Biomass Fuel Harvesting in the Northern Forest: Effects on Stand Structural Complexity and In Situ Forest Carbon Storage

Principal Investigator: William S. Keeton
Affiliation: University of Vermont
Email: william.keeton@uvm.edu
Mailing address: 308 Aiken Center
Rubenstein School of Environment and Natural Resources
University of Vermont
Burlington, VT 05405
Co-Principal Investigator: Donald R. Tobi
Affiliation: University of Vermont, Entomology Research Lab
Email: dtobi@uvm.edu
Collaborators: Anna Mika, Caitlin Littlefield, and Thomas Buchholz
Completion date: Dec. 31, 2012

Bioenergy harvesting effects on stand structure and wildlife habitats were highly variable across the range of sites and operations evaluated in this study, suggesting a need for harvesting guidelines aimed at encouraging retention of ecologically important structural attributes. Neither the type of harvest nor amount of bioenergy generated were most predictive of post-harvest C flux, but rather the type of harvesting machinery and the specifics of silvicultural treatment. Modeled over 160 years and at landscape scales, and accounting for temporally and spatially staggered harvests, all bioenergy scenarios resulted in an increase in net emissions to the atmosphere compared to non-bioenergy harvests. This held only when the baseline is assumed to be the opportunity cost of foregone carbon sequestration and storage under less intensive management. Mitigation measures such as structural retention and lightly managed reserves are recommended.

Funding support for this project was provided by the Northeastern States Research Cooperative (NSRC), a partnership of Northern Forest states (New Hampshire, Vermont, Maine, and New York), in coordination with the USDA Forest Service.
http://www.nsrcforest.org

Project Summary

Demand for forest bioenergy fuel is increasing in the northern forest region of eastern North America and beyond, but ecological impacts—particularly on habitat—of bioenergy harvesting remain poorly explored. In addition, there is uncertainty over the net greenhouse gas emissions associated with wood bioenergy production. Particularly uncertain are the net carbon (C) effects of multiple harvests staggered spatially and temporally across landscapes in which bioenergy is typically only one of many products in integrated operations Relatively few studies have evaluated these concerns using field data from actual bioenergy harvests. This study addresses these questions in two components, one devoted to effects on habitat, the other focused on net greenhouse gas emissions at stand and landscape scales. Both research components employed field inventory data from the same set of 35 recent harvests in northern hardwood–conifer forests, pairing harvested areas with unharvested reference areas in northern New York, Vermont, and New Hampshire.

Classification and regression tree (CART) analysis suggested that the strongest predictors of habitat effects were harvesting treatment and equipment type rather than the proportion of harvested volume allocated to bioenergy uses. In general, harvesting impacts were highly variable across the 35 sites sampled, supporting a role for harvesting guidelines aimed at encouraging retention of ecologically important structural attributes. Bioenergy harvests using Whole Tree Harvesting methods generated fewer wood products and resulted in more emissions released from bioenergy than the other two types of harvests, which resulted in a greater net flux of C. Multivariate analyses determined that it was not the type of harvest or amount of bioenergy generated, but rather the type of skidding machinery and specifics of silvicultural treatment that had the largest impact on net C flux. Operational factors often associated with WTH may result in an overall intensification of C fluxes. The intensification of bioenergy harvests, and subsequent C emissions, that result from these operational factors could be reduced if operators select smaller equipment and leave a portion of tree tops on site. Simulations of landscape scale dynamics using the Forest Vegetation Simulator showed that choice of analytical perspective yields profoundly contrasting conclusions about wood bioenergy emissions. Relative to starting landscape condition, all the bioenergy scenarios evaluated added carbon to terrestrial sinks and/or offset fossil fuel emissions, and could by this measure be considered carbon neutral. If foregone C sequestration potential (or "opportunity cost") is the benchmark, and if harvest intensities increase, then our results show wood bioenergy to result in net increased emissions over both near (10-20 years) and long-term (160 year) timeframes. A variety of measures are recommended to help mitigate and minimize these potential emissions, including structural retention and incorporation of reserves into large scale planning to offset emissions from more intensively managed areas.

Research Questions

- What are the impacts of bioenergy harvests on stand structure and wildlife habitat characteristics?

- What are the net carbon fluxes at stand and landscape scales?

Methods

Ecological Effects of Bioenergy Harvesting:

We collected stand structure data from 35 recent harvests in northern hardwood–conifer forests, pairing harvested areas with un-harvested reference areas. Biometrics generated from field data were analyzed using a multi-tiered nonparametric uni- and multivariate statistical approach.

Post-Harvest C Fluxes:

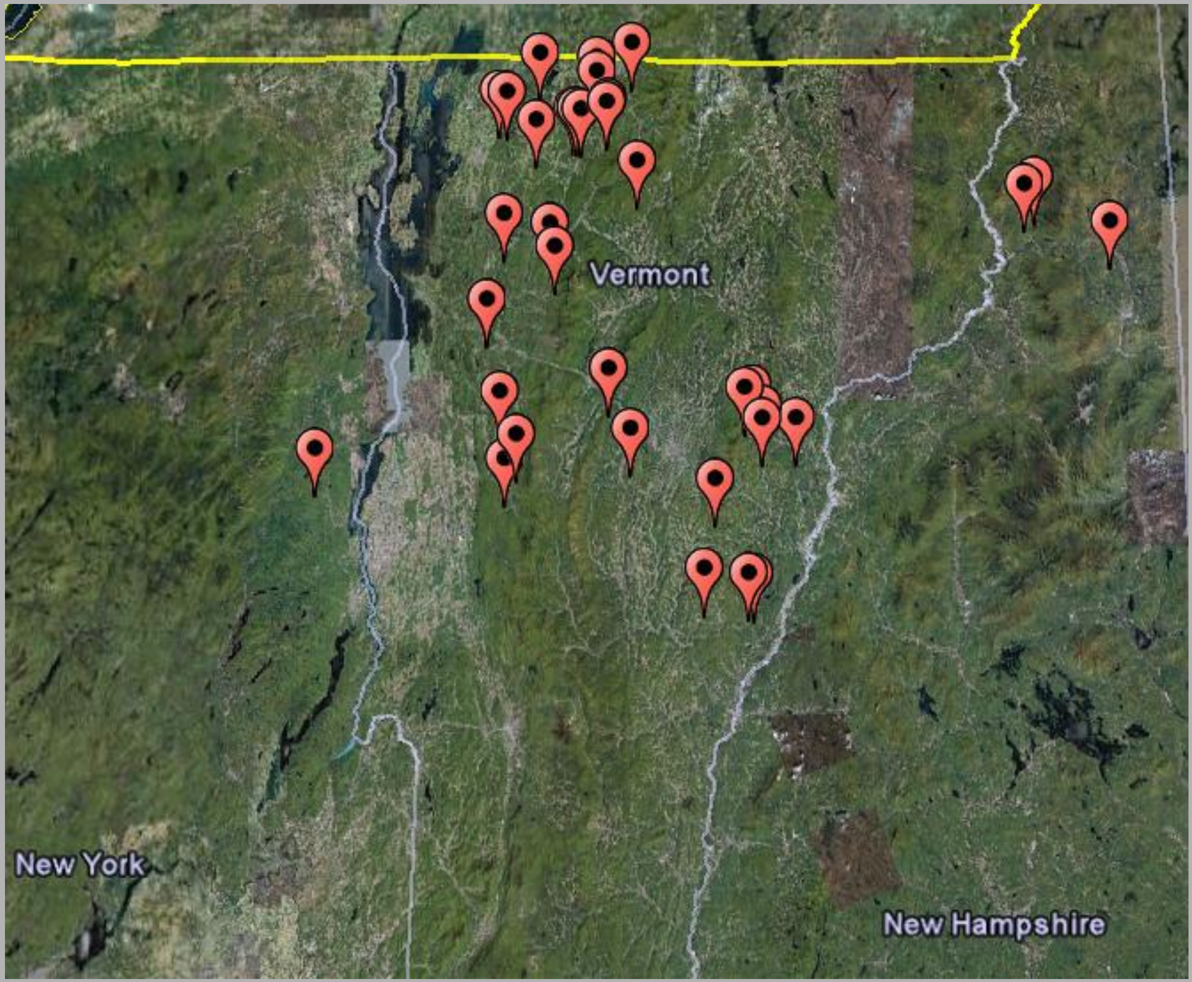
We assessed C reductions and net fluxes immediately postharvest from whole-tree harvests (WTH), bioenergy harvests without WTH, and non-bioenergy harvests at 35 sites across the northeastern United States. We compared the aboveground forest C in harvested with paired un-harvested sites, and analyzed the C transferred to wood products and C emissions from energy generation from harvested sites, including indirect emissions from harvesting, transporting, and processing.

Long-Term Net Greenhouse Gas Emissions at Landscape Scales:

We used field data to formulate bioenergy harvest scenarios, applied them to Forest Inventory and Analysis stands, and projected growth and harvests using the Forest Vegetation Simulator. We compared net change in C when various proportions of the landscape are harvested for bioenergy: 0% (“non-bioenergy”); 25% (BIO25); 50% (BIO50); or 100% (BIO100), with three levels of harvest intensification relative to non-bioenergy harvests. We compared the net cumulative C fluxes between scenarios, calculated as the change between C uptake minus emissions at the end of the 160-year simulation study. We accounted for C stored in aboveground pools and wood products, included direct and indirect emissions from wood products and bioenergy, and counted avoided direct and indirect emissions from fossil fuels as an offset.

METHODS:

- 35 Sites
- Site matching criteria
- Paired reference at each location
- Harvested within last 3 years
- Range of harvesting intensities and product mixes



Simulation modeling in FVS:

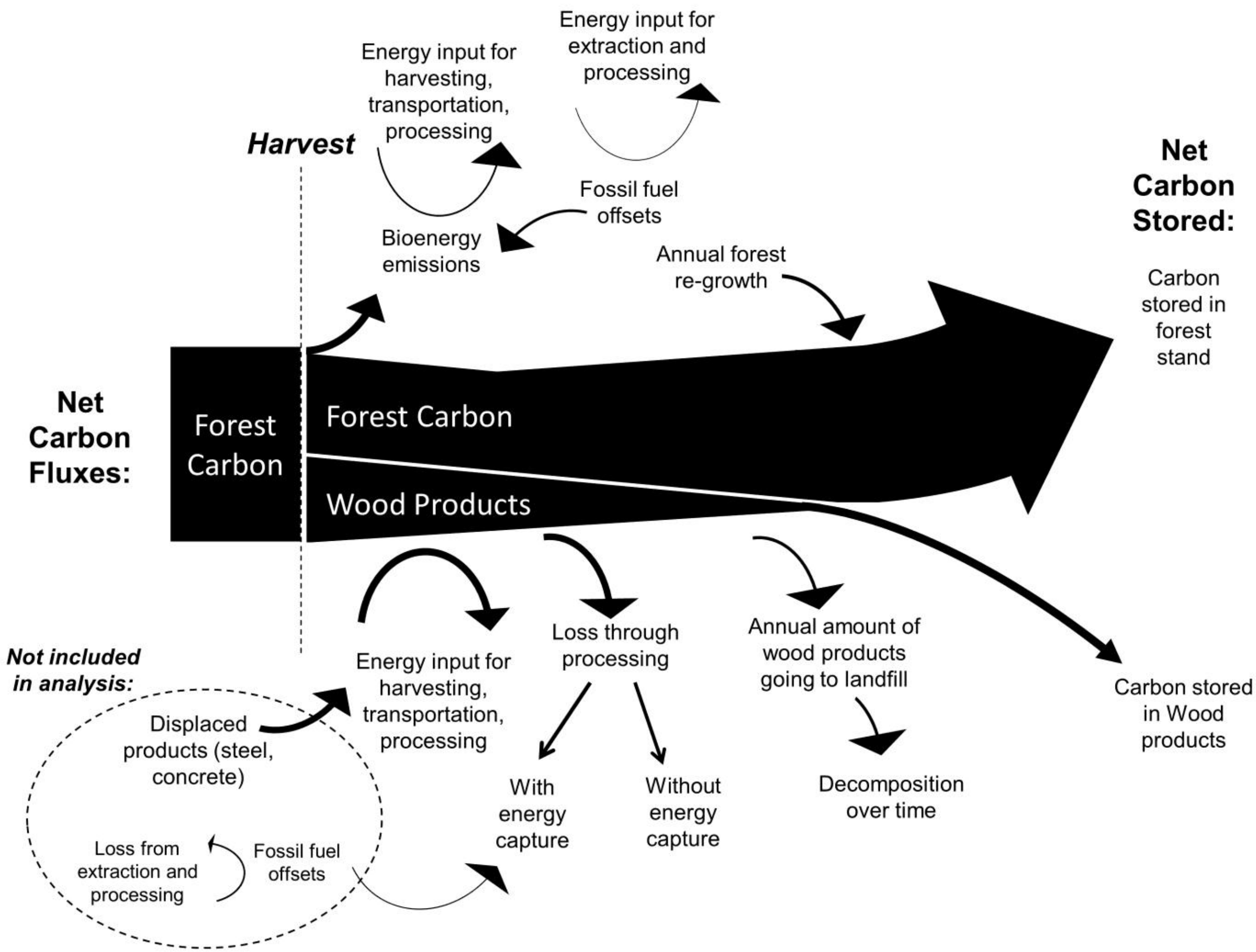
Data:

- 362 FIA plots from New York, Vermont, New Hampshire and Maine
- Randomly selected from 3,306 sites meeting criteria
- Representative of age class and stocking distributions for the Northeast

Scenarios and scheduling:

- Bioenergy intensification from Mika and Keeton (2012)
    - Mean and 75 percentile
- Silvicultural scenarios proportionate to use
    - Selection harvest
    - Shelterwood
    - Clearcut/patch cut
- Bioenergy scenarios applied to 25%, 50%, and 100% of landscape
- Minimum residual stocking threshold for some scenarios.
- Stands randomly selected for “cutting” when they attain harvestable stocking levels
- Regeneration inputs from Nunery and Keeton (2010)

Sankey diagram showing the net carbon fluxes included in this study. The stocks and flows are proportional to the size of the pool or emission of carbon.



Results

Ecological Effects of Bioenergy Harvesting:

In analyses comparing harvested to reference areas, sites that had been whole-tree harvested demonstrated significant differences (relative negative contrasts, P , 0.05) in snag density, large live-tree density, well-decayed downed coarse woody debris volume, and structural diversity index (H) values, while sites that had not been whole-tree harvested did not exhibit significant differences. Classification and regression tree (CART) analyses suggested that the strongest predictors of structural retention, as indicated by downed woody debris volumes and H index, were silvicultural treatment and equipment type rather than the percentage of harvested volume allocated to bioenergy uses.

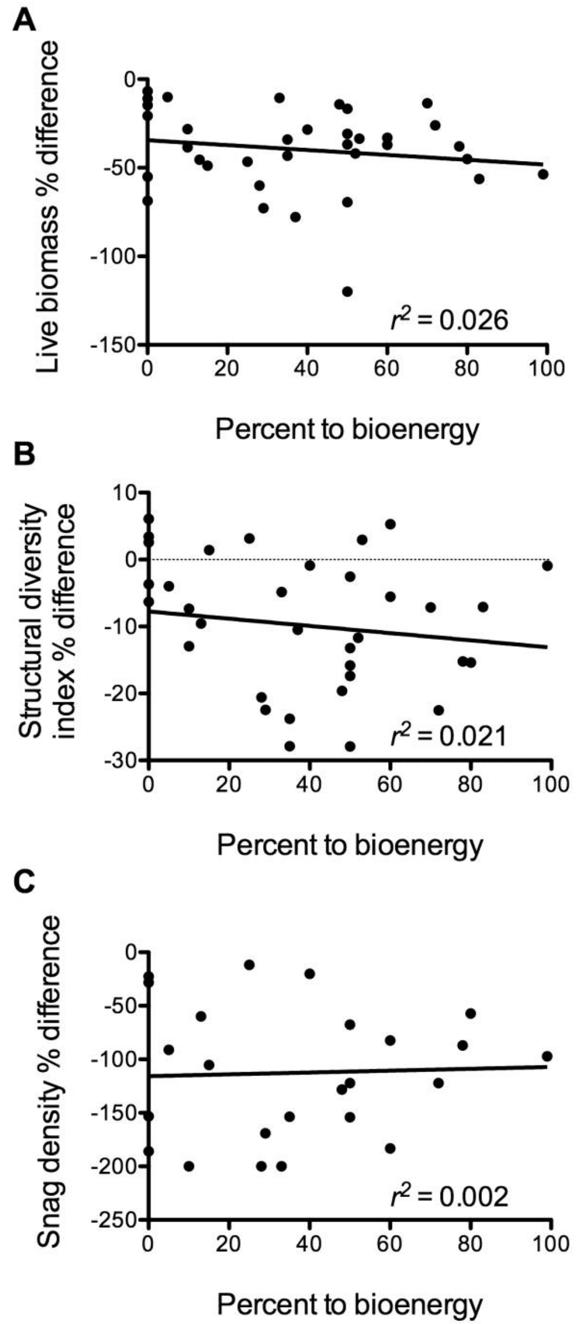
Post-Harvest C Fluxes:

All harvests reduced live tree C; however, only bioenergy harvests using Whole Tree Harvesting (WTH) significantly reduced C stored in snags ($P < 0.01$). On average, WTH sites also decreased downed coarse woody debris C while the other harvest types showed increases, although these results were not statistically significant. Bioenergy harvests using WTH generated fewer wood products and resulted in more emissions released from bioenergy than the other two types of harvests, which resulted in a greater net flux of C ($P < 0.01$). A Classification and Regression Tree analysis determined that it was not the type of harvest or amount of bioenergy generated, but rather the type of skidding machinery and specifics of silvicultural treatment that had the largest impact on net C flux. Operational factors often associated with WTH may result in an overall intensification of C fluxes.

Long-term Net Greenhouse Gas Emissions at Landscape Scales:

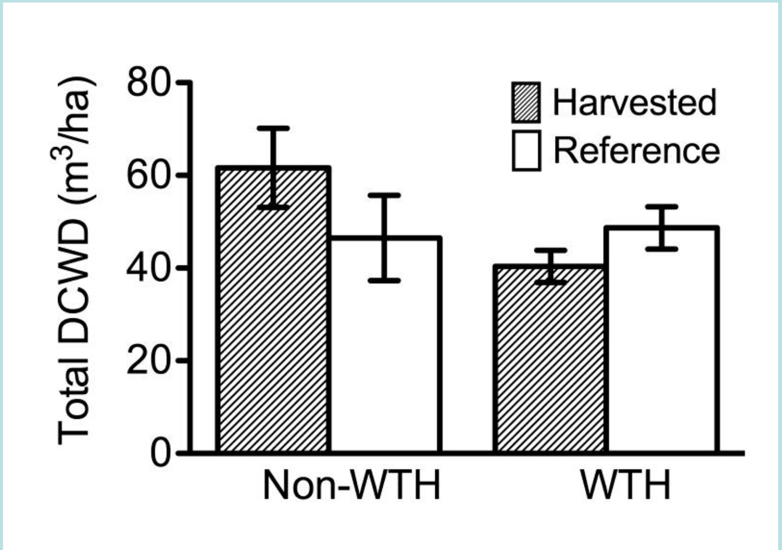
At the end of the 160 year simulation period, although 82% of stands were projected to maintain net positive C benefit (defined as a storage + fossil fuel emissions offsets), net flux (emissions) remained negative compared to non-bioenergy harvesting for the entire period. BIO25, BIO50, and BIO100 scenarios resulted in average annual emissions of 2.47, 5.02, and 9.83 Mg C ha^{-1}, respectively, compared to non-bioenergy harvests. Using bioenergy for heating decreased the relative emissions relative to electricity generation as did removing additional slash from thinnings. However, all bioenergy scenarios resulted in an increase in net emissions to the atmosphere compared to the non-bioenergy harvests. Multivariate statistical analysis indicated that stands having high initial aboveground live biomass may incur higher net emissions from bioenergy harvest, simply because more volume is available for remove and conversion to energy.

Effects as a function of percent of harvested volume allocated to bioenergy

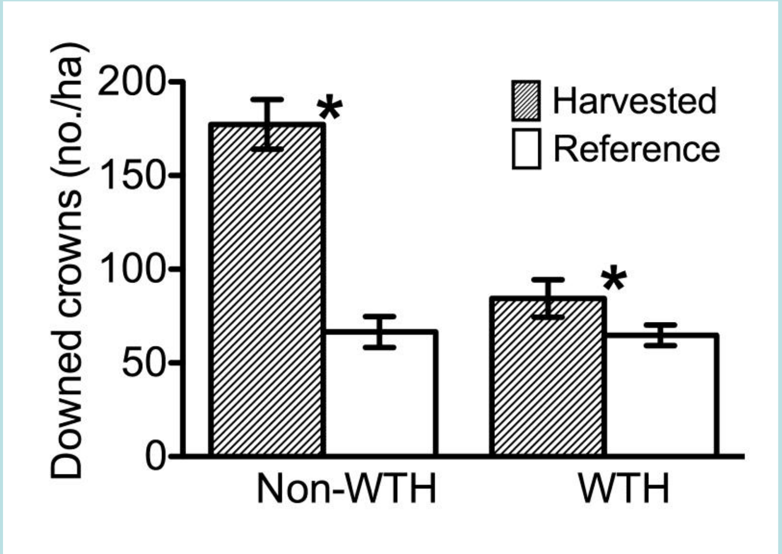


Whole Tree vs. Non-Whole Tree Bioenergy

Downed coarse woody debris



Downed tree crowns



Independent variables used in multi-variate analysis

From: Littlefield and Keeton 2012. Ecological Applications

Variable†	Levels	No. sites
Land ownership	private: family, family co-op, non-profit, small institution	26
	private: recent or current industrial	3
	public	6
Government incentive program‡	yes	23
	no	12
Easement	yes	6
	no	29
Certification§	yes	11
	no	24
Sugarbush	yes	28
	no	7
Harvest type	whole-tree harvest	25
	non-whole-tree harvest	10
Treatment	crop tree release	8
	group selection	4
	shelterwood	4
	single-tree selection	6
	single-tree/small-group selection combination	3
	thinning from below (incl. some co-dominant removal)	10
Marked by professional forester	yes	28
	no	7
Winter-only harvest	yes	16
	no	19
Cutting equipment	chainsaw	10
	shear	20
	both	5
Skidders	cable	15
	grapple	10
	both	7
	none	3
Pulp also generated	yes	16
	no	19
End user of chips	municipal	24
	municipal/school	2
	pulp-mill or municipal/pulp-mill	3
	not applicable (no chips)	6
Bioenergy percentage¶	continuous	35

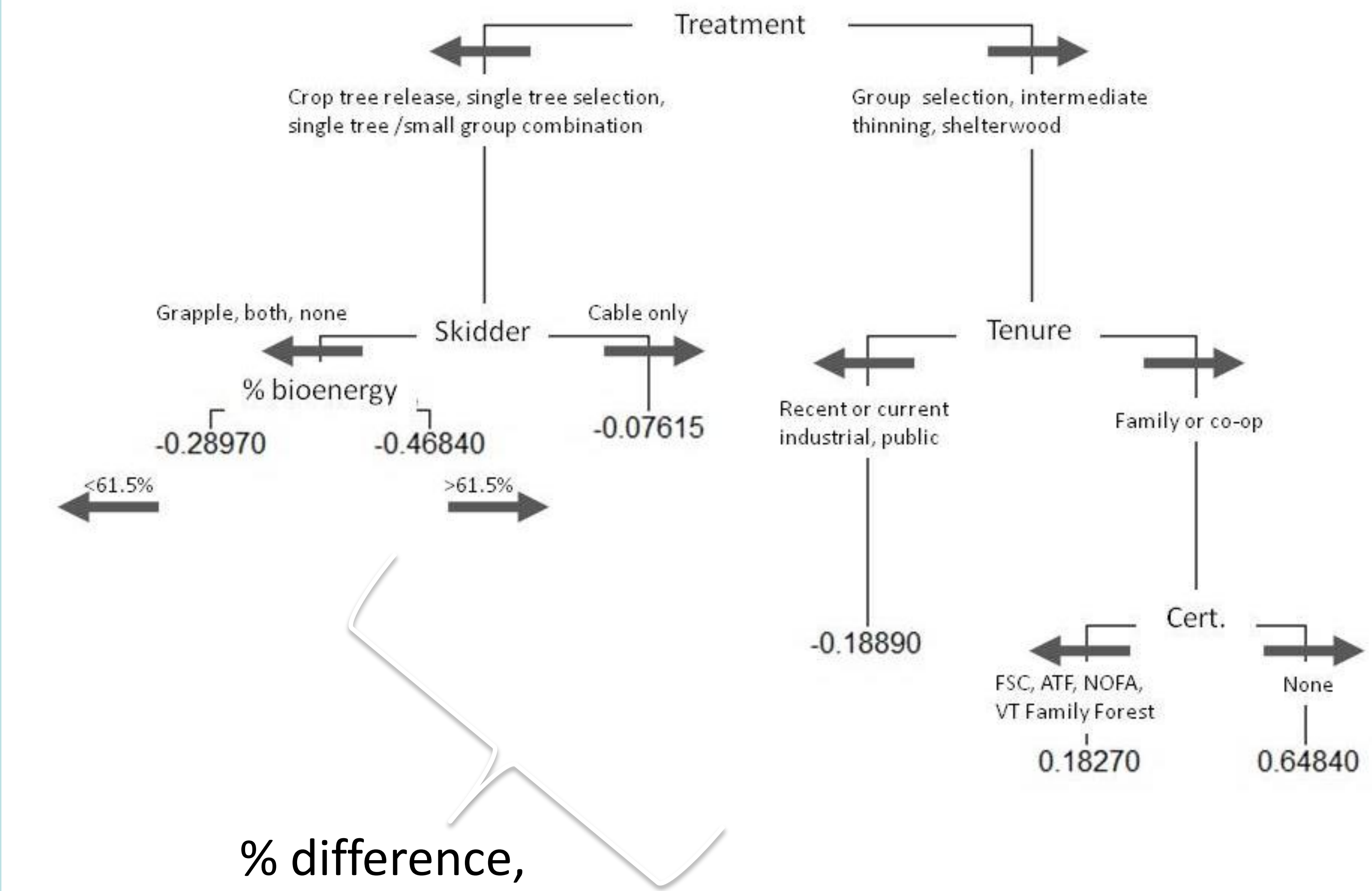
†All variables are categorical, except the percentage of the harvested volume used for bioenergy (which is continuous).

