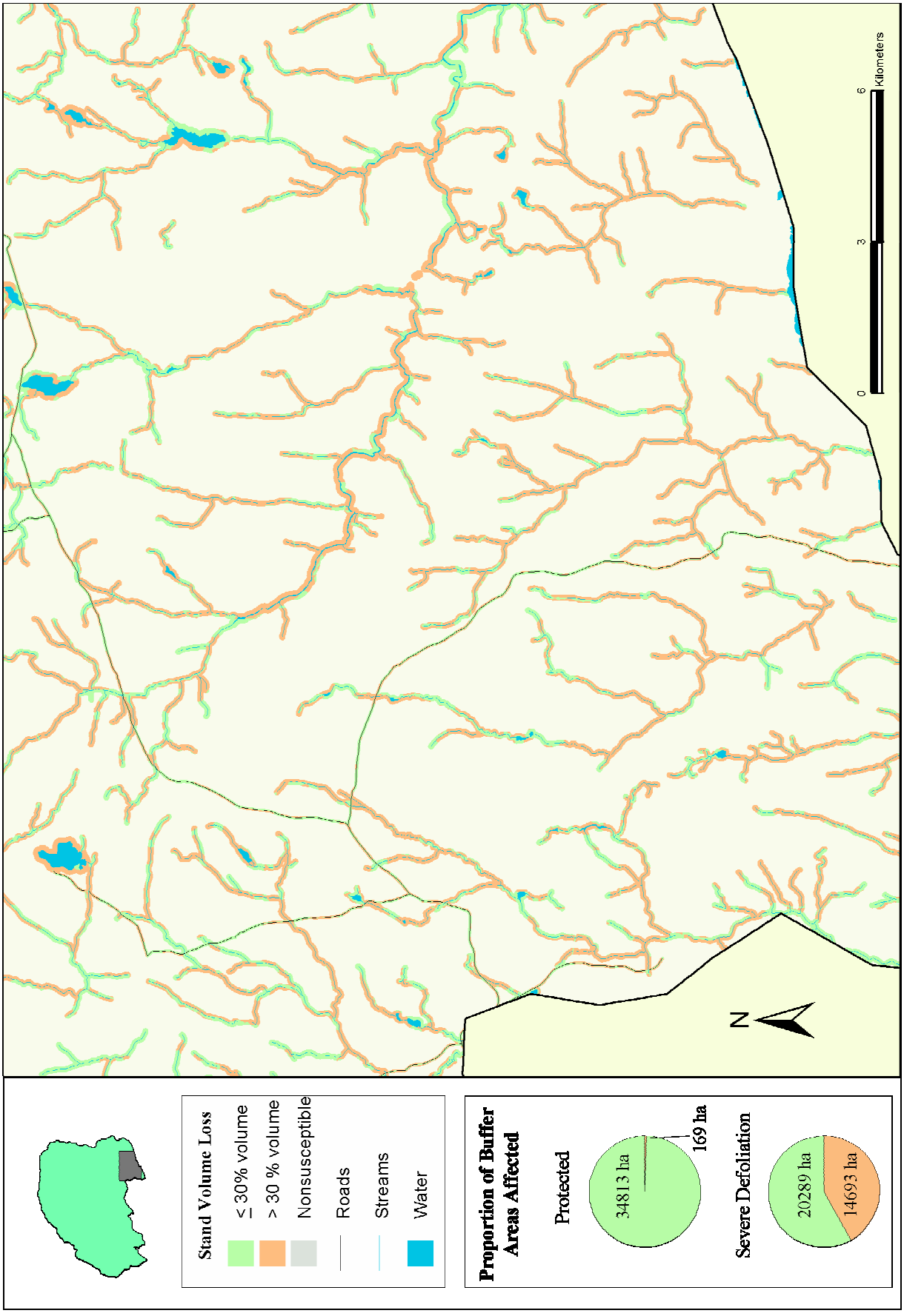

Figure 11. Projection of volume loss in buffer areas for a portion of the Fundy Model Forest in 2015 after severe spruce budworm outbreak.

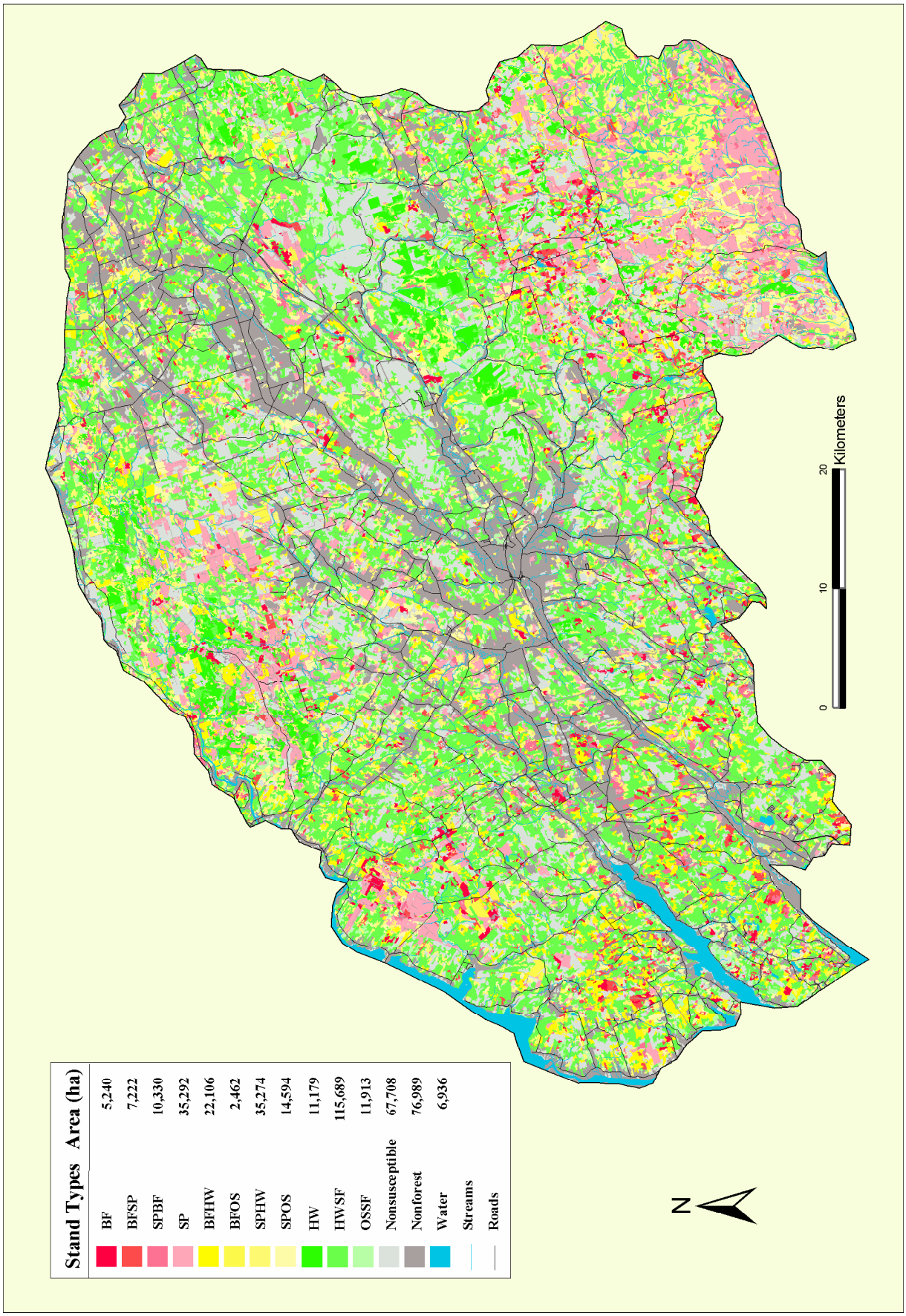

Figure 12. Projected budworm forest stand types in 2015 after no spruce budworm outbreak.

