



**Northeastern States Research Cooperative (NSRC) FY2020
USDA FS Award #: 20-DG-11242307-025
Final Report**

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Administration

The Northeastern States Research Cooperative (NSRC) is a competitive grant program for applied Northern Forest research, jointly directed through the USDA Forest Service, [Northern Research Station](#), the [Hubbard Brook Research Foundation](#), and a designated institution in each of the four Northern Forest states: the [Rubenstein School of Environment and Natural Resources](#) at the University of Vermont, the [University of New Hampshire](#), the [Center for Research on Sustainable Forests](#) at the University of Maine, and the State University of New York College of Environmental Science and Forestry.

This award was granted in 2020 and defined the first year of “NSRC 2.0”. After a lapse in funding from 2016–2019, the leadership team found direct collaboration and service to stakeholders and non-academic partners was a key area for growth. To ensure alignment with on-the-ground issues and emerging priorities, Tribal consultants and an External Advisory Committee representing forest industry, natural resource management, conservation, wildlife, and economic development annually set the research agenda for the general requests for proposals. See the [External Advisory Committee report](#) and the [Tribal consultants report](#). Additionally, the NSRC Executive Committee seeks regular input on NSRC outcomes and function and NSRC 2.0 has broadened engagement with US Forest Service including R&D, the Forest Products Laboratory, and National Forest System.

In this award, the NSRC facilitated two Requests for Proposals (RFP); the general fund and, for the first time, the Indigenous Forest Knowledge Fund (IFKF). For the general grant, proposals addressed, (1) the state of the forest; (2) measuring and quantifying impacts; and/or (3) developing tools for response. Although the general RFP encourages projects of high cultural significance to Indigenous communities (e.g., the health of brown ash, Indigenous peoples’ access to lands for hunting, fishing, gathering materials), NSRC created a separate funding pool to, 1) acknowledge and address barriers in opportunities for Indigenous youth to participate in forest research; and 2) invest in the cultural and intellectual sovereignty of Tribal forest traditions alongside other forms of applied forest research funded through IFKF.

In response to these two funding calls, NSRC received 50 research project proposals requesting \$6.3 million in funding. In total, 11 General Fund projects and 2 IFKF projects were funded totaling \$1.6 million in federal funding and generated \$800,000 in matching funds (see table 1 below) and over \$4 million in leveraged funds.

The objectives outlined in this award were all met.

- 1. Develop a multi-stakeholder platform for the Northern Forest to inform research priorities and recruit a strategic roster of funded research projects.**

The EAC and tribal consultants provided guidance on the NSRC priorities for funding. Once projects were proposed, they went through technical reviews then sent to the Full Proposal Review Panel, consisting of key stakeholders in the region who ranked the proposals based on relevancy.

2. Support high priority scientific research through efficient research administration, data archiving and sharing, and annual financial and technical monitoring and reporting.

80% of the funding of this award was allocated directly to research projects. The remaining 20% went toward administration and communications. The research funded through this award resulted in 13 peer-reviewed publications, 8 publications in preparation and expected to be published this year, and more than 40 other resources including theses, technical reports, videos, and more. (see all products in Appendix A: Products). The projects supported at least 30 graduate students, 65 undergraduate students, and 14 post-docs or professionals. This research also resulted in **over \$4 million in match or leveraged funding**. Project data can be found in our Forest Ecosystem Monitoring Cooperative (FEMC) Collection.

3. Share and foster dialog regarding research findings and synthesis to stakeholders through multiple communication channels.

During this award period, NSRC rebranded with a new logo and a [recently launched website](#). All projects are available on our new website with research findings, publications, and news highlighted. We also held an NSRC session at each annual FEMC conference in Burlington, Vermont. In addition to web-based materials, we developed annual one-pagers with project titles and a summary of the program, and developed a general brochure for tabling events. Project PIs presented their work at more than 60 events (see Presentations in Appendix A: Products)

NSRC 2020 General Research Projects	PI	Lead Institution
Assisted Migration: A Viable Silvicultural Technique for Facilitating Adaptation of Northern Forest Tree Species to a Warmer and Drier Future World?	Asbjornsen, Heidi	University of New Hampshire
Escaping to the Northern Forest: Migration, Housing, and Community Implications in the Time of COVID	Carson, Jessica A.	University of New Hampshire
Evaluating the Efficacy of Audubon's Bird-friendly Maple: Can Managing Sugarbushes for Birds Provide Additional Benefits to Biodiversity, Ecosystem Services, and Forest Resilience?	Faccio, Steven D.	Vermont Center for Ecostudies
Influence of Multiple Impacts on User Experience and Decision Making in the Northern Forest	Feldpausch-Parker, Andrea	SUNY College of Environmental Science and Forestry
Integrating Genetic and Ecological Data Using a New Circuit Theory Approach to	Murdoch, James D.	University of Vermont

Measure and Map Wildlife Connectivity across the Northeast		
A New Silvicultural Guide for Northern Conifers in the Northeast	Simons-Legaard, Erim	University of Maine
Pheromone-based Monitoring and Control Program for Browntail Moth in the Northeast	Mech, Angela M.	University of Maine
Predicting Density and Occurrence of Keystone and Umbrella Species Using Drone-based LiDAR	Sirén, Alexej P. K.	University of New Hampshire
*Quantifying the Genetic Impacts of Forest Management Strategies on Sugar Maple (<i>Acer saccharum</i>) in the Northern Forest	Fernando, Danilo D.	SUNY College of Environmental Science and Forestry
The State of the Northeastern Forest Carbon Cycle: High-Resolution Carbon Accounting for The Regional Forest Sector	Hayes, Daniel J.	University of Maine
Vermont Town Forest Census for Covid, Carbon and Capacity-Building	Danks, Cecilia M.	University of Vermont
NSRC 2020 Indigenous Forest Knowledge Fund (IFKF) Projects	PI	Lead Institution
Haudenosaunee Forest Principles	Kimmerer, Robin	SUNY College of Environmental Science and Forestry
NEBI (Water): Connecting N'dakinna (Land), Bilowagizegad (Climate), and Alnobak (People)	Wymore, Adam S.	University of New Hampshire

The remainder of this report consists of individual research project final reports.

Assisted Migration: A Viable Silvicultural Technique for Facilitating Adaptation of Northern Forest Tree Species to a Warmer and Drier Future World?

Principal Investigator: Dr. Heidi Asbjornsen, University of New Hampshire

Co-Principal Investigators:

Anthony D'Amato, University of Vermont

Cameron McIntire, USDA forest service

Matthew Vadeboncoeur, University of New Hampshire

Jay Wason, University of Maine

Completion date: March 31, 2025

This project was a common garden drought experiment with 5 species and 3 ecotypes showed that, contrary to expectation, the effect of drought on height and diameter growth rates was independent of source location, and that ecotypes sourced from drier climates did not necessarily have a growth advantage over mesic ecotypes under drought.

These findings suggest that when selecting tree species for forest assisted migration to maximize drought adaptation, selecting the appropriate species may be more important than selecting ecotypes from a specific source location.

While we expected tree seedlings sourced from more mesic climates to suffer greater reductions in growth and physiological performance, we observed that source location only had significant impacts on foliar gas exchange rates for three of five species and that the effect of drought on height and diameter growth rates was independent of source location.

Project Summary

Forest managers are increasingly turning to adaptive forest management strategies to cope with the current and potential future effects of changing environmental conditions on forest health and productivity. One such strategy involves forestry assisted migration; the intentional planting of tree species and populations adapted to the future climate of a region. While this strategy has gained traction in recent years, many fundamental questions remain unanswered for the Northern Forest region, including 1) how to select the most appropriate species and populations, and 2) how does drought shape the utility of forestry assisted migration?

To answer these questions, we planted bareroot seedlings of black cherry, eastern white pine, northern red oak, sugar maple, and white oak from three source locations (Michigan, New Hampshire, Virginia) at the UNH MacFarlane Greenhouses (Durham, NH). For two growing seasons, we monitored growth, anatomical, and physiological metrics under various levels of drought and in temperatures 3.7 °C warmer than the New Hampshire state 30-year average. We hypothesized that 1) under well-watered conditions, seedlings from warmer climates will exhibit higher growth rates and greater foliar gas exchange (photosynthesis and transpiration) compared to those from cooler climates, and 2) under water-limited conditions, seedlings from more arid regions will have the smallest reductions in growth and physiological performance during drought.

We found that, when given ample water, trees from the warmest site rarely had higher growth. This hypothesis was only supported in eastern white pine diameter growth. Contrary to our hypothesis, all other species showed no significant growth differences or differences in which ecotype grew the most. However, the responses of several physiological performance metrics supported our hypothesis, namely black cherry and white oak from warmer climates had higher stomatal conductance and photosynthetic rates.

When exposed to drought, ecotypes from more arid sites did not show greater resilience in terms of their growth response. Instead, ecotypes generally responded similarly to the drought treatment. The more mesic black cherry and white oak ecotypes showed larger declines in gas exchange than the ecotypes from drier regions. In northern red oak, we saw differences across ecotypes but not in the expected direction. From these findings, we conclude that relationships between the ecotype's native climate and the responses of growth and physiology are not unidirectional (i.e. for some species the ecotypes from warmer and drier climates outperformed the local one and vice versa) and that there is substantial variation across species in the magnitude of ecotype effects in response to drought.

Background and Justification

Climate models forecast that the Northeast U.S. (NE) will experience warming temperatures and increases in the amount and variability of precipitation events, a combination that may increase the frequency and severity of drought in this region. Several adaptive forest management frameworks have been proposed to address the potential negative impacts on forest health and productivity caused by these and other changing environmental conditions. One such framework is “resistance, resilience, transition”, where the transition component involves facilitating or directing forests towards novel conditions using tools like forestry assisted migration (FAM). A novel silvicultural tool in the NE, it is uncertain which species would benefit most from FAM and where to source seedlings for planting in Northern Forests. Recent droughts in this region

highlight the potential importance of sourcing seedlings from drier regions where the ecotypes are presumably more drought-adapted, thereby potentially enhancing the successful application of FAM techniques in a future drier climate.