‡ For example, Current Use or Biomass Crop Assistance Program.

§ Land certification (e.g., American Tree Farm, Forest Stewardship Council, Northeast Organic Farming Association, Vermont Family Forests). Each promotes a degree of sustainable management practices, but with widely varying standards.

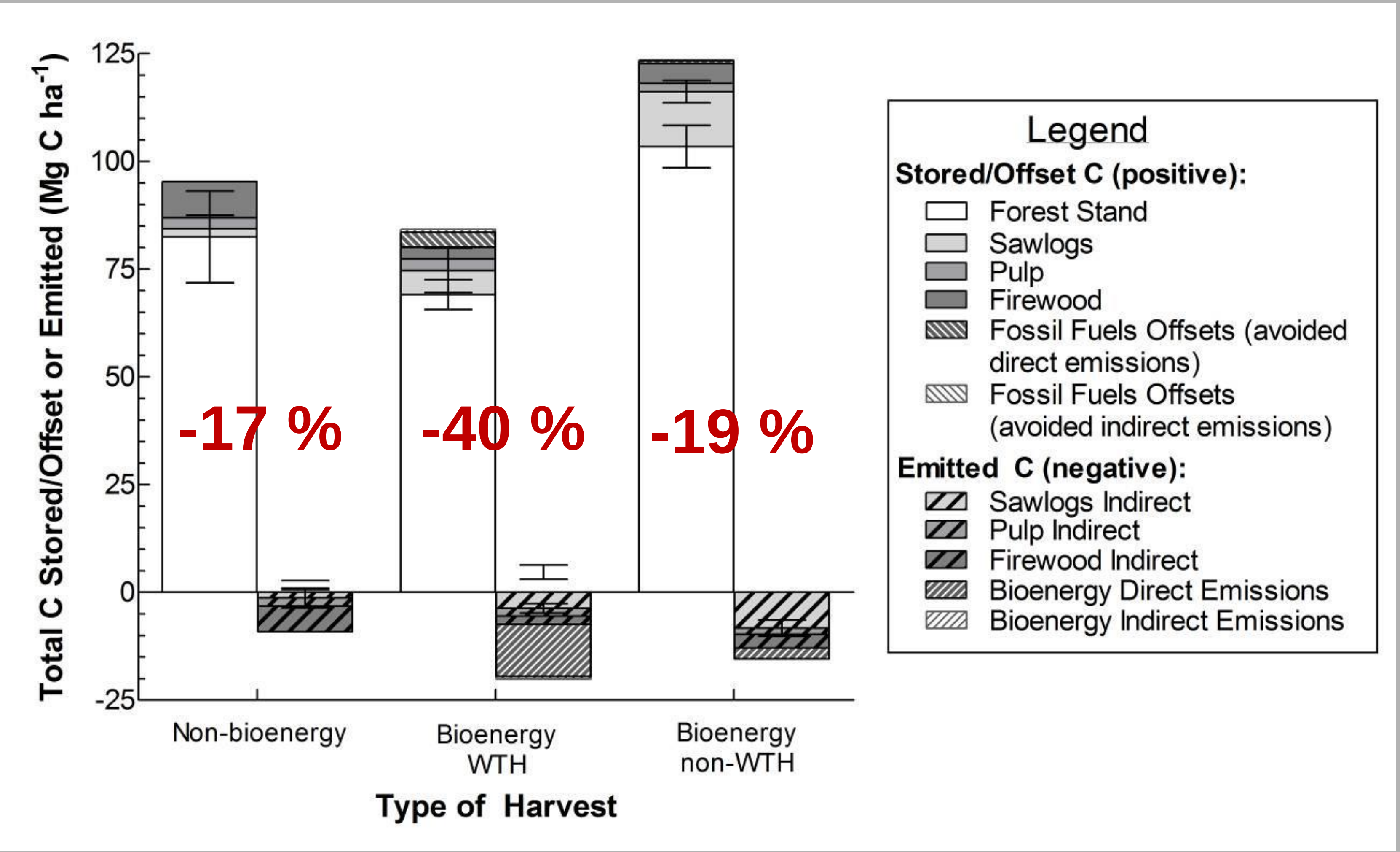
¶ Percentage of total harvested volume used for bioenergy.

