30 YEARS OF FOREST CONVERSION IN THE NORTHEAST: HISTORICAL PATTERNS, ECOSYSTEM SERVICE IMPACTS AND FUTURE PROJECTIONS

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- While the rate of forest cover loss has varied over the last 30 years, the spatial patterns highlight an increasingly fragmented landscape, driven primarily by rural/suburban development pressures.
- Fragmentation risk maps identify locations across the region that are vulnerable to future changes, with important implications for biodiversity and ecosystem services provided by this important resource.

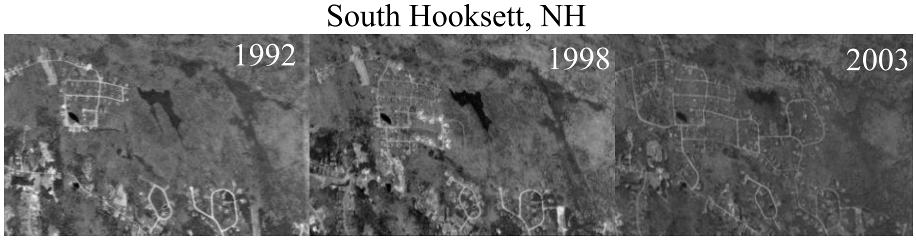
Funding support for this project was provided by the Northeastern States Research Cooperative (NSRC), a partnership of Northern Forest states (New Hampshire, Vermont, Maine, and New York), in coordination with the USDA Forest Service.
http://www.nsrcforest.org

Project Summary

Using novel remote sensing techniques to more accurately map forest basal area, we generated a region-wide forest cover database from 1984 to 2015. This resource was then used to examine historical patterns of forest loss and fragmentation in order to understand what drives forest loss, project changes in forest cover into the future and identify areas at risk.

The 30 year archive of forest species and basal area mapping products created here provide the most detailed and accurate record of forest cover currently available. These maps allow us to examine historical changes forest cover, species composition and ecosystem services provided in order to understand and model how the forest resource may continue to change.

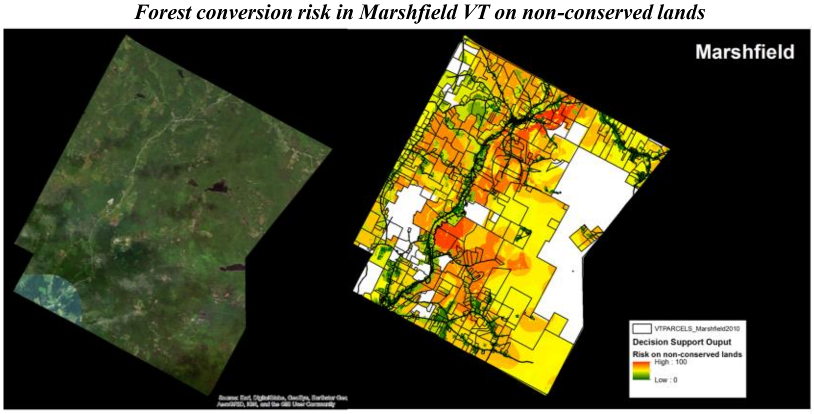
South Hooksett, NH



Project Summary

The resulting maps of current and projected forest cover, carbon and habitat fragmentation risk allow us to understand the nature and extent of changes over time, and identify areas vulnerable to future changes. This information is critical to inform forest management and planning efforts.

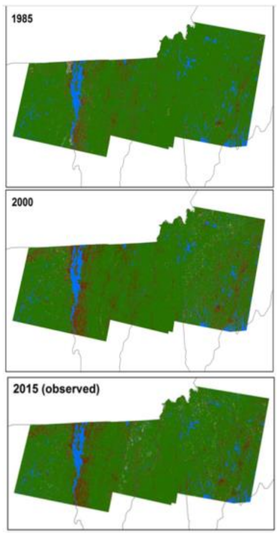
Town-level case study:
Forest conversion risk in Marshfield VT on non-conserved lands



Background and Justification

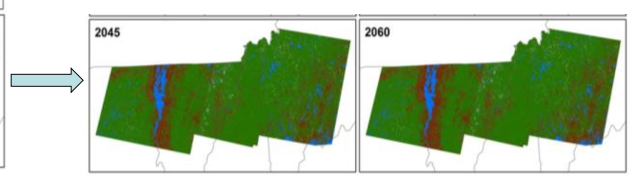
- The ability to monitor and assess changes in forest cover is critical to sustainably managing this important resource across the region.
- In particular, rural residential development can fragment forest cover and impact a range of ecosystem processes and services.
- However, current mapping of land use and land cover (LULC) across the Northern Forest has primarily been limited to coarse scale national datasets, or limited time frames.

