Long-term outcomes and tradeoffs of forest policy and management practices on the broad-scale sustainability of forest resources: wood supply, carbon, and wildlife habitat

Principal Investigator:
Erin Simons-Legaard, School of Forest Resources, University of Maine, Orono, ME 04469-5755, erin.simons@maine.edu

Co-Principal Investigators:
Kasey Legaard, School of Forest Resources , University of Maine, kasey.legaard@maine.edu
Jeremy Wilson, Harris Center for Conservation Education, wilson@harriscenter.org
Steve Sader, School of Forest Resources, University of Maine, sasader@maine.edu

Collaborators:
Andrew Lister, U.S. Forest Service Northern Research Station, alister@fs.fed.us
Brian Sturtevant, U.S. Forest Service, Northern Research Station, bsturtevant@fs.fed.us

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- We used the forest landscape model LANDIS-II to simulate future forest conditions (2010-2110) across 10 million acres of commercial forestland in Maine
- Projections suggest that wood supply, carbon stocks, and habitat availability for wildlife dependent on late-successional forest would be benefitted if forest management were less reliant on partial harvesting.

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http://www.nsrcforest.org

Project Summary:

The natural resources of the Northern Forest and the economies that depend on them are coming under increasing threat from a complex of anthropogenic disturbances. Many of these disturbances originate in large part outside the region (e.g., acid rain, mercury pollution, climate change) and will require regulatory or market-based solutions. Other disturbances have roots in the region (e.g., harvesting, fragmentation, parcelization), providing a valuable opportunity for research to quantify disturbance effects and facilitate better land management.

In large commercially-managed forests, particularly those that are highly parcelized and privately owned, understanding how management will impact landscape pattern and future forest dynamics requires consideration of differences in management between landowners. We used the spatially-explicit forest landscape model LANDIS-II (LANDscape Disturbance and Succession) to simulate future forest conditions (2010-2110) across 10 million acres of commercial forestland in Maine under alternative scenarios of forest management. Maine is a major producer of timber and wood products in the Northern Forest, however, concerns over the long-term sustainability of Maine's forest resources have arisen as forest policy change, parcelization, and ownership change have reshaped timber harvesting trends and patterns. We designed scenarios to compare the current harvest regime , characterized by a reliance on partial harvesting, to the regime that was present prior to forest policy change in the early 1990s, which included more clearcutting but fewer total acreage harvested annually. **Simulations allowed us to address the hypothesis that management strategies that include very limited even-aged management and extensive partial harvesting in a predominantly spruce-fir forest will result in *timber harvesting rates that are unsustainable, reduced forest carbon stocks, and negative impacts on wildlife habitats*.**

Results predict that current harvest rates, if maintained, will be marginally sustainable over the next 100 years, but aboveground live biomass (and, thus, carbon stocks) would be greater if the relative proportion of acreage clearcut vs. partial harvest were to increase. Predictions also suggest that there would be more late-successional forest in the future with more clearcut harvesting because fewer total acres would be harvested annually in order to achieve the same volume. Much of the Northern Forest has experienced similar changes in policy, ownership and forest management as have occurred in Maine; our approach and analyses, thus, will be readily transferable to other areas of the Northern Forest and similar working forests in northern hardwood-conifer regions.

Background and Justification:

Over the last few decades, timber harvesting patterns on Maine's commercial forestlands have evolved under the influence of significant changes in forest management strategy and forest policy. During the 1970s and 1980s, timber harvest rates were driven by the salvage of spruce-fir forest infested by the spruce budworm ((*Chorisoneura fumiferana* (Clem.)) via clearcut harvesting. This native pest periodically infests the spruce-fir forests of the boreal and subboreal regions of eastern North America and causes widespread defoliation, growth reduction, and mortality of balsam fir (*Abies balsamea*) and spruce (*Picea* spp.) trees. Public concern about the size of the openings created by some large clearcuts ultimately led to the passage of Maine's first harvest regulations (i.e., the Maine Forest Practices Act (MFPA)) in 1989.

In the wake of implementation, rates of clearcut harvesting declined from ~40% of the harvest acreage in 1990 to <5% in 2000 (Figure 1). Accompanying this intended effect was the unintended effect that the total annual acreage doubled during that same period as landowners increased their rates of partial harvesting in order to maintain rates of volume removal. This effect was also unanticipated as no attempt was made prior to implementation of the MFPA to forecast the potential impacts of the policy changes on future forest conditions or the sustainability of Maine's forest resources. Further, those same policy changes may have also contributed to the later widespread divestiture of timberland by forest product companies in Maine. Between 1995 and 2005, greater than 80% of the timberland in Maine, for example, changed ownership, often 2 or three times. What was a vertically-integrated landscape owned by large forest products companies is now substantially more parcelized and owned primarily by financial investment firms that are less tied to sustainable timber production than the previous industrial owners. These trends, and a lack of understanding about their effects, are not unique to Maine, and to address critical knowledge gaps we proposed to use the forest landscape model LANDIS-II (Scheller et al. 2007) to simulate future forest conditions across 10 million acres of commercial forestland in Maine (Figure 2).