Methods

In 2022, we planted 1-2 year old bareroot seedlings of eastern white pine (*Pinus strobus*), black cherry (*Prunus serotina*), sugar maple (*Acer saccharum*), white oak (*Quercus alba*), and northern red oak (*Q. rubra*) from three source locations that represent distinct ecoregions and capture the geographic and ecological extent of these species' range—NH State Forest Nursery (Boscawen, NH), VA Department of Forestry Nursery (Charlottesville, VA), and Cold Stream Farm (Free Soil, MI). The experiment was conducted in a semi-open greenhouse (University of New Hampshire; Durham, NH) over two growing seasons, with seedlings exposed to different watering regimes: in 2022, seedlings experienced either well-watered or droughted conditions, while in 2023, the drought treatment was split into moderate and severe intensities.

We measured height and diameter growth four times per growing season, foliar gas exchange on a twice weekly basis in 2023, and leaf anatomical traits at the end of the experiment in 2023 (specific leaf area and stomatal size/density). Statistical analyses, including ANOVA and non-parametric tests, were used to determine the effects of ecotype, drought treatment, and their interaction on growth and physiological traits.

Key Findings

- ✎ We observed ecotype level differences in growth rates, anatomy and/or physiology for all species except sugar maple.
- ✎ The hypothesis that ecotypes originating from warmer sites would have higher growth rates in a warm greenhouse environment was only supported in diameter growth for eastern white pine.
- ✎ The hypothesis that ecotypes originating from drier sites would be least impacted by our drought treatments was largely unsupported.

Implications and Applications in the Northern Forest Region

These results suggest that while intentionally selecting ecotypes for FAM could enhance seedling growth during the crucial early stages of development, matching seedling origin to outplanting sites—particularly regarding potential temperature and drought stress—remains challenging for these species. Forest managers who wish to implement forestry assisted migration will be faced with the uncertainty of whether seedlings sourced from a non-local nursery will have

performance advantages over local seedlings or natural regeneration. Our results provide evidence that species selection will likely be a more important consideration than ecotype for forestry assisted migration decision making.

Forestry practitioners in the Northern Forest Region seeking to implement assisted migration with the species examined in this study face significant limitations in the availability of nursery stock. Among the relatively few nurseries offering these species, many lacked detailed records confirming that their seedlings were grown from locally sourced seed. While using seeds instead of seedlings could enhance the genetic and geographic diversity of planting stock, it also introduces additional challenges, including germination difficulties, vulnerability to predation, and increased competition during establishment.

Future Directions

As part of a separately funded NRSC project, Emily Anders (PhD student, UNH) is conducting field research to assess genotypic and phenotypic variation among ecotypes within the Northern Forest region (including several species used in our common garden experiment). This work will guide future common garden experiments and provide a framework for enhancing within-species diversity in local nurseries.

Future research could include reciprocal transplant experiments using the same species and nurseries in this study, where seedlings are transplanted across a wide range of climatic conditions to test the boundaries of survival and growth for species suitable for assisted migration in the Northern Forest Region. See TransX experiment led by Loic D'Orangeville for example.

Although we observed anatomical differences among ecotypes in this study, the genetic diversity of nursery stock in the eastern U.S. remains poorly understood. Gaining a better understanding of how genetically distinct—or similar—nursery stocks are across the region would be valuable for informing if nurseries should work towards diversifying their seedling stock to support assisted migration efforts.

Escaping to the Northern Forest: Migration and Community Implications in the Time of COVID

Principal Investigator: Jessica A. Carson, University of New Hampshire

Completion date: October 31, 2023

Between 2020 and 2021, nearly 13,000 more people moved into the Northern Forest than moved out, reversing the region's decade-long trend of losing 7,000 residents per year. We find evidence that Northern Forest in-migrants tended to have higher incomes than existing residents and that many in-migrants plan to stay in their new communities long-term.

Project Summary

At the start of the COVID-19 pandemic, popular press described urban residents “fleeing” to rural regions to escape from the virus, including to the Northern Forest region of Northern New England and upstate New York. This descriptive mixed methods study uses multiple quantitative data sources, plus primary interviews with Northern Forest movers and real estate agents, to quantify the extent of migration, characterize migrants, and identify community characteristics associated with intensive migration (e.g., “pull factors”) during the pandemic.

We find that between 2020 and 2021, nearly 13,000 more people moved into the Northern Forest than moved out, reversing the region's decade-long trend of losing 7,000 residents per year. Mover-specific data are limited, but Internal Revenue Service tax filing data shows that Northern Forest in-migrants tended to have higher incomes than existing residents. We also find some evidence that in-migrants were also disproportionately older. Across the region, counties historically defined as retirement destinations had the highest net domestic migration rates, as did counties with a high shares of housing units vacant for seasonal or occasional use. These counties may be well known and have strong visitor or transitional infrastructure but will need to consider how that infrastructure accommodates both newcomers and existing residents. Understanding pandemic-era migration in the Northern Forest can inform community planning for forthcoming migration related to climate change and continuing Baby Boomer retirements.

Figure 1. Northern Forest Region Locator Map (shaded)



Source: Carsey School of Public Policy map, created in Datawrapper, using information from the Northeastern States Research Cooperative.

Background and Justification

The Northern Forest—a 34-county swath of northern Maine, New Hampshire, Vermont, and New York—has long attracted tourists for its outdoor recreational amenities. With a recreation-heavy economy, the region traditionally serves seasonal skiers and hikers with an expansive mix of short-term rentals and second homes.² This combination of rural features and occasional-use housing took on special meaning at the start of the Covid-19 pandemic when as early as April 2020, **popular media began to report a pattern of urban residents fleeing cities to take refuge from Covid-19 in these amenity-rich rural regions.**³ But was this true? And if true, what might this mean for communities in the Northern Forest region?

Key research questions:

1. What was the extent of Covid-era migration into Northern Forest communities?
2. What were the characteristics of Covid-era migrants into the Northern Forest?
3. What community characteristics were associated with especially intensive migration (e.g., “pull factors”)?

Methods

Most of this work was descriptive. We documented county-wide patterns of population change using secondary data. This included:

- Quantifying net migration in the region via Census Bureau data.
- Identifying migrants’ origins and income pattern among both movers and stayers using IRS tax filing data.
- Investigating region-wide characteristics to explore whether region-wide changes helped us better understand the implications of in-migration over time.

Then we explored markers of “pull counties” with the strongest migration, framing with four literature-driven hypotheses. We posited that migrants sought:

- More rural places
- Places with a “destination” infrastructure (e.g. ample seasonal-use housing)
- Places that facilitated remote work, and/or
- Places that had fewer housing market constraints.

Table 1. Interviewees by State

	Movers	Real estate agents
Maine	3	1
New Hampshire	4	2
New York	5	1
Vermont	4	1
All four states	-	1
Total	16	6

We interviewed 16 individuals who had moved into the Northern Forest region between March 2020 and the time of the spring 2023 interview (“movers”). Three movers had relocated to the Northern Forest in Maine, four in Vermont, five in New York, and four in New Hampshire. Of the six real estate agents interviewed, two served New Hampshire, one served Maine, one served Vermont, one served New York, and one served all four states within the region.

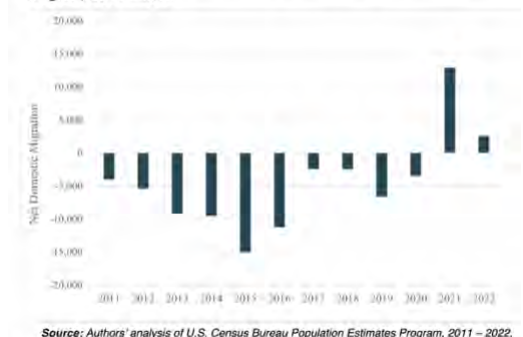
Primary Interview data:

To ensure our interpretations reflected “on the ground” experiences, we conducted 22 semi-structured interviews with people who had moved to, or sold real estate in, the region since the pandemic began.⁵ Interviews were conducted by Zoom or phone in spring 2023 and lasted an average of 17 minutes; movers were compensated with a \$25 gift card to Amazon for their participation. Conversations were recorded and transcribed, then analyzed using Dedoose software. The analysis followed a flexible coding approach akin that outlined in prior literature.⁶

Key Findings

- Covid-era migration was substantial into the Northern Forest region.
- On average, the region was losing 7,000 residents a year prior to the pandemic.
- Then, between 2020 and 2021, almost 13,000 more people moved into the Northern Forest than moved out
- Analysis of IRS data show that in-migrants tend to have higher incomes than existing residents.
- Mover-specific demographic data is hard to come by, but we find some evidence that in-migrants were also especially likely to be older adults.
- Counties defined as retirement destinations had the highest net domestic migration rates.
- Counties with a high share of housing units vacant for seasonal or occasional use were also Implications and Applications in the Northern Forest Region:
- Moving forward, migrant-attracting communities will need to consider how their infrastructure accommodates both newcomers and long-time residents.
- The implications of such intense migration aren’t fully visible yet, but one of the most immediate impacts is on housing stock and costs.
- Communities may grapple with how to address housing challenges—particularly in consideration of long-standing and emerging disparities between residents—and may use

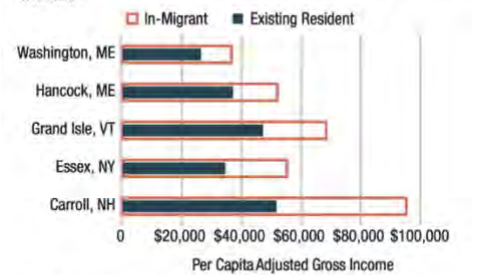
Figure 2. Annual Net Domestic Migration in the Northern Forest Region, 2011 – 2022



the information here as context on “pull factors” as they accommodate, leverage, and strategically manage migration into their communities.

- Communities will also need to consider how newcomers might be brought into the fold of communities they intentionally sought out and use their positions of relative advantage for local good.
- At least at the highest level, our interviewees described themselves as valuing many of the same things that long-time Northern Forest residents seem to: the region’s clean, rugged landscape; opportunities to enjoy the outdoors through sport and recreation; nearness to family; neighborliness; and privacy.

Figure 3. Per Capita Income in Northern Forest Counties with Largest Gap Between In-Migrant and Existing Resident Income



Notes: “Per capita income” is per capita adjusted gross income (AGI). “Largest gap” is defined as the percent difference between in-migrant and existing resident per capita AGI. IRS Statistics of Income (SOI) data include tax filers only; not all individuals are required to file an individual income tax return. Movers are filers whose 2021 tax filing (regarding income earned in 2020) had a different mailing address than their 2020 tax filing (regarding income earned in 2019). Because the address used for matching is a mailing address at filing time, it may not reflect the taxpayers’ location at the time the income was earned.
Source: Carsey School analysis of IRS SOI 2020–2021 data.

