**Natural Resources**
Biodiversity Conservation and Forestry Technical Report Series

Research Report | Forestry Tech Report 2026-003 | June 2026

# Live Retention Levels in Highland Fir Forests Following a Spruce Budworm Outbreak

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## 1. Introduction

Spruce budworm (SBW) is a dominant natural disturbance agent in Nova Scotia that is characterized by relatively frequent, severe stand-replacing disturbances in the balsam fir dominated stands of the Cape Breton Highlands. The time between SBW outbreaks is typically between 30 and 40 years (Taylor et al., 2020). After the 1970's SBW outbreak, mortality caused by defoliation was 78-89% of merchantable balsam fir volume (Ostaff & MacLean, 1989). Stand structure can change drastically after a budworm outbreak, with 21% blowdown, over 50% bare tops and 60% broken tops (Ostaff & MacLean, 1989).

This study examines levels and variation of tree mortality associated with the SBW outbreak of the 1970s and 1980s in the Cape Breton Highlands. To do so, randomly located forest inventory permanent sample plots (PSPs) were analyzed to assess mortality and survival rates. The overarching purpose of the Department of Natural Resources' (NSDNR) on-going research on natural disturbance regimes (NDR) in Nova Scotia (Taylor et al., 2020; MacLean et al., 2021) is to inform the emulation of NDR in management as part of an ecological forestry approach (Lahey, 2018). The results of this study could provide some context for live retention targets in timber harvests in the Cape Breton Highlands. Live retention in harvests contribute biodiversity conservation in forest management (Mori & Kitagawa, 2014) and on-going research is needed on subjects like retention levels as addressed in this study, but also other subjects like live retention distribution in harvest blocks and the interplay of live retention and deadwood retention.

## 2. Methods

All PSPs classified as a Highland (HL) vegetation type under Nova Scotia's Forest Ecosystem Classification (FEC) system (Neily et al., 2013) by inventory field staff were selected. This analysis focused on zonal, softwood-leading vegetation types (HL1 Balsam Fir/Mountain Ash/Large-Leaved Goldenrod and HL2 White Spruce/Wood Aster), particularly mature balsam fir (HL1) stands. The assumption was that while vegetation type may change over time, forest group will not in the Highlands (Neily et al., 2013) and the historical vegetation types were classified for past sample years based on species composition by basal area.

Of these 92 HL PSPs, only 45 were established before/during the SBW outbreak. This number was reduced further to 23 PSPs used in the final analysis after screening out PSPs that were HL3 (Yellow Birch – Balsam Fir/Eastern Spreading Wood Fern/Wood Sorrel) or HL4 (Birch/Wood Fern-Wood Sorrel) at the time of the outbreak, that were harvested, or had species composition and stand structure that revealed the PSP was not suitable (e.g., several PSPs were established after a stand-replacing disturbance but the disturbance type and pre-disturbance conditions were not known, though could have been harvest or other insect disturbance).

The 23 PSPs were used to identify median rates of survival and an associated range of natural variation. Mortality of trees that survived the initial SBW disturbance occurs over an extended period of time as they become more susceptible to exposure, windthrow, other insects and pathogens, and senescence. Consequently, a final rate of percent basal area survival for a given PSP was identified as trees that survived until the re-establishment of the new stand after the SBW disturbance, with re-establishment being recruitment of the majority of new cohort trees from sapling tallies to individual tree data in the PSP records.

## 3. Results

Percent retention in the PSPs ranged from 0% to 30% across all PSPs analyzed(Fig. 1, Table 1). Mortality of plots affected by SBW was highest in the first five-year measurement cycle after disturbance but continued for 20 years or more afterwards (Fig. 2).