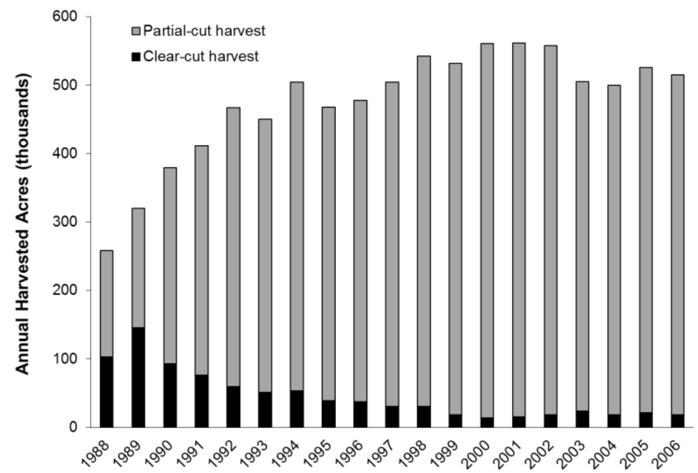

Figure 1. Annual acres harvested by clearcut (black bars) and partial harvest (gray bars) between 1988 and 2006.

Background and Justification:

Landscape simulation has become an essential tool for understanding the long-term effects of land-use activities across large areas. Spatially explicit simulations of forest disturbance and succession provide information about future forest conditions critical to evaluating interactions between resource management and ecosystem process. Forest landscape models such as LANDIS (LANDscape DIsturbance and Succession) have been used to simulate the effects of alternative management strategies on forest composition and landscape pattern (Mehta et al. 2004, Radeloff et al. 2006, Zollner et al. 2008), wildfire dynamics (Sturtevant et al. 2009), habitat suitability (Larson et al. 2004, Shifley et al. 2006, Shifley et al. 2008), and carbon sequestration (Swanson 2009). This body of research suggests that even a small difference in management strategy can be a primary driver of broad-scale forest dynamics, and that modifying forest management plans to incorporate non-timber objectives such as biodiversity, recreation, or sequestration of atmospheric carbon typically requires important tradeoffs when trying to meet both ecological and economic objectives.

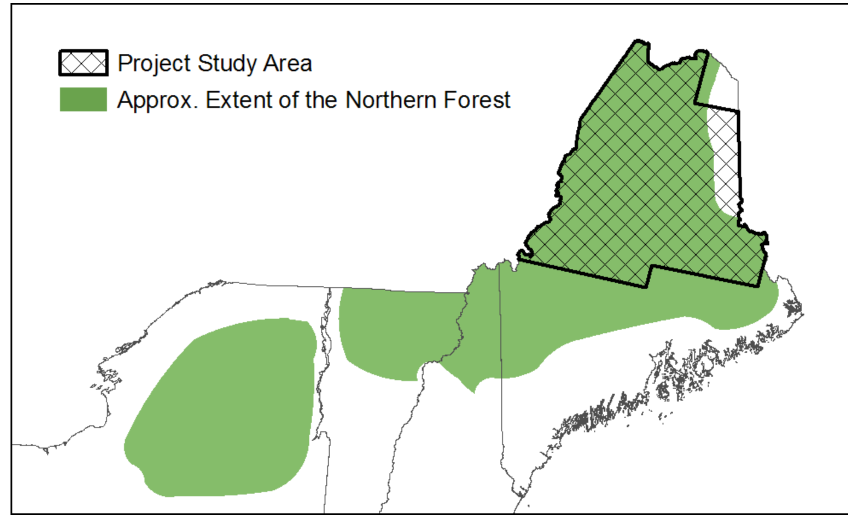

Figure 2. Study area encompassed approximately10 million acres of commercial forestlands in Maine and the Northern Forest.

The goal of our project was to use landscape simulation to provide a better understanding of the interacting effects of forest policy and forest management strategy on the long-term sustainability of important forest resources in the Northern Forest. Our objectives were to: 1) quantify recent (2000-2010) forest harvesting rates and patterns; 2) parameterize the forest landscape model LANDIS-II to northeastern tree species assemblages; 3) simulate future (2010-2110) forest conditions under recent harvesting trends (Objective 1) and alternative trends, including patterns and rates pre-dating current forest policy in Maine; and 4) quantify and compare the future status and trends of wood supply, carbon stocks, and key wildlife habitats under current and alternative harvesting scenarios.

Methods:

We used LANDIS-II to emulate disturbance-succession dynamics across a diverse landscape, including a variety of private landowner types (e.g., Timber Investment Management Organizations, Real Estate Investment Trusts, and Non-profit organizations (e.g., The Nature Conservancy)), as well as state and federal public and reserve areas. Within LANDIS-II, the forest is represented by a grid of interacting cells and conditions within each cell are identified by tree species and forest age (Figure 3). We modeled 13 ecologically and economically important hardwood and softwood species (Table 1). We used maps of percent biomass developed in a companion study (Sader et al. 2013 *Unpublished Report*[1]) to identify the three most abundant species for each cell, and assigned cohorts based on relative species abundance.

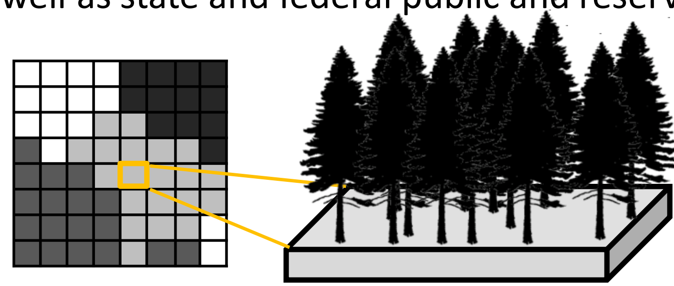

Figure 3.Example of the cell-based system used by LANDIS-II to represent a single species (Red Spruce) even-aged (100 year old) area of forest. Conditions within each cell are assumed to be homogenous.

