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Changes in Dead Wood Structure Following Clearcut Harvesting in Nova Scotia Softwood Forests

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Introduction

Decaying wood is an essential component of a healthy forest ecosystem. Snags and coarse woody debris (CWD) provide wildlife habitat, affect forest floor and streambed morphology, and contribute to nutrient cycling (Stevens, 1997). Hollow trees and logs (which only form while trees are living) provide unique habitat structures, while partially decayed logs provide nursery conditions important for regeneration of some species (Bull *et al*., 1999; Pelletier, 1997). Dead wood plays a critical role in changing the forest's susceptibility to fire and insect outbreaks (Gore and Patterson, 1986). Production and removal of timber from the forest can significantly affect the dead wood cycle and species diversity (Bull *et al*., 1997; Stevens, 1997).

The primary objectives of this study were to document the levels of snags and coarse woody debris naturally present in previously unmanaged[1] softwood forests in Nova Scotia and to determine the immediate effects of forest harvesting on dead wood quantities. This was achieved by measuring volumes of woody material of various types (coarse woody debris, snags, and stumps), sizes, and decay classes before and after conventional clearcut harvesting. The study was conducted in 1998 and included commercially mature (i.e. > 40 years) spruce/fir stands representative of the most commonly occurring and typically harvested forest types in the province (NSDNR, 1999; NFDP, 2003). The study also documents levels of fresh, potentially merchantable logging residue and presents methods and equations for measuring dead wood volume in coarse woody debris, snags, and stumps.

Methods

Stand Selection

Eight stands across central Nova Scotia were selected for study from the annual operating plans of Stora Enso Port Hawkesbury Ltd., J.D. Irving Ltd., and Bowater Mersey Ltd. Selection criteria submitted to the companies specified spruce-fir scheduled for immediate clearcut logging using cut-to-length mechanical harvesters with on-site processing.

Measurement

Five sample points were systematically established in each stand prior to harvest and then re-measured immediately following logging. At each point, a 90 m line transect triangle was used to measure coarse woody debris and a $2m^2$ basal area factor (BAF) horizontal point sample was used to measure standing live and dead trees.

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[1]No known silviculture or tending treatments applied.

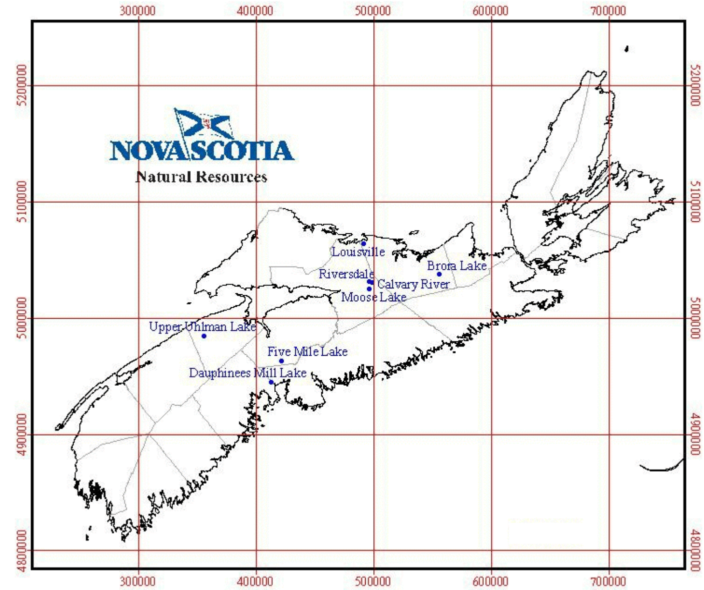

Figure 1: Locations of eight dead wood study sites. Projection: Universal Transverse Mercator (UTM); Datum NAD83.

Coarse Woody Debris

Each sample plot centered around the horizontal sample point and consisted of a 90 m line transect laid out in the shape of an equilateral triangle (Appendix I). The slope (%) of each line was measured with a clinometer (Suunto) in order for a slope correction factor to be applied during data analysis. Methods used for coarse woody debris assessment were adapted from McRae *et al.* (1979) and Van Wagner (1968) (Appendix II).

Coarse woody debris was defined as fallen dead wood leaning more than 45° from vertical, with a diameter at the point of intersection ≥ 9.1 cm. Each piece of coarse woody debris intersected by transect line was assessed for: species; diameter at the point of intersection (perpendicular to the piece, in 2 cm classes); tilt angle of piece (if greater than 15°); and decay class (Appendix III). During post-harvest assessment, potential merchantability was also recorded. Merchantability was defined as freshly dead, ≥ 2.4 m long, ≥ 9.1 cm minimum diameter at 2.4 m length, with ≤ 1/3 soft rot.

At five of the eight stands, short portions of line transect could not be assessed in the post-harvest measurement because of deep slash piles along the line where delimbing was conducted. For these stands, post-harvest coarse woody debris volumes might be underestimated if it was buried deeply under the piles. Omitted line distances are recorded in Appendix IV.

The total length (m/ha) of coarse woody debris was calculated using a "length factor"

(Equation 1), corresponding to the meters per hectare represented by each intersected piece of downed wood (Ducey and Grove, 1999). A slope correction factor (Equation 2, McRae *et al.*, 1979) and a tilt angle correction factor (Equation 3, Van Wagner, 1968) were incorporated into the basic length factor equation to produce the "corrected"length factor formula (Equation 4) used in this report. Ducey and Grove (1999) suggest applying the correction factors when slopes exceed 30% (or angles >15°). The length factor multiplied by the number of pieces of coarse woody debris recorded in the line transect plot yielded estimates of total bole length per hectare.

[Equation 1]: *Basic Length Factor Equation:*

$$F = 10\,000\pi / 2L$$

where, F = length factor (m/ha), and;
L = length of sampling line (m).

[Equation 2]: *Slope Correction:*

$$S = \sqrt{(1 + (ps/100)^2)}$$

where, S = slope correction factor, and;
ps = slope of line transect (%).

[Equation 3]: *Tilt Correction:*

$$T = \cos h$$

where, T = tilt angle correction factor, and;
h = angle of woody piece (degrees from the horizontal).

[Equation 4]: ***Length Factor Equation with tilt and slope correction:***

$$\mathbf{F = 15\,708\; S / L\; T}$$

where, F = length factor (m/ha);
S = slope correction factor (Equation 2);
L = length of sampling line (m), and;
T = tilt angle correction factor (Equation 3).