Classification and Regression Tree (CART)



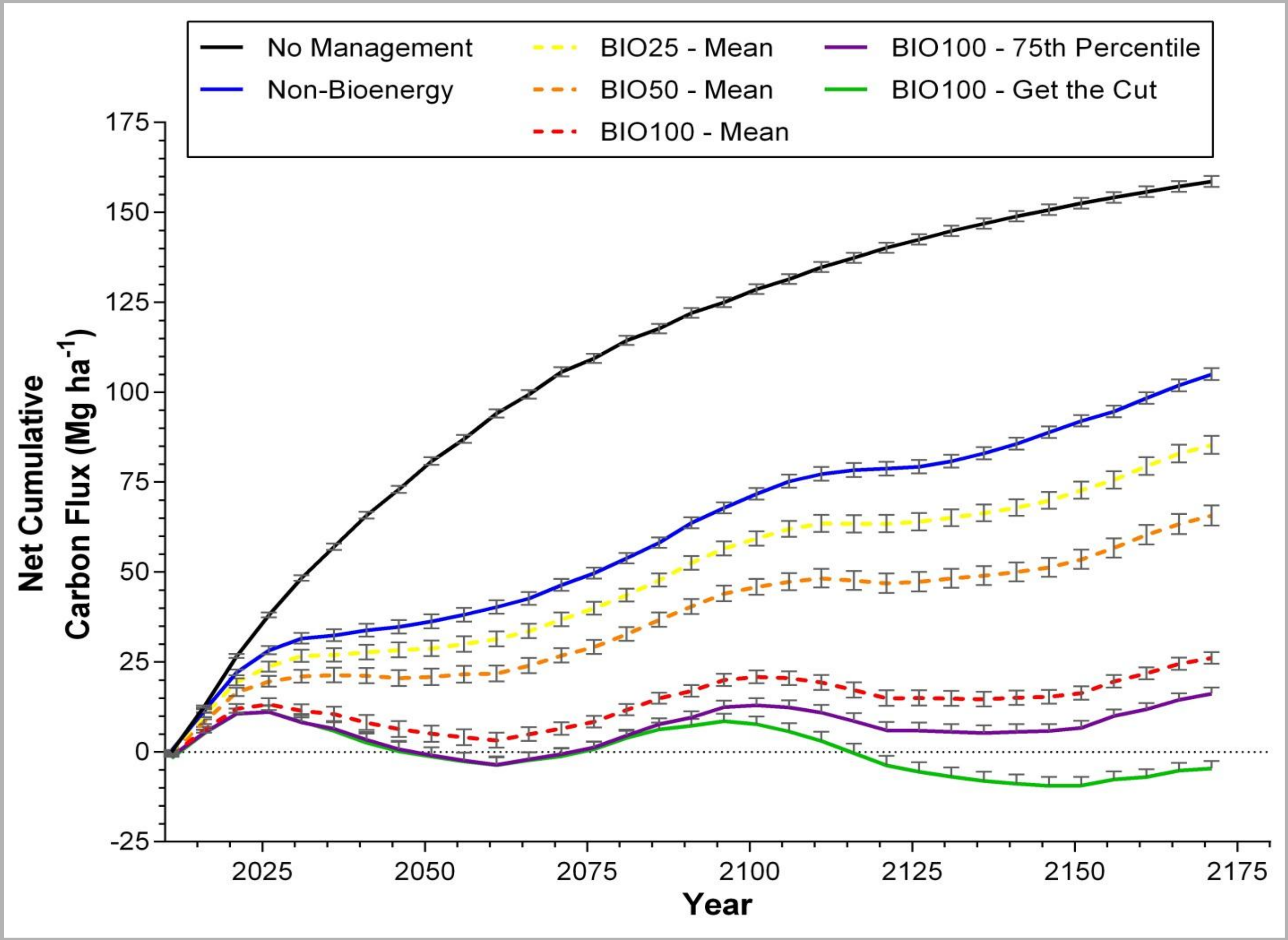
% difference, CWD volume

Net C Flux Post-Harvest

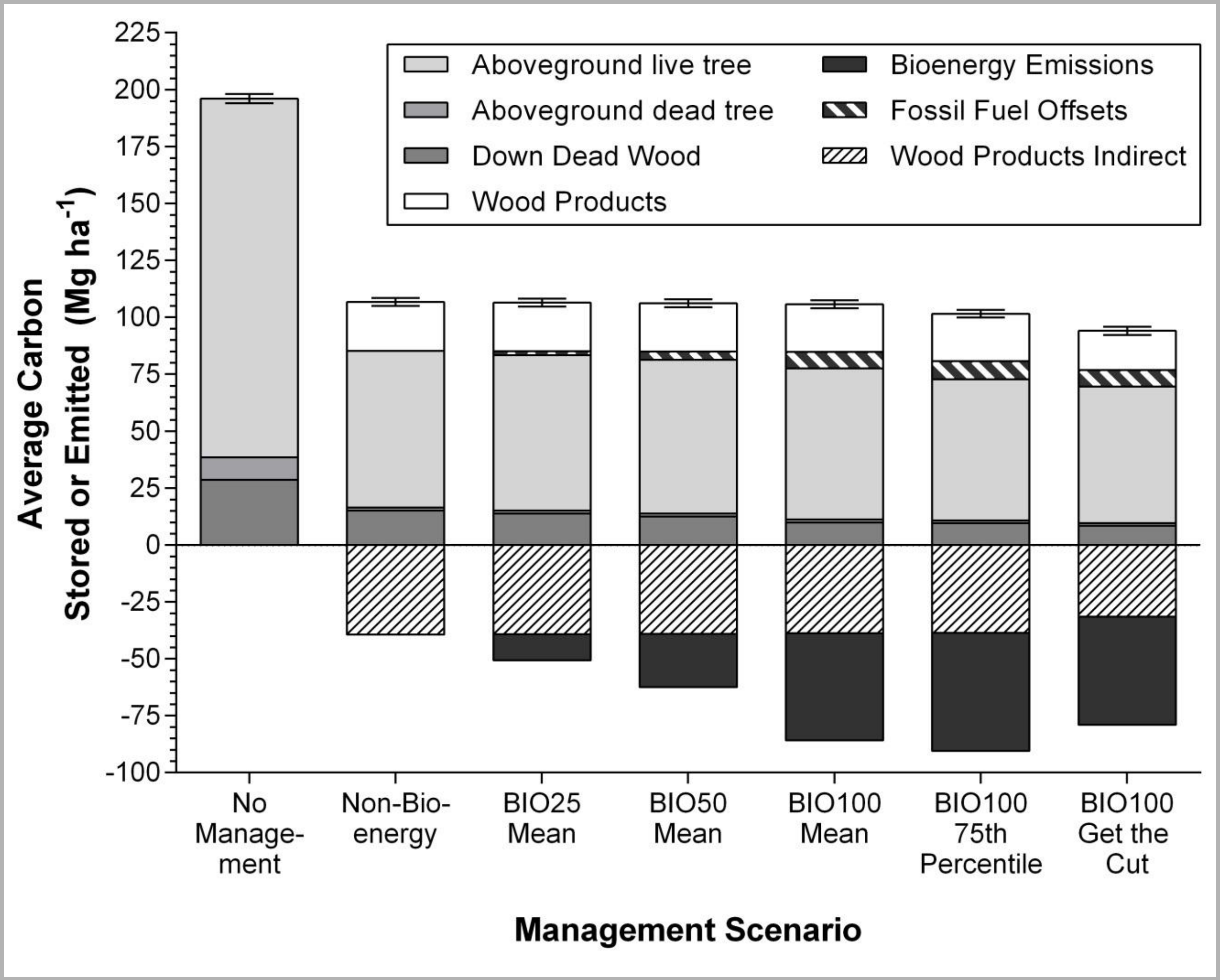


From: Mika and Keeton 2012.
Global Change Biology: Bioenergy

Net carbon flux projected over 160 years in NE-FVS (N = 362)

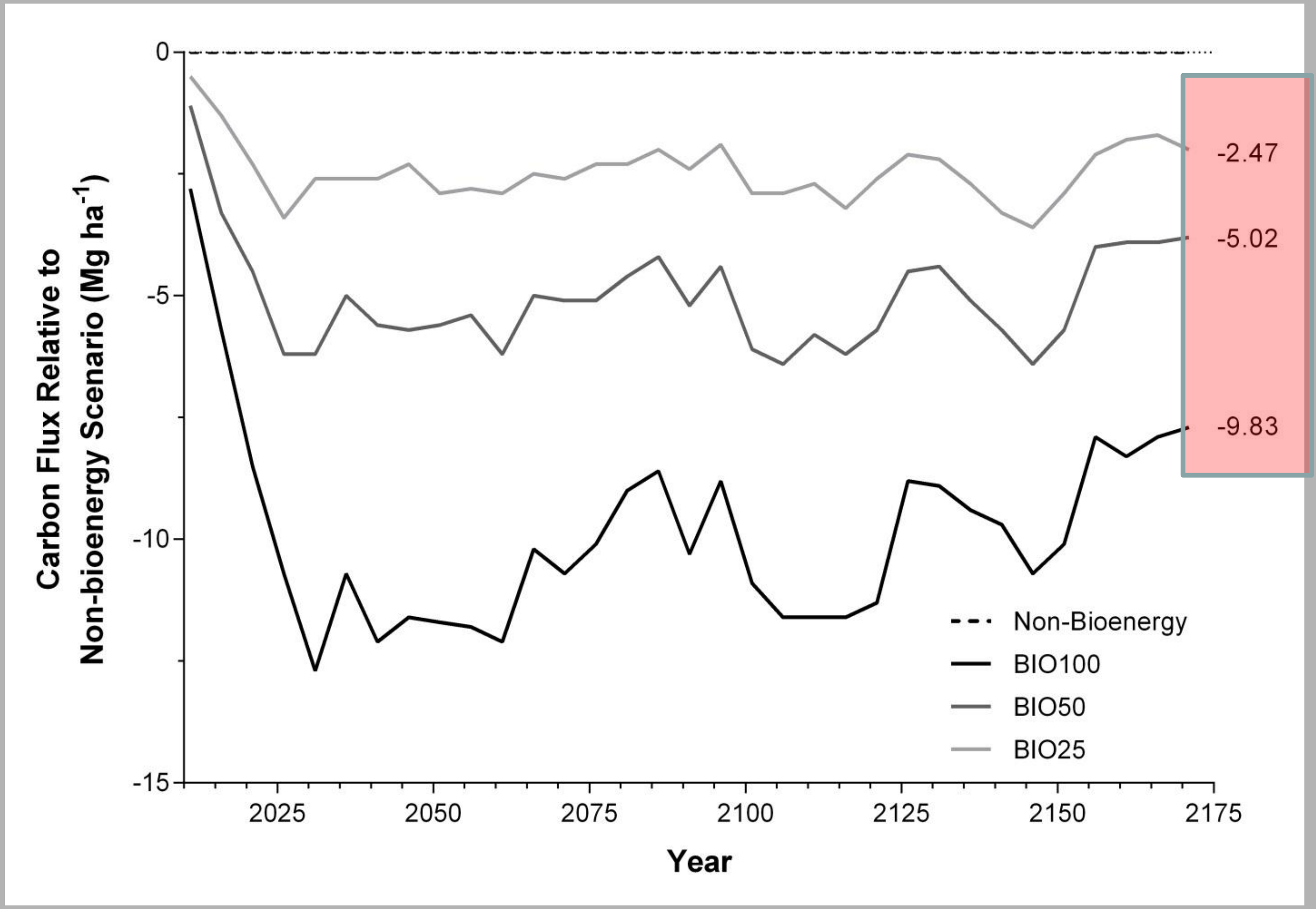


Average fluxes projected over 160 years in NE-FVS



From: Mika and Keeton 2013. In Review.

Projected net carbon flux compared to baseline (non-bioenergy harvesting)



From: Mika and Keeton 2013.
In Review.

Implications and applications in the Northern Forest region

- While previous research has tended to downplay the variability evident in harvesting practices—for instance, by strictly categorizing harvests as either bioenergy or nonbioenergy, or whole-tree vs. non-whole tree – our research highlights the importance of considering bio-energy as a continuous variable in the context of multiple harvest objectives.
- Findings from this study can inform development of structural retention guidelines for bioenergy harvesting in the northern hardwood region.
- We found that 30% of the WTH bioenergy harvests and all non-WTH bioenergy operations are already meeting or exceeded retention standards set by professional organizations. Thus guidelines can play a positive role encouraging others to improve harvesting practices.
- Silvicultural practices such as increasing rotation length and structural retention may result in less drastic C fluxes from bioenergy harvests.
- C emissions resulting from potential intensification of harvests could be reduced if operators select smaller equipment and leave a portion of tree tops on site.
- Silvicultural practices such as increasing rotation length and structural retention may result in less drastic C fluxes from bioenergy harvests. Finally, we recommend designation of un-harvested or lightly managed reserves to offset emissions from harvested stands.