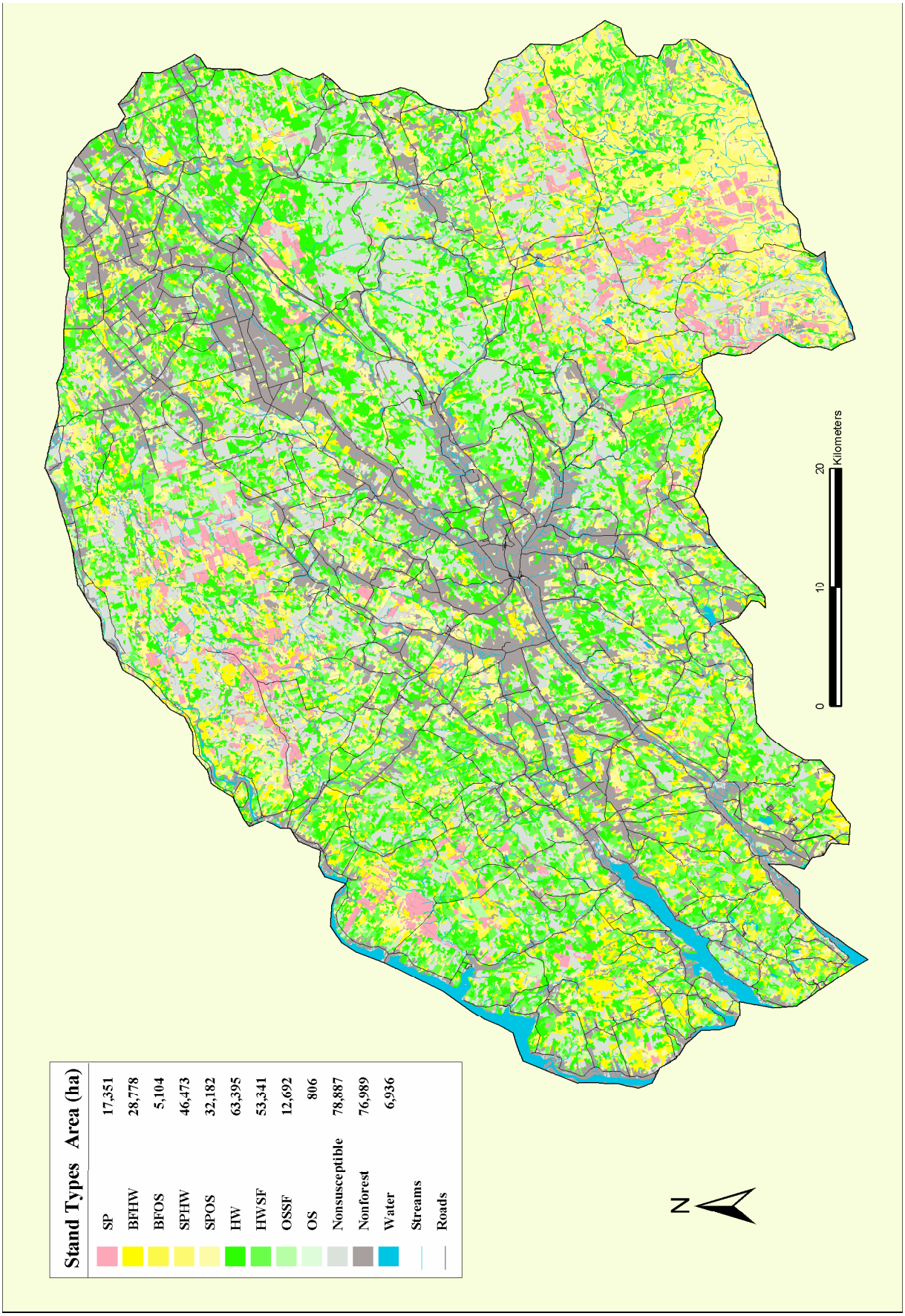

Figure 13. Projected budworm forest stand types in 2015 after a normal spruce budworm outbreak.