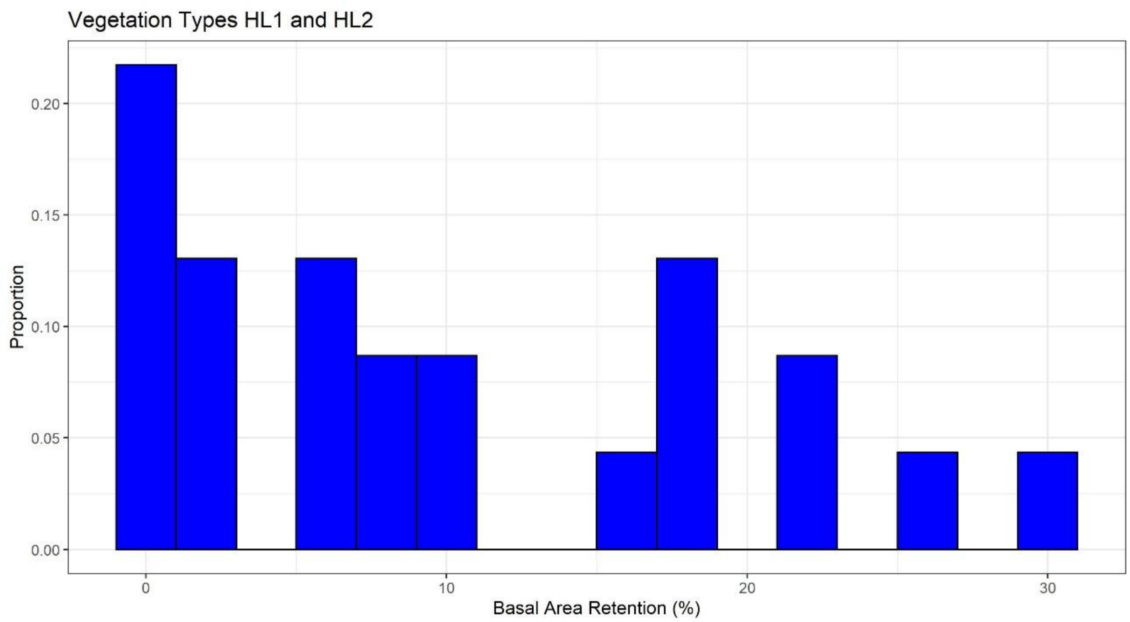


Fig. 1. Range of natural variation of basal area survival (%) after spruce budworm disturbance for HL1 (*N* = 22) and HL2 (*N* = 1) permanent sample plots in the Cape Breton Highlands, as shown by proportion of all plots.

Table 1. Percent survival in permanent sample plots by 10% survival class.

| Survival Class | Percent of Plots |
|---|---|
| 0% to 5% | 35 |
| 5.1% to 10% | 26 |
| 10.1% to 20% | 22 |
| 20.1% to 30% | 17 |