Background and Justification



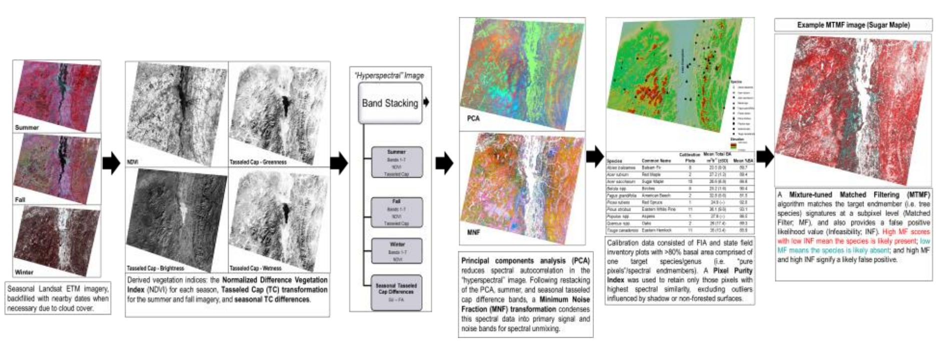
Mapping how forest cover has changed over time allows us to:

- Quantify changes in overall cover and species composition
- Identify drivers of forest conversion
- Predict future changes and identify regions at risk, and
- Inform forest management and planning decisions.



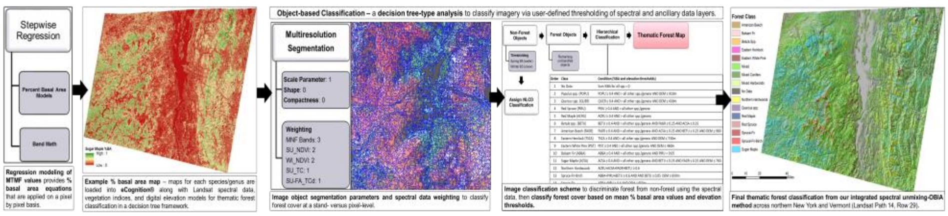
Forest Mapping Methods

- Multi-seasonal Landsat TM imagery between 1985 and 2015
- Stacked and analyzed using a novel spectral unmixing model to quantify basal area for 10 key forest species.



Forest Mapping Methods

- Basal area maps are then run through an object based rule set to classify forest types at 5 year time steps between 1985 and 2015.



Species-Type level (left) and coarse-type level (right) accuracy based on 50 independent federal and state forest inventory plots from across Vermont.

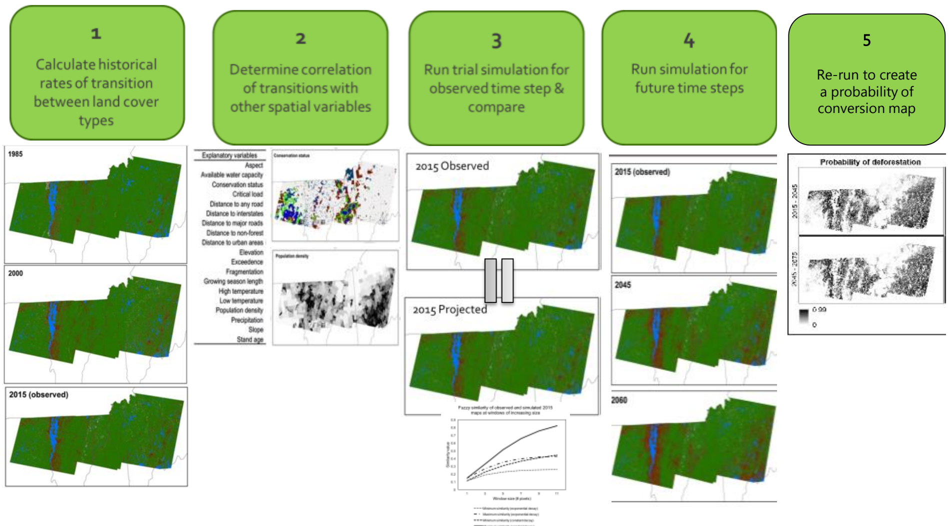
	Species Type			Coarse Forest Type	
Product	# forest classes	Overall Accuracy	Fuzzy Accuracy	# forest classes	Overall Accuracy
Gudex-Cross et al.	16	38%	0.84	10	74%
NFTM	6	18%	0.7	6	62%
Landfire	6	28%	0.8	3	66%
NLCD		*NA*		3	56%