Interview Results:

Finding	Illustrative Quote
The natural environment and opportunities for outdoor recreation were interviewees’ top-reported attractants to the Northern Forest.	“I am able to, from a five-minute drive from three directions of my apartment, go for some of the most beautiful hikes I’ve ever seen.”
Most movers interviewed intend to stay in the region permanently.	“We see ourselves growing old here and being here forever.”
Interviewees did not report fear of Covid infection as a motivator for moving, although for many, the pandemic provided an opportunity to execute a move they were already considering.	Participant could finally “live wherever I wanted, as long as I had a relatively good internet connection”
Real estate agents identified some potentially worrisome impacts of this recent migration, particularly around housing costs.	That house that used to be \$180,000 that Joe Blow Local could buy is now \$300,000 or \$400,000...That obviously is having a negative impact on affordable housing.”

Future Directions

Pandemic-era migration is not a one-time event, but rather, part of a broader migration story in the region. Lessons learned from Covid-era migration can provide guidance to community and economic development stakeholders regarding impending migration ebbs and flows related to climate change and ongoing Baby Boomer retirements.

Footnotes:

1. Northern Forest Center. 2023. <https://northernforest.org>; Economic Research Service. 2017. "County Typology Codes." Washington, DC: U.S. Department of Agriculture. <https://www.ers.usda.gov/data-products/county-typology-codes>.
2. Bailey, Adams Nicholas. 2022. "Municipal Short-Term Rental Policies: Analysis and Recommendations for Adirondack Communities." *Master's Thesis*. Ithaca, NY: Cornell University. <https://northernforest.org/wp-content/uploads/2023/01/Short-Term-Rentals-in-the-ADKs.pdf>.
3. Ropeik, Annie. 2020. "Locals Bristle as Out-of-Towners Fleeing Virus Hunker Down in New Hampshire Homes." NH News, April 2. Concord, NH: New Hampshire Public Radio. <https://www.nhpr.org/nh-news/2020-04-02/locals-bristle-as-out-of-town-ers-fleeing-virus-hunker-down-in-new-hampshire-homes#stream/0>; Stephens, Kay. 2020. "The Impact of COVID-19's Urban Flight on Mainers." September 9. Penobscot Bay Pilot. <https://www.penbaypilot.com/node/137406>; Urquhart, Adam. 2020. "Affluent Out-of-State Homebuyers Look to New Hampshire for Escape." November 6, The Keene Sentinel. https://www.sentinel-source.com/news/local/affluent-out-of-state-homebuyers-look-to-new-hampshire-forescape/article_3ca0fb6c-e9c3-5c34-b2f2-64117c75af12.html.
4. Given the volume of indicators in this compiled dataset, we thematically group available indicators into categories to test each of the four hypotheses, first through bivariate correlations (Pearson's, Bonferroni corrected) then through ordinary least squares regressions. Given the small number of counties in this analysis, we strive for parsimony in our modeling approach to avoid overfitting the data. We test each batch of indicators in distinct models, and when all incorporated into the final model, we remove non-significant indicators in a stepwise method, beginning with the measure with the lowest t-statistic, assessing changes to basic model fit (F-test, adjusted R-squared) at each stage. After the final model is fitted, we calculate a predicted value and residual for each observation and use the resulting values for a series of diagnostic graphics (e.g., RvF plots) to identify heteroskedasticity and instances of especially poor fit. Alpha has been set to $p < 0.05$ throughout, except where corrected for multiple tests as noted. All analyses were conducted in Stata SE 17.0.
5. Protocol was approved by the University of New Hampshire's Institutional Review Board for the Protection of Human Subjects in Research; UNH IRB-FY2022-395.
6. Deterding, N. M., & Waters, M. C. (2021). Flexible Coding of In-depth Interviews: A Twenty-first-century Approach. *Sociological Methods & Research*, 50(2), 708–739. <https://doi.org/10.1177/0049124118799377>

Evaluating the Efficacy of Audubon Vermont's Bird-friendly Maple

Principal Investigator: Steven D. Faccio, Vermont Center for Ecostudies

Co- Principal Investigator(s): Steve Hagenbuch, Audubon Vermont; Brendan Fisher, University of Vermont; Anthony D'Amato, University of Vermont

Completion date: August 31, 2023

Sugarbush management that creates small canopy gaps provides suitable habitat for early successional species and for birds that prefer older forests with well-developed shrub layers. Percent herbaceous cover, litter depth, coarse woody material, and high canopy cover explained variation in probability of occupancy and/or expected abundance of the forest bird community.

Project Summary

Maple sugaring is experiencing rapid growth across the Northern Forest in the scale of operations, acreage impacted, and number of people involved. As a result, it is becoming increasingly important to better understand how sugarbushes can be managed to benefit both maple sap production and biodiversity conservation. Traditional sugarbush management may result in park-like stands dominated by mature sugar maple with open understories; stands that likely support a low diversity and abundance of birds and other wildlife. In contrast, Audubon Vermont's Bird-friendly Maple Project recommends forest management activities that promote sugarbush stands with a diversity of tree species and vertical habitat structure. Additionally, the long-term sustainability of maple sap production is entirely contingent on healthy forests, but our knowledge is nascent on how the complex drivers of increased production intensity, differing management strategies, and climate change will affect biodiversity, ecosystem services, and overall ecological health of sugarbushes. During 2020 and 2021 we conducted field surveys of breeding birds, foliage- and litter-dwelling arthropods, and vegetation metrics at 14 active sugarbushes (seven in each year), representing a gradient of sugaring production and management intensities, to determine the most biologically significant habitat covariates that explain variation in forest bird occupancy and abundance across sites. Additionally, in 2021 we sampled native bees at seven sugarbushes.

This research provides the first quantitative study of how forest bird communities respond to habitat structure resulting from actively managed sugarbushes. Point count surveys were conducted at 353 points where observers noted 10,332 observations of 72 species, with a mean of 9.3 birds/point. For the overall forest bird community, our results show that percent herbaceous cover, litter depth, volume of CWM, and percent high canopy cover explained

variation in probability of occupancy and/or expected abundance. Managers that maintain or enhance these variables are likely to improve conditions for the bird community. Three warbler species (Chestnut-sided Warbler, Mourning Warbler, and Black-throated Blue Warbler) increased as both low woody vegetation and sapling richness increased. This suggests that both the density of the shrub layer and the diversity of that layer are important for these species. Our results suggest that sugarbush management can create suitable habitat for both early-successional species (particularly Mourning and Chestnut-sided warblers), and for birds that prefer older forests with well-developed shrub layers (including Veery and Black-throated Blue Warbler), using treatments that create small canopy gaps with a diversity of sapling and shrub species.

Background and Justification

Maple sugaring is experiencing rapid growth across the Northern Forest. Despite this growth and the importance of maple sugaring across the region, relatively little is known about how maple production practices affect Northern Forest biodiversity, ecosystem services, and resilience to ecological stressors, including climate change.

Traditional sugarbush management may include understory removal, which can eliminate forest regeneration, resulting in closed-canopy monocultures of sugar maple that lack structural complexity. This may have a variety of negative effects on biodiversity ranging from declines in understory species richness (Leniere and Houle 2006) to reduced abundance and diversity of breeding forest birds and their primary food source—arthropods.

To address this issue, [Audubon Vermont](#) initiated the [Bird-friendly Maple Project](#), which promotes sugarbush management practices that strive to improve forest habitat value, native plant diversity, and long-term forest productivity. Audubon recommends managing for:



- A diversity of canopy tree species
- Layers of vegetation; from small seedlings to saplings and shrubs, to the canopy overhead
- Standing dead trees and live trees with cavities—the bigger the better
- Logs and branches on the forest floor



Top: A sugarbush stand with structural complexity.

Bottom: Understory removal results in maple monocultures that lack vertical structure.

In exchange for following Audubon’s guidelines, cooperating maple producers are eligible to promote their products through the use of special “bird-friendly maple” labels, signage, and other marketing tools.

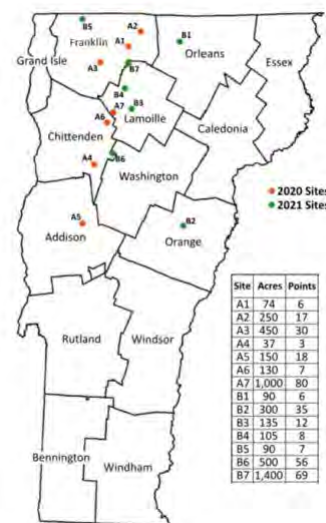
However, empirical data regarding the efficacy of Audubon Vermont’s management recommendations to provide measurable benefits to bird populations are lacking. With other maple-producing states across the Northern Forest region showing an interest in developing similar projects, it is important to provide management guidelines that produce desired outcomes.

Project Objectives:

1. Quantify forest breeding bird communities across a gradient of sugarbush production and management intensities;
2. Examine how differences in vegetation structure and arthropod biomass influence breeding bird communities;
3. Use results to revise silvicultural recommendations for Audubon Vermont’s Bird-friendly Maple Project and provide guidance in developing sustainable sugarbush management policies that will be relevant across the Northern Forest region.

Methods

We conducted field surveys of breeding birds, foliage- and litter-dwelling arthropods, and vegetation at 14 active sugarbushes across northern Vermont. Seven sites were sampled in 2020 and seven in 2021, when we also sampled native bees. The study sites were distributed across six northern Vermont counties and ranged in size from 37 to 1,400 acres (see map). The 14 sites were working sugarbushes producing syrup and other maple sap products, representing a gradient of sugaring production and management intensities. Nine (56%) were enrolled in Audubon Vermont’s Bird-friendly Maple Project.



Breeding

353 point counts were conducted (range = 3 – 80/site); 161 points in 2020, and 192 in 2021.

Birds

Three consecutive 4-min, fixed-radius (50 m) point counts (12-minutes total/point) were conducted during June. Each count was independent, allowing for greater power in estimating detection probabilities ([Reidy et al. 2011](#)).

Arthropod Biomass

The primary food items for forest songbirds, arthropods were sampled using two different methods in order to target leaf litter-dwelling and foliage-dwelling organisms. All arthropod lengths were converted to biomass (mg/m²) using length-mass regressions from the literature.

Native Bees

Abundance and diversity of forest bee communities were sampled along three 50m transects at each of seven study sites visited in 2021 using “bee bowls” (100 ml plastic cups half full of soapy water with fluorescent dye) (Droege et al. 2017).