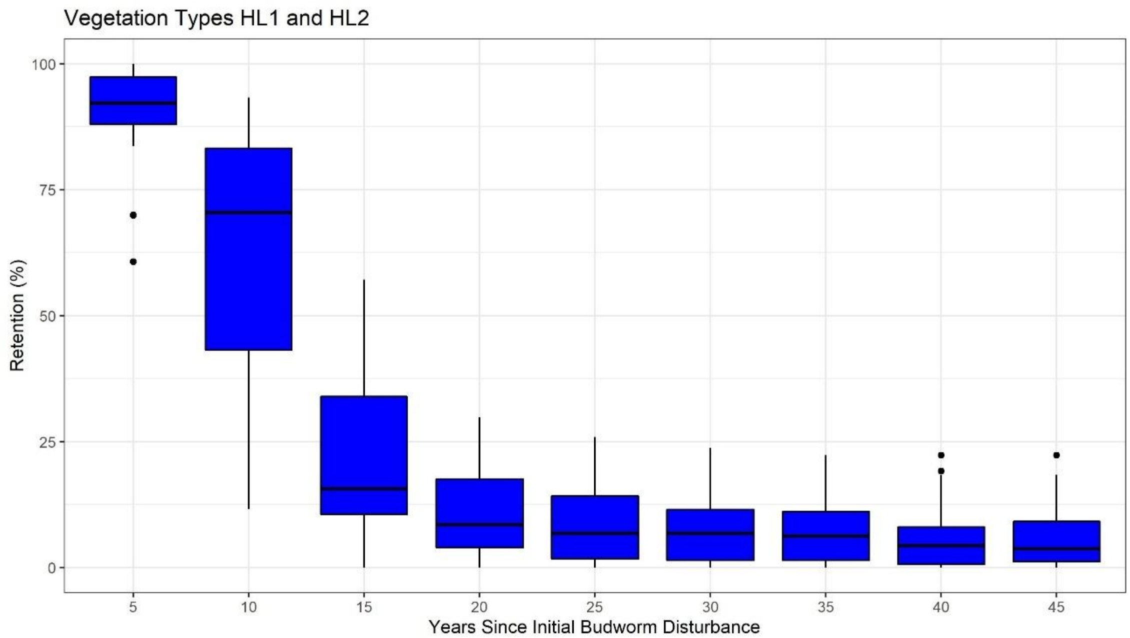


Fig. 2. Basal area retention (%) after spruce budworm disturbance over five-year sample periods for HL1 (N = 22) and HL2 (N = 1) permanent sample plots in the Cape Breton Highlands.

Fig. 3 shows an example of a low-retention PSP with 1.2% survivorship at the time of stand re-establishment in the 2001 sample year, while Fig. 4 shows an example of a higher-retention PSP with 17.7% survivorship at the time of stand re-establishment in the 1990 sample year. However, the exact year of stand re-establishment can be variable and/or drawn out over multiple sample years and is a source of uncertainty in these live retention estimates.

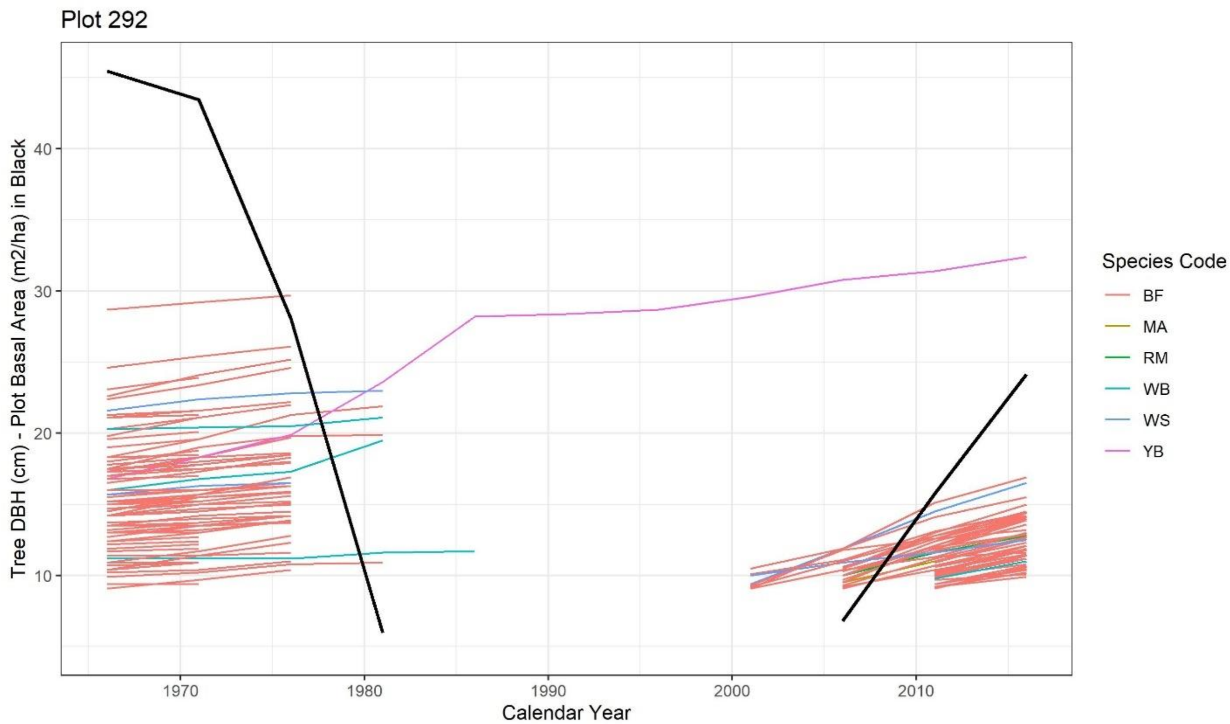


Fig. 3. Tree diameter at breast height (DBH) by species for each five-year sample period with plot-level basal area shown in black for permanent sample plot 292.

