Assessing the influence of stem form and damage on commercial hardwoods growth, volume, and biomass in Maine

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http://www.nsrcforest.org

Project Summary

Rationale: Northern hardwood species display a wide variety of stem forms and defects which can considerably reduce stem quality and complicate the management objectives of these species. Although commonly cited as limiting attributes of hardwood species, the influence of both stem form and damage remain largely unaccounted for in volume/biomass equations, assessments of internal wood quality, or even growth and yield models. In addition, the limited integration of these attributes in quantitative applications has left the efficacy of current tree classification systems used to manage these species untested. The purpose of this study was to determine the influence of stem form and damage on product potential, growth, survival, future sawlog value, and internal stem quality for prominent northern commercial hardwood species. The findings from these analyses will be used to propose a framework for a tree classification system that can be used to facilitate management of hardwood species in the northeast region.

Methods: Standing hardwood species on continuous forest inventory plots in Maine and New Hampshire were measured and received classifications based on their stem form and risk using a classification system developed by the Northern Hardwood Research Institute of New Brunswick. Hardwood and softwood species were also destructively sampled across several locations in the northeastern United States to assess the occurrence of internal stem decay for trees of varying stem form and risk. Using the standing tree data, regression analyses were conducted to predict the influence of stem form and risk, on potential sawlog recovery, annual diameter growth and probability of survival. These resultant equations were then incorporated as modifiers into FVS-ACD to quantify the impact of form and risk on future projections of sawlog value. Destructively sampled trees were modeled using a novel approach to simultaneously predict the occurrence and extent of decay. Various species-, climatic-, and tree-level factors were assessed to determine which had the greatest overall influence on decay prevalence.

Project Summary

Results: Potential sawlog recovery was found to be significantly lower for trees demonstrating multiple sweeps or stems, significant lean, significant forks on the lower portion of the bole, or extensive damage relative to trees of ideal stem form. Annual diameter growth was found to be 21% lower for trees with severe or extensive damage compared to those with little or moderate damage. The annual probability of survival was shown to be significantly lower for trees with multiple sweeps or stems compared to those with ideal form. Long term simulations using FVS-ACD indicated that forecasted stand level sawlog value was 16 – 28% lower when stem form and risk were accounted for depending on the percentage of non-ideal hardwood stems in a stand. Decay was 1.8 times more likely to occur in trees with signs of damage that were perceived have a moderate to high probability of mortality. The most influential factors for predicting the probability that decay would occur were tree taper and crown ratio.

Implications: Overall the results from this study indicated that stem form and risk have important implications on growth and yield as well as internal stem quality for hardwood species. The results from this work indicate that predictions from growth and yield models could be biased if not accounting for stem form and risk. A tree classification system which characterizes four classes of stem form and two classes of risk could be used to facilitate valuation of hardwood species and their management in the northeast region of the United States.

Background and Justification

- Northern hardwood and mixed-wood forests occupy approximately 20,000,000 ha of the forest land base spanning from New York into eastern Canada.

- The hardwood species in the northeast region generate substantial economic value as they have potential to yield high-value saw timber and veneer products.

- As an example of their value, in 2011 hardwood species accounted for one third of harvested saw log volume across Maine, New York, New Hampshire and Vermont. (NEFA 2013).

- USFS Forest Inventory and Analysis data indicates an increased prevalence of hardwood species in Maine and management of these species will likely become increasingly important.

Background and Justification

- Although hardwood species can derive valuable wood products, their stem quality is much more variable compared to softwood species.
- The variation in stem quality results from the wide range of stem forms and damage that these species can display.

Stem form attributes

- Significant forks
- Multiple stems
- Severe sweep

Stem damage

- Cavities
- Decay
- Fungal pathogens
- Cracks
- Seams and scars

Fork

Multiple stems

Decay

Fungal pathogens

- The high variation in stem quality can complicate both stem valuation and management of these species.

Background and Justification

1. Despite it being common knowledge that hardwood stem quality is highly variable, relatively little research has quantified the influence of stem form and damage on product recovery, internal stem quality, as well as growth and yield.

2. Exclusion of stem quality metrics such as stem form and damage in growth and yield models could lead to biased predictions of volume, biomass , growth, and survival.

3. In addition, the lack of formal assessments of these attributes leave the efficacy of silvicultural tools such as tree classification and marking systems untested.