Vegetation -- we quantified habitat structure and diversity using two different protocols; an intensive protocol at each point count location, and a “rapid assessment” protocol at three surrounding sub-plots 20m away.

Analytical Modeling

We used community occupancy models and community N-mixture (abundance) models to jointly analyze patterns in occupancy, abundance, and detection probabilities of the avian community. We selected 17 site-specific covariates based on their perceived importance to forest birds and relevance to Audubon Vermont’s Bird-friendly Maple Project guidelines with which to model occupancy and abundance of forest birds.

Community occupancy models ([Dorazio and Royle 2005](#), [Gelfand et al. 2005](#)) are built upon the idea that not all individuals or species are detected during survey methods. The models account for this imperfect detection in order to get a more accurate measure of the bird community.

Key Findings

During point count surveys 10,332 observations of 72 species were made. Of the 72 species, 47 were detected at fewer than 10% of the sampling points, while just 15 species were detected at more than 20% of points. Six species detected were listed as Species of Greatest Conservation Need in Vermont’s Wildlife Action Plan ([Vermont Fish and Wildlife Department 2015](#)), including two “High Priority” species (Wood Thrush and Canada Warbler), and four “Medium Priority” species (Black-throated Blue Warbler, Chestnut-sided Warbler, Ruffed Grouse, and Black-billed Cuckoo).

Modeling Covariate
Ground Cover
Fern/club moss cover (%)
Woody vegetation (<5m) cover (%)
Bare soil cover (%)
Herbaceous cover (%)
Grass/sedge cover (%)
Bryophyte cover (%)
Litter depth
Canopy Cover
Basal area of sugar maple (%)
High canopy cover (%)
Non-sugar maple overstory richness
Understory Diversity
Large sapling richness
Small sapling/shrub richness
Seedling richness
Dead Wood
Snag density (number/acre)
Coarse Woody Material (m ³ /ha)
Arthropods
Litter-dwelling arthropod biomass
Foliage arthropod biomass

Bird Community Occupancy Model

Avian community occupancy models (all species combined) were developed for 17 covariates. We found significant positive relationships between occupancy probability and three covariates (coarse woody material volume, percent herbaceous cover, and litter depth), and significant negative relationships with four covariates (percent bryophyte cover, snags per acre, foliage arthropod biomass, and percent low woody vegetation). Nineteen species showed significant relationships with nine covariates. Black-throated Blue Warbler, Chestnut-sided Warbler, Mourning Warbler, and Veery had significant positive relationships with small sapling richness. Black-throated Blue, Black-throated Green, and Mourning warblers had positive relationships with percent cover of woody vegetation <5m in height. However, only Black-throated Blue and Mourning warblers had positive relationships with both of these covariates, suggesting that both percent cover of low woody vegetation and the diversity of that cover are important for these species.



Bird Community N-Mixture Model

Results from the community N-mixture model, which estimated expected abundance for all birds in the community, were largely consistent with occupancy model results, with significant positive relationships between expected abundance and three covariates (percent high canopy cover, litter depth, and percent herbaceous cover), and significant negative relationships with four covariates (percent basal area of sugar and red maple, snag density, percent woody vegetation <5m in height, and foliage arthropod biomass).

Although the overall community response to low woody vegetation was negative, three understory specialists (Mourning, Chestnut-sided, and Black-throated Blue warblers) significantly increased in abundance as percent cover of low woody vegetation increased.

Similarly, a suite of six ground/understory specialists showed significant positive response to species richness of small saplings, including Veery, Mourning Warbler, Dark-eyed Junco, Chestnut-sided Warbler, Black-throated Blue Warbler, and American Robin.

Implications and Applications in the Northern Forest Region:

Four habitat covariates were important to the forest bird community:

1. Herbaceous cover
2. Litter depth
3. Coarse woody material

4. High canopy cover

Management Recommendations

- Increase and/or maintain a high percentage of native, shade-tolerant herbaceous cover. Identify invasive species and apply best practices to control. When possible, treat invasive plants before harvest and clean tires of forestry equipment to minimize spread.
- Invasive earthworms can deplete leaf litter. Pay attention to litter depth and earthworm presence/distribution to detect potential changes.
- Leave downed logs and treetops whenever possible to increase woody material.

Sugarbush management can create suitable habitat for both early-successional species (particularly Mourning and Chestnut-sided warblers) as well as ground/shrub species (including Veery and Black-throated Blue Warbler) using treatments that create small canopy gaps.

Management Recommendations

- Consider intensive group selection harvests, which create small canopy gaps while leaving areas between gaps untouched. [Tozer et al. \(2010\)](#) found this technique retained forest interior species while attracting gap specialists better than typical group selection harvests.
- When possible, emulate natural disturbance regimes in both scale and frequency, to which our forest birds are well adapted.
- When creating canopy gaps, strive to increase the species richness of the sapling/shrub layer.



Steve Faccio

Future Directions:

- This study will contribute to a broader effort being conducted by Cooperator and PhD candidate, Liza Morse (along with UVM Co-PIs), whose dissertation work is investigating how the intensity of maple sugar production affects biodiversity and the sustainability of working maple landscapes, while assessing its impacts on ecosystem services (such as carbon sequestration and storage) and resilience to increasing disturbances under climate change.
- Co-PI Steve Hagenbuch will be updating Audubon Vermont's Bird-friendly Maple guidelines to reflect outcomes from this project.



Visitor versus Local Community Perceptions of Crowding and Risk in the Adirondack Park

Principal Investigator: Dr. Andrea Feldpausch-Parker, Professor at SUNY-ESF

Co-Principal Investigator: Dr. Anita Morzillo, Associate Professor at UConn

Completion date: March 31, 2025

Most recreationists used the hiking trails in the recreational areas on weekends and in the afternoon, with locals and non-locals more likely to be observed at different recreation areas and responding differently to weather conditions. Issues such as vandalism to man-made structures, trailhead access (i.e., parking), pet waste, pets off-leash, trail condition (i.e., widened trails, loss of vegetation, soil erosion, and overcrowding), and inappropriate or unsafe situations for children and pets were notable impacts to the recreational experience. Locals and non-locals perceived their recreational experiences similarly overall, but directionality suggested that locals were more likely than non-locals to perceive access conditions less positively; safety and social conditions were likely to have a greater negative influence on experience for non-locals.

Project Summary

Since early in the twentieth century, silvicultural guides have been written for specific U.S. forest types. These guides provide information about site potential, species ecology, stand compositions and structures, damaging agents, and recommended approaches (i.e. silvicultural systems) for growing healthy trees and producing desired outcomes. Just like the forests themselves, silvicultural recommendations have changed over time with the advancement of science and emergence of concerns and values – such as biodiversity and climate change – that were unknown to our predecessors. Yet the silvicultural guide for the northern conifer forest type covering 6 million acres of New England is close to 50 years old with little relevance to the conditions and challenges facing forest managers today. This project remedies that problem by synthesizing and interpreting an additional half-century of research to develop scientifically robust and ecologically sound silvicultural recommendations within the context of contemporary forest management needs. Outputs include a new silvicultural guide for northern conifers based on the best available science and published by the U.S. Forest Service, a professionally produced companion video, and a field workshop for practitioners.

Background and Justification

Research indicates that higher levels of crowding and congestion in nature-based tourism and outdoor recreation settings have been shown to decrease levels of user satisfaction. For example, The High Peaks region of the Adirondack Park is particularly popular among outdoor recreationists, and between 2007 and 2017, hiking on High Peaks trails has increased 77%. Demand for recreation in such scenic areas has only grown since the onset of the Covid-19 pandemic, along with associative impacts proportional to use. This dramatic increase has led Park staff to report exacerbated heavy automobile and foot traffic, illegal parking on roadside trailheads, user conflicts, unprepared hikers requiring rescue, ecological damage from trampling, and increased problems with litter, human waste, and toilet paper.

This project directly addressed the needs and concerns of the region's stakeholders by identifying and evaluating multiple impacts to user experience in the Lake George Wild Forest in Adirondack Park in New York State, Steep Rock-Hidden Valley Preserves in Connecticut, and Bulls Bridge Scenic Area in Connecticut. These locations serve as case studies that are applicable to other areas of the Northern Forest. From this information, managers will be able to isolate which impacts or stressor are most limiting to the user experience and thus manage impacts more efficiently and appropriately.

Research Methods

For this project, four field sites were included with two in New York State and two in Connecticut: Shelving Rock Road and Pilot Knob Road by Lake George, NY, and Bulls Bridge Scenic Area and Steep Rock Preserves in CT. A stratified random sampling design was developed to maximize data collection across days of the week and time intervals. Human subjects approval was received in May 2022. Two data collection components were completed. First, site access and use density, with a focus on parking density and longevity, were assessed using unique vehicle information (license plates) collected during car counts at parking lots at each study site. Additional information collected included daily weather and information to assess distance traveled by visitors (e.g. car dealer identifiers on plate mounts). Second, signs and flyers containing QR codes were placed at all parking lots to collect survey data from visitors about site access and conditions, impacts and conflicts, visitor experiences, and demographics. In the second year of the project, intercept surveys were added to the survey protocol to increase survey participation. In the final year of the project, interviews with key stakeholders were conducted to give further context to what was asked in the surveys.

Key Findings

Car count data findings:

Locals and non-locals recreate differently based on weather and overcrowding at the trailhead parking lots, with locals more willing to adapt to the situation.

Weekend and afternoons are the preferred time to hike (i.e., peak hiking time).

Survey data findings:

Locals and non-locals perceive trail conditions similarly with vandalism to man-made structures, trailhead access, pet waste, pets off-leash, trail condition, and inappropriate or unsafe situations for children and pets being the major issues.

Interview findings:

Motivations for trail usage included seeking inner peace and reflection and overcoming physical and mental challenges

Widened trails, loss of vegetation, soil erosion are common indicators of trail degradation and overuse.

There are conflicts between locals and non-locals due to overuse of the trails and hiking behaviors.

Implications and Applications in the Northern Forest Region

It is important to note differences in the usage of recreational trails between locals and non-locals, with locals being more likely to adapt their trail usage (e.g., finding somewhere else to hike) based on the trail usage by non-locals who were less willing to deviate from their usage based on crowding and weather.