Carbon Storage Mapping Methods

- Forest basal area maps were used to quantify carbon storage estimates and compared to traditional carbon accounting methods based only on broad land use types.

Model	Short description	Carbon storage calculation inputs
A	Relative basal area	Forest cover maps of relative basal area for the 10 major tree species in the northeastern U.S., as well as Smith et al. (2006) carbon storage tables, weighted according to the species' relative percent basal area
B	Species association	Classified forest cover map of dominant species association, derived from Gudex-Cross et al. (2017) and reclassified to match Smith et al. (2006) species association categories. Uses the Smith et al. (2006) carbon storage tables for carbon storage values.
C	Smith-based IPCC-style	Degraded Gudex-Cross et al. (2017) forest cover map to match forest type categories from the IPCC (2006)—temperate continental, temperate mountain, and boreal coniferous, above and below 20-year stand age. Carbon storage values are derived from Smith et al. (2006) carbon storage tables, averaged to create carbon storage values comparable to the IPCC (2006).
D-high	IPCC-high values	Forest classification and association maps as in Model C. Carbon storage values are from the IPCC (2006); this model uses the high end of the range provided.
D-mid	IPCC-mid values	Forest classification and association maps as in Model C. Carbon storage values are from the IPCC (2006); this model uses the middle number provided.
D-low	IPCC-low values	Forest classification and association maps as in Model C. Carbon storage values are from the IPCC (2006); this model uses the low end of the range provided.

Fragmentation Modeling Methods



Project outcomes

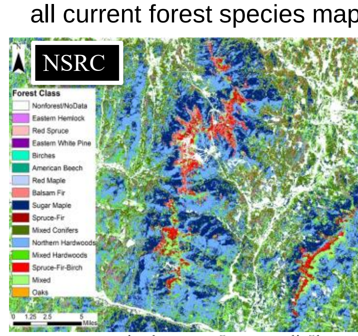
Species %BA Accuracy

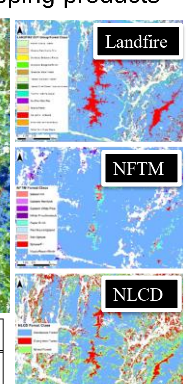
- Using this method it is possible to map fractional abundance in a complex landscape dominated by mixed forests.
- Accuracy is highest for common species with many pure training plots

Tree Spp./Genus	r^2	Adj. r^2	Mean %BA	RMSE	PRESS RMSE
Balsam Fir	0.34	0.32	0.15	0.11	0.12
Red Maple	0.47	0.46	0.08	0.06	0.06
Sugar Maple	0.46	0.44	0.28	0.16	0.17
Birches (*Betula* spp.)	0.32	0.30	0.13	0.08	0.09
American Beech	0.6	0.59	0.07	0.06	0.07
Red Spruce	0.52	0.51	0.07	0.06	0.06
Eastern White Pine	0.3	0.29	0.1	0.1	0.1
Aspens (*Populus* spp.)	0.25	0.24	0.04	0.04	0.04
Oaks (*Quercus* spp.)	0.49	0.48	0.05	0.05	0.05
Eastern Hemlock	0.32	0.30	0.11	0.09	0.1

Classification Accuracy

- Classification accuracy and detail surpasses all current forest species mapping products



