Classifying and Evaluating Partial Harvests and Their Effect on Stand Dynamics in Northern Maine

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Occurrence and intensity of partial harvest operations are driven both by stand- and tree-level attributes such as ownership, stand density, and bioclimatic conditions as well as species, size, and competitive status of individual trees.

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http://www.nsrcforest.org

Project Summary

Rationale

In-depth characterization and quantification of partial harvesting in Maine and its effect on post-harvest stand characteristics and dynamics are lacking but vital because limited knowledge of subsequent stand development fundamentally impedes accurate wood supply analyses and predictions of future forest productivity.

Project Objectives

Using both field measurements and remote sensing data sources we aimed to quantitatively characterize harvesting trends across the entire state of Maine:

- Refine and evaluate the distribution of partial harvest conditions in northern Maine.
- Map incremental changes in partial harvest conditions across a ~10 million acre study area and a ~30 year time period.
- Predict and quantify change in species composition and structure of residual stands created following partial harvest.

Approach

- Map partial harvest conditions across a ~30 year time period using spatial models of basal area removed, residual basal area, and pre-harvest species composition.
- Predict/project the characteristics and development of residual stands created from partial harvesting using newly developed harvest related models.

Project Summary

Major findings

- Analysis of trends in harvest conditions found little evidence of contemporary shifts in partial harvest practices as characterized by the proposed harvest classification system.
- Maps and developed models revealed that regional differences in factors that influence harvest regimes such as ownership, forest management legacy, and bioclimatic conditions caused apparent regional differences in post-harvest conditions.

Implications for the Northern Forest region

- Derived harvest probability & intensity functions as well as harvest response equations were incorporated as new submodels into the Acadian Variant of the Forest Vegetation Simulator (FVS-ACD) and will improve prediction accuracy of stand-level post-harvest conditions and dynamics substantially.
- Findings suggest that that harvesting in northern Maine might be less opportunistic and short-term driven than generally perceived.
- Highlights the complex array of factors that influence harvesting patterns and provides a framework for better representing contrasting harvest behavior in future
- wood supply projections.

Background and Justification

- The Acadian Forest of Maine is an exemplary region demonstrating the forestry paradigm shift from intensive, large-scale management operations to spatially more restricted, partial harvest activities.

- Within several years of implementing a Forest Practice Act in 1989, clearcutting in Maine decreased dramatically from close to 50% in 1989 to about 5-7% of the total harvest area today while the area of partial harvesting has more than doubled from about 50,000 ha yr^{-1} in the mid-1980s to about 125,000 ha yr^{-1}.

- Given the potential widespread application of novel partial harvest operations in recent years, forest dynamics as well as the resulting potential wood supply are likely to change in the mid- and long-term.

- Unfortunately, the harvest reporting required of landowners by the Maine Forest Service does not provide a clear description of partial harvests beyond several simple harvest categories.

- As a result, detailed information on extent and characteristics of the area potentially available for different harvest types, so called potential candidate acreage, is lacking.

Background and Justification

- A more in-depth characterization and quantification of partial harvesting and its effect on post-harvest stand characteristics and dynamics are vital because limited knowledge of subsequent stand development fundamentally impedes accurate wood supply analyses and predictions of future forest productivity.

- Using both field measurements and remote sensing data sources we aimed to quantitatively characterize harvesting trends across northern Maine with the following supporting objectives:
  1) Refine and evaluate the distribution of partial harvest conditions in Maine.
  2) Map incremental changes in partial harvest conditions across a ~10 million acre study area and a ~30 year time period.
  3) Predict and quantify change in species composition and structure of residual stands created following partial harvest.

Methods

- USFS Forest Inventory and Analysis plot measurements (2000-2015) were used to classify harvest events according to a previously proposed harvest classification system based on basal area removal, residual basal area, and overstory composition (hardwood/softwood proportions).

- Satellite-derived maps from previous NSRC projects and other sources were evaluated as a basis for mapping harvest classes across the state. Existing maps presented difficulties in characterizing harvesting trends and residual stand conditions due to variations in map accuracy and biased detection of harvests.

