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QUEBEC'S FOREST RESILIENCE TO SPRUCE BUDWORM INFESTATIONS

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Figure 1. Balsam fir landscape in southern Quebec, Canada. Extensive, connected areas dominated by primary SBW host species have the potential to trigger infestation outbreaks

HIGHLIGHTS

- Quebec's boreal forests have shown resilience to SBW infestations, although climate changes may exacerbate infestation severity
- Resilience outcomes to infestations are primarily driven by changes in climate, canopy cover, and species composition
- Despite climate plays a strong role in shaping forest resilience, management strategies should target forest structure, composition, and configuration to mitigate the effects of climatic changes

Forests are increasingly threatened by disturbance pressures and climatic changes. For decades, forest managers have sought to understand what forest characteristics may reduce the negative impact of natural disturbances and foster stand recovery, a concept known as forest resilience. However, disentangling the complex relations between forest characteristics and disturbance dynamics has been challenging at a scale that is relevant for landscape-level interventions and monitoring. This is particularly important in sensitive environments such as the Canadian eastern boreal forests, where repeated infestations of eastern spruce budworm (*Choristoneura fumeraria Clem*., SBW) have become more severe and have resulted in widespread balsam fir (*Abies balsamea* (L.) Mill.) and secondary host tree species mortality (Figure 1).

Traditionally, our understanding of forest disturbance dynamics has come from aerial observations over broad areas (i.e., aerial overview surveys), characterizing aspects of forest disturbances such as extent and severity (Figure 2).

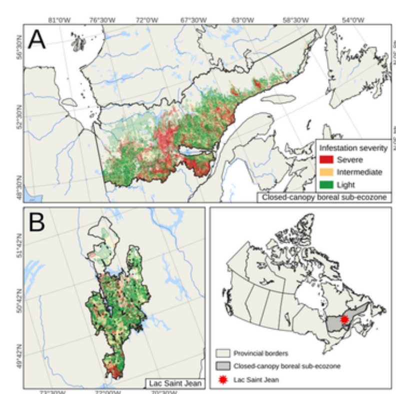

Figure 2. Map of the two study areas used in our project: (A) closed-canopy boreal sub-ecoregion of Quebec and (B) Lac Saint Jean. Infestation severity is derived from the provincial aerial overview surveys.

Remote sensing has unlocked fine- and broad-scale analyses of forests over time in a spatially explicit fashion, enabling more accurate characterization, mapping, and monitoring of disturbance dynamics. Through a remote sensing lens, our work has focused on disentangling which forest characteristics and climate variables have supported greater forest resilience to infestations, expressed in terms of lower disturbance impact and faster recovery towards pre-disturbed conditions.

WHICH FOREST CHARACTERISTICS SUPPORT RESILIENCE TO INFESTATIONS?

In our first study, we conducted a change detection analysis in the Lac Saint Jean, Quebec area (Figure 2B) where we demonstrated the value of bi-temporal airborne laser scanning (ALS) data in characterizing changes in the forest structure associated with SBW infestations of various severity levels between 2014 and 2020. Through cluster analysis, we found that sparser canopy cover (< 65%) and shorter trees (< 7.5 m), as derived from ALS data, were associated with less severe infestations over the 7-year period considered (Figure 3). Our results were consistent across a gradient of environmental conditions, including characteristics like temperature, precipitation, elevation, and productivity.

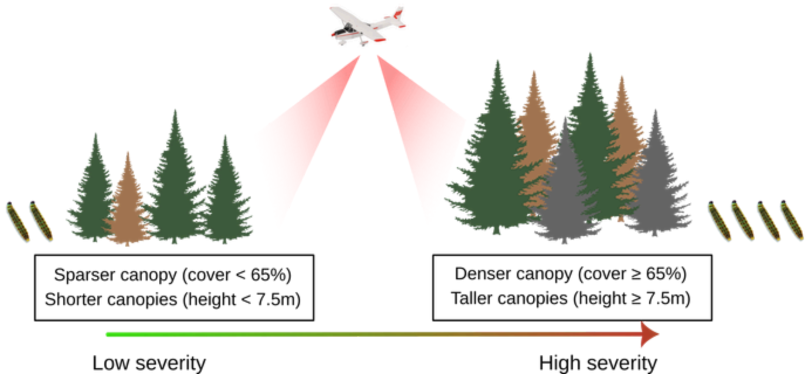

Figure 3. Illustration of the effect of canopy cover and height, as derived from airborne laser scanning data, on infestation severity.

In a later study, we expanded our study area to encompass the closed-canopy boreal sub-ecoregion of Quebec (Figure 2A) where we leveraged nearly forty years of Landsat time series data to investigate the relative contribution of forest structure, composition, configuration, and climate variables in shaping forest resilience outcomes to infestations. Resilience was captured via two main components derived from Landsat imagery: spectral impact and spectral recovery rate. Impact represents the drop in a spectral values following an infestation, while recovery rate is the speed of recovery towards pre-disturbed conditions. By combining impact and recovery rate responses of forest stands at the landscape level, we built a bivariate space of impact-recovery responses that served as basis for estimating forest resilience (Figure 4).