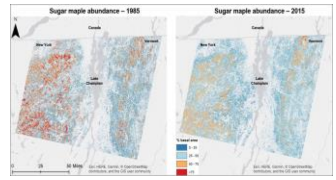


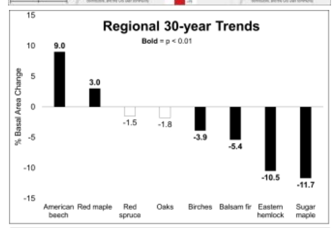
Product	# Forest Classes	Spatial Resolution (m)	Spp-Type Accuracy	Fuzzy Accuracy	Coarse-type Accuracy
MTSU	16	30	42%	86%	76%
LANDFIRE	17	30	28%	80%	66%
NFTM	29	250	18%	70%	62%
NLCD	3	30	--	--	56%

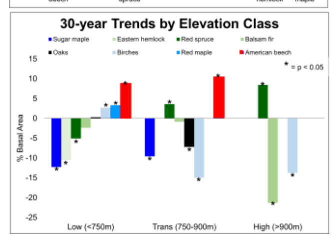
Project outcomes

Species Abundance Spatiotemporal Trends

- We detected significant region-wide reductions in sugar maple, eastern hemlock, balsam fir, and birches, and increases in American beech and red maple.
- These changes varied by elevation and showed significant spatial clustering indicating that changes in species composition are mitigated by local site and climate factors.
- Co-occurring, compatriot species often exhibited opposing trends (e.g., increased balsam fir with decreased red spruce at high elevations, and increased American beech with decreased sugar maple), indicating potential shifts in competitive dynamics.





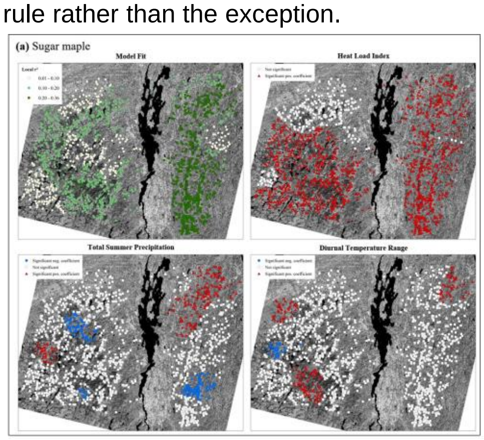


Project outcomes

Climate Drivers of Species Changes

- Climate factors were the dominant predictors of changes in species abundance.
- These relationships varied across the landscape indicating that localized responses to climate are the rule rather than the exception.

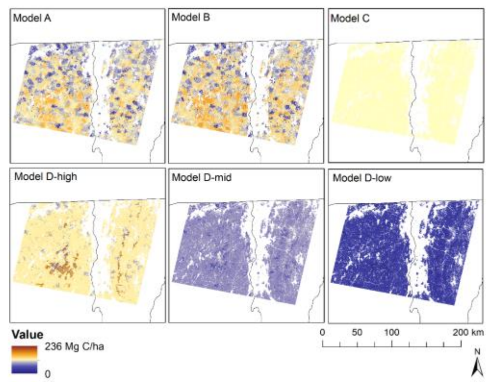
Species	Significant model parameters	Effect	"Global" p-value
American beech	Winter temperature minimum	-	<0.0001
	Annual temperature range	+	<0.0001
	Heat load index	+	0.005
Balsam fir	Winter temperature minimum	-	<0.0001
	Elevation	-	<0.0001
	Heat load index	-	<0.0001
Birches	Annual temperature range	+	<0.0001
	Elevation	-	<0.0001
Eastern hemlock	Summer total precipitation	+	<0.0001
	Winter total precipitation	-	<0.0001
	Heat load index	+	<0.0001
Oaks	Elevation	-	<0.0001
Red maple	Winter temperature minimum	+	<0.0001
Red spruce	Annual temperature range	-	0.01
	Annual total precipitation	+	0.003
	Elevation	+	<0.0001
Sugar maple	Diurnal temperature range	-	<0.0001
	Summer total precipitation	+	<0.0001
	Heat load index	+	<0.0001



Project outcomes

Carbon Storage Accounting

- Using more detailed forest classification inputs to carbon accounting results in the most accurate carbon storage estimates.
- Detailed forest classification carbon estimates are significantly higher than that derived 2013 field-based U.S. Forest Service estimates, but significantly lower than coarse land-use based assessments utilized for global carbon accounting.
- Stand age input maps contribute significant spatial uncertainty to mapped carbon storage estimates, highlighting the need for updated forest disturbance maps to further improve carbon storage estimates.