The volume of coarse woody debris per hectare was calculated using an adaptation of Equation 5 (Van Wagner, 1968). The slope correction factor (Equation 3) and tilt angle correction factor (Equation 4) were incorporated into Van Wagner's basic volume equation to produce the final combined volume formula (Equation 6) used in this report.

[Equation 5]: *Basic CWD Volume Equation:*

$$V = \pi^2 \Sigma (d^2 / 8L)$$

where, V = volume of wood per unit area (m^3/ha);
d = diameter of woody piece at intersection (cm), and;
L = length of sample line (m).

[Equation 6]: ***Volume Equation with tilt and slope correction:***

$$\mathbf{V = (1.23 / L)\, \Sigma\, (d^2\, S / T)}$$

where, V = volume of wood per unit area (m^3/ha);
L = length of sample line (m);
d = diameter of woody piece at intersection (cm);
S = slope correction factor (Equation 2), and;
T = tilt angle correction factor (Equation 3).

Snags

A sample point was established at the centre of each line transect plot. Horizontal point sampling using a 2 m^2 basal area factor (BAF) prism was conducted to measure snags and live trees (Husch *et al*., 1982). Snags were defined as standing dead wood, with a maximum lean not exceeding 45° from vertical, a minimum length of 1.3 meters, and with a minimum diameter at breast height of 9.1 cm. Snag length was measured to a minimum top diameter of 9.1 cm. The following data were recorded for each snag: species; diameter at breast height (in 2 cm classes); top diameter (in 2 cm classes, estimated); height (m); and decay class (Appendix III).

The volume of each snag was calculated using Smalian's formula (Equation 7) (Husch *et al.*, 1982). Individual snag volumes were multiplied by the tree density appropriate for each diameter class to yield the volume per hectare (m^3/ha) represented by each snag sampled.

[Equation 7]: $V = [(B\ T) / 2]\ h$

Snag Volume Equation: where, V = volume of snag (m^3);
B = area at the base of the snag (breast height, m^2);
T = area at the top of the snag (m^2), and;
h = height of the snag (m).

Live Trees & Stumps

In addition to snags, live trees (≥9.1 cm dbh) were also measured by horizontal point sampling to quantify the live tree composition before harvesting. Species and diameter at breast height (cm) were recorded for each tree sampled. The height (m) and age (years) of the dominant tree in at least two plots per stand was measured to provide an estimate of land capability and stand age.

The above ground volume of stumps remaining after harvest was calculated using pre-harvest live tree data (density and diameter) and a post-harvest sampling of stump heights. During the post-harvest assessment, the heights of four stumps closest to each point of the line transect plot triangle were measured and an average stump height was calculated. Total stump volume (m^3/ha) was calculated for each stand by multiplying average stump volume by stump density. Average stump volume was determined using the equation for a cylinder (Equation 8). The stump radius used in this equation was determined using Honer's table for softwood stump diameter (Equation 9) (Honer *et al*., 1983), to convert a quadratic mean diameter at breast height to a mid-point stump diameter. Residual trees left after the harvest were removed from the stump data.

[Equation 8]: $V = \pi r^2 h$

Stump Volume Equation: where, V = average stump volume (m^3);
r = average stump radius (using ½ diameter from Equation 9), and;
h = average stump height (m).

[Equation 9]: ***Softwood Stump Diameter Equation:***

$$DS = D\,(1 - (0.04365\,B2))\,(1 + (B1\ \mathrm{LOG}\,(1.6764 / (S + 0.3040))))$$

where, DS = average stump diameter (m);
D = quadratic mean diameter at breast height (m);
S = average stump midpoint height (m);
$B1$ = 0.181;
$B2$ = 0.155, and;
LOG = natural logarithm (LN).

Results

Pre-harvest stand description

The eight study sites were even-aged spruce/fir stands ranging in age from 42 - 97 years (Table 1). They were located on moderately productive sites with an average land capability rating of 4.8 m^3/ha/yr. Stand diameters averaged 20.9 cm, and ranged from 16.7 to 29.0 cm. The volume of live merchantable wood averaged 220 m^3/ha, and ranged from 112 m^3/ha at Upper Uhlman Lake to 382 m^3/ha at Five Mile Lake.

Table 1: Inventory of live trees (≥ 9.1 cm dbh) prior to harvest.

Stand Location	Species Composition Weighted by Basal Area[1] (10% classes)	Mean age[2] (years)	Volume[3] (m^3/ha)	Basal Area (m^2/ha)	Mean DBH[4] (cm)	Density (trees/ha)	Mean height[5] (m)	Land Capability (m^3/ha/yr)
Brora Lake	5BF 2RM 2RS 1YB	42	230.0	35.2	18.8	1847	14.3	6.4
Riversdale	7BF 2RS 1(WS, RM)	48	243.0	33.2	20.3	1179	16.3	5.1
Moose Lake	6BF 4RS	58	207.9	30.8	19.1	1261	14.5	4.8
Upper Uhlman Lake	5BS 3BF 2(RM, RP, WB, WP, RS)	60	112.3	18.4	16.7	995	13.3	4.4
Calvary River	6RS 3BF 1RM	60	225.6	33.6	19.5	1144	14.1	3.7
Louisville	3BF 3BS 1RM 1WS 1TL 1(GB, RS, WP)	66	164.5	27.2	17.3	1397	13.2	3.8
Five Mile Lake	8RS 1RM 1(BF, YB)	88	382.2	41.2	29.0	668	20.7	6.0
Dauphinees Mill Lake	3RS 2RM 1BF 1WB 1RO 1BS 1WP	97	193.9	24.8	26.6	672	17.7	4.4
AVERAGE (±1 S.D.)		**65 (± 19)**	**219.9 (± 77.9)**	**30.6 (± 7.0)**	**20.9 (± 4.5)**	**1145 (± 386)**	**15.5 (± 2.6)**	**4.8 (± 1.0)**

[1] BF = balsam fir (*Abies balsamea* (L.) Mill); RM = red maple (*Acer rubrum* L.); RS = red spruce (*Picea rubens* Sarg.); YB = yellow birch (*Betula alleghaniensis* Britt.); WS = white spruce (*Picea glauca* (Moench) Voss); WB = white birch (*Betula papyrifera* Marshall); BS = black spruce (*Picea mariana* (Mill.) BSP.); RP = red pine (*Pinus resinosa* Ait.); WP = white pine (*Pinus strobus* L.); TL = eastern larch (tamarack) (*Larix laricina* (DuRoi) K. Koch); GB = grey birch (*Betula populifolia* Marshall); RO = red oak (*Quercus rubra* L.).
[2] Age determined from dominant trees selected for land capability.
[3] Volume calculated using metric Diameter-Height Ratio equations (Honer *et al*., 1983).
[4] Quadratic Mean DBH = diameter of tree of average basal area (Husch *et al*., 1982).
[5] Loreys's Height = height of tree of average basal area (Husch *et al*., 1982).