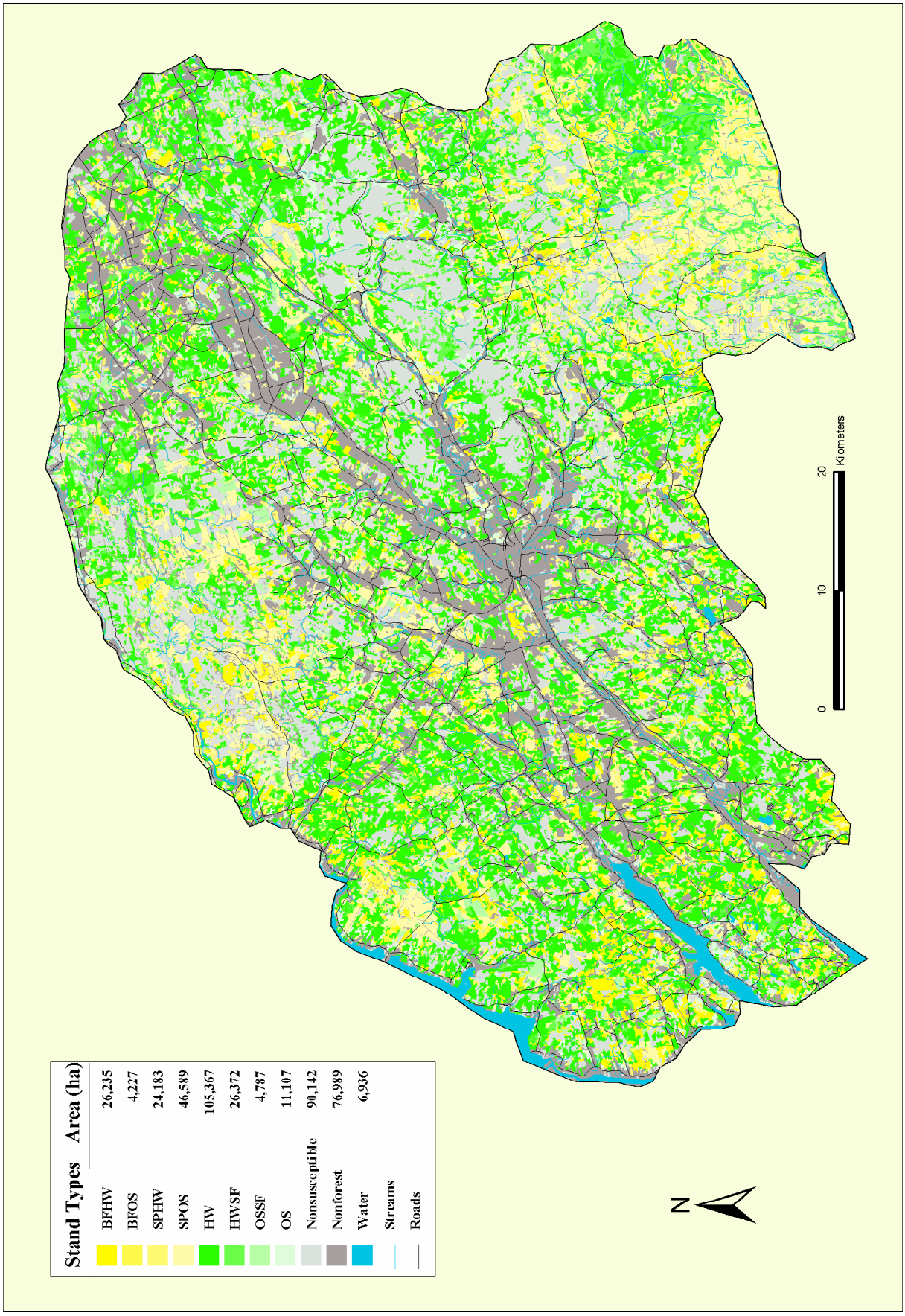

Figure 14. Projected budworm forest stand types in 2015 after a severe spruce budworm outbreak.

between 50-79% spruce/fir (coded in yellow), are less dramatically affected by a spruce budworm outbreak. With no outbreak these stand types will occupy 74 436 ha or 22 % of the productive land base; after a normal outbreak 112 537 ha or 33% of the productive land base; and after a severe outbreak 100 234 ha or 30% of the productive land base. Spruce budworm outbreaks appear to slightly increase the occurrence of these stand types in the future.

Those stands with relatively low vulnerability, those containing between 10-49% spruce/fir (coded green) remain relatively stable in area occupied though the various outbreak scenarios. Fifteen years after no outbreak, normal outbreak, and severe outbreak these stand will occupy 138 780 ha or 41%, 130 234 ha or 39% and 147 633 ha or 43% of the productive land base, respectively.

As the spruce/fir component is reduced with a budworm outbreak, the non-susceptible portion of the land base or those stands containing less than 10% spruce/fir (coded in light grey) increases. The nonsusceptible portion of the land base within the productive forest increases from no outbreak, to normal outbreak, to severe outbreak from 67 708 ha or 20%, to 78 887 ha or 23 %, to 90 142 ha or 27% of the productive land base, respectively.

The resulting forest 15 years after a spruce budworm outbreak would contain less volume of fir and spruce. Over time, young fir and spruce seedlings that had regenerated under the most vulnerable stand types prior to the budworm outbreak or had become established from seed blown in from surrounding stands, would grow and occupy the dominant forest layer. So the most vulnerable stand types would not be permanently lost from the forest community.

Forest management guidelines for New Brunswick (NB DNRE 2000) make provisions for maintaining the full range of naturally occurring forest types. These stand types have been categorized into 9 vegetation communities. The 3 vegetation communities that would be susceptible to a budworm outbreak, and therefore at risk of being reduced in abundance, would be the black spruce, spruce, and balsam fir communities.

Diameter Class Distribution

Not only is species composition affected after a spruce budworm outbreak, but the diameter class distribution is altered as well. Figures 15, 16, 17, 18, 19, 20, 21, 22 and 23 illustrate the change in diameter class distribution under various outbreak scenarios. Figures 15-17 illustrate the change in stands where spruce and balsam fir predominate (Budworm Impact Classes 7, 8 and 9). Figures 18-20 represents the change in diameter class distribution in stands where balsam fir dominates (Budworm Impact Classes 16, 17 and 18), while figures 21-23 show the change in diameter class distribution in stands where spruce dominates (Budworm Impact Classes 22, 23 and 24).

The first 4 diameter class groupings represent a 5 cm range in diameter class (2-6, 8-12, 14-18 and 20-24). The last grouping represents an 11 cm range in diameter class. The last grouping covers a wider range, as there are far fewer trees in these diameter class ranges.

When comparing the initial density at year 2000 to the density 15 years later with no budworm outbreak, the (a) portion to the (b) portion of each of these figures respectively, it is evident there is a great deal of natural thinning of spruce and balsam fir even in the absence of spruce budworm. The (c) portion and (d) portion of each of these figures depicts the diameter class distribution after a normal and severe outbreak, respectively. It is not only mortality of the fir and spruce from defoliation that affects the diameter distributions, the loss of foliage also reduces the growth of those trees that survive.

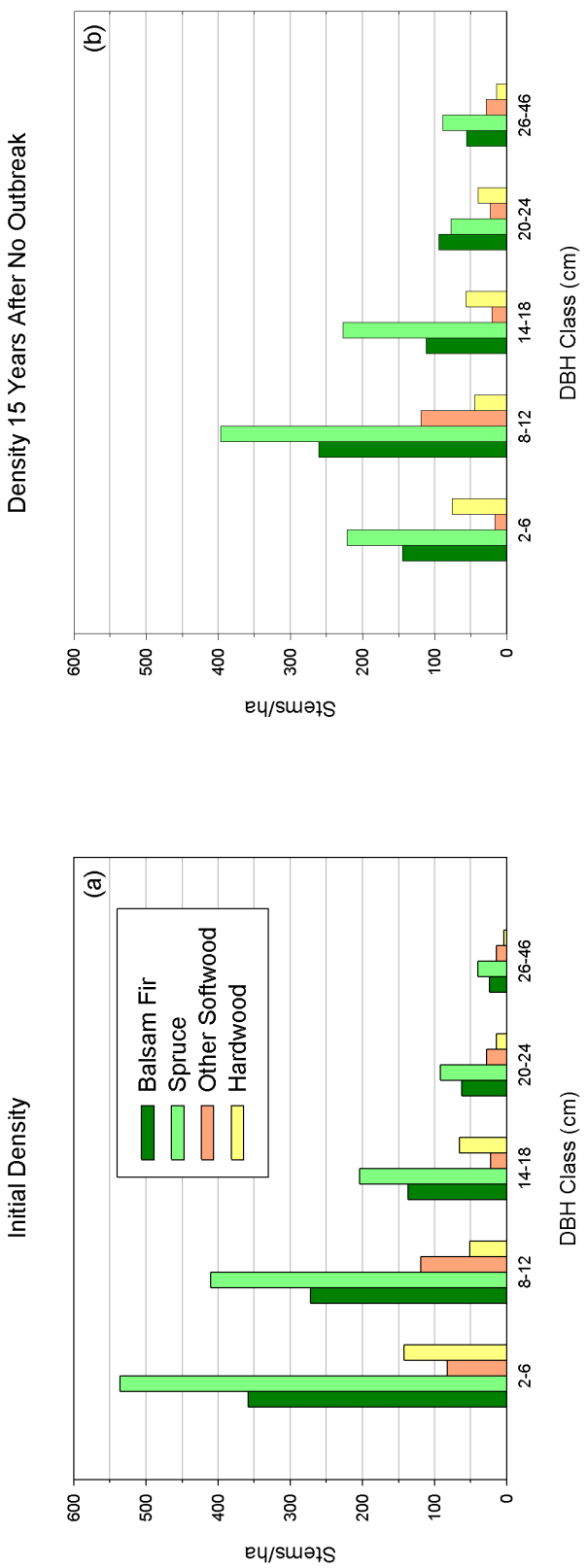

Figure 15. Distribution of stems/ha under three outbreak scenarios for budworm impact class 7 where % spruce/balsam fir content > 80%, spruce > balsam fir and stand age < 40 years old.