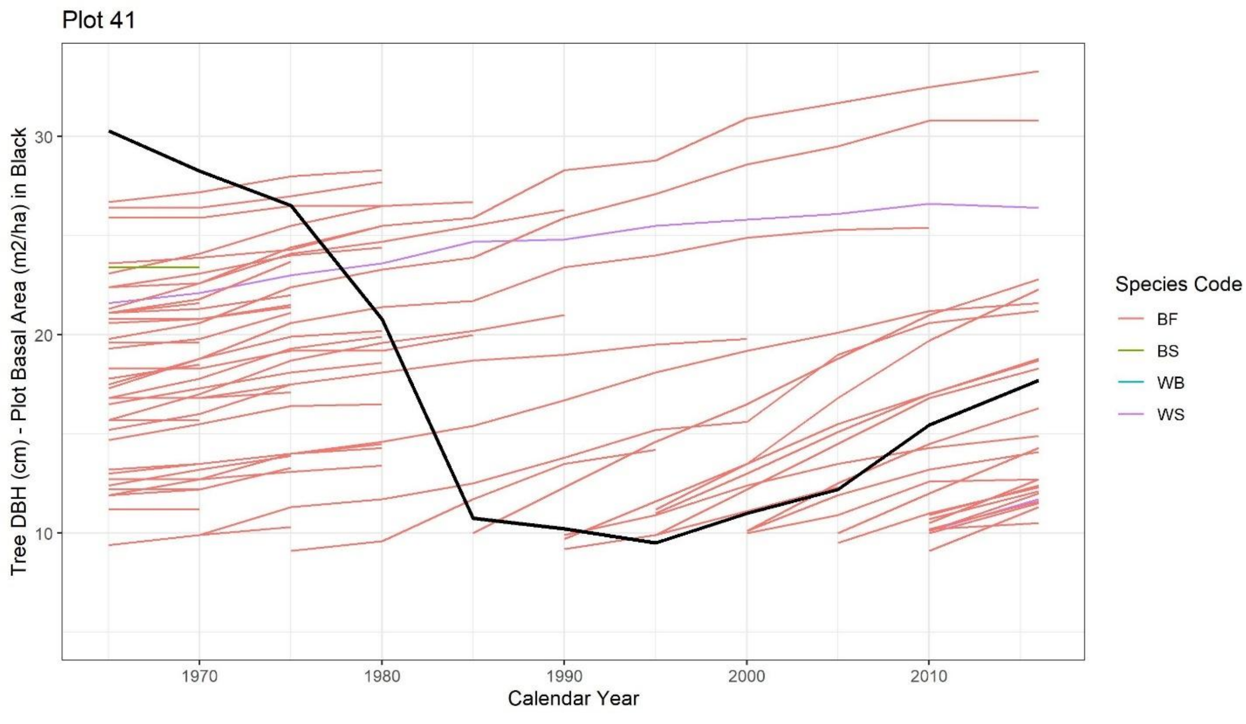


Fig. 4. Tree diameter at breast height (DBH) by species for each five-year sample period with plot-level basal area shown in black for permanent sample plot 41.

The survivorship results from this analysis are similar to those seen in the literature. For example, MacLean and Ostaff (1989) examined 70 plots in 20 mature balsam fir stands in the Cape Breton Highlands and found that almost half (9 stands) had 90-100% mortality while the remainder had mortality rates between 80-90% (5 stands), 70-80% (3 stands), and 60-70% (1 stand). Mortality and survivorship by species were also variable (Fig. 5, 6, & 7, Table 2).

Table 2. Percent survivorship and counts of trees by species that survived spruce budworm disturbance to the time of new cohort establishment. Note that these values include all sources of mortality that may have occurred post-budworm (i.e., hardwood species are not impacted by spruce budworm), such as wind and spruce beetle (*Dendroctonus rufipennis*; Ostaff & Maclean, 1989).

| | | ***N*** | |
|---|---|---|---|
| **Species** | **Survival (%)** | **Pre-disturbance** | **Post-disturbance** |
| BF | 5.2 | 920 | 48 |
| BS | 26.5 | 34 | 9 |
| RM | 66.7 | 3 | 2 |
| TL | 0.0 | 4 | 0 |
| WB | 57.6 | 33 | 19 |
| WS | 30.8 | 26 | 8 |
| YB | 50.0 | 2 | 1 |