- We adopted a new approach to Landsat-based harvest mapping using multi-objective machine learning algorithms that balance errors of omission and commission, yielding more consistent and more accurate estimation and spatial representation of harvest area.

- This machine learning approach is computationally demanding and relies on extensive reference data to train ML models. We have leveraged other funding to partner with software and cyberinfrastructure engineers in the University of Maine System Advanced Computing Group in order to develop algorithm implementations and workflows needed to map harvests statewide over a multi-decadal period.

Methods

- To further evaluate post-partial harvest stand characteristics different stand- and combined stand- with tree-level modeling approaches to predict stand- and/or tree-level harvest probability and intensity were examined:
  1) Direct prediction of stand-level basal area removal as a percentage of initial total stand basal area.
  2) Prediction of stand-level harvest probability and subsequently stand-level basal area removal as a percentage of initial total stand basal area of harvested plots only in a single two-part model.
  3) Prediction of stand-level harvest probability and subsequently individual tree harvest probability for only harvested plots in a single two-part model.

- Permanent plot data collected across Maine by the FIA Program were utilized.

- Various stand- and tree-level attributes were evaluated as potential explanatory variables, e.g. quadratic mean diameter (QMD), total basal area, relative density, elevation and slope, site productivity, horizontal distance to nearest improved road, ownership, species, crown ratio, basal area in larger trees.

Methods

- Owing to their binary or proportional structure, all response variables (stand- and tree-level harvest probability, proportion of stand-level basal area removed) were modeled using nonlinear mixed effects modeling (*NLME*) and a logistic function of the following form:

$$Y = \left(\frac{1}{1 + exp\big(-(X\beta)\big)}\right)^{\frac{1}{YIP}}$$

  where Y is the response variable, $X\beta$ is the model-specific explanatory variable design matrix with the associated estimated parameters and YIP is years in period to allow for the prediction of annualized values by accounting for the approximately 5-year inventory cycles.

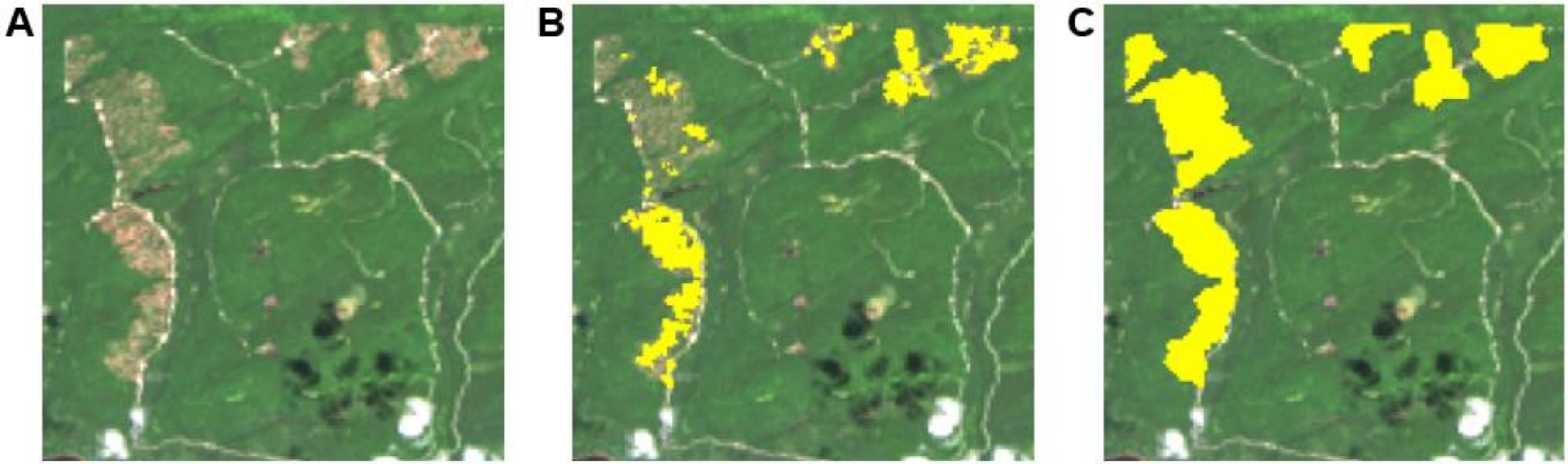
Results

- Classification of USFS FIA plot data produced little evidence of contemporary shifts in partial harvest practices as characterized by basal area removal, residual basal area, and coarse measures of overstory composition (i.e., proportions of softwood and hardwood basal area). We considered several strategies for modifying the harvest classification system to capture greater detail in either silvicultural practices or stand characteristics, but found none that were likely to support extension of plot-level analyses to Landsat-based mapping objectives using available data.