We assigned age to each cell using a combination of disturbance history (Sader et al. 2013) and U.S. Forest Inventory and Analysis (FIA) data made available through a collaborative agreement[2]. Cells that had received a stand- replacing disturbance 1970-2010 were assigned age based on time since disturbance; otherwise, age was assigned randomly to contiguous cell neighborhoods based on the distribution of stand age for mature FIA plots (50 –150 years old).

Within LANDIS-II, the accumulation of live aboveground biomass for each cohort is modeled as a function of age, species' maximum annual net primary productivity ($ANPP_{max}$), and maximum aboveground biomass (B_{max}) (Scheller et al. 2004). Both $ANPP_{max}$ and B_{max} can be varied to reflect species' response to ecoregional variability in environmental conditions. We divided our study into 6 ecoregional types based on climate and site conditions and used the process model PnET-II (Aber et al. 1995) to estimate $ANPP_{max}$ for each ecoregion (Table 1) in a manner similar to Ravenscroft et al. (2010). Like $ANPP_{max}$, the probability that a species will establish at a site (P_{est}) varies based on a combination of species traits and environmental conditions. We estimated P_{est} for each species by comparing the number of FIA plots (2004-2008) with seedlings to the number of plots with seedlings and 1" saplings within our study area (Figure 2).

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[1] http://nsrcforest.org/project/using-satellite-imagery-map-forest-vulnerability-spruce-budworm-outbreaks

[2] USFS Northern Research Station, FS Agreement No. 11-MU-11242305-035

Table 1. Percent foliar nitrogen and maximum specific leaf mass used to estimate ANPPmax in PnET-II ecosystem model (Aber et al. 1995) for the 13 modeled tree species. ANPP values represent the range across the 6 ecoregional types defined based on climate and site conditions.

Species	Common name	Foliar Nitrogen (%)[1]	Leaf mass (g/m^2)[2]	Est ANPPmax (g/m^2)
Abies balsamea	Balsam fir	1.67	204	915 - 1031
Acer rubrum	Red maple	1.95	71	416 - 496
Acer saccharum	Sugar maple	2.06	63	419 - 483
Betula alleghaniensis	Yellow birch	2.58	66	677 - 791
Betula papyrifera	Paper birch	2.47	74	695 - 816
Fagus grandifolia	American beech	2.41	61	543 - 640
Fraxinus americana	White ash	2.34	61	510 - 602
Picea glauca	White spruce	1.14	286	839 - 932
Picea mariana	Black spruce	1.0	286	724 - 829
Picea rubens	Red spruce	1.12	305	852 - 966
Pinus strobus	White pine	1.4	174	397 - 545
Thuja occidentalis	Northern white cedar	1.17	161	594 - 621
Eastern hemlock	Tsuga canadensis	1.29	170	586 - 638

[1] Foliar nitrogen values were obtained from the Northeastern Ecosytstem Research Cooperative (NERC) foliar chemistry database. <http://www.folchem.sr.unh.edu >

[2] Specific leaf mass value were obtained from Hoffmeyer et al. (2010) for Northern white cedar and Smith and Martin (2001) for all other species.

Methods:

We used the timber harvest extension to LANDIS-II (Gustafson et al. 2000) to design scenarios that allowed us to compare the effects of recent (ca. 2000-2010) and past (ca. 1985-1995) regimes of forest management. Management units were based on ownership circa 2010, encompassing 1040 parcels and more than 80 private forestland owners (Figure 4). We estimated recent rates of annual harvest (total and stand-replacing) for all owners based on three intervals (2001-2004, 2004-2007, 2007-2010) using satellite-derived disturbance information (Sader et al. 2013[1]). Our baseline scenario emulated the median rate of harvesting using two harvest prescriptions: a clearcut harvest and a partial harvest designed to remove 50% of the biomass of a stand via group selection. The clearcut rate for each owner was assigned based on the rate of stand-replacing harvest, assuming an average 4% clearcut rate across owners following recent statewide trends (Figure 1).

To emulate the past regime, it was necessary to account for the tradeoff between volume and area harvested when comparing partial and clearcut harvests. We assumed that in order to achieve the same volume the area of a partial harvest must be 2x the area of a clearcut. We adjusted the median clearcut and partial harvest rates to reflect an increase in the proportion of total harvest by clearcut from 4 to 40% (on average across the landowners), while controlling for volume removed. This strategy ensured that differences between the recent and past scenarios could be attributed to the effects of harvest area and intensity and not differences in volume removed. In addition to the median rate, we repeated the same process for the minimum and maximum rates to capture the uncertainty within the system generated by owner-to-owner intra-annual variability in harvest rates.