Greater numbers of trail users were concentrated during particular times of the day (i.e., weekends and afternoons), and a large number of short visits indicated a constant turnover of users. Anecdotally, at peak times, I observed vehicles attempting but unable to access parking lots and consequently having to park elsewhere. Thus, during high-volume use times, it would be helpful for recreation managers to provide signage for additional parking to users seeking access to amenities while passing through the area. Furthermore, roadside signage may help to increase visitation by helping users less familiar with the area (i.e., non-locals) find amenities that are not visible from the road.

Additional signage about trail rules addressing vandalism, trailhead access, pet waste, pets off-leash, and inappropriate or unsafe situations for children and pets being could be beneficial for self-policing and the establishment of social norms on the trail. Temporary signage addressing

trail conditions during or after weather events could also be beneficial to warn against potentially unsafe or more challenging conditions.

Future directions

It would be beneficial to add the signage suggested above and determine if this signage is having any impacts on user behaviors. It would also be useful to examine social norms around trail usage to determine what factors influence people's willingness to conform to requested behaviors.

Integrating Genetic and Ecological Data to Measure and Map Wildlife Connectivity Across the Northeast

Principal Investigator: Dr. James Murdoch, University of Vermont, RSEN

Co- Principal Investigator: Dr. Stephanie McKay, University of Missouri, CAFNR

Completion date: January 2024

Landscape connectivity is a common, high-priority goal for supporting the persistence of wildlife populations. The northern forests of New England represent an important region for terrestrial wildlife movement and gene flow, yet face challenges like habitat alteration, fragmentation, and loss, and climate change. We developed models and maps of species movements and gene flow across northern New England using a circuit theory approach to inform wildlife and land management in the region.

Project Summary

The northeastern United States represents a vital region for wildlife connectivity. The region provides key habitat that allows for movement and genetic exchange of animals across several states and provinces, which promotes healthier and more resilient populations. It also represents a critical linkage for movement of species northward as climate conditions change. However, habitat fragmentation, alteration, and loss represent persistent conservation problems that substantially impact wildlife populations by limiting how and where species move across the landscape.

Non-profit organizations, state and federal agencies, and academic researchers have made numerous attempts to measure, map, and identify wildlife connectivity. However, nearly all efforts have been assessments of physical and ecological requirements of species and have largely neglected genetic characteristics, which are critical to understanding animal movement across the landscape.

We integrated ecological and genetic data using a new circuit theory approach to map connectivity for 10 managed species with high ecological, economic, and cultural importance: black bear, bobcat, coyote, deer, fisher, marten, moose, raccoon, red fox, and striped skunk. Models revealed distinct patterns of movement and gene flow for different species and provide a more precise and comprehensive depiction of wildlife connectivity across the region that can be used to support management decision-making at multiple spatial scales. We are working to apply the approach to the Green Mountain National Forest with partners at the USDA Forest

Service to evaluate effects of routine forest management activities on connectivity to improve strategic decision-making that maximizes benefits for species while considering other objectives.

Background and Justification

The Northeast is a vital region for wildlife connectivity with multiple wildlife linkage areas identified based on expert opinion and landcover data. Landscape connectivity across the region facilitates gene flow, contributing to resilience and health of wildlife populations.

Northern New England may provide a critical linkage for species moving northward due to changing climate conditions. Persistent problems of habitat alteration, fragmentation, and loss and climate change impacts wildlife populations, restricting movement across the landscape.



Critical wildlife linkage areas identified by the [Staying Connected Initiative](#).

Understanding landscape connectivity at large scales requires new approaches that integrate multiple sources of information, including about animal movement, distribution/abundance, and genetics. Information on gene flow, in particular, can provide a more comprehensive picture of landscape connectivity for wide-ranging species.

Methods

Overview of methodology

Our approach involved modeling and mapping connectivity for 10 terrestrial mammal species that combined 1) genetic data from samples collected across the region and 2) information on each species' distribution based on models of occupancy. Genetic data were used to create resistance surfaces depicting historical patterns of how genes flowed across the landscape.

An omnidirectional circuit theory approach called [Omniscape](#) was used to integrate genetic data with species distribution information to map landscape connectivity for each species.

Genetic sample collection

We worked with project collaborators in VT, NH, and ME on an extensive effort to collect tissue or hair samples from all focal species. Samples were primarily collected from hunters and trappers who harvested animals during regulated seasons. Additional samples were collected from roadkill animals; many were collected by USDA Wildlife Services in



Photos © Josh Blouin, VFWD

each state. Samples were then placed into cryovials, organized by species, and sent to UC Davis for DNA extraction and analysis.



Right: Graduate x Caitlin Drasher collects wildlife tissue samples at VFWD furbearer necropsy sessions. **Above:** Samples were collected at deer check stations in VT and NH during hunting season.

Genetic analyses

The Mammalian Ecology and Conservation Unit at UC Davis performed DNA extraction on the samples. Bobcat, coyote, fisher, raccoon, red fox, and skunk samples had SNP markers sequenced using Genotype-by-Sequencing (GBS) methods. Bear and deer samples had microsatellite loci sequenced for analysis. Existing sample data for moose (Rosenblatt et al. 2022) and marten (Aylward et al. 2020) were used for these species.

Landscape resistance development based on genetic data

Sufficient samples were collected for bear, bobcat, coyote, deer, fisher, moose, raccoon, red fox, and skunk; sample collection was challenging for gray fox, so we excluded this species from further analyses. Landscape resistance surfaces related genetic data to landcover characteristics. We used landcover data from the North American Land Change Monitoring System ([NALCMS](#)), reclassified into 8 landcover groups hypothesized to be relevant for gene flow for the suite of species. We built landscape resistance surfaces optimized with the genetic data collected for each species using the [resistanceGA](#) package in R (Peterman 2018). These models are computationally intensive and will be updated in spring 2024.

Landscape connectivity models

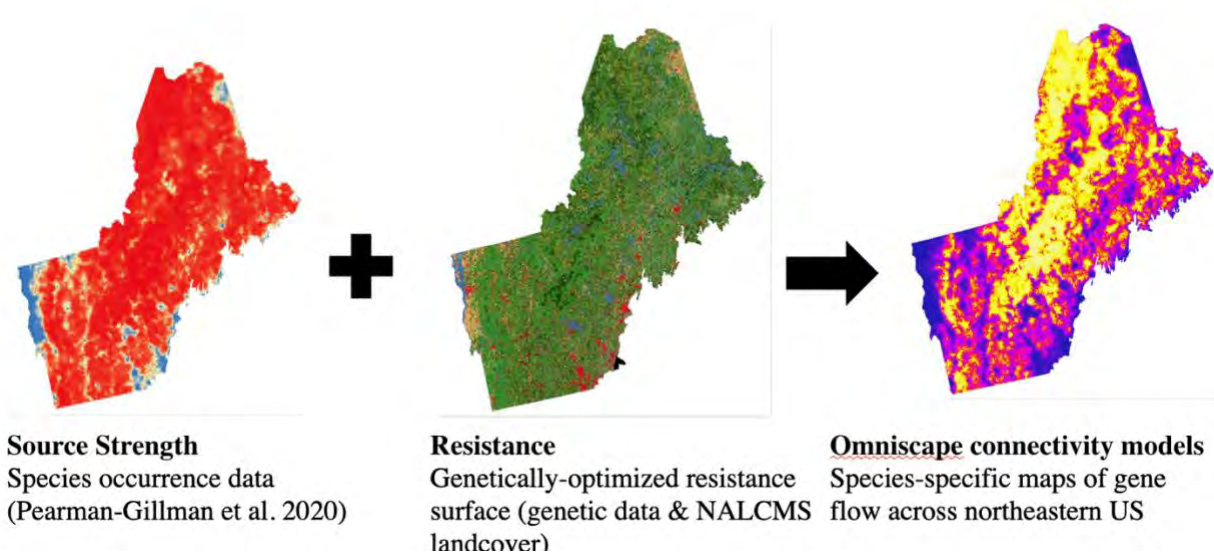


Graduate student Caitlin Drasher with 700 wildlife samples sent to the Mammalian Ecology and Conservation Unit at UC Davis for DNA extraction and sequencing.

We integrated the species-specific landscape resistance surfaces with existing wildlife occurrence models (Pearman et al. 2020) and average species dispersal distances to model movement and gene flow across the study area.

Results

Species-specific connectivity models produced for bear, bobcat, coyote, deer, moose, raccoon, red fox, and striped skunk (due to lack of regional occupancy data for fisher, this species was excluded from connectivity modeling). Regional species-specific connectivity models are shown below and will be updated to include the additional genetically-optimized landscape resistance surfaces – these products will be available in spring 2024 through the FEMC website.



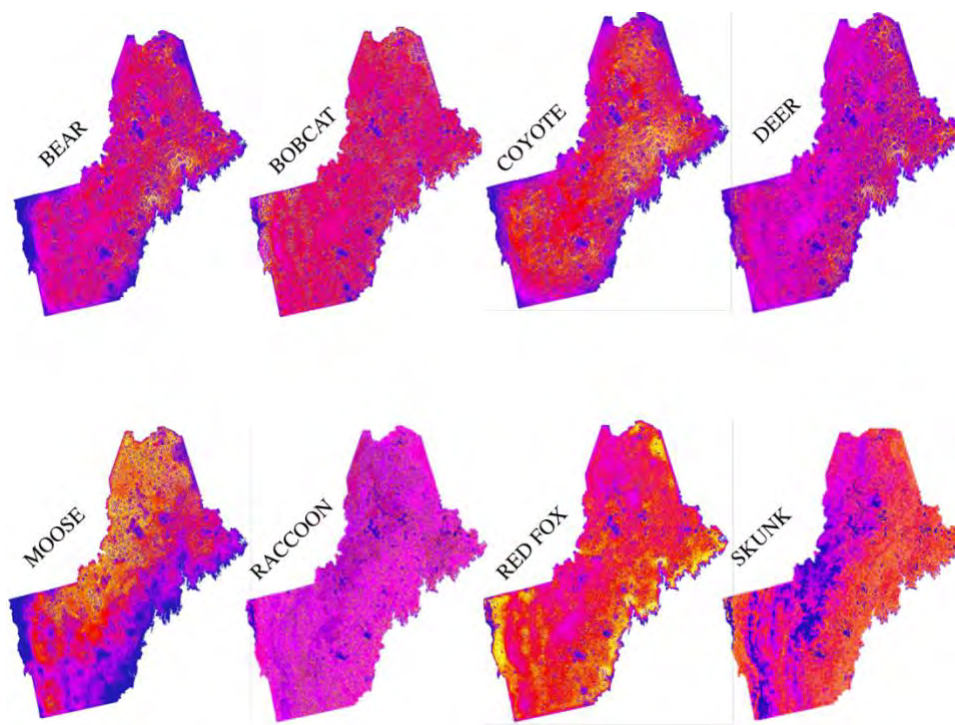


Table 1. Total number of genetic samples collected by state. Existing moose and marten samples were used from Aylward et al. 2019 and Rosenblatt et al. 2022.