Research Objectives

1. Assess the prevalence of different stem forms and damage across several prominent commercial hardwood species.

2. Quantify potential saw log product recovery as a function of a tree's size, stem form, and risk (stem damage).

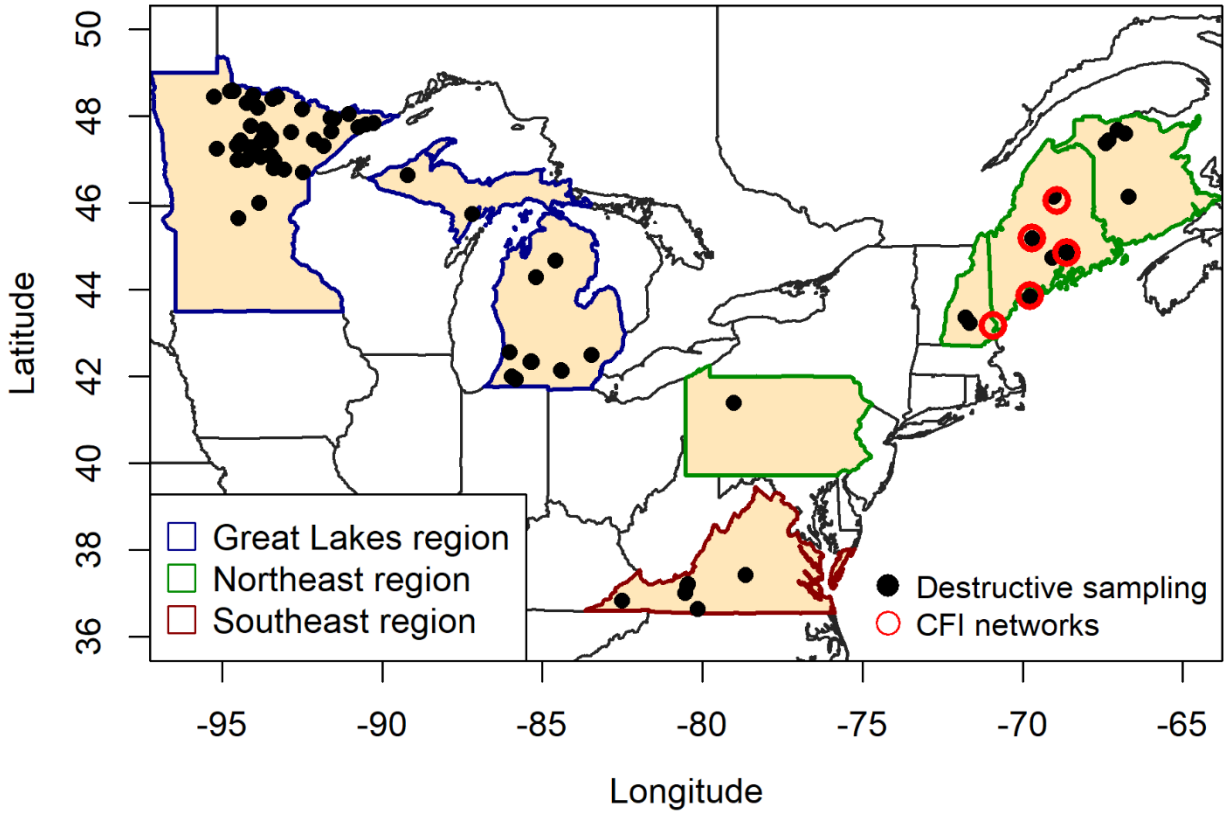
3. Incorporate stem form and risk into predictions of annual diameter growth, survival and future sawlog value.

4. Link tree, site, and species level variables to predictions of the occurrence and extent of internal stem decay.

5. Use findings from analyses to provide a recommendation for a tree classification system.

Methods: Data Collection

- Standing tree measurements were taken across five continuous forest inventory networks (Objectives 1- 3).
- Destructively sampled trees spanning 3 distinct geographic regions were used to assess internal stem decay (Objective 4).
- Destructively sampled trees were obtained from ongoing biomass sampling efforts, product recovery assessments conducted by the Northern Hardwood Research Institute (NHRI, New Brunswick), and past USFS biomass studies.



CFI Networks

- Austin Pond Research Forest
- Holt Research Forest
- Kingman Farms Research Forest
- Penobscot Experimental Forest
- Scientific Forest Management Area

Methods: Data Analysis

Objective 1: Binomial regression was used to assess the probability of occurrence of different stem forms and damage across red maple, red oak, sugar maple, and yellow birch.

Objective 2: Beta regression was used to model the ratio of sawlog to merchantable stem volume on an individual tree basis as a function of a tree's size, stem form, and risk.

Objective 3a: Nonlinear regression models were developed to test the effect of stem form and risk on predictions of annualized diameter growth and survival.