- Available maps suggested regional differences in factors that influence harvest regimes such as ownership, forest management legacy, and bioclimatic conditions. However, Landsat-derived maps made available from previous NSRC projects also presented some difficulty in characterizing harvest trends and residual stand conditions due to spatiotemporal variability in map accuracy.

- Satellite-based change detection maps from other sources were evaluated for use, but were found to be of insufficient accuracy to support detailed analyses of harvest trends. Available Landsat-derived maps characteristically omit light partial harvests, introducing bias in analyses of harvest practices.

Results



Example of annual forest harvest detection outcomes, 2017-2018. A Landsat 8 image acquired during the summer of 2018, displayed as a natural color composite (A), reveals multiple partial harvests executed during the previous year. Available global forest change data[1] (B) captures the harvest area of greater apparent intensity (lower residual canopy cover). Our multi-objective machine learning approach to harvest mapping (C) is capable of capturing both light and heavy partial harvests at high accuracy.

- We adopted a new approach to Landsat-based harvest mapping that relies on multi-objective machine learning algorithms to balance errors of omission and commission, yielding more consistent estimation and spatial representation of harvest area. Applied to annual time series of Landsat images, this approach is capable of improved detection and spatial representation of light partial harvests missed by other data sources.

[1] Hansen, M. C, et al. (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science, 342*, 850-853. doi: [10.1126/science.1244693](https://doi.org/10.1126/science.1244693)

Results

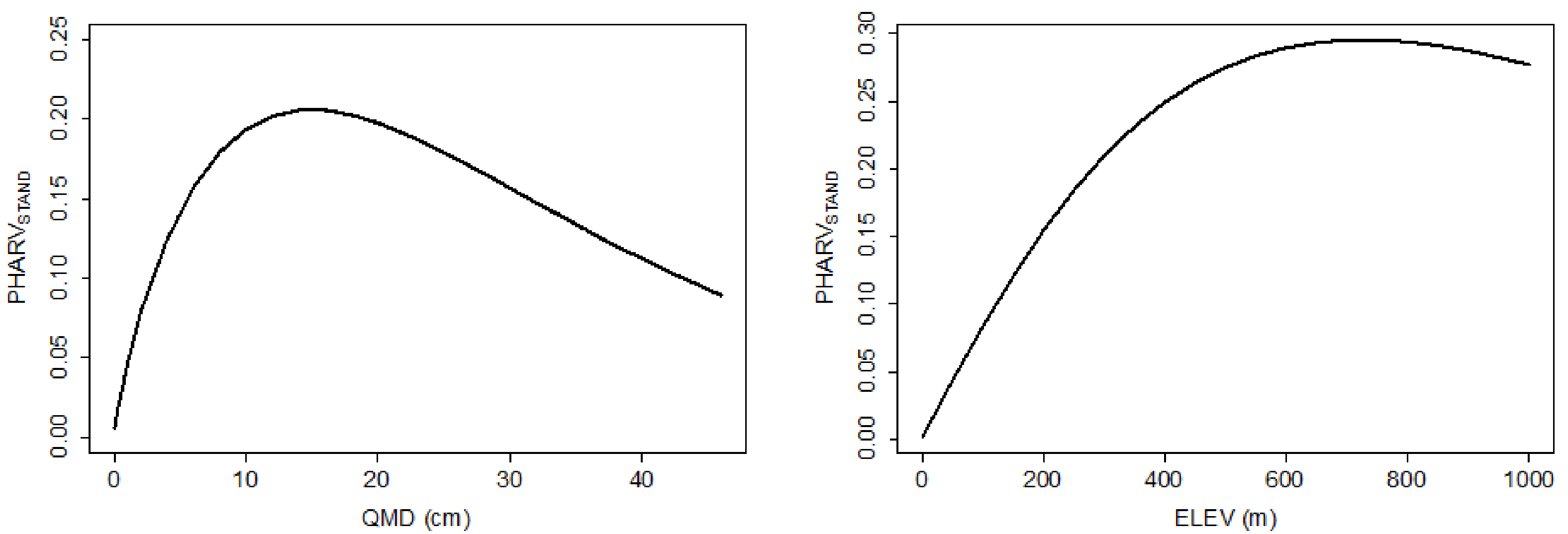
- Our multi-objective machine learning approach to harvest mapping uses computationally demanding algorithms and extensive reference data to train and validate models. To build this approach into a tractable solution for large-area analyses, we have leveraged other funding to partner with software and cyberinfrastructure engineers in the University of Maine System Advanced Computing Group. Over the course of this project, we have developed highly parallelized algorithm implementations and efficient image processing and reference data handling workflows.