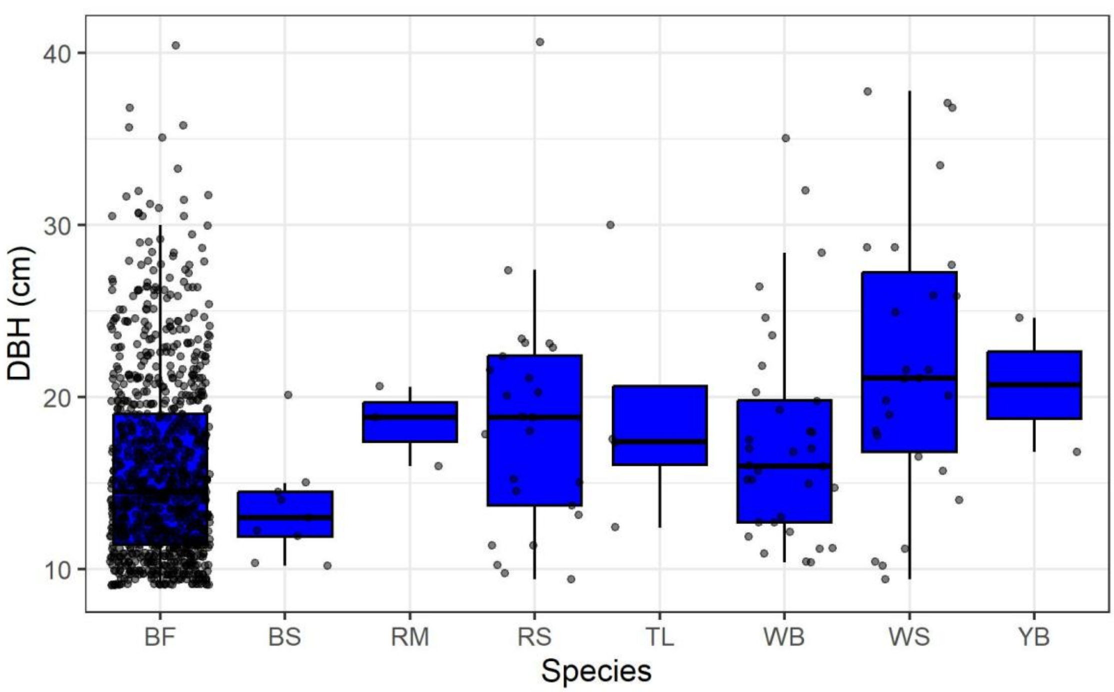


Fig. 5. Living tree diameters by species at the time of the 1970s spruce budworm disturbance.