Objective 3b: Sawlog volume, growth, and survival modifiers were incorporated into FVS-ACD to assess the influence of form and risk on long term projections of stand level sawlog value.

Objective 4: Using destructively sampled trees, the occurrence and extent of internal stem decay were quantified using several different modelling frameworks.

Results: Objective 1

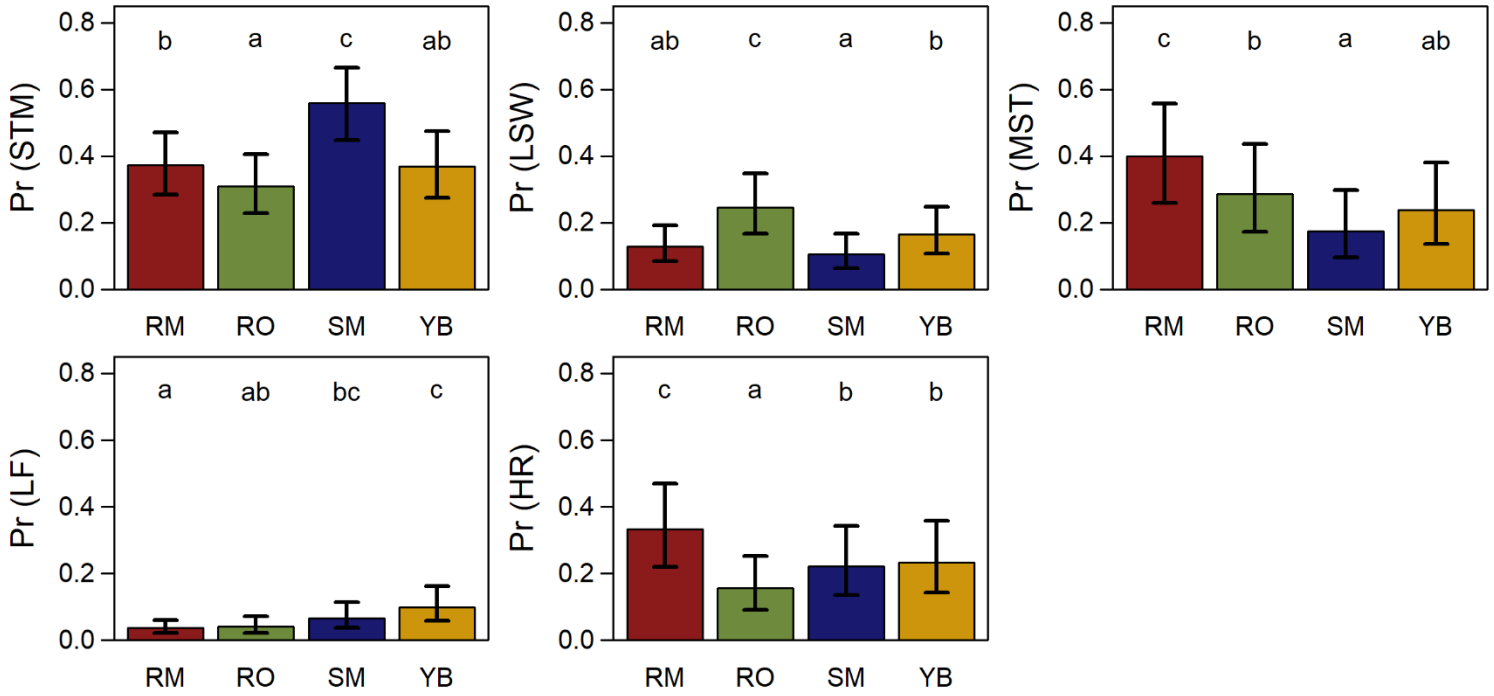


Figure 1. Least square means with 95% standard error by species (red maple – RM, red oak – RO, sugar maple – SM, yellow birch – YB) at a given diameter at breast height (DBH) for the probability of having either a single straight stem (STM), lean or sweep (LSW), multiple stems (MST), low forks (LF) or being high risk (HR). Unique letters indicate means that are statistically different from one another at $p < 0.05$

- Substantial variation in stem form and risk across hardwood species was observed.
- Sugar maple had the largest proportion of ideally formed trees (STM).
- Red maple demonstrated the largest range of stem form and risk.