- Our newly developed software will overcome computation and data management barriers that have thus far limited work to a northern Maine study area. Statewide expansion of analysis objectives will be made possible by efficient, semi-automated production of new maps with substantially improved detection accuracy for partial harvests.

- We have implemented similar multi-objective machine learning algorithms and image processing workflows to develop new maps of forest composition, including more detailed forest typing and predictions of individual tree species relative abundance. Combined with more accurate and less biased maps of partial harvests, these data will enable more accurate and detailed spatial analyses of harvest effects than data available at the onset of this project.

Results

- Stand density, elevation, number of seedlings of commercially valuable hard- and softwood species, and ownership were among stand-level attributes most influential on stand-level harvest probability and intensity.
- Forest stands on private property not only were more likely to be harvested, harvest intensity was also greater compared to (harvested) public forests.
- Harvest operations appeared to be postponed until a sufficient number of seedlings of preferred tree species established underneath the beneficial canopy of potential seed trees.
- The observed sigmoidal relationship between QMD and stand-level harvest probability likely reflects prevailing forest management considerations, namely i) delay of first harvest intervention in younger stands until the operation is economically viable and ii) retention and/or conservation of older, potentially less disturbed and thus ecologically valuable forest patches.

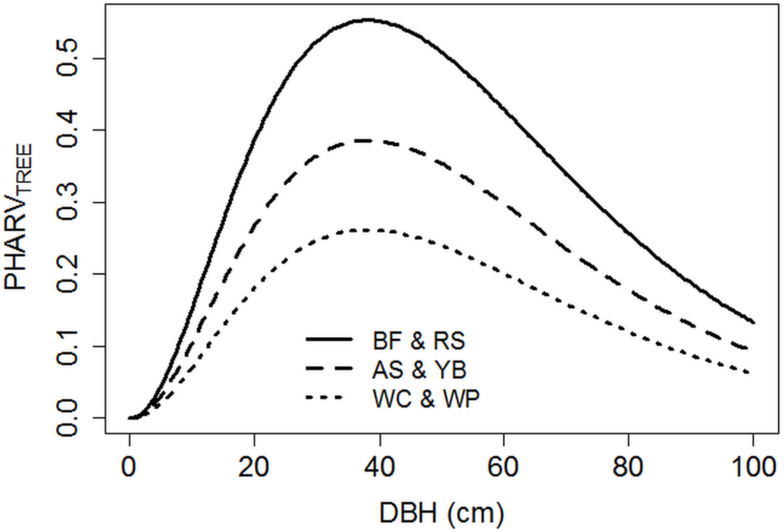


Predicted 5-year stand-level harvest probability ($PHARV_{STAND}$) as a function of quadratic mean diameter (QMD) and elevation (ELEV) with all other explanatory variables of the underlying model equation set to their mean.

Results

- Intermediate and suppressed trees with comparatively small crown exhibited a higher harvest probability.
- Decreasing tree-level harvest probability of individuals approximately > 40 cm DBH observed in our study likely are in part a result of retaining ecologically valuable habitat or legacy trees of lower commercial value.
- With the exception of red spruce, most commercially valuable species appeared to be less likely to be harvested compared to less economically important ones in our study.