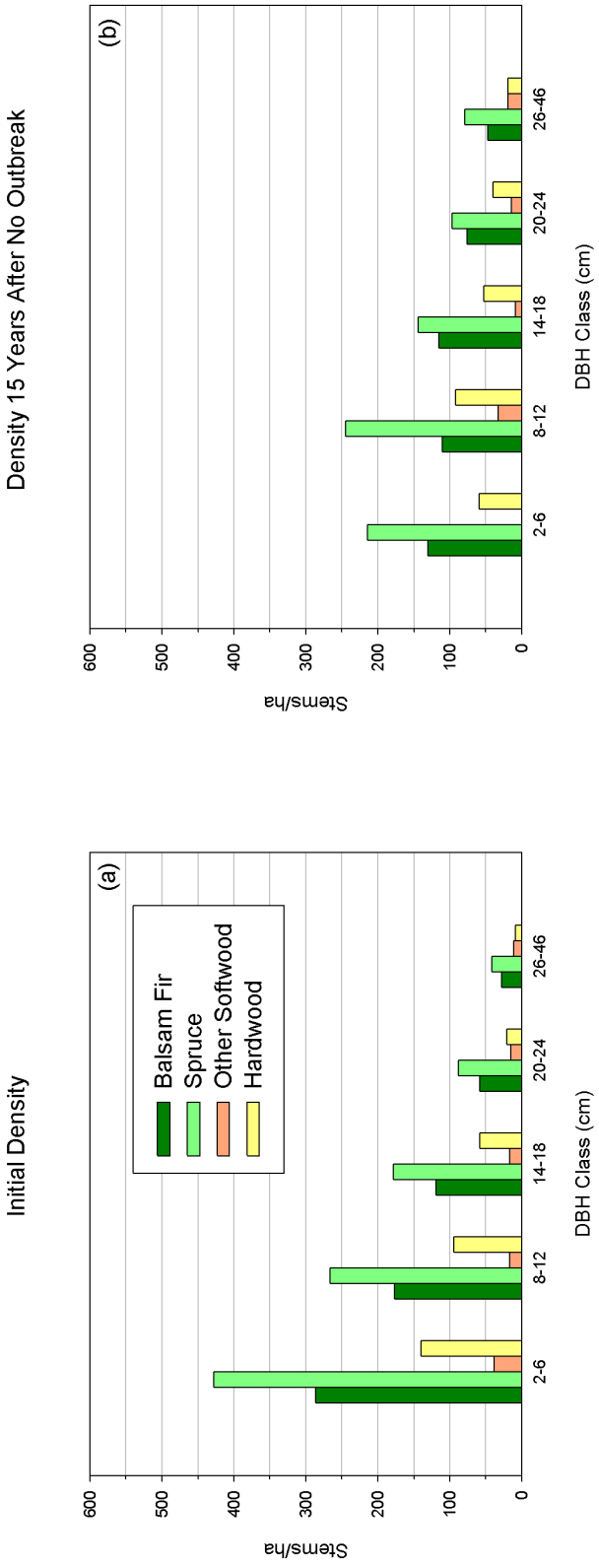

Figure 16. Distribution of stems/ha under three outbreak scenarios for budworm impact class 8 where % spruce/balsam fir content > 80%, spruce > balsam fir and stand age 41 – 80 years old.

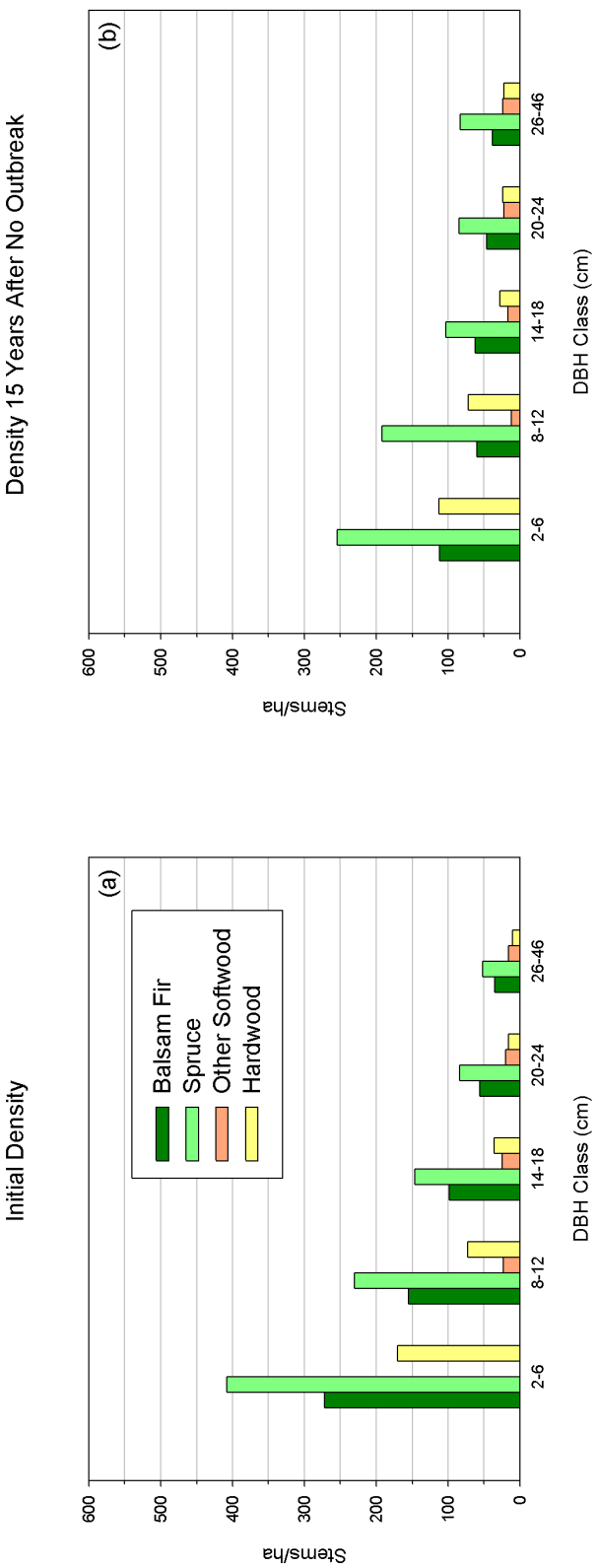

Figure 17. Distribution of stems/ha under three outbreak scenarios for budworm impact class 9 where % spruce/balsam fir content > 80%, spruce > balsam fir and stand age > 80 years old.