Results: Objective 2

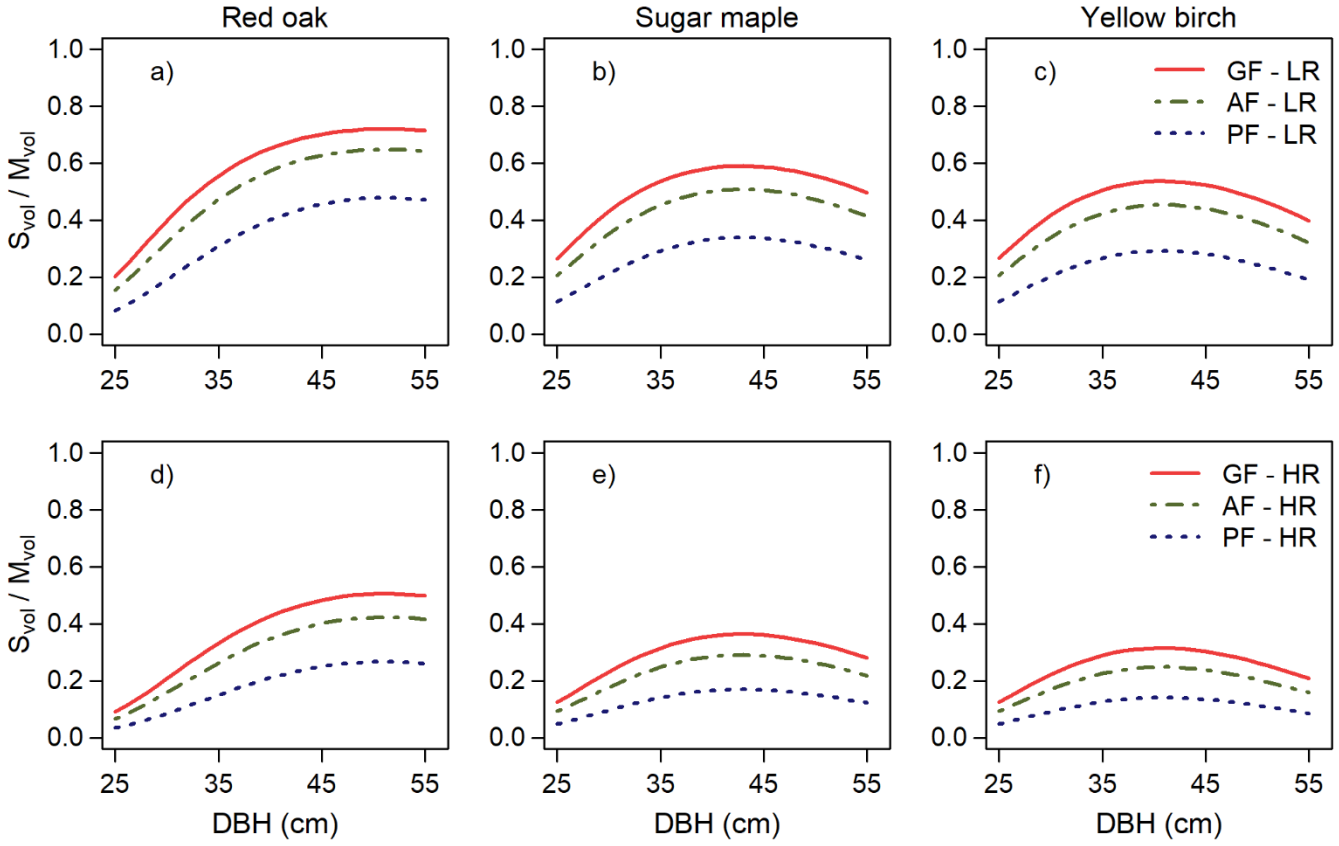


Figure 2. Predictions of sawlog to merchantable volume ratio (S_{vol}/M_{vol}) across species, diameter at breast height (DBH; cm), form (good form - GF, acceptable form - AF, poor form – PF) and risk class (low risk – LR and high risk - HR) for red oak (a,d), sugar maple (b, e) and yellow birch (c, f). AF, GF and PF correspond to acceptable form (tree with multiple stems, sweep or significant lean), good form (tree with single straight stem) and poor form (tree with at least 1 significant fork on first 5 m of stem) respectively. LR and HR correspond to low risk (trees with little or no damage) and high risk trees (trees with extensive or severe damage) respectively.

- Potential sawlog recovery was 8% lower for AF trees and 22% lower for PF trees compared to trees of ideal form (GF).
- Trees considered to be HR (severe or extensive damage) had 20 % lower potential sawlog volume than LR trees.