Species	<i>Number of samples collected by state</i>			Total
	Vermont	New Hampshire	Maine	
American black bear	15	47	0	62
American marten	<i>Samples from Aylward et al. 2019</i>			
Eastern bobcat	85	38	89	212
Eastern coyote	41	28	21	90
Fisher	76	18	33	127
Gray fox	12	17	12	41
Moose	<i>Samples from Rosenblatt et al. 2022</i>			
Raccoon	37	38	48	123
Red fox	20	19	38	77
Striped skunk	36	23	19	78
White-tailed deer	65	157	89	311
Total	387	385	349	1,121

Implications and Applications in the Northern Forest Region

Genetic based resistance surfaces describe the importance of different landcover variables for genetic connectivity in the northeastern US. They can be used to understand how landcover types

facilitate or impede gene flow and explore how future landscape changes will impact gene flow across the region.

Our connectivity models that integrated ecological and genetic information can inform the management of species and habitats across the region to promote genetically connected and resilient populations. Connectivity results provide a robust measure of landscape connectivity for each species and can be incorporated into decision-making at multiple scales.

Future Directions

We will continue to use model results to inform USFS management objectives in the Green Mountain National Forest and within state-managed lands. The team plans to build a decision-making framework that integrates landscape genetic data for individual species or species groups that would result in maximizing gene flow while considering other forest management objectives. Connectivity models will also be available publicly and to state wildlife agency partners to inform species management objectives.

Data will be available through the Forest Ecosystem Monitoring Cooperative website once products are finalized and following publication.

A New Silvicultural Guide for Northern Conifers in the Northeast

Principal Investigator: Erin Simons-Legaard, University of Maine

Co-Principal Investigators: Laura Kenefic, U.S. Forest Service; Keith Kanoti, University of Maine

Completion Date: March 31, 2025

Researchers and practitioners working in the northern conifer (spruce – fir and associated species) forest of the Northeast co-produced new silvicultural (forest management) guidance for public and private land managers in the region.

Project Summary

Since early in the twentieth century, silvicultural guides have been written for specific forest types. These guides provide information about site potential, species ecology, stand compositions and structures, damaging agents, and recommended approaches (i.e., silvicultural systems) for growing healthy trees and producing desired outcomes. Just like the forests, silvicultural recommendations change over time with the advancement of science and emergence of concerns and values – such as biodiversity and climate change – that were unknown in the past. Yet the silvicultural guide for the northern conifer forest type covering more than 7.2 million acres of New England was 50 years old with little relevance to conditions and challenges facing forest managers today. This project remedied that problem by synthesizing and interpreting an additional half-century of research to develop scientifically robust and ecologically sound silvicultural recommendations within the context of contemporary forest management needs. We ensured applicability and stakeholder perspectives through a process of co-production in which an advisory panel of stakeholders from state and federal agencies, Tribal nations, landowners, forestry practitioners, and others provided guidance on content and delivery. With two dozen authors and even more technical advisors, we have produced robust silvicultural guidance for northern conifers based on the best available science. The guide is under review and will be published by the U.S. Forest Service and accompanied by a companion video. In the interim, multiple technical and scientific reports, presentations, and in-field engagements have been delivered by our team. Outcomes include more effective near-term management with improved long-term sustainability of northern conifers and the communities they support in the Northern Forest region.

Background and Justification

The northern conifer forest supports a robust regional economy associated with rural communities, outdoor recreation, and wood extraction, transport, and processing. They are

home to many wildlife species, including some state- or federally listed threatened or endangered (e.g., northern long-eared bat, Canada Lynx), and yield ecosystem services in four states where more than 20 million people live. They are also on the front lines of climate change, because range limits of eastern broadleaf and boreal species co-occur across the region. Finally, these forests experienced changes in landownership and product potential in recent decades – including loss of many vertically integrated forest product industries – resulting in new ownership motivations and tenures. For these reasons, sustainable management is of the utmost importance and must include consideration of diverse values and forcing agents including nonnative invasive species and market fluctuations.

Silvicultural guides are the foundation for sustainable management, but the previous guide for northern conifers (spruce – fir) was written when desired wood products and markets were different, and before wildlife habitat or biodiversity were incorporated into most forestry prescriptions. Also, though the northern conifer forest was regarded as “spruce – fir” in the past, it has always had important components of other softwoods (e.g., eastern white pine, eastern hemlock, and northern white-cedar) and hardwoods (e.g., red and sugar maple, paper and yellow birch, and aspen). As such, a focus on spruce and fir in mixture with other species (i.e., “northern conifers”) is more appropriate. Finally, numerous short- and long-term studies have been conducted across the region in the last 50 years that contribute importantly to our understanding of the ecology and management of this forest type. In sum, the guide for northern conifers was obsolete and a new one was needed.

Methods

Unlike past efforts in which one or a few individuals prepared silvicultural guides based on research and their expertise, we adopted an inclusive, co-production approach. The PI, co-PIs, and a project manager defined the scope of work and provided a framework for knowledge synthesis. We then solicited and formed a panel of practitioners to advise us on the project, seeking additional input through online and in-person presentations at regional meetings and field engagements. With feedback received on priorities issues, needed tools, and preferred delivery, we both developed tools (e.g. stand density management charts) and solicited additional authors with subject area expertise. The final author team includes federal and university scientists from multiple institutions, tribal natural resource managers and a tribal relations expert, and practitioners from public, non-governmental, and private organizations. Working together to lead sections but contribute to the whole under the guidance of lead authors, this team has produced a new kind of silvicultural guide that represents multiple perspectives and areas of expertise. In addition, supporting work has been produced and delivered to managers throughout the process.

Key Findings

The team worked with cooperating researchers to develop new quantitative tools (stocking guides and density management diagrams) for use in the northern conifer forest, including across or within different ecoregions and stand compositions. Further, our reviews and discussions with practitioners underscored the need to strengthen relationships between silvicultural recommendations and underlying soil – site conditions, and to provide pathways to accomplish a range of desired outcomes for a given stand type. To maximize interpretability and application, we co-developed content with practitioners to pair “case studies” describing real-world examples with silvicultural guidance. We placed greater emphasis on the principles behind the prescriptions, delivering not only recommendations but the foundational knowledge practitioners need to forge their own path.

Implications and Applications in the Northern Forest Region

The co-production approach we used, including integration of tribal perspectives and collaboration among two-dozen authors and the practitioner advisory panel, is unusual for forest type-level silvicultural guides. The relationship building and collaboration associated with this effort will continue to benefit more integrated and informed management of northern conifers. The guide is applicable to all forests in the Northeast where balsam fir or a native spruce species predominates, with wide application and implications for more productive and healthy forests.

Future directions

The teams’ work continues with cooperator review of the guide (review to be completed mid-summer), with delivery of the final guide, a supporting video, and in-field engagement later in 2025. Many involved in this project will continue their work with a mixedwood (hardwood – softwood) management guide, for which a co-production workshop and field tour have already occurred and authors from across the Northeast and Canada recruited to work on the publication. That guide covers a greater diversity of forest types, focusing on those in which hardwoods and softwoods co-occur (e.g. oak – pine, hemlock – hardwood). Continued collaboration of this kind will incrementally strengthen the scientific basis for and relevance of management in the Northern Forest region.

Partners/Stakeholders/Collaborators

Authors of the guide: Laura Kenefic (U.S. Forest Service) and Nicole Rogers (Maine Forest Service) with Jennifer Ballinger (U.S. Forest Service), Russ Briggs (SUNY ESF), Kyle Burdick (Baskahegan), Sean Flint (U.S. Fish and Wildlife Service), Keith Kanoti (University of Maine), Alexandra Kosiba

(University of Vermont), Thomas LaPointe (U.S. Fish and Wildlife Service), Chuck Loring (Penobscot Nation Department of Natural Resources), David MacLean (University of New Brunswick), Cameron McIntire (U.S. Forest Service, State, Private and Tribal Forestry), Andrew Mech (University of Maine), Nancy Olmstead (The Nature Conservancy), Mike Pouch (Maine Bureau of Public Lands), Dave Ray (formerly University of Maine), Skylar Roach (U.S. Forest Service, Northern Research Station), Erin Simons Legaard (University of Maine), Justin Schlawin (Maine Department of Inland Fisheries and Wildlife), Sarah Spencer (Maine Department of Inland Fisheries and Wildlife), Ben Stevens (Penobscot Nation Department of Natural Resources), Steve Tatko (Appalachian Mountain Club), Bishnu Wagle (formerly University of Maine), Aaron Weiskittel (University of Maine), Carolyn Ziegra (Appalachian Mountain Club), Jenna Zukswert (U.S. Forest Service, Northern Research Station)

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Organizations: U.S. Forest Service, Northern Research Station; Maine Forest Service; University of Maine; University of New Brunswick; SUNY ESF; University of Vermont; Cooperative Forestry Research Unit; Penobscot Nation Department of Natural Resources; U.S. Forest Service, State Private and Tribal Forestry; U.S. Fish and Wildlife Service; U.S. Forest Service, National Forest System; Maine Bureau of Public Lands; Maine Department of Inland Fisheries and Wildlife; Appalachian Mountain Club; The Nature Conservancy; Baskahegan; Forest Society; New England Forestry Foundation Wagner; Acadian Timber; Seven Islands Land Company; Huber Resources; Landvest; Vermont Land Trust; Northern Forest Conservation Services

Pheromone-based monitoring and control program for browntail moth in the Northeast

Principal Investigator: Angela Mech, University of Maine

Co-PI: Jeff Garnas, University of New Hampshire

Completion Date: 04/30/2025

The browntail moth synthesized pheromone can be used in traps for a monitoring program, and is showing promise as a contributor for a mating disruption control program. Female flight behavior indicates that they are not strong fliers, increasing the likelihood for an effective mating disruption control program

Project Summary

Browntail moth (BTM) is an outbreaking, polyphagous, invasive species that has economic, ecological, and public health impacts. The current outbreak, which started in Maine in 2015, has been spreading across the state. The goal of this research project is to contribute to a long-term BTM management plan by developing a monitoring program using BTM mating pheromones, and to test if pheromones could be used for a mating disruption program. These tactics are successfully used to monitor and control BTM's close relative, the spongy moth. In addition, we were interested in the flight capabilities of BTM, particularly the females, since they are much larger than the males and are the drivers of dispersal and the subsequent spreading risk. Trials were conducted to find the best trap style and lure chemistry. Results found that white, more open traps (with 360° ventilation) and more volatile chemistries worked best at attracting males BTM. Pheromone-baited traps were set up in areas that varied in BTM densities and were successful at detecting and monitoring populations at all densities. In another project, significantly fewer males were able to find virgin BTM females when she was surrounded by the synthesized pheromone, indicating a mating disruption program may be effective at reducing populations. Lastly, flight mill studies found that female BTM are weaker fliers than males. There are also strong indications that the females are utilizing wind rather than direct flight potential for dispersal. Overall, these results contribute to the knowledgebase needed to create an effective management plan for this invasive species, with these initial results showing promise as a means of developing a more sustainable monitoring program and targeted control option. In addition, flight behavior of the adults show a potential influence of wind. This indicates that the risk to the Northern Forest region west of Maine may be low since the winds predominantly blow in a northeasterly direction during the flight period in July.