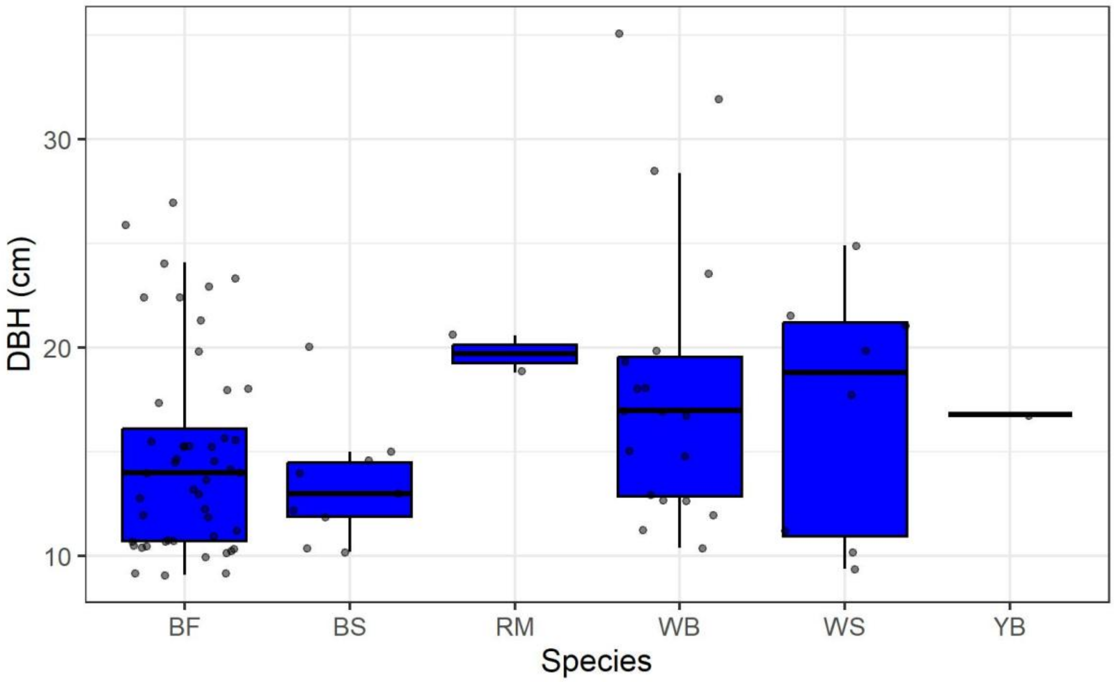


Fig. 6. Living tree diameters by species of trees that survived spruce budworm disturbance to the time of new cohort establishment.

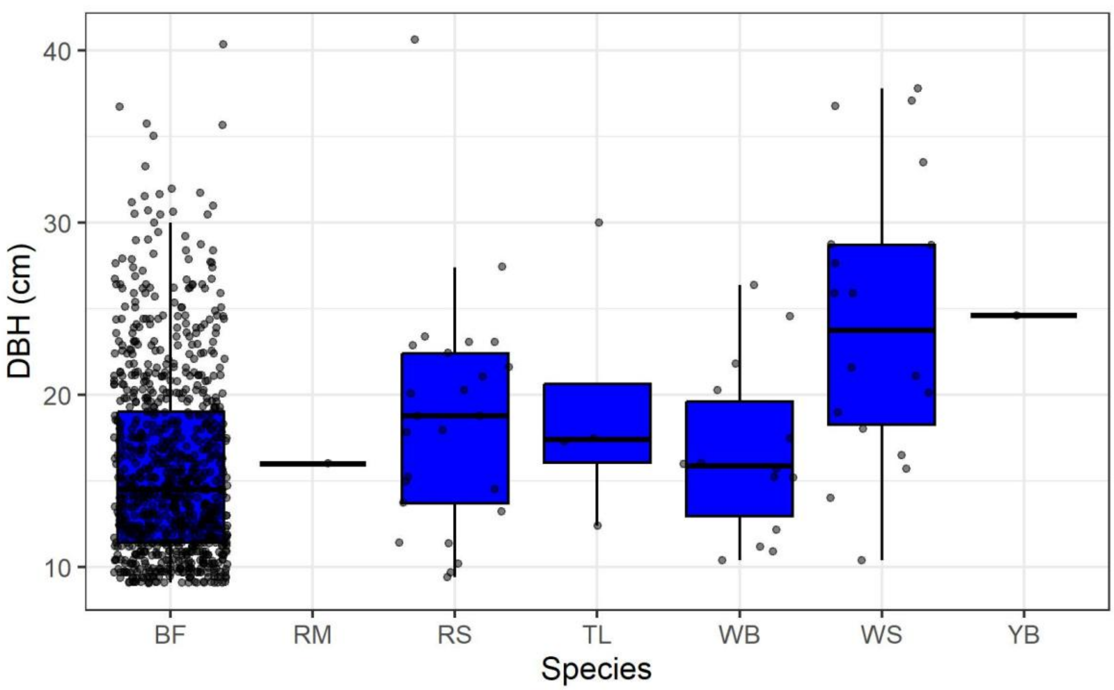


Fig. 7. Dead tree diameters by species of trees that did not survive the spruce budworm disturbance to the time of new cohort establishment.

## 4. Discussion and Conclusions

The intent of this study is to describe retention levels in balsam fir dominated stands in the Highland Forest Group after the last spruce budworm outbreak. Such results could potentially inform future retention objectives in the Highlands under an approach of emulating natural disturbance regimes in forestry. The current prescribed retention during harvest for these treatments is typically 10%. This study's findings show that retention following spruce budworm has a range of natural variation (i.e., between 0% and 30%).