Results: Objective 3a

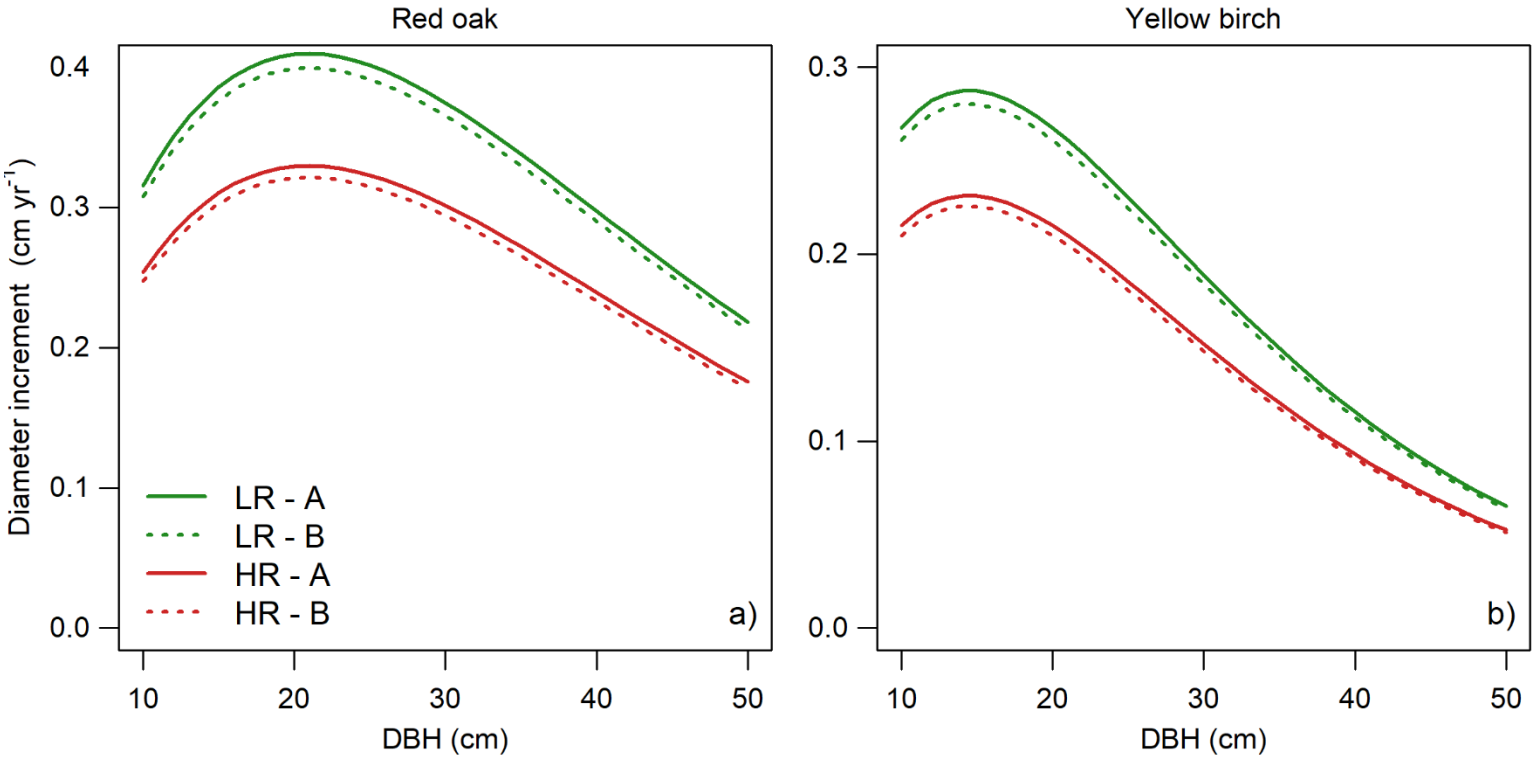


Figure 3. Predictions of annual diameter increment across DBH, stem form (A, B), risk class (LR, HR) for red oak (a) and yellow birch (b). Form class A corresponds to trees with single straight stems or those with significant forks on the lower portion of their bole and form class B corresponds to trees with either multiple stems, multiple sweeps, or significant lean. LR and HR correspond to low risk (trees with little or no damage) and high risk trees (trees with extensive or severe damage).

- Difference in annual diameter growth between form classes was statistically significant but the magnitude of the difference was minimal (2.5%).
- High risk trees had 21.7% lower annual diameter growth than low risk trees.