Dead wood

Prior to harvest, the stands contained an average dead wood volume of 60.0 m^3/ha, which ranged from 27.4 m^3/ha at Upper Uhlman Lake to 112.6 m^3/ha at Five Mile Lake (Table 2). Overall, 57% of the dead wood was coarse woody debris and 43% was snags. The proportions of dead to live wood volume generally increased with stand age, and ranged from a high of 42% at Dauphinees Mill Lake (the oldest stand) to a low of 17% at Brora Lake (the youngest stand). After logging, the average volume of dead wood increased to 67.0 m^3/ha, ranging from 33.2 m^3/ha at Upper Uhlman Lake to 98.1 m^3/ha at Dauphinees Mill Lake. This consisted of 87% coarse woody debris, 12% stumps, and 1% snags. The oldest stands, Five Mile Lake and Dauphinees Mill Lake, had the highest amounts of dead wood, both before and after harvest (112.6 and 81.8 m^3/ha, respectively before harvest and 78.9 and 98.1 m^3/ha, after harvest).

The volume of snags was considerably reduced after harvesting. However, the volume of coarse woody debris increased in seven of the eight stands, resulting in an average increase in total dead wood volume of 12.8 m^3/ha (range of 4.0 m^3/ha at Calvary River to 31.6 m^3/ha at Brora Lake). Five Mile Lake was the only site where the volume of dead wood declined as a result of harvesting (with a reduction of 33.7 m^3/ha). The decline in deadwood at this stand can be attributed to the high proportion of coarse woody debris found in advanced decay classes four and five prior to harvesting, much of which appears to have been crushed by the harvest operation (Figure 2).

Table 2: Volume of dead wood (m^3/ha) with diameter ≥ 10 cm before and after harvest.

Stand Location	Pre-harvest				Post-harvest				Difference of Pre- and Post-Harvest Dead Wood Volume	Change in Dead Wood Volume (%)
	CWD (m^3/ha)	Snags (m^3/ha)	Total (m^3/ha)	Prop. Dead to Alive[1] (%)	CWD (m^3/ha)	Snags (m^3/ha)	Stumps (m^3/ha)	Total (m^3/ha)		
Brora Lake	23.3	16.1	39.4	17	63.5	1.7	5.8	71.0	31.6	80
Riversdale	25.1	31.7	56.8	23	57.7	1.4	8.8	67.9	11.1	20
Moose Lake	32.5	27.1	59.6	29	59.7	–	9.3	69.0	9.4	16
Upper Uhlman Lake	15.7	11.7	27.4	24	27.6	–	5.6	33.2	5.8	21
Calvary River	21.9	24.5	46.4	21	38.0	–	12.4	50.4	4.0	9
Louisville	30.3	26.2	56.5	34	62.1	–	5.4	67.5	11.0	19
Five Mile Lake	68.0	44.6	112.6	30	65.8	0.7	12.4	78.9	- 33.7	-30
Dauphinees Mill Lake	54.7	27.1	81.8	42	91.9	–	6.2	98.1	16.3	20
AVERAGE (± 1 S,D,)	**33.9 (± 18.0)**	**26.1 (± 9.9)**	**60.1 (± 26.6)**	**27.5 (± 8.0)**	**58.3 (± 19.2)**	**0.5 (± 0.7)**	**8.2 (± 3.0)**	**67.0 (± 19.1)**	**6.9 (± 18.5)**	**19.4 (± 29.8)**

[1] Proportion of total dead wood volume to live tree volume existing prior to harvest (from Table 1).

Coarse woody debris

Prior to harvesting, the volume of coarse woody debris averaged 33.9 m^3/ha and ranged from 15.7 m^3/ha at Upper Uhlman Lake to 68.0 m^3/ha at Five Mile Lake (Table 2; Appendix V). After harvesting, the average volume of coarse woody debris increased by 72% to 58.3 m^3/ha, ranging from 27.6 m^3/ha at Upper Uhlman Lake to 91.9 m^3/ha at Dauphinees Mill Lake. The volume of coarse woody debris increased after harvesting in all stands except Five Mile Lake, which decreased by 2.2 m^3/ha (Figure 2). On average, the volume of dead wood classified as decay classes one, two, and three increased after harvesting by 15.9 times, 2.4 times, and 2.3 times, respectively. The volume of wood in decay class four decreased by 1.5 times and decay class five decreased by 5.7 times following harvest. The increase of decay class one is the result of harvesting related inputs (i.e. large branches, unmerchantable trees, etc). Increases in decay classes two and three can be mainly attributed to inputs of snags that were cut or knocked over during harvesting. The decrease in volume of coarse woody debris in decay classes four and five is likely the result of harvesting machines crushing the decayed wood during the operation. Machine damage might also be responsible for advancing pieces of dead wood into higher decay classes in the post-harvest assessment.