Higher retention plots might be explained by several factors. First, a higher component of yellow birch, white birch, or red maple (i.e., hardwood species present in the data but not susceptible to budworm) are certainly a factor. Additionally, white spruce is an important component of softwood forests in the Cape Breton Highlands but are a less-preferred host species for spruce budworm (Ostaff & MacLean, 1989). It is likely that a higher white spruce component in a given stand reduced overall mortality rates. Lastly, wind exposure was certainly a factor, as the living retention in disturbed stands would be more susceptible to windthrow.

Regarding the emulation of natural disturbances, future retention levels in timber harvests might aim to retain hardwood species when present, as well as white spruce. However, future research on white spruce dominated stands in the Cape Breton Highlands should occur, as only one of the 23 plots analyzed was HL2 and in fact regenerated as HL1 after the outbreak. The PSP data did show increased levels of white spruce after the previous outbreak across the study area.

Lastly, it is important to note that live retention after natural disturbances in zonal sites in the Maritime Boreal Ecosite Group, including the Highlands, has different dynamics than for zonal sites in the Acadian Ecosite Group (Neily et al., 2013). Live retention in the Acadian forest, while still subject to increased risk of mortality, is more likely to remain live or standing and be incorporated into the future stand as a living biological legacy or separate cohort. In the Maritime Boreal forest where the NDR are more frequent and zonal ecosites are not characterized by LIT species, mortality rates among retention trees are higher. Considering management implications, retention levels in harvests should also be focused on biodiversity and wildlife (standing and down dead woody material as well as live retention), soil health, and potentially aesthetics.

NDR-based guidance on live retention levels in the Cape Breton Highlands is needed. However, rather than limit the discussion to live retention, it is recommended that the deadwood (i.e., snags and coarse woody material [CWM]) retention also be addressed. Deadwood structure of mature, SBW-origin stands from PSPs and Forest Ecosystem Classification (FEC) plots should be used to develop post-harvest deadwood targets in the future. The ecology of these stands and silvics of the dominant species within them control the structure and function of retention, which is substantially different from the Acadian forest (Neily et al., 2013).

In softwood stands in the Cape Breton Highlands, tree species are short-lived and those that survive to the point of new cohort establishment (i.e., live retention trees identified in this analysis) still all tend to experience mortality in a relatively short period of time (Fig. 2). A focus on live retention only presents a risk of a) unrealistic expectations for live retention survivorship over time and b) discounting the importance of retaining deadwood (i.e., snags and CWM). Additionally, the live retention that remains for variable lengths of time after widespread mortality from spruce budworm (e.g., 5 or 10 years) does benefit biodiversity even if it does not survive to the point of new cohort establishment.

Future research should investigate methods of integrating deadwood retention and targets into silvicultural treatments in the Cape Breton Highlands that consider inputs from mortality in post-treatment live retention as well as from harvest residues and mortality in wildlife clumps and buffers. Past Department research and external research has shown what levels of deadwood might be expected in mature fir stands. Taylor and MacLean (2007) examined PSP data in New Brunswick over a 15-18 yr period and found that CWM accumulation ranged from 30 $m^3$/ha in non-declining fir-spruce stands to 140 $m^3$/ha in declining fir-spruce, with declining spruce-fir stands having 80 $m^3$/ha. Similarly, accumulated snag volumes were 45 $m^3$/ha non-declining fir-spruce, 50 $m^3$/ha for declining fir-spruce, and 39 $m^3$/ha for spruce-fir (Taylor & MacLean, 2007). Six FEC plots in natural, mature, fir-dominated stands in the Cape Breton Highlands (located in the National Park and a Wilderness Area) showed that CWM had an average of 81 $m^3$/ha, ranging from 29 to 156 $m^3$/ha, while snag volumes showed an average of 5 $m^3$/ha, ranging from 2 to 10 $m^3$/ha.

Deadwood in the form snags and CWM provide important ecosystem functions (Harmon et al., 2004). Deadwood retention after harvesting will never be equivalent to deadwood levels following SBW disturbance, but by examining mature, natural, balsam fir stands in additional FEC and PSP plots alongside the existing literature and new field data collection, some acceptable deadwood thresholds/targets could be identified. Importantly, this future research should also address specific wildlife/biodiversity functions of deadwood and deadwood life cycles so that any new deadwood retention requirements are evidence-based and providing a necessary ecosystem function.