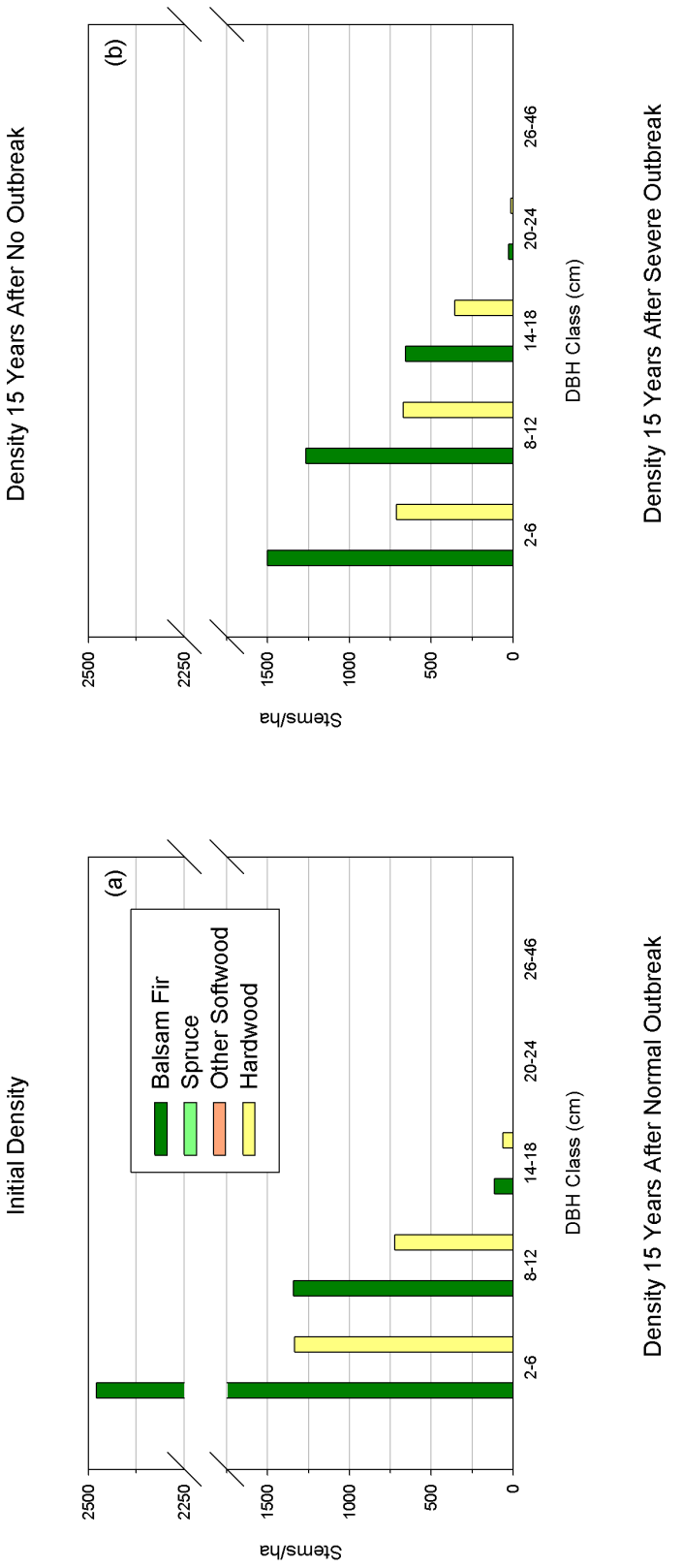

Figure 18. Distribution of stems/ha under three outbreak scenarios for budworm impact class 16 where % spruce/balsam fir content between 50-79%, balsam fir > spruce, hardwood > other softwood and stand age < 40 years old.

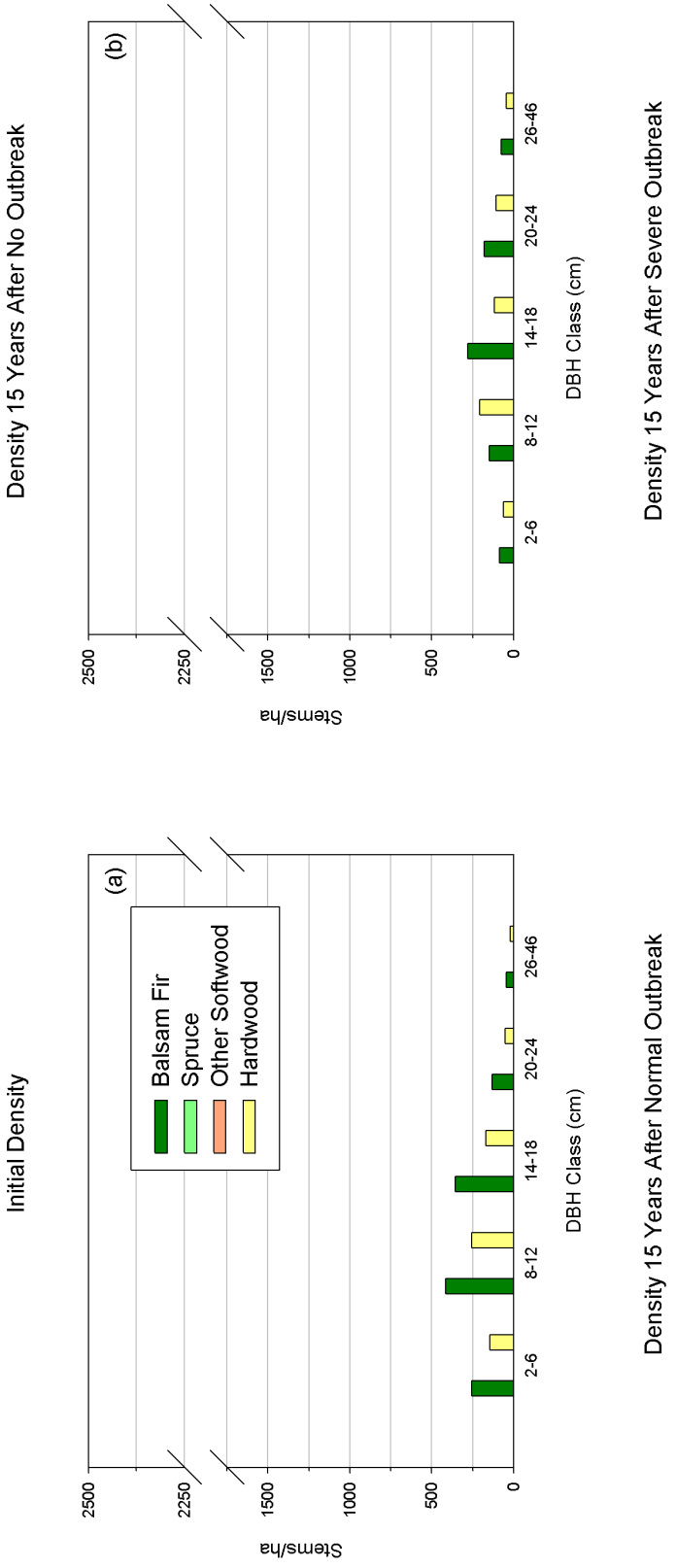

Figure 19. Distribution of stems/ha under three outbreak scenarios for budworm impact class 17 where % spruce/balsam fir content between 50-79%, balsam fir > spruce, hardwood > other softwood and stand age 41 – 80 years old.