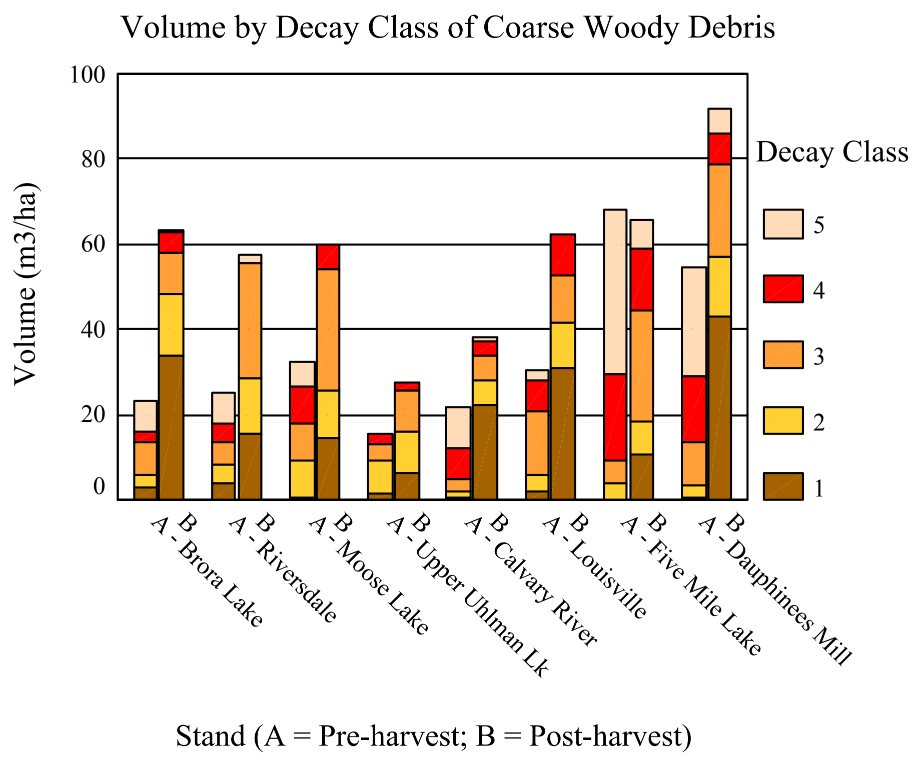

Figure 2: Volume of CWD (m^3/ha) by decay class (scale of 1-5; Appendix III) before and after harvest.

Most of the coarse woody debris, both before and after harvest, was small in diameter (Figure 3). Before harvesting, 92% (by volume) was in the 10-18 cm and 20-28 cm diameter classes. After harvesting, 85% of the coarse woody debris was in these size classes. Small diameter logs have a role in nutrient cycling, shelter for small animals, and harbouring insects and other food sources; however, small logs play a minimal role as habitat for larger animals. Hollow logs provide suitable dens if the cavity is > 30 cm in diameter, which requires logs with outside diameters of at least 40 cm (Bull *et al*., 1997). By volume, 4% of the coarse woody debris before harvesting and 8% of the coarse woody debris after harvesting was > 40 cm diameter. Only Five Mile Lake and Dauphinees Mill Lake contained large diameter (> 40 cm) coarse woody debris pieces prior to harvesting, each with 35 m/ha of bole length. Following harvest, the bole length of coarse woody debris > 40 cm in diameter remained unchanged at Five Mile Lake, but increased to 131 m/ha at Dauphinees Mill Lake. The Calvary River stand received harvesting inputs resulting in 35 m/ha of coarse woody debris > 40 cm in diameter.

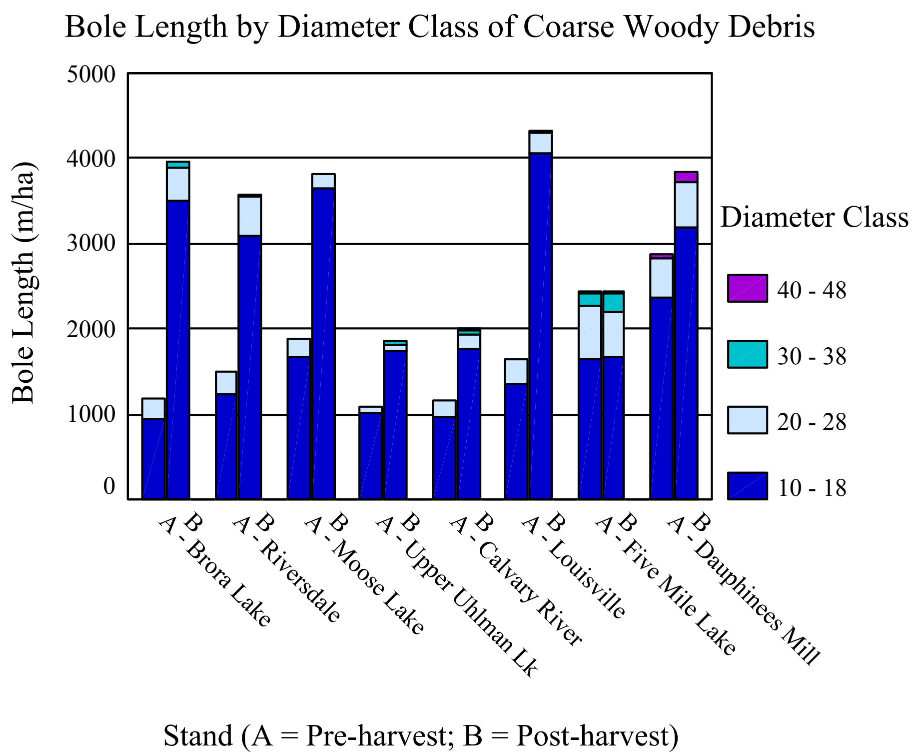

Figure 3: Total bole length of coarse woody debris (m/ha) by 10 cm diameter class before and after harvest.

The post-harvest assessment included identification of coarse woody debris with merchantable characteristics (fresh, ≥2.4 m length, ≥ 9.1 cm minimum diameter, ≤ 1/3 soft rot), and thus the potential to have been harvested (Table 3). The percentage of total coarse woody debris considered potentially merchantable averaged 14.0% and ranged from 1.7% at Moose Lake to 28.5% at Brora Lake. When compared to pre-harvest estimates of merchantable live volume, the data suggested that levels of potentially merchantable "logging residue" averaged 4.3% of the original live volume and ranged from 0.5% at Moose Lake to 10.8% at Dauphinees Mill Lake.

Table 3: Volume (m^3/ha) and proportion of potentially merchantable wood remaining after the harvesting operation as coarse woody debris.

Stand Location	Volume of Potentially Merchantable CWD (m^3/ha)	Percentage of CWD Volume assessed as Merchantable (% by Volume)	Logging Residue (Merchantable CWD: Live Tree Volume) (% by Volume)
Brora Lake	18.1	28.5	7.9
Riversdale	3.7	6.4	1.5
Moose Lake	1.0	1.7	0.5
Upper Uhlman Lake	0.7	2.4	0.6
Calvary River	5.1	13.3	2.3
Louisville	13.6	21.9	8.3
Five Mile Lake	9.8	14.9	2.6
Dauphinees Mill Lake	20.9	22.7	10.8
AVERAGE (±1 S.D.)	**9.1 (± 7.8)**	**14.0 (± 10.0)**	**4.3 (± 4.0)**

Snags

The average volume of snags before harvest was 26.1 m^3/ha, and ranged from 11.7 m^3/ha at Upper Uhlman Lake to 44.6 m^3/ha at Five Mile Lake (Table 2; Appendix VI). The volume of snags virtually disappeared as a result of logging (Figure 4), where like many logging operations, no effort was made to retain snags.