Results: Objective 3a

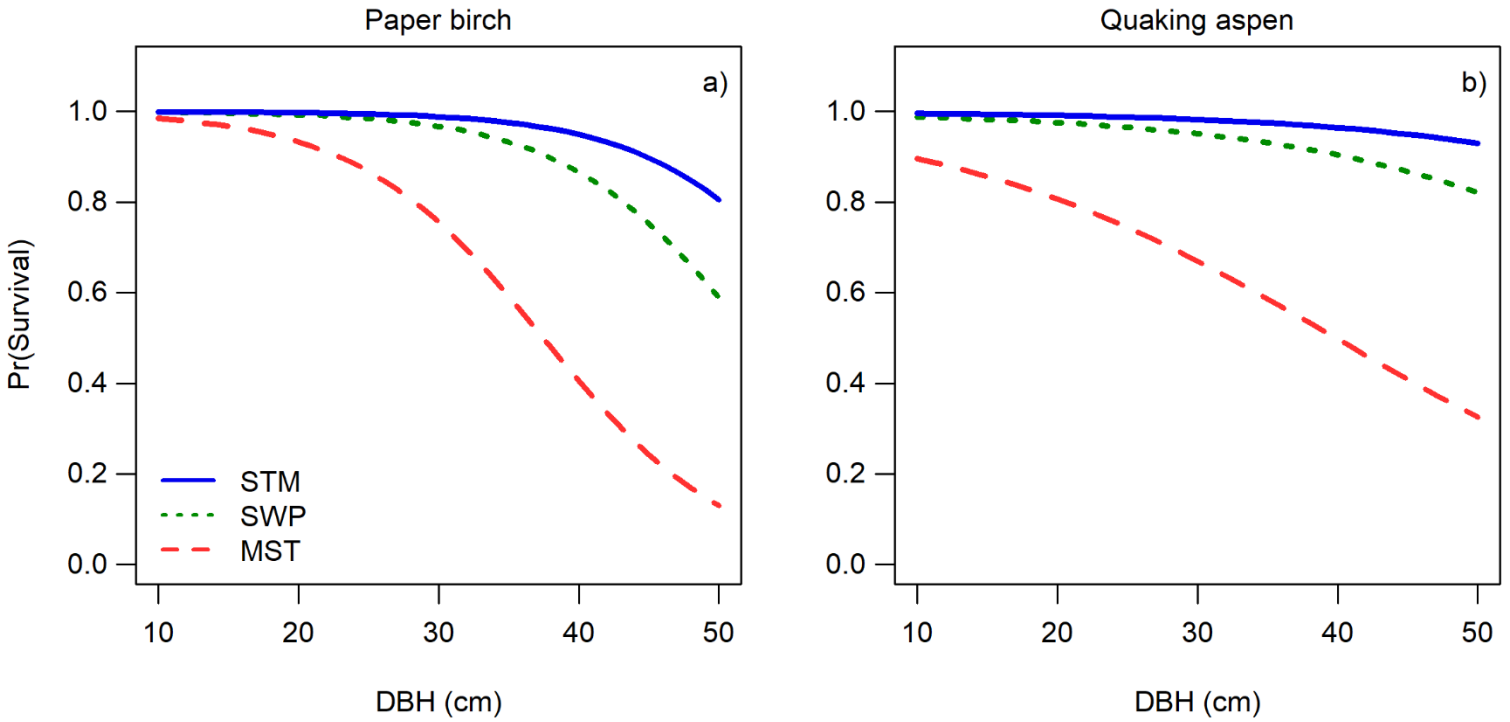


Figure 4. Predictions of annual probability of survival (Pr(Surivival)) across DBH and stem form (STM, SWP, MST) for paper birch (a) and quaking aspen (b). Form class STM corresponds to trees with single straight stems, form class SWP corresponds to trees with multiple sweeps, and form class MST corresponds to trees with multiple stems.

- Trees displaying multiple sweeps (SWP) or multiple stems (MST) had significantly lower survival probabilities than trees of ideal form (STM).