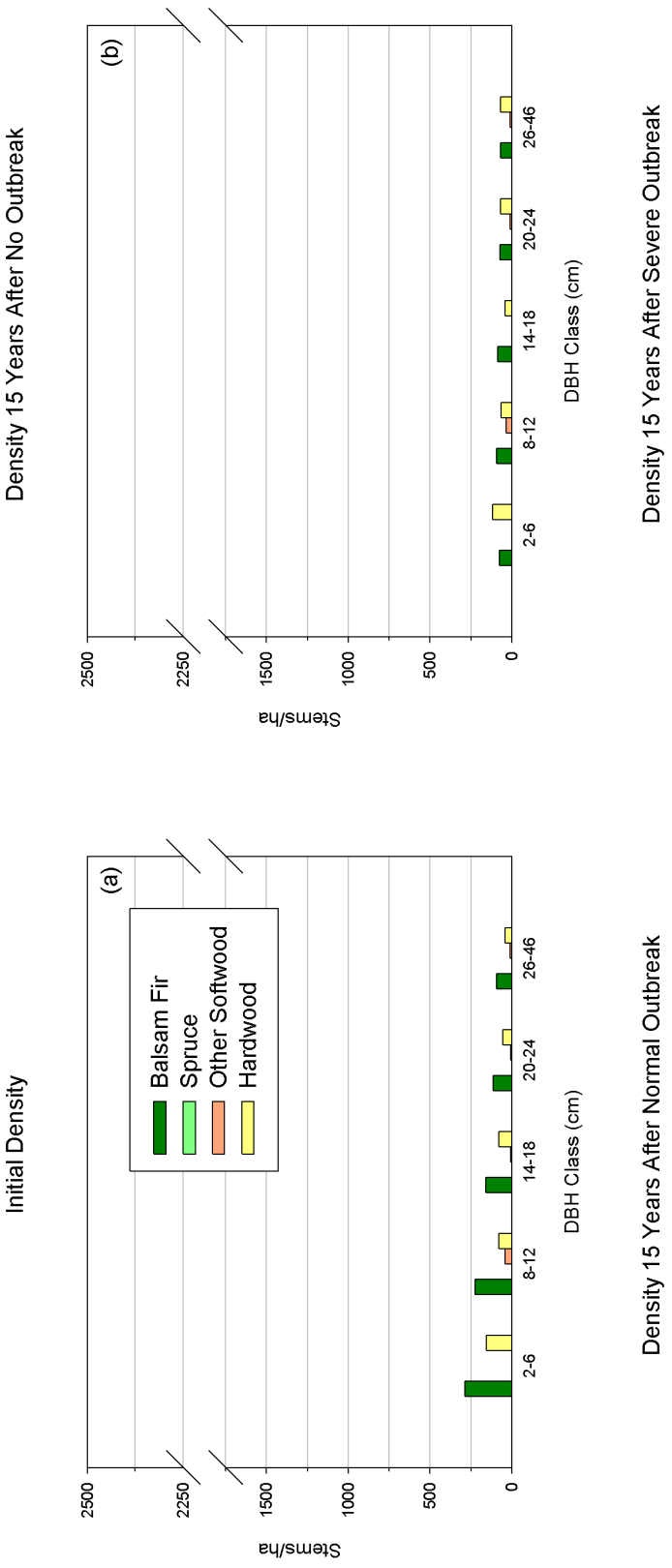

Figure 20. Distribution of stems/ha under three outbreak scenarios for budworm impact class 18 where % spruce/balsam fir content between 50-79%, balsam fir > spruce, hardwood > other softwood and stand age > 80 years old.

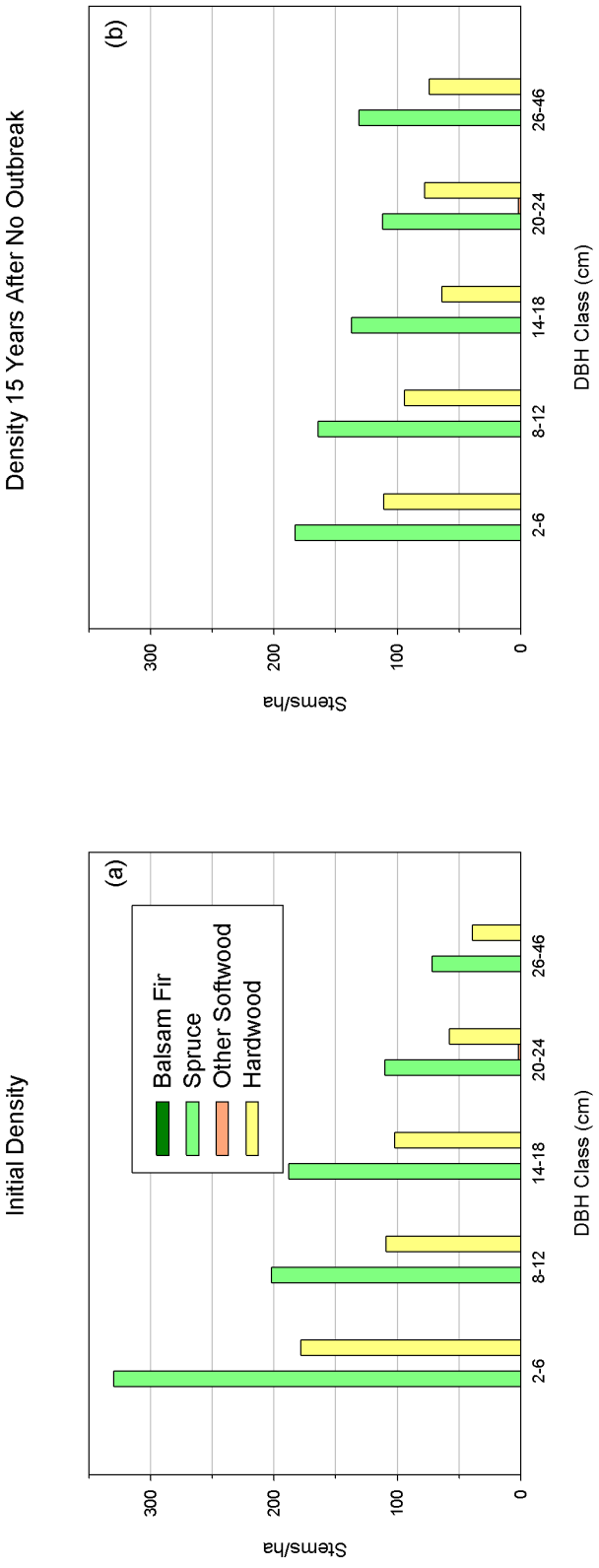

Figure 21. Distribution of stems/ha under three outbreak scenarios for budworm impact class 22 where % spruce/balsam fir content between 50-79%, spruce > balsam fir, hardwood > other softwood and stand age < 40 years old.