It is difficult to estimate the extent to which snags could be retained during harvest as many factors such as safety, logging efficiency, and general disturbance contribute to the conversion of snags to coarse woody debris. This trend may have significant effects on wildlife that rely on snags for survival and represents a major difference between logging disturbance and natural disturbances such as fire and insects. As with the coarse woody debris, many snags in an advanced state of decay (class four) were probably crushed during harvesting, while snags in decay class three that were knocked over might have advanced to decay class four in the post-harvest assessment because of machine damage.

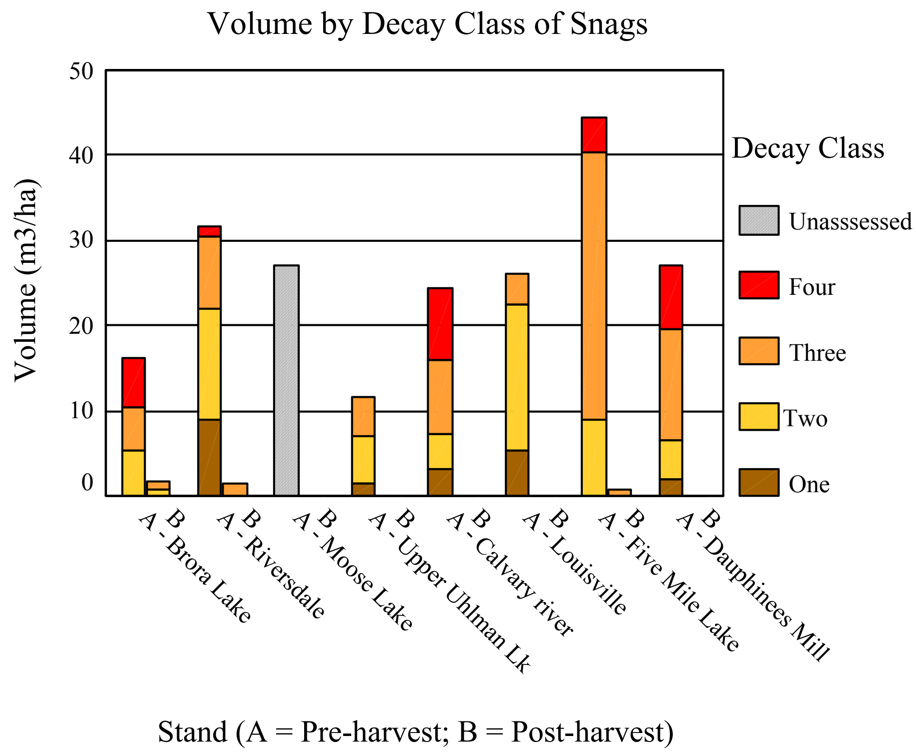

Figure 4: Volume of standing dead wood (snags) (m^3/ha) by decay class (scale of 1-4; Appendix III) before and after harvest.

The density of snags prior to harvest averaged 274 stems/ha and ranged from 170 stems/ha at Five Mile Lake to 371 stems/ha at Louisville (Figure 5, Appendix VI). Most of these (83 %) were in the smallest measured diameter class (10 - 18 cm). All sites contained snags larger than 20 cm, with measured densities averaging 50 stems/ha (range 16 - 88). Snags larger than 30 cm were relatively uncommon, and were only found at the four oldest stands, Calvary River, Louiseville, Five Mile Lake, and Dauphinees Mill Lake. At these sites an average of 12 snags/ha were recorded in the 30 - 38 cm class and 1 snag/ha in the 40 - 48 cm class. Following the harvest operations only 3 of the 8 sites had any surviving snags, and only the Five Mile Lake site retained any snags larger than 30 cm dbh. These observations suggest that management efforts to retain snags following harvesting would be most effective if concentrated on retaining the few number of large diameter snags.

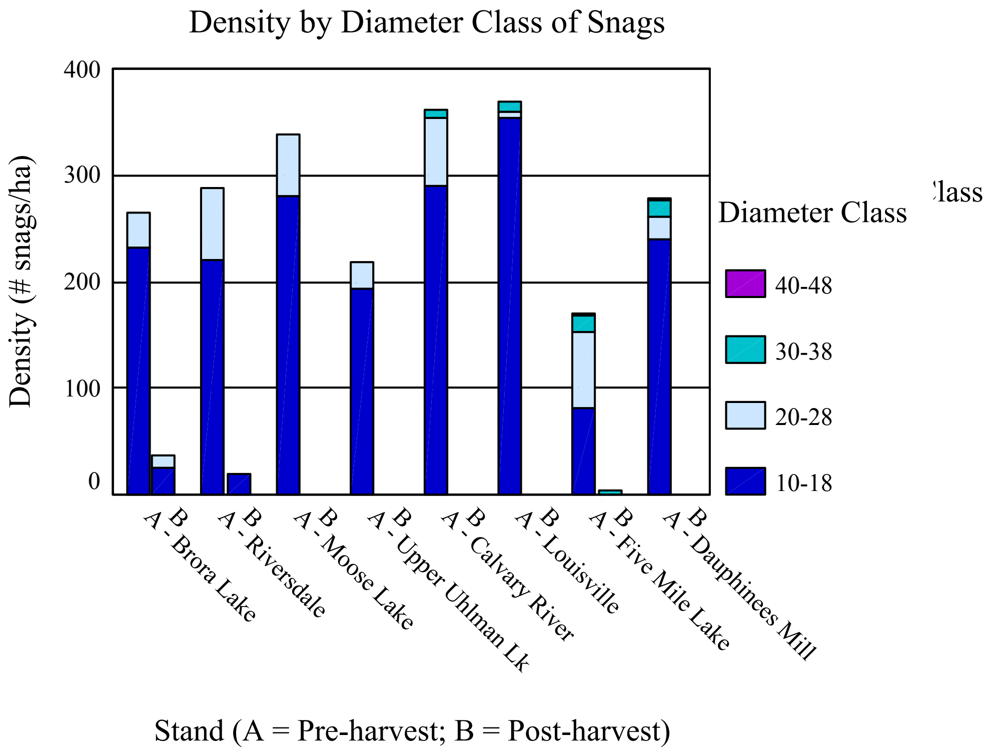

Figure 5: Density of snags (# snags/ha) by 10 cm diameter class before and after harvest.