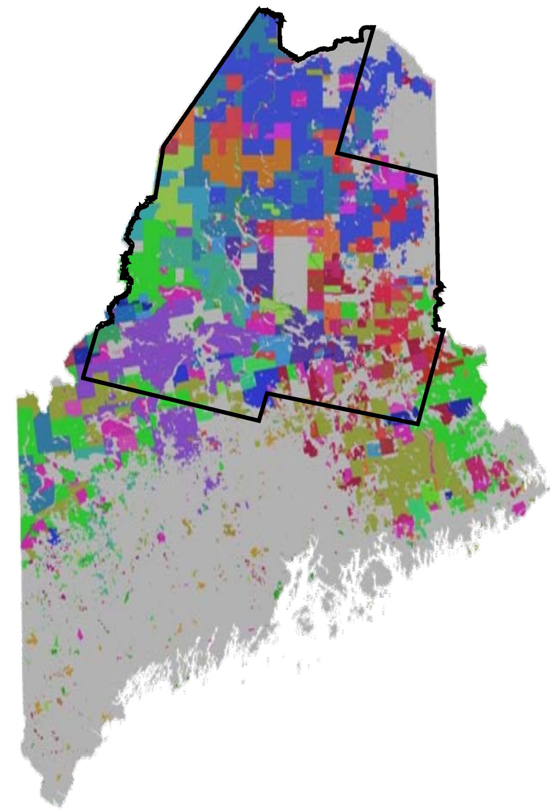

Figure 4. Study area (black outline) encompassed more than 80 private landowners, including Timber Investment Management Organizations, Real Estate Investment Trusts, and Non-profit organizations (e.g., The Nature Conservancy), as well as state and federal public and reserve areas.

Results:

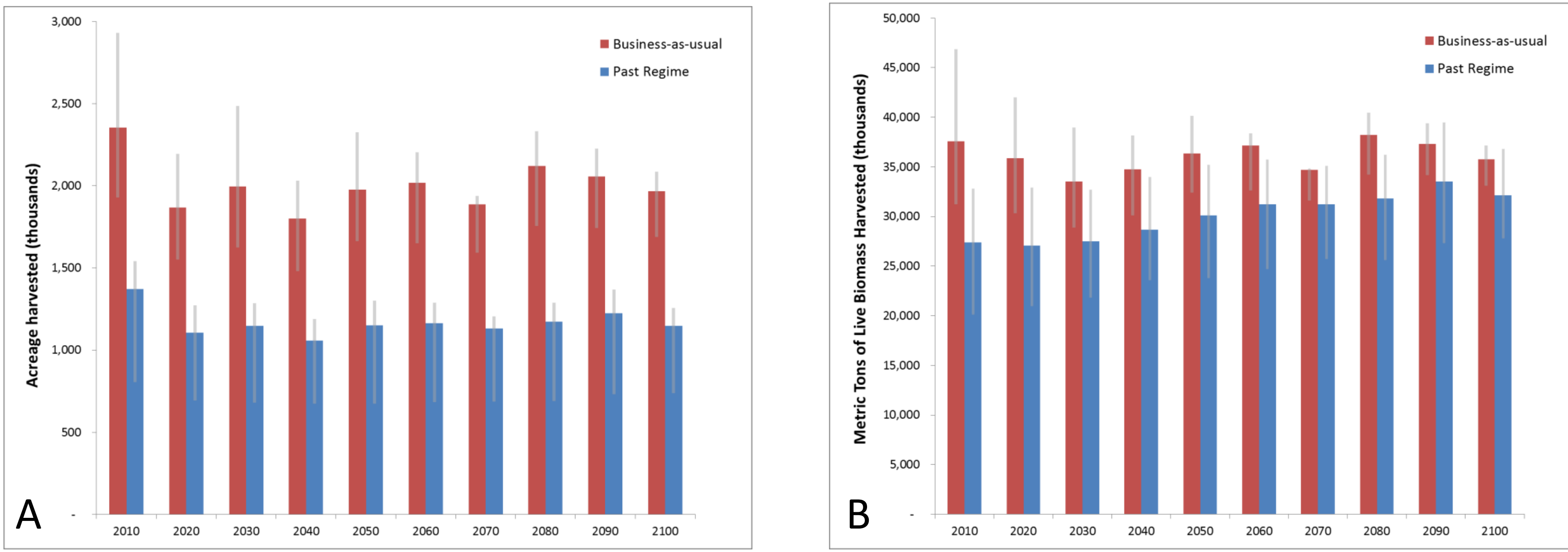

Figure 5. If the recent harvest regime, characterized by extensive partial harvesting and very little clearcutting, continues over the next 100 years , and recent harvest rates persist (red bars; Figure A), projections suggest that landowners in our study area will collectively harvest approximately 2 million acres every 10 years. Those harvests would remove on approximately 35 million metric tons of live biomass every 10 years (red bars; Figure B). If clearcuts accounted for closer to 40% of the acreage harvested (blue bars) compared to the current 4% (red bars), the total harvest footprint would be on average 40% smaller each 10-year period. This difference between scenarios is robust to uncertainty generated by owner-to-owner and year-to-year variability in achieved harvest rates (shown in gray). On average 83% (range 64 - 100%) of the same biomass would be removed.