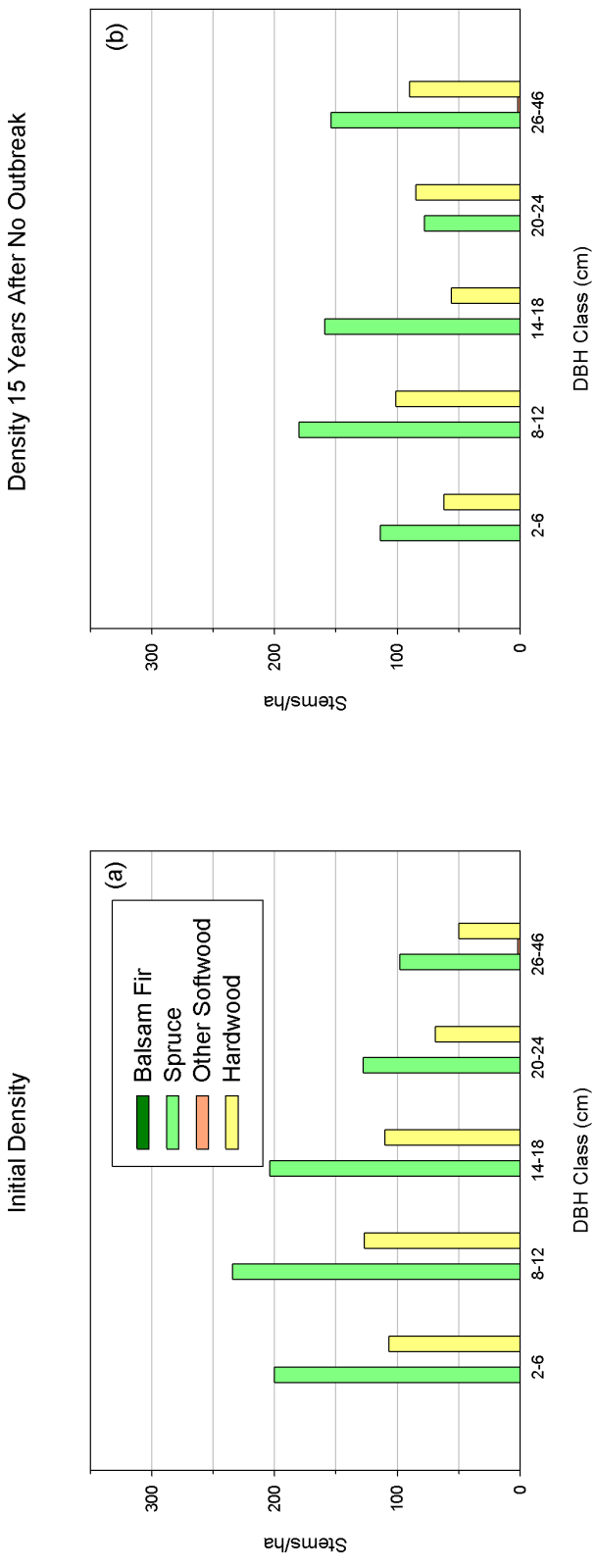

Figure 22. Distribution of stems/ha under three outbreak scenarios for budworm impact class 23 where % spruce/balsam fir content between 50-79%, spruce > balsam fir, hardwood > other softwood and stand age 41 – 80 years old.

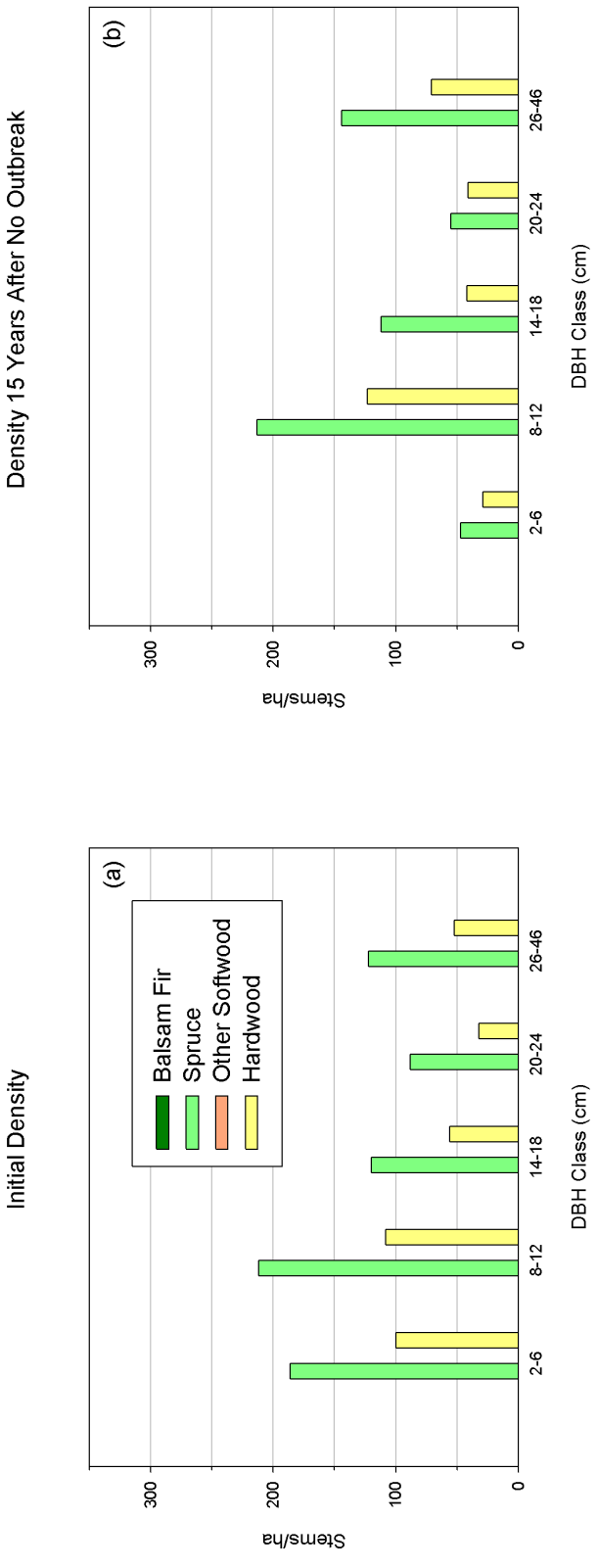

Figure 23. Distribution of stems/ha under three outbreak scenarios for budworm impact class 24 where % spruce/balsam fir content between 50-79%, spruce > balsam fir, hardwood > other softwood and stand age > 80 years old.