Future directions

- Integrate datasets and findings into on-going regional ecosystem service modeling
- Evaluate tradeoffs between bioenergy harvesting and provision of other ecosystem services, such as biodiversity and water
- Help develop a comprehensive understanding of the potential for ecologically sustainable bioenergy production, with minimized emissions risk, with the region’s overall energy portfolio

List of products

Journal Papers:

- Littlefield, C.E. and Keeton, W.S. 2012. Bioenergy harvesting impacts on ecologically important stand structure and habitat characteristics. Ecological Applications 22(7):1892–1909.
- Mika, A.M. and W.S. Keeton. 2012. Factors contributing to carbon fluxes from bioenergy harvests in the U.S. Northeast: an analysis using field data. Global Change Biology: Bioenergy. published on-line
- Mika, A.M. and W.S. Keeton. In Review. Net carbon fluxes at stand and landscape scales from wood bioenergy harvests in the U.S. Northeast. Ecological Applications.
- Gunn, J. A., D. J. Ganz, and W. S. Keeton. 2012. Biogenic vs. geologic carbon emissions and forest biomass energy production. Global Change Biology: Bioenergy 4:239-242.
- Buchholz, T., A.J. Friedland, C.E. Hornig, W.S. Keeton, G. Zanchi, and J. Nunery. 2013. Mineral soil carbon fluxes in forests and implications for carbon balance assessments. Global Change Biology: Bioenergy In Press

Graduate Theses:

Mika, M. A. 2013. Impacts of land-use change and wood bioenergy harvesting on carbon storage and net emissions in the northeastern United States. Ph.D. Dissertation. University of Vermont.

Littlefield, C.E. Effects of wood bioenergy harvesting on ecologically important stand structure characteristics in northern hardwood forests. M.S. Thesis. University of Vermont.

Reports:

Biomass Energy Working Group. 2012. Biomass Energy Development Working Group Final Report. Legislative Council, Vermont State Legislature, Montpelier, VT. 196 pp.

Biomass Energy Working Group. 2011. Biomass Energy Development Working Group 2011 Interim Report. Leglislative Council, Vermont State Legislature, Montpelier, VT. 54 pp.

List of products

Invited Presentations to Date:

- Keeton, W.S. Toward a unified theory of forest carbon management. Middlebury College, Environmental Colloquium, Middlebury, VT. Oct 11., 2012.
- Keeton, W.S. Toward a holistic approach to forest carbon management. University of Wisonsin-Madison, Department of Forest Ecology and Wildlife, Madison, Wisonsin. March 23, 2012.
- Keeton, W.S. Bioenergy harvesting impacts on stand structure and carbon fluxes based on field data. Symposium on Long Term Ecological Research. Harvard University, Harvard Forest. Petersham, MA. March 20, 2012.
- Keeton, W.S. Effects of bioenergy harvesting on stand structure and carbon fluxes in northern hardwood forests based on field data. Invited presentation to the annual meeting of the Hubbard Brook Committee of Scientists, Cary Institute of Ecosystem Studies, Millbrook, NY, October 5, 2011.
- Keeton, W.S. Toward a unified theory of forest carbon management. Invited speaker at Cornell University, Division of Neurobiology and Behavior. September 16, 2011.
- Keeton, W.S. Effects of biomass energy harvesting on stand structure and carbon fluxes in northern hardwood forests. Invited presentation to the Biomass Energy Working Group, Vermont State Legislature. Montpelier, VT. May 17, 2011.
- Keeton, W.S. Wood Biomass Energy: Looking Back, Moving Forward. Invited Keynote presentation to UVM Bioenergy Research Symposium. Burlington, VT, April 28, 2011.
- Buchholz, T. and W.S. Keeton. Bioenergy From Forests: The Debate on Carbon Accounting. Invited seminar presented to Dartmouth College, Environmental Studies Program, Hanover NH, February 7, 2011.
- Keeton, W.S., A. Mika, C. Littlefield, and T. Buchholz. Invited presentation. Fuel from the Forest: Land, Climate, and Energy Implications of Woody Biomass. Yale University, School of Forestry and Environmental Studies. Jan 11, 2011, New Haven, CT.
- Keeton, W.S. Toward a Unified Theory of Forest Carbon Management. Invited presentation to the Society of American Foresters, Green Mountain Division Annual Meeting. Montpelier, VT.
- Keeton, W.S. Towards a unified theory of forest carbon management. Invited presentation to the Belgian Earth Observatory Program, Department of Earth and Environmental Sciences, Leuven Catholic University, Leuven, Belgium. December 12, 2010.

List of products (Cont.)

Invited Presentations to Date:

- Keeton, W.S. Towards a unified theory of forest carbon management. Invited presentation to the Yale Forest Forum, Yale University, School of Forestry and Environmental Studies. New Haven, CT. November 4, 2010.
- Buchholz, T. and W.S. Keeton. Forest Carbon Cycle. Sustainable Use of Renewable Energy (SURE): Renewable Technologies and Carbon Cycling State University of New York, College of Environmental Science and Forestry (SUNY-ESF), Syracuse NY November 4, 2010.
- Keeton, W.S. Towards a unified theory of forest carbon management. Invited Keynote presentation to the Eastern Canada/U.S.A Forest Science Conference (ECANUSA). Edmunston, New Brunswick, Canada. October 14, 2010.

Additional outreach and dissemination:

Data and products posted at:

www.youtube.com/watch?v=17cvzjEqzso

www.uvm.edu/~cdl

www.uvm.edu/~cfcm/symposium/

List of products (Cont.)

Contributed Presentations to Date:

- Keeton, W.S. Bioenergy harvesting impacts on stand structure and carbon fluxes in northern hardwood forests. Vermont Monitoring Cooperative annual meeting, Oct. 29, 2012, Burlington, VT.
- Littlefield, C. and W.S. Keeton. Bioenergy harvesting impacts on ecologically important stand structure and habitat characteristics. Ecological Society of America annual meeting. Portland, OR, Aug. 5-11, 2012.
- Mika, A. and W.S. Keeton. Factors contributing to carbon fluxes from bioenergy harvests in the U.S. Northeast: An analysis using field data. Ecological Society of America annual meeting. Portland, OR, Aug. 5-11, 2012.
- Keeton, W.S., T. Buchholz, C. Littlefield, and A. Mika. Scientific Assessment of Biomass Harvesting Impacts in the Northeastern U.S.. UVM Bioenergy Research Symposium. Burlington, VT, April 28, 2011.
- Buchholz, T. and W.S. Keeton. Economics of Biomass Fuel Harvests in the Northeastern Forest. Heating the Northeast with Renewable Biomass Conference. Manchester, NH, April 14-15, 2011.