Results:

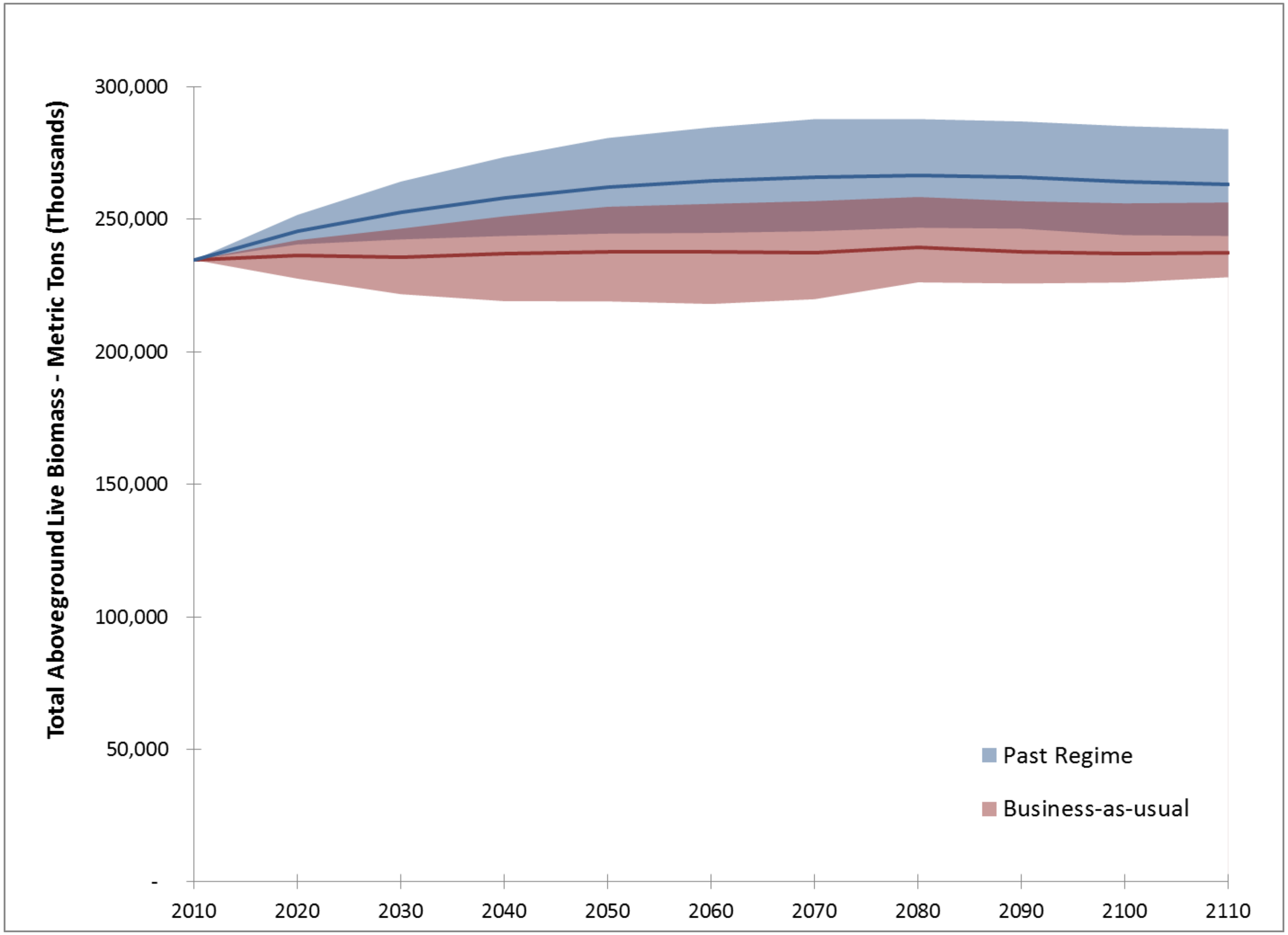

Figure 6. Projections suggest that total live aboveground biomass would be 4 - 30% greater over the next 100 years if forest management were to shift towards greater utilization of clearcuts and reduced application of partial harvesting (blue) compared to the recent harvest regime (red). Shaded areas show uncertainty associated with projections induced by owner-to-owner and year-to-year variation in harvest rates.

Results:

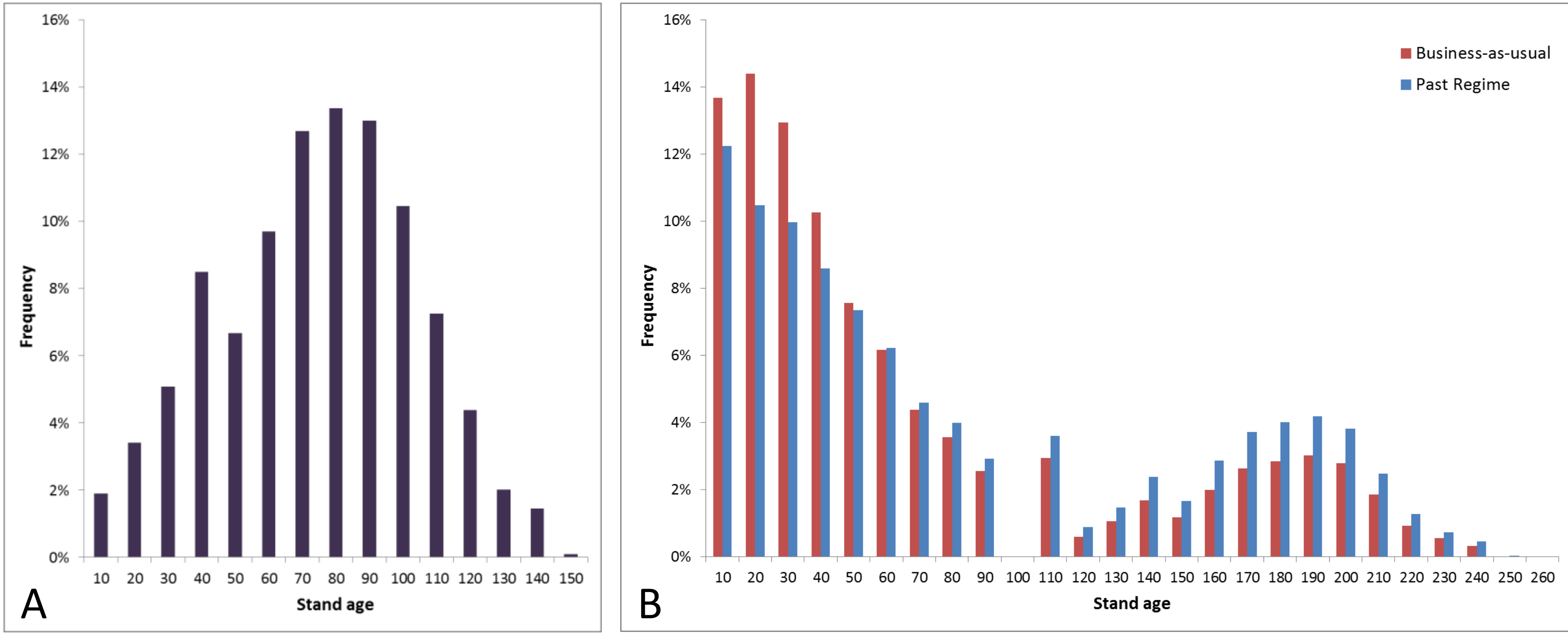

Figure 7. Much of the difference between scenarios apparent in Figure 6 can be attributed to differences in the amount of mature forest left uncut. (A) According to FIA, the age structure of the forest in our study area ca. 2010 was dominated by the mid-successional (i.e., 50-100 years old) condition. A total of 26% of the forest is in a late-successional condition (i.e., >100 years old). (B) After 100 years, the proportion of the forest in a late-successional condition (24%) would remain largely unchanged if recent trends continue (red bars). Alternatively, if management shifted towards less reliance on partial harvesting (blue bars) late-successional forest would increase on the landscape (34%), and those areas would continue to sequester carbon and accumulate biomass well past the typical merchantability age. Overall the age structure would be more balanced after 100 years. (Note: Results from median values shown in B.)

Results:

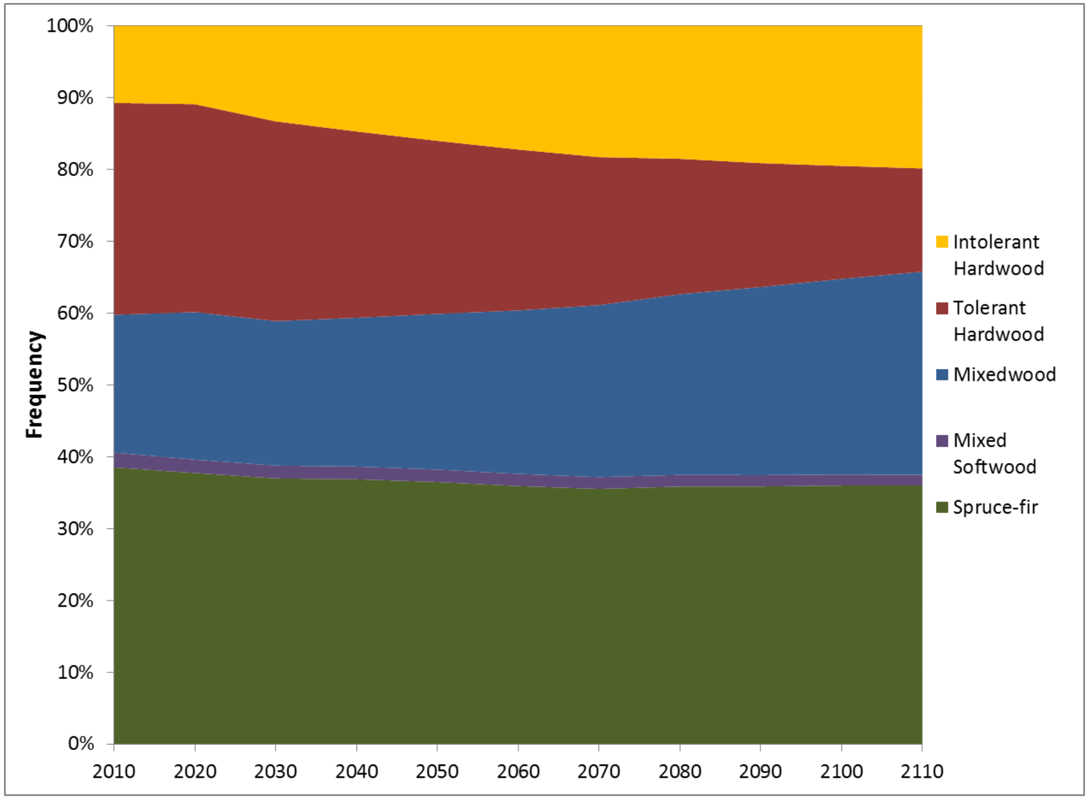

Figure 8. In 2010, softwood- and hardwood-dominated forest, (i.e., ≥75% of the live biomass softwood or hardwood, respectively) occurred in roughly equal proportions (~40%) on our study area. Under the business-as-usual scenario, changes in forest type and species dominance over the next 100 years will largely be driven by the increasing abundance and distribution of balsam fir and shade-intolerant hardwoods. Our projections suggest that those increases will come at the expense of northern hardwoods. The area of forest dominated by northern hardwoods (red) will decline >50% as some areas transition to intolerant hardwood dominance (orange) and others become more mixed due to fir expansion (blue). Although our projections suggest fir biomass will increase in the future, the area of spruce-fir forest (green) is also likely to decline (8%) due to encroachment by intolerant hardwoods. With a shift in management towards decreased reliance on partial harvesting, our projections suggest that patterns of forest type turnover would be similar but rates would be reduced. (Note: Results from median values shown.)