Stumps

Stump volumes (Figure 6) are directly related to the size and density of live trees harvested. The volume of stumps was considerably lower than the volume of coarse woody debris on all sites, representing, on average, 12.3% of the total volume of dead wood following harvest (Table 2). Total stump volumes averaged 8.2 m^3/ha and ranged from 5.4 m^3/ha at Louisville to 12.4 m^3/ha at Five Mile Lake and Calvary River. Stumps are sources of carbon and other nutrients during the decay process and are suitable habitat or substrates for a variety of organisms.

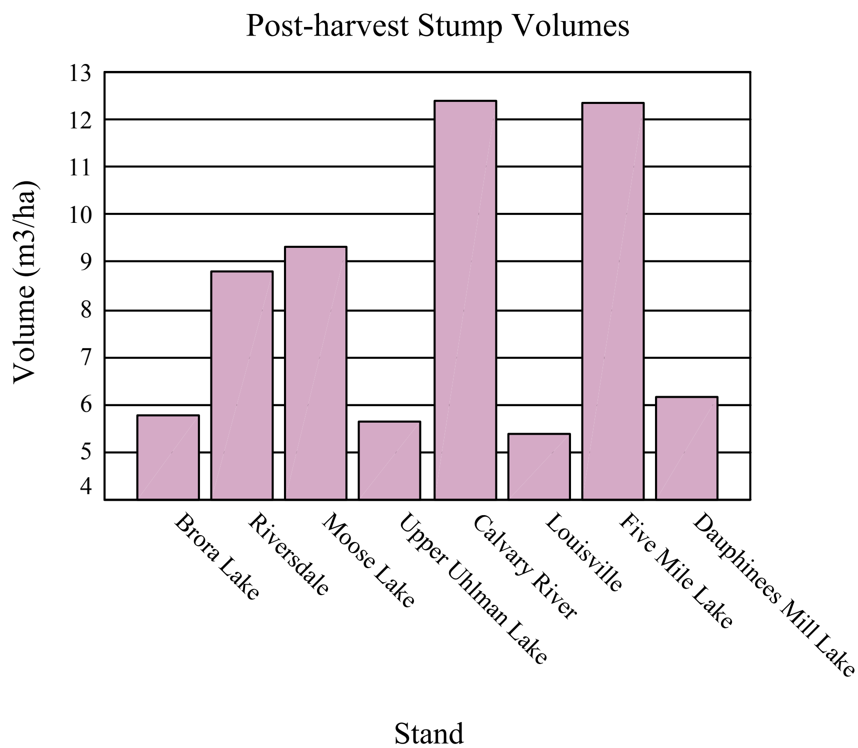

Figure 6: Stump volumes (m^3/ha) at the stands following harvesting.

Conclusions and Summary

In 1998, a study was conducted to determine the effects of clearcut logging on levels of dead wood in eight previously unmanaged spruce/fir stands. Included in the assessment was an inventory of live trees before the harvest, and volumes of coarse woody debris, snags, and stumps prior to and/or following the harvest. The study measured all wood larger than 9 cm in diameter. The following summarizes the major outcomes.

- Prior to harvest the total volume of dead wood at the eight stands averaged 60.0 m^3/ha (27.3 m^3/ha to 112.6 m^3/ha). This consisted of 33.9 m^3/ha coarse woody debris (15.7 m^3/ha to 68.0 m^3/ha) and 26.1 m^3/ha snags (11.6 m^3/ha to 44.6 m^3/ha).

- Following harvest, the volume of dead wood increased by an average 12% to 67.0 m^3/ha (33.2 m^3/ha to 98.1 m^3/ha). Eighty-seven percent of the post harvest volume consisted of coarse woody debris, which averaged 58.3 m^3/ha (27.6 m^3/ha to 91.9 m^3/ha). Stumps were the next most abundant form of dead wood, averaging 8.2 m^3/ha (5.4 m^3/ha to 12.4 m^3/ha). Snags virtually disappeared as a result of logging.

- While the total volume of coarse woody debris increased following harvest, volume in decay classes 4 and 5 decreased by 1.5 times and 5.7 times after harvesting. This was attributed to harvesting machines crushing the decayed wood. The volume of coarse woody debris in decay classes one, two, and three increased by 15.9 times, 2.4 times, and 2.3 times, respectively, following harvesting. This was the result of harvesting related inputs from live trees and snags that were cut or knocked over during harvesting.

- The occurrence of large deadwood with diameters ≥30 cm was relatively uncommon. Prior to harvest coarse woody debris of this size only occurred at the two oldest sites with levels of 16.4 and 5.3 m^3/ha. Following harvest large coarse woody debris was recorded on 7 of the 8 sites, at average levels of 8.6 m^3/ha overall. Large snags (≥30 cm dbh) were only present on the 4 oldest sites prior to harvest, with average densities of 13 large snags/ha. Only one site retained any large snags following logging.

- In pre-harvest condition, the proportion of total dead wood volume to live tree volume averaged 27.5% (17% to 42%).

- The proportion of potentially merchantable coarse woody debris left on site following harvesting was 4.3% (0.5% to 10.8%) of live tree volume. Complete utilization of all potentially merchantable material would have reduced the reported coarse woody debris volumes by 14.0% (1.7% to 28.5%).

Management Interpretations

Nova Scotia Wildlife Habitat and Watercourses Protection Regulations (Nova Scotia, 2001), introduced since the completion of this study, state that forestry operators shall emulate natural patterns of snags and coarse woody debris. The following recommendations, based on the study results, highlight practices to further incorporate the value of dead wood into forest planning.

- Concentrate efforts on conserving large diameter coarse woody debris by protecting existing pieces and adding new large logs during the harvest. Large logs benefit a wider range of species than small logs and decay more slowly, allowing them to retain their structure over a longer period of time (Bull *et al*., 1997). Stands in this study contained very little downed wood greater than 30 cm in diameter and most of the coarse woody debris was smaller than the average stand diameter at breast height.

- Protect and retain existing large diameter snags as well as potential future snags, especially those with cavities and hollow stems. As with coarse woody debris, large snags are more beneficial to wildlife than small ones (Bull *et al*., 1997). This study indicates that most stands contained only a small number of snags larger than 30 cm, making large existing snags particularly valuable and relatively easy to manage. Hollow logs are most valuable as hollowness only develops in living trees.