The reduced growth (diameter increment) delays their shifting to the next larger diameter class.

Budworm Impact Classes 7, 8 and 9

Figure 15 depicts stands where the spruce/balsam fir content is > 80%, the spruce content is greater than the balsam fir content, and the stand age is < 40 years. Figure 15 (a) shows the initial diameter class densities in the year 2000. Figure 15 (b) illustrates the diameter class densities 15 years into the future. Figures 15 (c) and 15 (d) illustrate the diameter class densities 15 years after the start of a normal and severe budworm outbreak, respectively. For balsam fir, the average percent loss of stems across all diameter classes after a normal outbreak is 27% with the largest loss in the 26-46 cm diameter class at 55%. After a severe outbreak the average percent loss across all diameter classes for balsam fir is 59% with the largest loss again in the 26-46 cm diameter class at 75%. For spruce, the stand density loss is less than for balsam fir. The greatest loss correspondingly occurs in the 26-46 cm diameter class. Fifteen years after a normal outbreak or fifteen years after a severe outbreak 43% or 58% of the stems would be lost, respectively. For the overall stand density, a normal budworm outbreak would have the greatest impact on the 26-46 cm diameter class where 37% of the stems would be lost. For a severe budworm outbreak the 26-46 cm diameter class would also incur the greatest loss where 50% of the stems would be lost.

For stands where the spruce/balsam fir content is > 80%, with the spruce content being greater than the balsam fir content, and the stand age is between 41 and 80 years, the loss is greater (Figure 16). For balsam fir, the average percent loss of stems across all diameter classes after a normal outbreak is 41% with the largest loss in the 26-46 cm diameter class at 64%. After a severe outbreak the average percent loss across all diameter classes for balsam fir is 78% with the largest loss again in the 26-46 cm diameter class at 83%. As in the previous younger age class, spruce incurs less loss than balsam fir. The 26-46 cm class is subject to the greatest loss at 51% and 75% for a normal and severe outbreak, respectively. For the overall stand density, a normal budworm outbreak would have the greatest impact on the 26-46 cm diameter class where 43% of the stems would be lost. For a severe budworm outbreak the 26-46 cm diameter class would also incur the greatest loss where 60% of the stems would be lost.

The loss is greatest in the stands where the spruce/balsam fir content is > 80%, the spruce content greater than the balsam fir content, and the stand age > 80 years (Figure 17). For balsam fir, the average percent loss of stems across all diameter classes after a normal outbreak is 51% with the largest loss in the 20-24 cm diameter class at 72%. After a severe outbreak the average percent loss across all diameter classes for balsam fir is 93% with the largest loss incurred in the 2-6 cm diameter class at 100%. Once again spruce incurs less loss than balsam fir. The 26-46 cm class is subject to the greatest loss at 42% and 84% for a normal and severe outbreak, respectively. For the overall stand density, a normal budworm outbreak would have the greatest impact on the 20-24 cm diameter class where 38% of the stems would be lost. For a severe budworm outbreak the 26-46 cm diameter class would be subjected to greatest loss where 63% of the stems would be lost.

Budworm Impact Classes 16, 17 and 18

Figure 18 depicts stands where the spruce/balsam fir content is between 50-79%. The balsam fir content is greater than the spruce content; hardwood content is greater than other softwoods. For the balsam fir component of the stands that are less than 40 years old, the greatest loss after a normal outbreak occurs in the 14-18 cm diameter class (24%). After a severe outbreak the greatest loss occurs in the 20-24 cm diameter class (59%).

For the overall stand density the greatest volume

losses after both a normal and severe outbreak would occur in the 20-24 cm diameter class at 17% and 40%, respectively.

For stands between 41-80 years old the greatest loss in balsam fir would be in the 26-46 cm diameter class for both the normal and severe outbreaks at 62% and 87%, respectively (Figure 19).

For the overall stand density, the greatest loss after a normal outbreak would be in the 26-46 cm diameter class at 39% while after a severe outbreak the greatest loss would be in the 14-18 cm diameter class at 57%.

For stands greater than 80 years old, after a normal outbreak, the greatest loss in the balsam fir component would be in the 20-24 cm diameter class at 72% while after a severe outbreak the greatest loss would be in the 26-40 cm diameter class at 94% (Figure 20).

For the overall stand density the greatest loss would be in t the 14-18 cm diameter class after either a normal or severe outbreak at 42% and 62%, respectively.

Budworm Impact Classes 22, 23 and 24

Figures 21-23 illustrate the change in diameter class distribution in stands that have a spruce/balsam fir content between 50-79%, spruce content greater than balsam fir and hardwood content greater than other softwood. For stands less than 40 years old (Figure 21), the largest loss of spruce stems occurs in the 26-46 cm diameter class for both the normal and severe outbreaks at 33% and 53%, respectively. For the overall stand, the greatest loss is in the diameter class 26-46 cm for both the normal and severe outbreaks at 21% and 34%, respectively.

For stands between 41 and 80 year old, the greatest spruce loss is also in the 26-46 cm diameter class for both the normal and severe outbreaks (Figure 22) at 42% and 70%, respectively. For the overall stand, the greatest loss is in the 26-46 cm diameter class at 26% and 44 % of stems for the normal and severe outbreaks, respectively.

For stands greater than 80 years old (Figure 23), the greatest loss is again in the 26-46 cm diameter class for both the normal and severe outbreaks at 34% and 78% loss of stems, respectively. Due to the in-growth and thinning effect on the hardwoods, the greatest loss for the whole stand after a severe outbreak is in the 14-18 cm diameter class at 55%. After a normal outbreak, for the whole stand, the greatest loss is in the 26-46 cm diameter class at 23% loss of stems.

In comparing stands that have >80% spruce/balsam fir content to stands that have between 50-79% spruce/balsam fir content, the latter stands incur a slightly lower percent stem loss in the various diameter classes through all age classes.

Management objectives that are concerned with maintaining a certain proportion of stands with large diameter stems could be in jeopardy after a spruce budworm outbreak.

Conclusions

A large portion of the forested area of the Fundy Model Forest contains species that are susceptible to attack from spruce budworm. As standing timber these stands provide structure for a variety of functions. A spruce budworm outbreak could seriously compromise some of those functions.

As outlined in MacLean et al. (1999), there are management activities that could be employed to lessen the impact of a spruce budworm outbreak. Once an outbreak has started the biological insecticide *Bacillus thuringiensis* (*B.t.*) or the insect growth regulator Mimic could be used to

prevent defoliation and keep trees alive. If a non-pesticide option was desired, then activities with a longer time horizon could be employed. These could include: planting nonsusceptible tree species such as jack pine (*Pinus banksiana* Lamb.) or hardwood species, or low susceptibility species such as black spruce (*Picea mariana* (Mill.) B.S.P.); and forest restructuring using precommercial thinning or harvest scheduling to reduce the occurrence of the most susceptible fir and spruce species at the stand or landscape level (MacLean 1996). These latter two options would need to be initiated fairly soon to have any effect during the next spruce budworm outbreak.

Acknowledgments

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