Results: Objective 3b

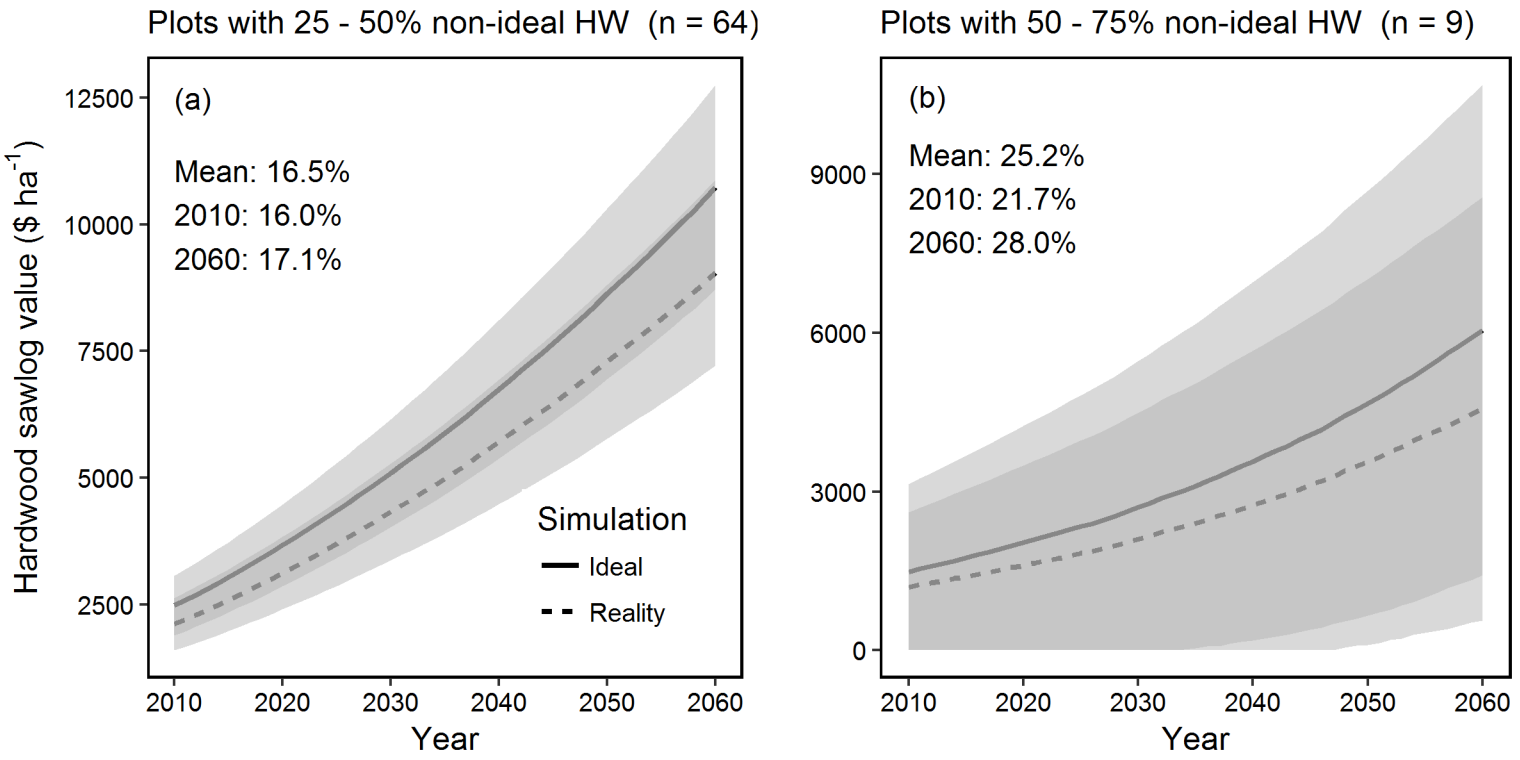


Figure 5. Predictions of future stand-level hardwood sawlog product value ($ ha^{-1}) with 95% confidence intervals between a dataset where trees were assumed to have ideal stem form and be low risk (Ideal) and a dataset where trees had form and risk classes assigned from the field (Reality). Projections are shown for plots with 25 – 50% non-ideal hardwood stems (trees that did not have ideal stem form or were high risk), (panel a) and 50 – 75% non-ideal hardwood stems (panel b). The average annual percent difference, and percent differences in 2010 and 2060 are shown between the two datasets.

- The average annual percent difference in stand level sawlog volume was substantially lower when stem form and risk were taken into consideration in 50 year FVS-ACD simulations.
- The magnitude of the difference in sawlog value was related to the percentage of non-ideal hardwoods in a stand.