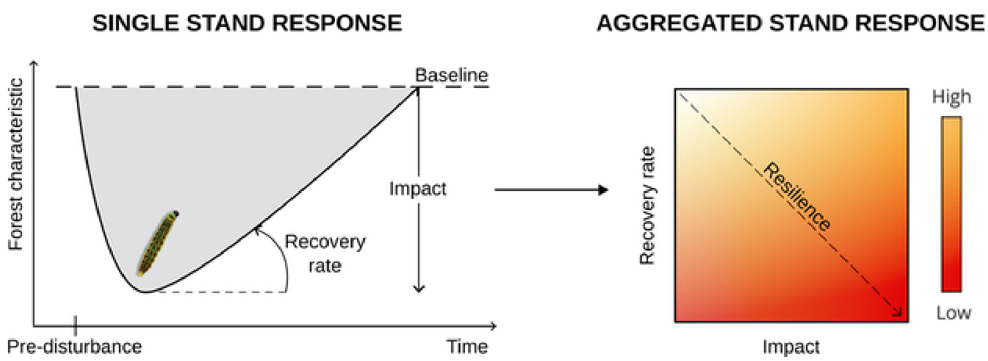

Figure 4. Illustration of resilience responses to SBW infestations at (left) stand and (right) landscape levels. At the stand level, we can track changes in a forest characteristic of interest (e.g. basal area) over time, following an infestations, in terms of impact and recovery rate. When we aggregate all the stand impact and recovery rate responses across the landscape, we obtain a bivariate space useful to estimate forest resilience at the landscape scale.

We found that summer precipitation as well as winter and summer temperature had the strongest influence on resilience outcomes, with lower precipitation and cooler temperature reducing infestation impact and promoting recovery (Figure 5). In addition, we observed that a greater proportion of remaining host tree species following infestations facilitated recovery. In turn, it may result in increased infestation impact as more food resources are available. Forest configuration, representing the spatial arrangement of forest stands, played a secondary role in these landscapes. In conclusion, we found that these effects were consistent across three key plant physiological processes, as captured by Landsat imagery, including vegetation greenness, structural development, and vegetation water content.

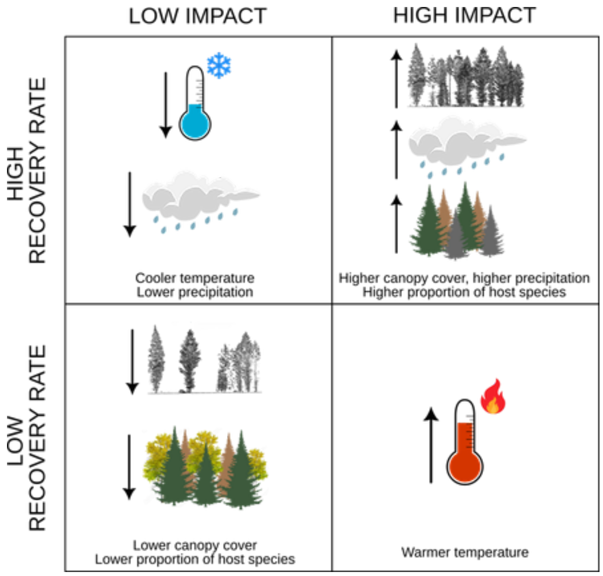

Figure 5. Effect of climate variables, species composition, and canopy cover on SBW infestation impact and subsequent recover rate. Greater forest resilience is represented by lower impact and faster recovery rates.

IMPLICATIONS FOR MANAGEMENT

While our project did not directly investigate the influence of management interventions on forest resilience to SBW infestations, it has highlighted four key areas of interest for forest managers at strategic and tactical levels:

- Forest structure, an attribute that can be directly manipulated through management interventions, such as thinning and harvesting, influences SBW infestation severity. Sparser and shorter canopies have proven to better resist infestations;
- Forest configuration, despite playing a secondary effect on resilience, has implications on disturbance severity. We found that a greater fragmentation of conifer stands, where these are intermixed with other land cover types, may increase infestation severity. This may be explained by SBW populations saturating the landscape as outbreaks peak;
- Resilience outcomes may vary by plant physiological processes, meaning that changes in basal area or canopy cover may be expected to yield distinct physiological responses linked to resilience, such as accelerated foliage recovery;
- As temperature and precipitation played a major role in shaping forest resilience outcomes to infestations, it is important to include climate in growth predictions, incorporate risk in management strategies, and continuous monitoring of forest resources.

This extension note was published as a summary of Tommaso Trotto's PhD project, chapters of which have been peer-reviewed and published in the Science of Remote Sensing (2024), Landscape Ecology (2025) and Ecological Indicators (2025).