Results:

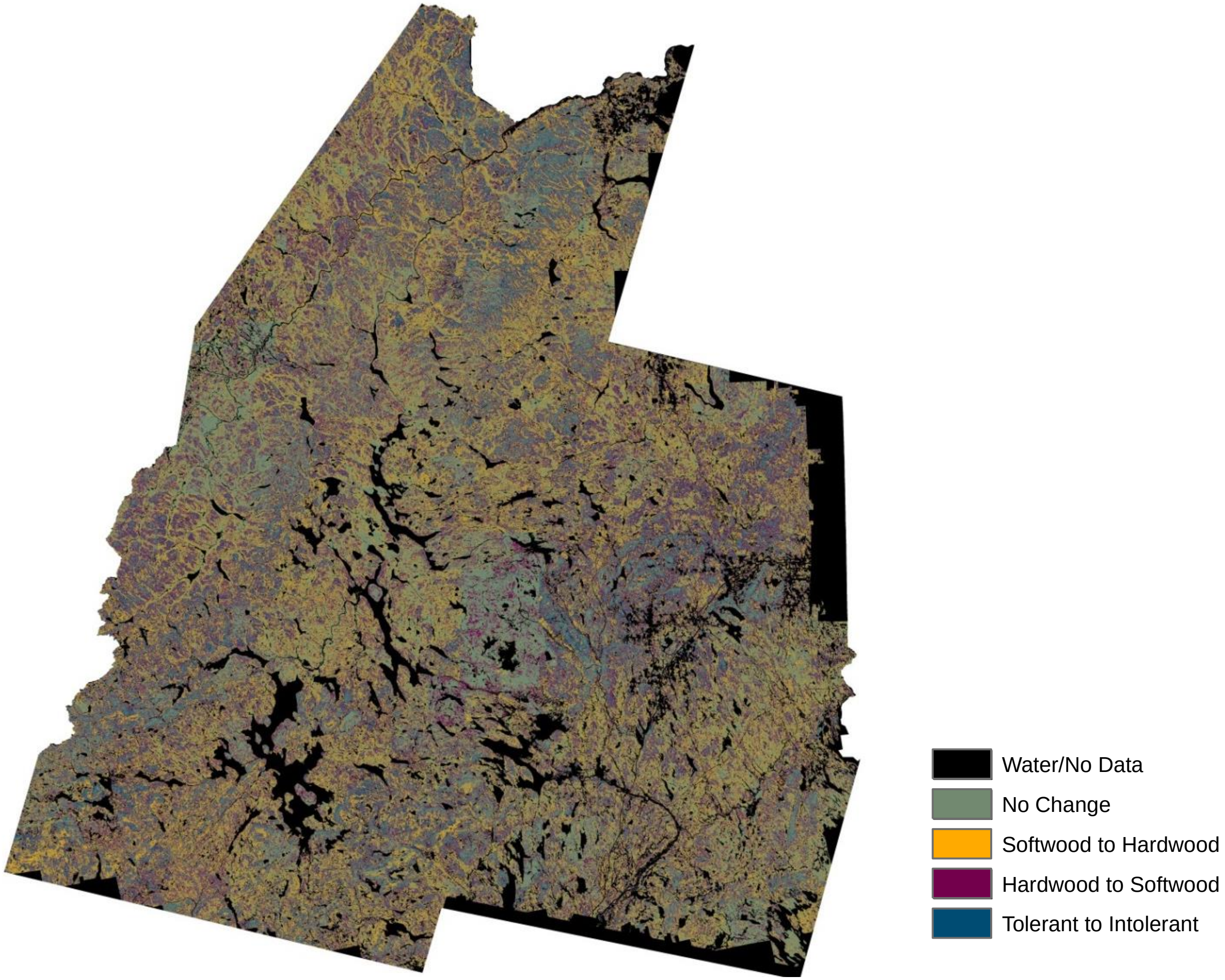

Figure 9. By the year 2110, under the business-as-usual scenario our projections suggest that balsam fir encroachment into areas currently dominated by hardwood species will drive a shift from hardwood to softwood dominance on 18% of the forestland in our study area (red). The expansion of primarily red maple and paper birch will lead to a shift from softwood to hardwood dominance on 15% of the forestland in our study area (orange) and a shift from tolerant to intolerant hardwood dominance on 9% (blue). Our projections also suggest that these trends in shifting dominance, particularly the loss of hardwood-dominated forest, would be reduced if forest management in our study area was less reliant on partial harvesting. (Note: Results from median values shown.)

Implications and applications in the Northern Forest region:

Forest management in the northeastern U.S. is currently dominated by strategies that are dependent on partial harvesting, and Maine has one of the highest rates of harvest in the region (Canham et al. 2013). Using the forest landscape model LANDIS-II we were able to emulate the effects of alternative forest management strategies across a 10 million acre study area, which encompassed a diverse landscape of more than 80 landowners. Simulations allowed us to address the hypothesis that management strategies that include very limited even-aged management and extensive partial harvesting in a predominantly spruce-fir forest will result in timber harvesting rates that are unsustainable, reduced forest carbon stocks, and negative impacts on wildlife habitats. Our results suggest that current harvest rates within our study area are marginally sustainable in the sense that total live aboveground biomass is likely to remain relatively stable over the next 100 years. An increasing proportion of the aboveground biomass will, however, be in young forests (i.e., <40 years old); late-successional forests will likely continue to represent <25% of the landscape.