Project outcomes

Forest conversion and Fragmentation

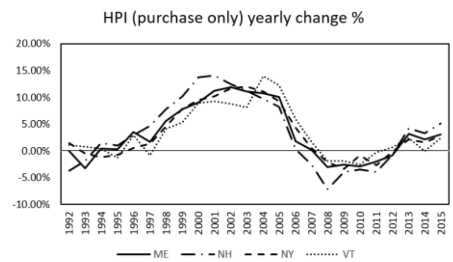
- Forest cover was lost at a rate of ~0.4% per year between 1985 and 2000 but held steady between 2000 and 2015 as development pressures decreased with the slowing economy.
- Fragmentation of forests increased consistently over the historical study period, even when forest cover was stable.

	Year	Mean forest patch size (ha)	Forest patch size standard deviation (ha)	Forest edge density (m/ha)	Total core forest area (million ha)
Observed	1985	148	19623	29	4.577
	2000	123	8550	40	4.049
	2015	107	7306	44	4.012
Projected	2030	46	11505	57	3.72
	2045	34	9710	59	3.575
	2060	29	8791	60	3.478

Project outcomes

Forest conversion and Fragmentation

- While the *rates* of forest loss vary over time based on economic pressures, forest area has and will continue to decrease over the next few decades, creating an increasingly fragmented landscape.
- Development pressures are a significant factor in which locations experience deforestation, while properties enrolled in various conservation programs have reduced risk of conversion.

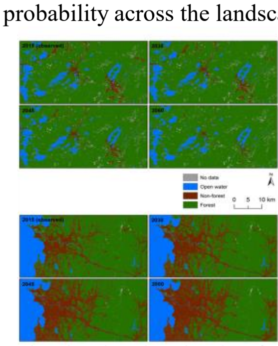


The high rate of deforestation coincides with a period of increasing home prices, while the following period of forest conversion stabilization tracks the housing market crash between 2000 and 2015.

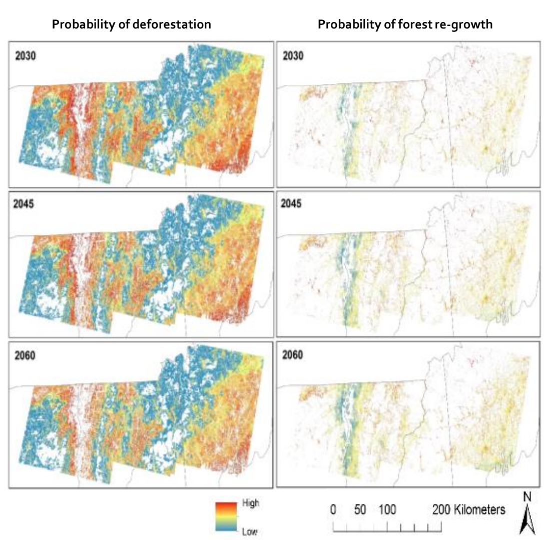
Project outcomes

Forest conversion and Fragmentation

- Applying this model across the region shows the highly variable nature of forest conversion probability across the landscape.

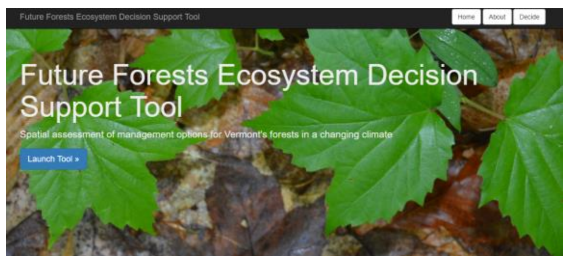


Observed 2015 data and example simulations for Adirondacks region in New York state (top) and Burlington, Vermont metro area (bottom). Adirondacks show increasing forest area, while Burlington shows decreasing forest area.