Predicted 5-year harvest probability ($PHARV_{TREE}$) for individual balsam fir/red spruce (BF & RS), ash/yellow birch (AS & YB), and northern white cedar/white pine trees (WC & WP) of harvested plots as a function of diameter at breast height (DBH) with all other explanatory variables of the underlying equation set to their mean.



- Overall, differences in prediction accuracy between the examined modelling approaches to predict harvest probability and intensity were small with the combined stand- and tree-level approach performing slightly better.

Implications and applications in the Northern Forest region

- The newly added, harvest related FVS-ACD submodels substantially improve prediction accuracy of stand-level post-harvest conditions and dynamics. Consequently, projections of stand characteristics after partial harvest will be more reliable and help to assess future forest productivity and wood supply potential.

- Overall, our findings suggest that harvesting in Maine might be less opportunistic and short-term driven than generally perceived.

Future directions

- Information derived from plot-level analyses and new maps of partial harvest conditions can be used to define common classes of partial harvest and the resulting residual stand conditions.
- Development of harvest response functions for common hardwood species such as yellow birch, red and sugar maple, and red oak to further improve prediction accuracy of the Acadian Variant of the Forest Vegetation Simulator (FVS-ACD).
- Using the updated FVS-ACD development of residual stands created from common classes of partial harvest to quantify short- and long-term shifts in species composition and structure can be projected.
- Finally, an all new wood supply analysis for the state of Maine can be conducted based on results from above research efforts.

List of products

Peer-reviewed publications

- Kuehne C., Weiskittel A.R., Legaard K.R., Simons-Legaard E.M. 2019. Development and comparison of various stand- and tree-level modeling approaches to predict harvest occurrence and intensity across the mixed forests in Maine, northeastern US. Scandinavian Journal of Forest Research 34(8): 739-750.
- Kuehne C., Weiskittel A.R., Wagner R.G., Roth B.E. 2016. Development and evaluation of individual tree- and stand-level approaches for predicting spruce-fir response to commercial thinning in Maine, USA. Forest Ecology and Management 376: 84-95.

Research report

- Kuehne C., Weiskittel A., Wagner R., Roth B. 2016. Development and evaluation of stand and individual tree-level growth and mortality modifiers for thinned spruce-fir (Picea-Abies) forests of the Acadian Region. In: Roth B.E. (ed.) Cooperative Forestry Research Unit: 2015 Annual Report. University of Maine. Orono, ME. 21-23.

Presentations

- Kuehne C., Weiskittel A.R., Wagner R.G. 2015. Growth and mortality modifiers for thinned spruce-fir stands of the Acadian Forest. 2015 Northeastern Mensurationists Organization (NEMO) Annual Meeting. Stowe, VT.
- Howard N., Colella N., Legaard K., Nellutla S., McCoy E., Whitsel L., Wilson C., Segee B. 2018. Adventures of two student research computing facilitators. Practice and Experience in Advanced Research Computing Conference Series, Pittsburgh, PA.
- Legaard K., Simons-Legaard E., Weiskittel A., Whitsel L., Wilson C. 2019. Use of multi-objective machine learning and high performance computing to reduce prediction bias in forest maps. USFS 2019 FIA Stakeholder Science Meeting. Knoxville, TN.

Other tangible products

- NSF Northeast Cyberteam Project, 2017. Using genetic algorithms and support vector machines in forest mapping. Legaard K., Segee B., Whitsel L., Wilson C.

Additional funding & leveraged grants

- $34,102 - Cooperative Forest Research Unit (CFRU, UMaine). Project title: Development of individual-tree and stand-level approaches for predicting hardwood mortality and growth response to forest management treatments in mixed-species forests of northeastern North America.
- $5,000 - University of Maine Research Reinvestment Fund Undergraduate Assistantship Award. Project title: Leveraging machine learning and high-performance computing to deliver the spatial data needed by Maine’s forest industry. University of Maine Research Reinvestment Fund Undergraduate Assistantship Award.