Background and Justification

Pheromones are the most widely used of all the semiochemicals used for insect monitoring and management. By definition, they are species-specific, though “eavesdropping” or co-attraction across species can occur. More commonly, however, this benefits managers and researchers as even incomplete or synthetic pheromone blends can successfully match their target species. Pheromone use for monitoring must be able to trap the target pest even at emergent or low-density populations. If detected early, these isolated populations can be managed, thus reducing their spread. This is especially important for species that outbreak, so growing populations can be detected before the explosion in their densities. Key to this is the use of the best trap design and the best lure chemistry. Mating disruption techniques using sex-pheromones of insect pests have been widely used and are a highly successful form of control, including in forest systems. Typically, a wild female moth will call to the males by releasing her pheromones into the air and the males follow the pheromone plume using their olfactory receptors until they find her and mate. Mating disruption hinders this communication by permeating the sex pheromone in huge quantities that makes it very difficult for the searching adult male to pick out the pheromone plume coming from an actual female, thus preventing mating. The use of pheromones for both monitoring and mating disruption have been utilized in the highly successful Slow the Spread program for the invasive spongy moth. One reason why mating disruption is so effective for spongy moth is because the adult females don’t fly, so they are unable to escape the pheromone plume. This is a key trait when considering a mating disruption program – if the females are strong fliers, they can escape the synthetic pheromone plume. Therefore, the flight capabilities of the female target pest should be known prior to the implementation of the control program.

Methods

1. Trap Preference (Added)

- 2021
 - 15 sites across Maine that varied in BTM densities
 - Each site had 2 traps tested: a) green delta trap, and b) green bucket trap (Fig. 1)
 - BTM male catches were compared between traps to determine the best trap
- 2022
 - 5 sites in Maine that had healthy BTM populations
 - Each site had 5 traps tested (5 with high purity lure and 5 controls with no lure): a) green bucket trap, b) multicolored bucket trap, c) white delta trap, d) white modified delta trap, and e) white Pherocon 1C trap (Fig. 1)
 - BTM male catches were compared between traps to determine the best trap



Figure 1. Trap types tested for browntail moth male catch efficacy. A) green delta trap, B) green bucket trap, C) multicolored bucket trap, D) white delta trap, E) white modified delta trap, and F) white Pherocon 1C trap.

2. Lure Preference (Added)

- 2021
 - 15 sites across Maine that varied in BTM densities
 - High purity lure vs. low purity lure in two different trap types
 - BTM male catches were compared between lures to determine the best lure
- 2022
 - 5 sites in Maine that had healthy BTM populations
 - Each site tested 4 different high-purity lures and a blank control; all lures placed in white Pherocon 1C traps: a) 250 μ L septa, b) 1000 μ L septa, c) 250 μ L in silicone square, and d) 250 μ L in a cup
 - BTM male catches were compared between lures to determine the best lure
- 2023
 - 6 sites in Maine that had healthy BTM populations
 - Each site tested 4 different high-purity lures and blank control; all lures placed in white pherocon 1C traps. Lures had modified chemistries deemed by the manufacturer to increase volatility and attractiveness.
 - BTM male catches were compared between lures to determine the best lure

3. Monitoring Program

- 2022
 - 20 sites across Maine that had variable BTM densities
 - Each site had 3 BTM traps (white Pherocon 1C with a high purity lure) and an additional trap with a spongy moth lure.

- BTM male catches were compared between the 3 BTM traps at each site to determine if there was variability within a site.
- BTM male catches were compared to estimated population densities to determine if they appear similar
- 2023
 - Similar to 2022 trial, but the number of sites were increased to 26 sites and the number of BTM traps were reduced to 2 per site. Lure stayed the same.
- 2024
 - Similar to 2023 trial, but the number of sites were increased to 40 but the 2 BTM traps contained different lures – one was the previously-used lure and one was a newer, more volatile lure.
 - BTM male catches were compared between the lures within the sites
 - 3-year trends in BTM populations were evaluated
- 4. Mating Disruption
 - Lab Trials
 - Multiple trials were conducted to test the lure's ability to mask a virgin female. 4 large tubs were set up for 4 different treatments. Males were released into all of the tubs shortly after emergence. a) a virgin female and a lure, b) a lure only, c) a virgin female only, and d) neither a virgin BTM female nor a lure. The following day, the number of males trapped in a funneled cup that contained either the virgin female or lure were counted.
 - Field Trials
 - 4 sites with moderate to high BTM populations were selected near the UMaine campus
 - Virgin females were used as bait in a Pherocon 1C trap: At the same site, one female trap was surrounded by 4 synthesized pheromone lures whereas the other female was not.
 - The number of males caught by each female were compared to see if the lure-surrounded female caught less
- 5. Flight Capabilities (Added)
 - Lab Trials
 - 77 adult moths (37 males and 40 females) were attached to a rotary flight mill. Each rotation of a known circumference was cataloged and used to determine each moth's speed, distance flown, and time spent flying
 - Averages were compared between males and females
 - The average and maximum flight distances for the females were used to estimate where the distribution range would be (based on these results) and compared to the actual BTM range.

Key Findings

Trap Preference: BTM males preferred white traps over green traps, and traps with 360° airflow. The Pherocon 1C trap is recommended for future monitoring programs due to its ease of use and lower price compared to the other white traps that had similar results (Fig. 2).

Lure Preference: BTM males preferred the high purity lure over the low purity lure. In addition, the high purity, high volatility, silicone square lure was the most effective lure (#2778 from Trece Inc.). It captured nearly twice as much as the previously used lure (#2714) (Fig. 3). Lure 2778 is recommended for future monitoring programs. This version of the lure is also recommended for future tests regarding mating disruption.

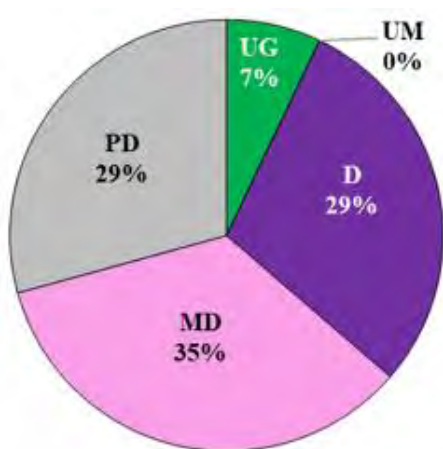


Figure 2. Comparison of the percentage of BTM males caught per trap type: (UG) green uni trap, (UM) multicolored uni trap, (D) white delta trap, (MD) white modified delta trap, and (PD) white Pherocon 1C trap.

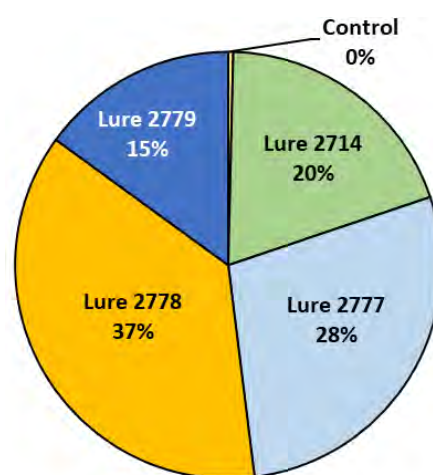


Figure 3. Proportion of browntail moth males caught by different high-purity lures. Lure #2714 was the septa lure previously used. Lure #2778 is the silicone square lure recommended.

Monitoring program: synthesized female sex pheromone-baited traps were successful at capturing BTM males. In addition, these traps caught males in low-density areas indicating that they would be effective at detection of BTM in new areas (Fig. 4). Lastly, the lack of variability between traps at the same site indicate that the placement of the trap in the site can be flexible, a valuable trait in a monitoring program.

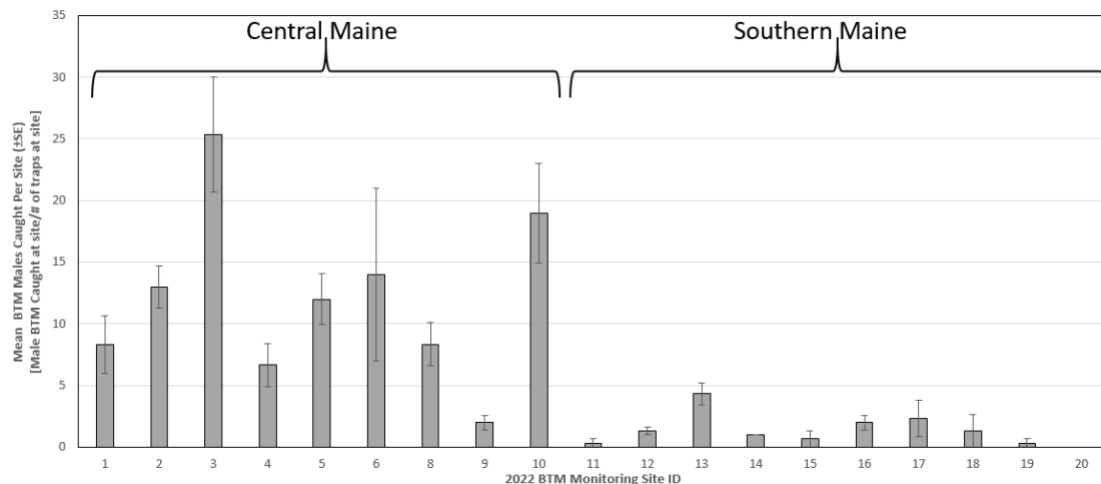


Figure 4. Browntail moth males catches from 20 sites across Maine that represented moderate to high population levels (central Maine) and those from low density areas (southern Maine); site order is arbitrary within each region. All traps were Pherocon 1C with lure #2714.