- Concentrate machine traffic onto designated trails to reduce crushing of decayed coarse woody debris as well as minimize the area subjected to ground disturbance. This study indicates that while overall levels of coarse woody debris increased upon harvesting, a large portion of pre-existing coarse woody debris from decay classes four and five was crushed.

- Plan for future snags and coarse woody debris through all stages of stand development. This is essential to yield large diameter snags and coarse woody debris, particularly in managed stands that have an expected rotation at less than 30 cm diameter. Retain selected live and dead trees during harvesting. Plan for snags and coarse woody debris during silviculture operations such as site preparation, weeding, and thinning. Promote and release trees with the potential to become large diameter stems. Retention of trees with low merchantability (i.e. poorly formed, damaged, and cavity trees) and uncommon species add unique forms and niche habitats to the stand (Pelletier, 1999; Bull *et al*., 1997). Retention patches required under the Wildlife Habitat and Watercourses Protection Regulations (Nova Scotia, 2001) can be effectively designed to accomplish dead wood management objectives (Pelletier, 1999).

- Preliminary data (unreported) suggest that prior to overmaturity, forests of anthropogenic origin (e.g. old field spruce) have very low levels of snags and coarse woody debris. Further investigation is required to quantify dead wood and develop recommendations for old field spruce and intensively managed stands.

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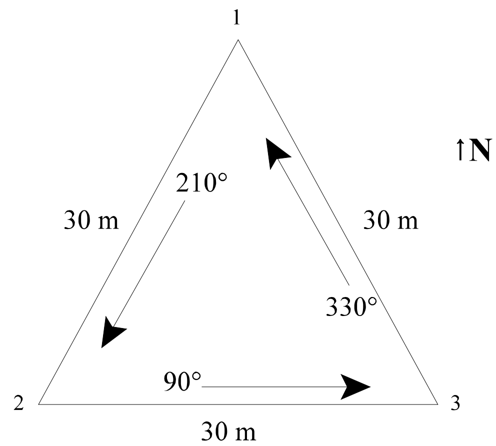
Appendix I: Line transect plot layout diagram.



Appendix II: Criteria for Coarse woody debris assessment (modified from McRae *et al* (1979) and Van Wagner (1968)):

1. Downed, dead woody material such as stems and branches from trees and shrubs. Dead branches attached to boles of standing trees were not assessed;

2. Material lying above the duff layer, leaning ≥ 45°, with a diameter ≥ 9.1 cm at the intersect point;

3. Fully decayed pieces that were completely colonized by forest floor vegetation and "flattened" to the forest floor were not counted. The distinction between decay class 5 and fully decayed wood is often the protrusion of the log above the forest floor and the presence of an internal woody structure;

4. Pieces with their central axis crossed by the transect line. Any piece with a central axis that coincided exactly with the line transect was not counted (which occurred seldom if at all);

5. Curved or angular pieces that intersected more than once (each intersection was tallied).

Appendix III: The five decay classes for dead wood (Sollins, 1982):

Decay Class	Description
1	Freshly dead, bark intact, branches intact (including small), needle/leaf retention, bole sound, bole raised off ground on branches.
2	Beginnings of decay but rot not well established in wood that was sound at time of death. Bark mostly intact, branch stubs, bole not raised on branches, bole mostly sound.
3	Rot becoming established but sound at core. Bark loose and mostly flaked off, bole beginning to rot but maintaining structural strength - round, straight, not sinking into ground.
4	Advanced decay. Bark mostly absent, bole mostly decayed with little or no sound wood present. Colonized with vegetation. Lacking structural strength - bole oval and bending to shape of ground. Last stage for snags which will be rotted, wobbly, and could be easily pushed over.
5	Rotted through, becoming humus. Sunken into mound on the ground, but retaining a woody character, not yet part of the soil.

Appendix IV: The lengths (m) and percentages of line that were excluded in the post-harvest assessment of Coarse woody debris because of large slash piles.

Stand Location	Plot	Total Length of Transect Line (m)	Length of Line Unassessed (m)	Percent of Line Unassessed (%)
Brora Lake	**2**	90.0	9.0	10.0
Brora Lake	**4**	90.0	3.0	3.3
Brora Lake	**5**	90.0	6.5	7.2
Riversdale	**2**	90.0	5.0	5.6
Riversdale	**3**	90.0	12.3	13.7
Riversdale	**5**	90.0	11.1	12.3
Moose Lake	**3**	90.0	7.7	8.6
Moose Lake	**4**	90.0	9.2	10.2
Calvary River	**1**	90.0	3.0	3.3
Louisville	**2**	90.0	12.0	13.3
Louisville	**4**	90.0	14.0	15.6
Louisville	**5**	69.0	5.0	7.2

Appendix V: Volume (m^3/ha) and bole length (m/ha) of Coarse woody debris by decay class and diameter class.