Results: Objective 4

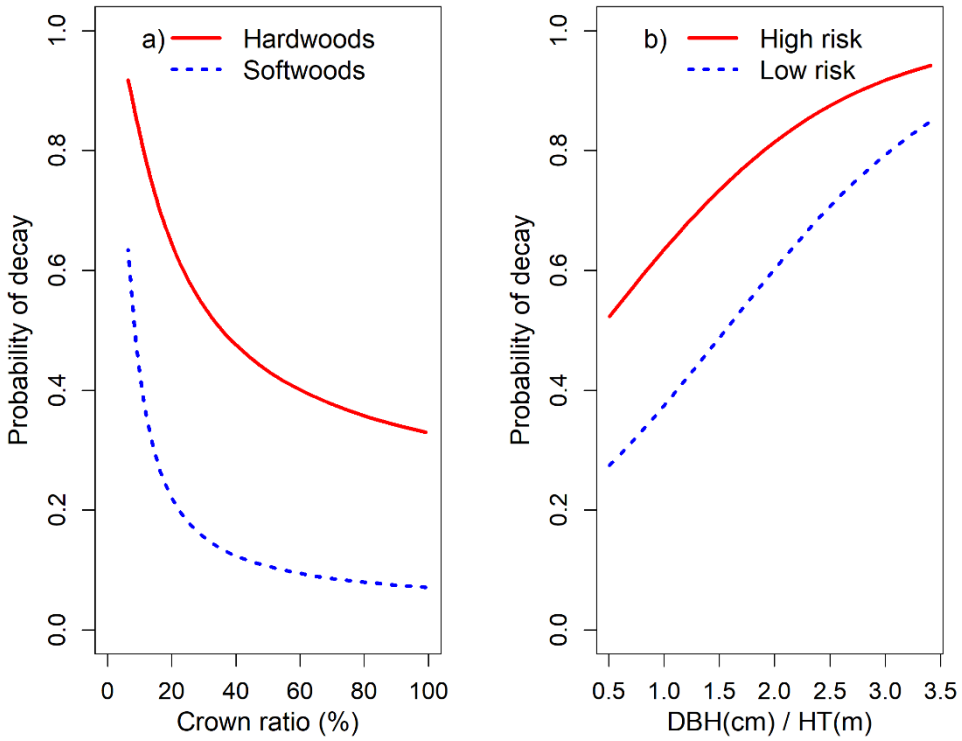


Figure 4. Probability of decay occurrence as a function of (a) crown ratio (%) and species group (hardwood/softwood) and (b) diameter to height ratio (DBH/HT) and risk classification (high/low) based on external symptoms which may lead to loss in value or increase in mortality.

- The probability of decay occurring decreased as crown ratio increased and increased as diameter-height ratio increased.
- The probability of decay occurring was 1.8 times higher in high risk trees and significantly higher in hardwoods (e.g. aspen and red maple) than softwoods (e.g. white pine).

Results: Objective 5

- Proposed tree classification system would be comprised of 4 categories of stem form and 2 categories of risk

Single straight stem

Multiple stems

Sweep - lean

Low fork

Low Risk	High Risk

Implications and Applications in the Northern Forest Region

- Tree classification systems can be used to facilitate hardwood management in the Northeast Region by being able to differentiate between trees of varying product potential and vigor.

- Inclusion of stem form and risk in growth and yield models can enhance forecasting of forest resources by improving predictions of product potential, growth, and survival.

- Long term simulations indicated that projections of future stand value could be biased if stem form and risk are not accounted for in growth and yield models.

Future Directions

- USFS FIA is currently implementing proposed tree classification framework on 20% of state wide inventory. Collected data will be used to further validate models developed in the current study.

- When possible, destructive sampling will continue. Data will be used to refine models of decay and biomass in trees of varying risk and form.

- The focus will shift from destructive sampling to using remote sensing technologies to assess tree form and improve estimates of tree volume. Terrestrial LiDAR scans (TLS) from the Harvard Forest are currently being processed. Upon completion, TLS will be evaluated as a tool for measuring stem volume and form. A field campaign is planned for the Acadia Research Forest this summer to obtain additional data.

List of Products

Peer Reviewed Journal Publications:

Castle, M.E., Weiskittel, A.R., Ducey, M.J., Wagner, R.G., Frank, J. and Pelletier, G., 2018. Evaluating the influence of stem form and damage on individual tree diameter increment and survival in the Acadian Region: Implications for predicting future value of northern commercial hardwood stands. Can. J. For. Res. Accepted.

Castle, M., Weiskittel, A., Wagner, R., Ducey, M., Frank, J. and Pelletier, G., 2017 Variation in stem form and risk of four commercially important hardwood species in the Acadian Forest: implications for potential sawlog volume and tree classification systems. Can. J. For. Res. 47, 1457–1467.

Frank, J., Castle, M.E., Westfall, J.A., Weiskittel, A.R., MacFarlane, D.W., Baral, S.K., Radtke, P.J. and Pelletier, G., 2018. Variation in occurrence and extent of internal stem decay in standing trees across the eastern US and Canada: evaluation of alternative modelling approaches and influential factors. Forestry. https://doi.org/10.1093/forestry/cpx054.

Theses:

Castle, M.E. 2017. Evaluating the Influence of Stem Form and Vigor on Product Potential, Growth, and Survival for Several Northern Commercial Hardwood Species, Master's thesis, University of Maine.