Implications and applications in the Northern Forest region

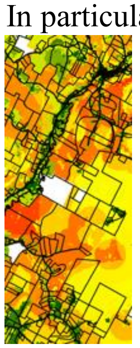
- The species composition, carbon storage and fragmentation risk maps developed here are currently incorporated into an online forest management decision support tool funded through the McIntire-Stennis Forestry research program.
- This brings the science directly to the land managers and planning specialists who need the information.



Implications and applications in the Northern Forest region

This information is particularly important in light of the continued stress of changing climate conditions and development pressures in this highly populated region.

In particular our results highlight:



- The importance of more detailed and accurate species maps to effectively monitor and manage the forest resource.
- Potential shifts in forest species of high ecological and economic significance for the region as a result of changing climate conditions.
- A need to conserve high priority parcels at risk of fragmentation in order to maintain forest integrity and ecosystem services provided.

Future directions

- This NSRC funding work for the northern forest region is **of interest to a larger group of regional stakeholders**.
- With their support, **we have secured funding to expand the geographic extent** of this work to the northeast, including MA, CT, RI, NY, PA and NJ.
- We are also working directly with the VT Agency of Natural Resources and Vermont Natural Resource Council to utilize these maps **to inform planning and forest management decisions** across public and private forest lands.

List of products

Referreed Journal Articles

Adams, A., Pontius, J., and D Guddex-Cross. In Review. Forest Fragmentation: Patterns, Trends, and Drivers across Northeastern US Forests. Landscape Ecology. (expected winter 2019 publication)

Gudex-Cross, D., Pontius, J. and Schaberg, P. In review. Recent changes in tree species abundance: 30-year patterns, trends, and potential drivers across northeastern United States forests. Canadian Journal of Forest Science. (expected winter 2019 publication)

Adams, A. Pontius, J. Galford, G., D. Gudex-Cross and S. Merrill. 2018. Modeling carbon storage across a heterogeneous mixed temperate forest: the influence of forest type specificity on regional-scale carbon storage estimates. Landscape Ecology. 33: 641-658.

Guddex-Cross, D., Pontius, J. and Adams, A. 2017. Enhanced forest cover mapping using spectral unmixing and object-based classification of multi-temporal Landsat imagery. Remote Sensing of Environment 196: 193-204.

Theses / Dissertations

Gudex-Cross, David James, "Remote Sensing Methods and Applications for Detecting Change in Forest Ecosystems" (2018). *Graduate College Dissertations and Theses*. 966. https://scholarworks.uvm.edu/graddis/966

Adams, Alison, "Methods for the spatial modeling of forest carbon in the Northern Forest" (2016). *Graduate College Dissertations and Theses*. 632. https://scholarworks.uvm.edu/graddis/632

Online Maps and Tools

Maps of Northern Forest cover change: probability of deforestation/reforestation 2015 - 2045. Forest Ecosystem Monitoring Cooperative Data Repository. https://www.uvm.edu/femc/data/archive/project/northernforest_change/dataset/map-northern-forest-forest-cover-change

Future Forests Ecosystem Decision Support Tool, FFEDS: integrates spatial data layers of current and future forest composition and function in a structured decision framework with outputs including current and future scenarios. https://www.uvm.edu/rsenr/mcintire-stennis-integrated-forest-ecosystem-assessment-support-sustainable-management

List of products

Presentations **Indicates a published abstract in Conference Proceedings*

Pontius, J., Gudex-Cross, D., and A. Adams. 2018. Changes in tree species abundance: 30-year patterns, trends, and potential drivers across the northeastern United States. Ecological Society of America Conference. August 5-10, 2018. New Orleans, LA.

Pontius, J. 2018. Geospatial Tools for Assessing and Managing Forest Health Issues. May 22-23, 2018. Lake Placid, NY.

Pontius, J. and J. Duncan. 2018. Sugar Maple Risk Mapping. VT Sugar Maker Association Annual Meeting. January 21, 2018. Brattleboro, VT.