Given that the PSPs used in this analysis were individual plots, not necessarily located within the same stand, we were unable to characterize within-stand variability of live retention that may exist in stands affected by budworm. Spatial variability in mortality is often high between stands/plots/or plots within stands and is more pronounced than temporal variability in mortality from budworm outbreaks (MacLean, 1980). Future research should examine the spatial variability of between-stand and within-stand structural characteristics resulting from spruce budworm.

Lastly, future research should also investigate the implications of pre-commercial thinning on retention in the Cape Breton Highlands. At the time of the 1970s SBW outbreak, most affected fir stands were of natural origin while currently pre-commercial thinning is now fairly standard practice. Treated stands will likely have lower levels of deadwood and smaller hardwood components than natural stands and therefore different disturbance dynamics.

## Acknowledgements

We would like to thank Dr. Dave MacLean and Dan Lavigne for their peer reviews of this technical note, Sean Power, Tara Crewe, Jean Robar, and other DNRR staff for their input on the study, and Forest Inventory staff for the PSP program and data.

## References

Harmon, M. E., Franklin, J. F., Swanson, F. J., Sollins, P., Gregory, S. V., Lattin, J. D., Anderson, N. H., Cline, S. P., Aumen, N. G., Sedell, J. R., Lienkamper, G. W., Kromack, K., & Cummins, K. W. (2004). Ecology of coarse woody debris in temperate ecosystems. *Advances in Ecological Research, 34*, 59-234.

Lahey, W. (2018). *An independent review of forest practices in Nova Scotia.* Halifax, NS: Nova Scotia Department of Lands and Forestry.

MacLean, D.A. (1980). Vulnerability of fir-spruce stands during uncontrolled spruce budworm outbreaks: A review and discussion. *The Forestry Chronicle, 56*, 213–221.

MacLean, D. A., & Ostaff, D. P. (1989). Patterns of balsam fir mortality caused by an uncontrolled spruce budworm outbreak. *Canadian Journal of Forest Research, 19*, 1087-1095.

MacLean, D. A., Taylor, A. R., Neily, P. D., Steenberg, J. W. N., Basquill, S. P., Quigley, E., Boone, C. K., Oikle, M., Bush, P., & Stewart, B. (2021). Natural disturbance regimes for implementation of ecological forestry: A review and case study from Nova Scotia, Canada. *Environmental Reviews, 30*, 128-158.

McGrath, T., Pulsifer, M., Seymour, R., Doucette, L., Forbes, G., McIntyre, R., Milton, R., Cogan, L., Retallack, M., & Crewe, T. (2021). *Nova Scotia silvicultural guide to the ecological matrix.* Halifax, NS: Nova Scotia Department of Lands and Forestry. Available from: https://novascotia.ca/ecological-forestry/docs/silvicultural-guide.pdf

Mori, A. S., & Kitagawa, R. (2014). Retention forestry as a major paradigm for safeguarding forest biodiversity in productive landscapes: A global meta-analysis. *Biological Conservation, 175*, 65-73.

Neily, P., Keys, K., Quigley, E., Basquill, S., & Stewart, B. (2013). *Forest ecosystem classification for Nova Scotia*. Truro, NS: Nova Scotia Department of Natural Resources. Available from: https://novascotia.ca/natr/forestry/programs/ecosystem-management.asp

Ostaff, D. P., & MacLean, D. A. (1989). Spruce budworm populations, defoliation, and changes in stand condition during an uncontrolled spruce budworm outbreak on Cape Breton Island, Nova Scotia. *Canadian Journal of Forest Research, 19*, 1077-1086.

Taylor, A. R., MacLean, D. A., Neily, P. D., Stewart, B., Quigley, E., Basquill, S. P., Boone, C. K., Gilby, D., & Pulsifer, M. (2020). A review of natural disturbances to inform implementation of ecological forestry in Nova Scotia, Canada. *Environmental Reviews, 28*, 387-414.

Taylor, S. L., & MacLean, D. A. (2007). Dead wood dynamics in declining balsam fir and spruce stands in New Brunswick, Canada. *Canadian Journal of Forest Research, 37*, 750-762.