Stand Location	Decay Class	Volume (m^3/ha)		Bole Length (m/ha)		Diameter Class (cm)	Volume (m^3/ha)		Bole Length (m/ha)	
		Pre-harvest	Post-harvest	Pre-harvest	Post-harvest		Pre-harvest	Post-harvest	Pre-harvest	Post-harvest
Brora Lake	*1*	2.8	33.9	139	2229	*10-18*	12.1	42.4	943	3513
	2	2.9	14.4	175	686	*20-28*	11.2	15.6	244	371
	3	7.8	9.9	489	645	*30-38*	0	5.5	0	73
	4	2.4	4.5	175	358	*40-48*	0	0	0	0
	5	7.4	0.8	209	39	***Total***	**23.3**	**63.5**	**1187**	**3957**
	Total	**23.3**	**63.5**	**1187**	**3957**					
Riversdale	*1*	4.0	15.3	279	1251	*10-18*	15.9	36.6	1222	3095
	2	4.0	13.2	210	848	*20-28*	9.2	18.3	279	451
	3	5.7	27.1	419	1412	*30-38*	0	2.8	0	35
	4	4.2	0	244	0	*40-48*	0	0	0	0
	5	7.2	2.1	349	70	***Total***	**25.1**	**57.7**	**1501**	**3581**
	Total	**25.1**	**57.7**	**1501**	**3581**					
Moose Lake	*1*	0.4	14.6	35	1082	*10-18*	24.2	51.5	1676	3641
	2	8.9	11.0	628	690	*20-28*	8.3	8.2	209	180
	3	8.7	28.3	559	1578	*30-38*	0	0	0	0
	4	8.5	5.8	419	471	*40-48*	0	0	0	0
	5	6.0	0	244	0	***Total***	**32.5**	**59.7**	**1885**	**3821**
	Total	**32.5**	**59.7**	**1885**	**3821**					
Upper Uhlman Lake	*1*	1.5	6.2	140	698	*0-18*	13.2	21.4	1012	1745
	2	7.6	10.0	454	628	*20-28*	2.5	2.8	70	70
	3	4.1	9.6	279	419	*30-38*	0	3.4	0	35
	4	2.5	1.8	209	105	*40-48*	0	0	0	0
	5	0	0	0	0	***Total***	**15.7**	**27.6**	**1082**	**1850**
	Total	**15.7**	**27.6**	**1082**	**1850**					
Calvary River	*1*	0.4	22.3	35	1236	*10-18*	14.4	21.4	977	1761
	2	1.4	5.7	104	246	*20-28*	7.5	7.8	175	176
	3	3.1	6.0	175	385	*30-38*	0	2.5	0	35
	4	7.1	3.1	419	105	*40-48*	0	6.3	0	35
	5	9.9	0.9	419	35	***Total***	**21.9**	**38.0**	**1152**	**2007**
	Total	**21.9**	**38.0**	**1152**	**2007**					
Louisville	*1*	1.8	31.0	70	2420	*10-18*	18.6	51.6	1362	4066
	2	3.8	10.5	244	716	*20-28*	11.7	8.0	279	226
	3	15.2	11.1	803	750	*30-38*	0	2.5	0	35
	4	7.3	9.5	384	441	*40-48*	0	0	0	0
	5	2.2	0	140	0	***Total***	**30.3**	**62.1**	**1641**	**4327**
	Total	**30.3**	**62.1**	**1641**	**4327**					
Five Mile Lake	*1*	0	10.7	0	559	*10-18*	27.4	24.8	1641	1676
	2	3.8	7.8	140	175	*20-28*	24.2	20.4	628	524
	3	5.2	26.0	209	733	*30-38*	12.0	16.2	140	209
	4	20.4	14.3	768	698	*40-48*	4.4	4.4	35	35
	5	38.6	7.0	1327	279	***Total***	**68.0**	**65.8**	**2444**	**2444**
	Total	**68.0**	**65.8**	**2444**	**2444**					
Dauphinees Mill Lake	*1*	0.3	42.8	35	1135	*10-18*	30.2	44.0	2373	3185
	2	3.1	14.2	244	742	*20-28*	19.2	22.3	454	524
	3	10.4	21.6	593	1178	*30-38*	0	0	0	0
	4	15.3	7.2	838	480	*40-48*	5.3	25.6	35	131
	5	25.6	6.1	1152	305	***Total***	**54.7**	**91.9**	**2862**	**3840**
	Total	**54.7**	**91.9**	**2862**	**3840**					

Appendix VI: Volume (m^3/ha) and density (#/ha) of snags by decay class and diameter class.

Stand Location	Decay Class	Volume (m^3/ha)		Density (#/ha)		Diameter Class (cm)	Volume (m^3/ha)		Density (#/ha)	
		Pre-harvest	Post-harvest	Pre-harvest	Post-harvest		Pre-harvest	Post-harvest	Pre-harvest	Post-harvest
Brora Lake	*1*	0	0	0	0	*10-18*	10.9	1.0	233	26
	2	5.4	0.7	113	11	*20-28*	5.2	0.7	32	11
	3	5.0	1.0	52	26	*30-38*	0	0	0	0
	4	5.7	0	100	0	*40-48*	0	0	0	0
	Total	**16.1**	**1.7**	**265**	**37**	***Total***	**16.1**	**1.7**	**265**	**37**
Riversdale	*1*	9.0	0	93	0	*10-18*	17.4	1.4	221	20
	2	13.0	0	64	0	*20-28*	14.3	0	68	0
	3	8.5	1.4	106	20	*30-38*	0	0	0	0
	4	1.2	0	26	0	*40-48*	0	0	0	0
	Total	**31.7**	**1.4**	**289**	**20**	***Total***	**31.7**	**1.4**	**289**	**20**
Moose Lake	*Decay Class Not Assessed*	27.1	0	339	0	*10-18*	17.3	0	281	0
			0		0	*20-28*	9.8	0	58	0
			0		0	*30-38*	0	0	0	0
			0		0	*40-48*	0	0	0	0
	Total	**27.1**	**0**	**339**	**0**	***Total***	**27.1**	**0**	**339**	**0**
Upper Uhlman Lake	*1*	1.4	0	20	0	*0-18*	8.9	0	193	0
	2	5.7	0	92	0	*20-28*	2.8	0	25	0
	3	4.6	0	106	0	*30-38*	0	0	0	0
	4	0	0	0	0	*40-48*	0	0	0	0
	Total	**11.7**	**0**	**218**	**0**	***Total***	**11.7**	**0**	**218**	**0**
Calvary River	*1*	3.2	0	4	0	*10-18*	11.7	0	290	0
	2	4.1	0	102	0	*20-28*	7.6	0	64	0
	3	8.7	0	106	0	*30-38*	5.2	0	8	0
	4	8.5	0	150	0	*40-48*	0	0	0	0
	Total	**24.5**	**0**	**362**	**0**	***Total***	**24.5**	**0**	**362**	**0**
Louisville	*1*	5.4	0	118	0	*10-18*	22.4	0	353	0
	2	17.2	0	220	0	*20-28*	0.8	0	6	0
	3	3.6	0	31	0	*30-38*	3.0	0	10	0
	4	0	0	0	0	*40-48*	0	0	0	0
	Total	**26.2**	**0**	**371**	**0**	***Total***	**26.2**	**0**	**371**	**0**
Five Mile Lake	*1*	0	0	0	0	*10-18*	12.1	0	82	0
	2	8.9	0	41	0	*20-28*	22.9	0	70	0
	3	31.5	0.7	113	4	*30-38*	8.1	0.7	16	4
	4	4.2	0	16	0	*40-48*	1.5	0	2	0
	Total	**44.6**	**0.7**	**170**	**4**	***Total***	**44.6**	**0.7**	**170**	**4**
Dauphinees Mill Lake	*1*	2.0	0	13	0	*10-18*	15.9	0	240	0
	2	4.5	0	51	0	*20-28*	3.0	0	22	0
	3	13.0	0	135	0	*30-38*	7.0	0	14	0
	4	7.6	0	80	0	*40-48*	1.2	0	3	0
	Total	**27.1**	**0**	**279**	**0**	***Total***	**27.1**	**0**	**279**	**0**