Our results suggest that future forest conditions in our study area and in the Northern Forest region would be improved if forest management were to shift toward greater utilization of clearcuts and reduced reliance on partial harvesting. The same level of production could be achieved with a much smaller harvest footprint, which has important implications for future carbon stocks and wildlife habitat, particularly for species dependent on mature or late-successional forest. The area of young forest would likely increase under either management regime, but greater utilization of clearcut harvesting would result in more late-successional forest as well, and a more balanced age structure overall. A shift in management toward reduced reliance on partial harvesting would have the added benefit of slowing the rate of expansion of balsam fir into areas currently dominated by other species.

Our methods are generally transferable to other northern forest regions and applicable to future studies exploring topics related to forest landscape change. Lack of sufficiently detailed input maps inhibits the use of LANDIS-II in many regions, and can limit inferences drawn from simulations. To more effectively parameterize LANDIS-II to contemporary forest conditions, we utilized newly developed techniques (Sader et al. 2013) to map forest attributes by linking widely available satellite imagery and geospatial data with forest inventory plot data provided through a collaborative agreement with the USFS Northern Research Station Forest Inventory and Analysis Program. These forest attribute maps should prove valuable for a wide range of future applications.

Future directions:

In the future, temperatures in the Northern Forest are likely to increase and precipitation patterns are likely to change as a consequence of climate change. The implications of these changes on future species distributions have been modeled broadly, and it is expected that balsam fir and spruce will decline, while red maple will increase (Iverson *et al.*, 2008). Projections of future species distributions have not, however, considered interactions with other disturbances such as timber harvesting. In addition, it is unclear how climate change will influence species and forest-level productivity. Under funding obtained from the NASA/USDA National Institute of Food and Agriculture (NIFA) Carbon Cycle Science program we are incorporating climatological effects into our landscape simulations. We have designed alternative scenarios that explore interactions between timber harvesting (business-as-usual), outbreaks of spruce budworm (light, moderate, and severe) and salvage harvesting, and climate change (low and high emission according to the Intergovernmental Panel on Climate Change).

Rates of residential development in rural forest have increased dramatically in all of the major timber producing regions of the United States. After broad-scale divestiture of timberland by forest product companies in the 1990s and 2000s, investment firms are now the predominant type of private landowner throughout the US. Unlike their industrial predecessors, these new owners operate over relatively short time horizons (i.e., 5-15 years) and are willing to consider multiple means of monetizing their asset, including development and real estate sales. Although development per se is not new to rural forests, residential development motivated by out-migration from nearby urbanizing areas and second home development represents a novel form of disturbance in the Northern Forest that may have cascading effects. Under funding obtained from the NSF Coupled-Natural Human Systems Program, we will expand our use of LANDIS-II to improve understanding of the coupled biophysical-social linkages that underpin patterns of landscape change within rural forests, and how specific linkages drive the direction of a forest ecosystem towards a particular state that may be more or less resilient to additional disturbance.

Products:

Manuscripts in preparation or planned on the following topics:

- Calibration of LANDIS-II to Acadian forest species and dynamics (anticipated submission 4/2014)
- Evaluating interactions between policy and management on resource sustainability (anticipated submission 8/2014)

Presentations:

- Simons-Legaard, E. M., K. Legaard, A. Weiskittel, and S. Sader. 2013. Evaluating the interacting effects of forest management and spruce budworm outbreaks on broad-scale, long-term forest conditions in the Northern Forest of the northeastern U.S. Oral presentation at the Annual Meeting of the Ecological Society of America, Minneapolis, Minnesota.
- Legaard, K.R., S. Sader, J. Wilson, E. Simons-Legaard, and A. Weiskittel. 2013. A spatial assessment of vulnerability to defoliation by spruce budworm across the commercial forestland of northern Maine. Oral presentation at the New England Society of American Foresters Spring Meeting, Bethel, Maine.
- Legaard, K.R., S. Sader, J. Wilson, E. Simons-Legaard, and A. Weiskittel. 2012. Mapping vulnerability to defoliation by spruce budworm using Landsat satellite imagery and FIA field plots. Poster presented at the Eastern CANUSA Forest Science Conference, Durham, New Hampshire.
- Simons-Legaard, E., K. Legaard, J. Wilson, A. Weiskittel, and S. Sader. 2012. Long-term outcomes and tradeoffs of forest policy and management practices on the borad-scale sustainability of forest resources: wood supply, carbon, and wildlife habitat. Poster presented at the Eastern CANUSA Forest Science Conference, Durham, New Hampshire.

Grants resulting in part from the success of this project:

- NSF Coupled-Natural Human Systems, 2013: When natural disturbance meets land use change: an analysis of disturbance interactions and ecosystem resilience in the Northern Forest of New England. Lead PI E. Simons-Legaard.
- NASA/USDA National Institute of Food and Agriculture (NIFA) Carbon Cycle Science, 2010: Carbon dynamics and forest management: A retrospective analysis and projection of the potential effects of land use, climate change, and natural disturbance in northeastern forests. Lead PI A. Weiskittel.

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