*Pontius, J. and J. Duncan. 2017. Linking Science and Management in an Interactive Geospatial, Mutli-Criterion, Structured Decision Support Framework: Use Case Studies of the "Future Forests Geo-visualization and Decision Support Tool". Forest Ecosystem Monitoring Cooperative Annual Meeting. December 15, 2017. Burlington, VT.

Pontius, J. and J. Duncan. 2017. Linking Science and Management in an Interactive Geospatial, Mutli-Criterion, Structured Decision Support Framework: Use Case Studies of the "Future Forests Geo-visualization and Decision Support Tool". American Geophysical Union Meeting. December 11-15, 2017. New Orleans, LA.

Adams, A., Pontius, J. and Gudex-Cross, D. 2017. Modeling carbon storage across a heterogeneous mixed temperate forest: the influence of forest type specificity on regional-scale carbon storage estimates. American Geophysical Union Meeting. December 11-15, 2016. New Orleans, LA.

Gudex-Cross, D., Pontius, J. and A. Adams. 2017. Recent Changes in Tree Species Abundance: Patterns, Trends and Drivers across Northeastern US Forests. American Geophysical Union Meeting. December 11-15, 2016. New Orleans, LA.

*Gudex-Cross, D. and J. Pontius. 2016. Changing tree species distributions: a 30 year investigation into spatiotemporal trends. Vermont Monitoring Cooperative Annual Meeting. December 9, 2016. Burlington, VT.

*Adams, A., Pontius, J., Galford, G. Merrill, S. and D. Gudex-Cross. 2016. 30 years of forest conversion in the Northeast: historical patterns and future projections. Vermont Monitoring Cooperative Annual Meeting. December 9, 2016. Burlington, VT.

List of products

Presentations (cont.) **Indicates a published abstract in Conference Proceedings*

*Gudex-Cross, D., Pontius, J., and A. Adams. 2016. Mapping Tree Species across Northern New York and Vermont using Spectral Unmixing of Multi-temporal Landsat Imagery. Vermont Monitoring Cooperative Annual Meeting. December 9, 2016. Burlington, VT.

*Gudex-Cross, D., Pontius, J., and A. Adams. 2016. Enhanced forest cover mapping using spectral unmixing and object-based classification of multitemporal Landsat imagery. ECANUSA Forest Science Meeting. September 30 – October 1, 2016. Burlington, VT.

*Adams, A., Pontius, J., Galford, G. and D. Gudex-Cross. 2016. 30 years of forest conversion in the Northeast: historical patterns and future projections. ECANUSA Forest Science Meeting. September 30 – October 1, 2016. Burlington, VT.

*Duncan, J. and J. Pontius. 2016. Introducing a multi-criteria decision support tool for managing forests under climate change. . ECANUSA Forest Science Meeting. September 30 – October 1, 2016. Burlington, VT.

Gudex-Cross, D., Pontius, J. and A. Adams. 2016. Mapping forest cover across the Northern Forest: Integrating pixel-based and object-based classification of multitemporal Landsat imagery. Ecological Society of America Annual Meeting. August 7-12, 2016. Ft. Lauderdale, FL.

Adams, A., Pontius, J. and G. Galford. 2016. 30 years of forest conversion in the Northeast: historical patterns and future projections. US- International Association of Landscape Ecologists Meeting. April 3-7, 2016. Ashville, NC.

Adams, A., Pontius, J. and G. Galford. 2016. Calculating carbon stored in a northeastern forest: a methods comparison. Earth Science Information Partners Winter Meeting, January 2016.

*Adams, A, Pontius, J., Galford, G., and D. Gudex-Cross. 2015. Calculating carbon storage in the Northern Forest: a methods comparison. Vermont Monitoring Cooperative Annual Meeting. December 11, 2015. Burlington, VT.

*Gudex-Cross, D., Pontius, J. and A. Adams 2015. A Novel Approach to Mapping Forest Cover in Vermont: Coupling Spectral Unmixing and Object-based Classification of Multitemporal Landsat TM Imagery Vermont Monitoring Cooperative Annual Meeting. December 11, 2015. Burlington, VT.

Adams, A., Galford, G. and J. Pontius. 2015. Accounting for tree species composition in landscape-scale forest carbon storage estimates. Ecological Society of America Conference. August 9-14, 2015. Baltimore MD.