Mating Disruption: Results from the field trial found that more males (80% of all males) located the female when she was alone compared to when she was surrounded by the lures. More males were caught when no lures masked the female all seven nights tested (Fig. 5). Lab trials found similar results with an 80% decrease in the number of males found with the virgin females when lure #2778 was present in the tub. Overall, more tests are needed before implementing large-scale tests of mating disruption, but results from both field and lab experiments are promising.

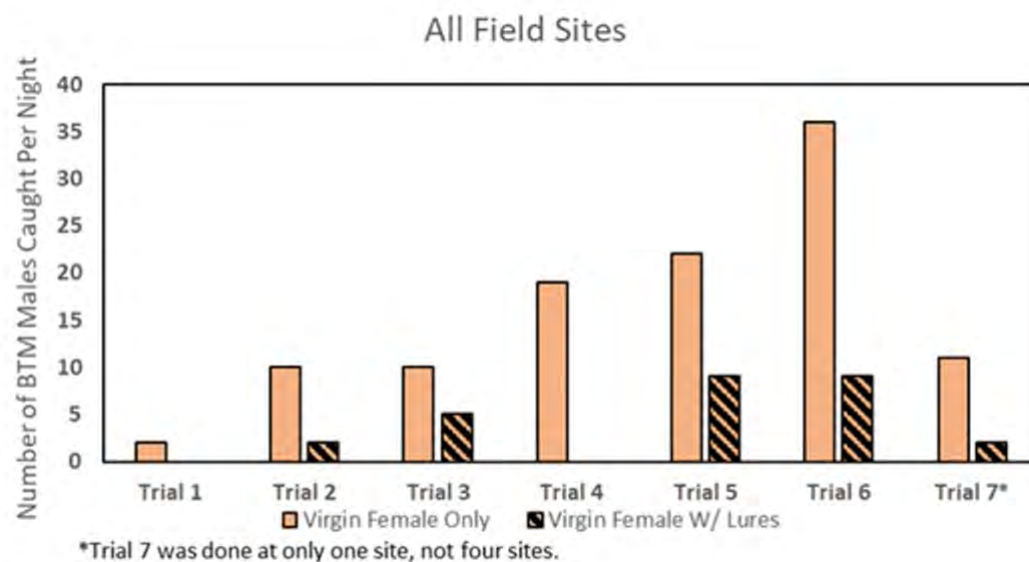


Figure 5. The number of browntail moth males caught in a field study testing the ability of a synthesized sex pheromone to mask a virgin female. The experiment was conducted at 4 sites over 6-7 nights during the flight season.

Flight Capabilities: Female moths flew less than 50% as far as males. Females flew an average of 2.7 miles (maximum 9.9 miles) compared to males, which flew an average of 6.6 miles (maximum 29.2 miles) (Fig. 6). Female adults also weighed almost twice as much as males, although their wingspans were not significantly different. When looking at the current range of BTM, it has travelled significantly further in a northeasterly direction (~150 miles) compared to south or westerly (~20 miles). Wind directions during the BTM flight season in Maine are predominantly northeasterly, suggesting that BTM females are likely poor fliers and may be strongly influenced by wind. This indicates that BTM monitoring efforts should be more targeted towards regions north or northeast of current populations, though nightly wind directions during the flight season should be considered.

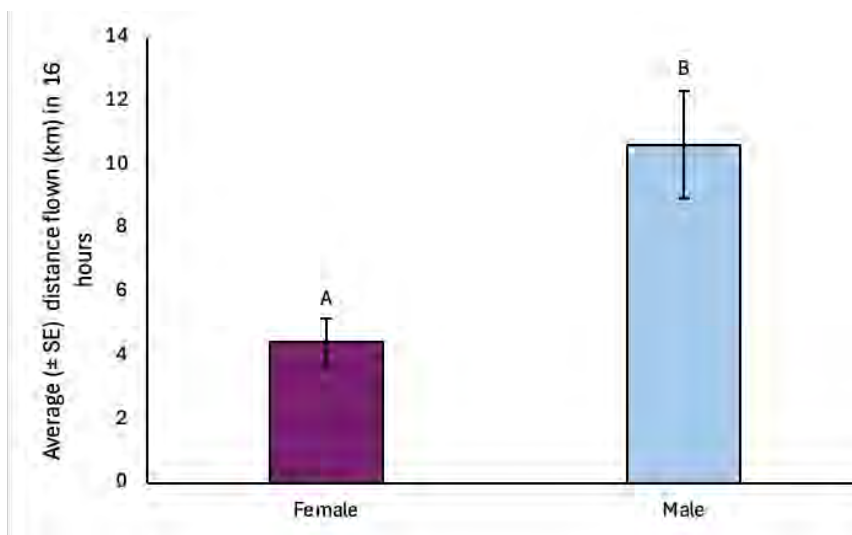


Figure 6. Average distance flown (km) on a rotary flight mill by male and female browntail moth in 16 hours. Different letters denote a significant difference.

Implications and Applications in the Northern Forest Region

This research has found the preferred lure and trap type needed for a largescale monitoring program for a problematic invasive species that threatens the people and hardwoods in the Northern Forest Region. In addition, pilot studies have found promising results regarding the usage of a synthesized female sex pheromone for a mating disruption management tactic. Future research should continue regarding this avenue of research. Lastly, the poor flight capabilities, and what appears to be a utilization of wind for dispersal, of female BTM found in this study help to explain the slow spread of BTM and the direction in which their range expands. This would allow stakeholders to prioritize areas for monitoring based on the risks associated with wind direction and speed. All work was conducted with the guidance of the Maine Forest Service and

with feedback from collaborators at the USDA Forest Service. Also, research from an additional USDA Forest Service grant contributed to this work.

Future Directions

Work will continue to determine the ability of the synthesized lure at masking female BTM. In addition, all years of monitoring data, including the upcoming 2025 season, will be used to determine what level of male BTM catches should be considered high risk. To determine this, trap catch data will be correlated with winter web surveys and/or satellite imagery. Lastly, there is value to further examination of BTM flight traits. For example, evaluating how female flight capacity changes with age and mating status, and examining flight in wind tunnels (where body mass is more relevant), would help improve our understanding of adult BTM dispersal. All of this information would contribute to an overall pest management plan for BTM.

Partners/Stakeholders/Collaborators

- Trece Incorporated – donated all traps and lures, and designed different lure chemistries to be tested for efficacy
- Bartlett Tree Experts – assisted with year one monitoring trap setup
- Maine Forest Service – assisted with project design, location ideas, permits, sharing of browntail moth winter web data, and life cycle updates
- New Hampshire Division of Forests and Lands – assisted with trap setup and catch counts for locations in New Hampshire

Predicting density and occurrence of keystone and umbrella species using dronebased LiDAR

Principal Investigator: Alexej Sirén, University of New Hampshire

Co- Principal Investigator: Michael Palace, University of New Hampshire; Franklin Sullivan, University of New Hampshire; Anthony D’Amato, University of Vermont; David Lutz, Dartmouth College

Completion date: 12/31/2023

Drone-based LiDAR can be used to efficiently inventory and map forest structure important for wildlife at scales relevant to land managers and provides similar results to traditional forest metrics that rely on plot-based sampling and are labor intensive. For example, we found that LiDAR-derived stem and shrub density had a positive influence on snowshoe hare habitat use and canopy closure had a positive influence on American marten probability of occurrence.

Project Summary

Identifying forest conditions that support and promote biodiversity is a central goal of ecological forestry practices and conservation biology. Many wildlife species require fine-scale habitat features (e.g., stem density) that are not easily detected or mappable at broader spatial scales. As such, it can be difficult to identify forested habitats that are suitable for species and ecological communities. Snowshoe hare (*Lepus americanus*) and American marten (*Martes americana*) are ideal species to evaluate animal-habitat associations and biodiversity as they have opposing habitat preferences. Hares are an early-successional species of boreal and boreal-temperate ecosystems, strongly influencing predator populations and forest development. Martens, on the other hand, are an umbrella species of mid- to late-successional forests. Thus, identifying the habitat conditions associated with the co-occurrence of these species may provide insight on patterns of biodiversity. We used forest and wildlife inventory data from our long-term studies of snowshoe hare, American marten, and other predators to evaluate the forest conditions associated with higher biodiversity. We mapped the microhabitats of 14 forested stands with high-resolution Light Detection and Ranging (LiDAR) data collected from unoccupied aerial vehicles (UAVs). We derived forest metrics from the LiDAR point cloud data and used these metrics as variables in models to predict snowshoe hare and marten habitat use. We also established new camera and audio monitoring sites ($n = 42$) to evaluate the extent to which mammal and avian species richness was associated with co-occurrence patterns of hares and martens and the habitat associations (derived from UAV-LiDAR) of these stands. We mapped

nearly 420 ha of forested habitat at our long-term monitoring sites with UAV-LiDAR (>300 returns/m²) and derived several traditional forest metrics (e.g., stem density) to compare with traditional plot-based vegetation sampling and to use as predictors of animal habitat use and species richness. We recorded 411,594 photographs at our camera sites, detecting >12 mammals and numerous bird species. Marten habitat use was associated with higher canopy closure and snowshoe hare habitat use was positively associated with sapling and shrub density and canopy closure. These findings are similar to our studies that used traditional plot-based inventories to evaluate marten and hare habitat use, indicating that UAV-LiDAR can be used to efficiently detect and predict wildlife habitat. One of the major implications of our research for the Northern Forest is that UAVs can be used to inventory large tracts of forest and map wildlife habitats at broad spatial scales.

Background and Justification

Our ability to understand biodiversity is limited by numerous factors, including reliable data on occurrence, abundance, and species richness, and the spatial and temporal factors that influence these ecological states¹. In particular, the spaces that species occupy and how these in turn influence demographic rates and community interactions is critical for understanding biodiversity². It is well-established that microhabitat features fulfill many life-history requirements for wildlife such as spaces to breed, rest, and obtain food³. However, our understanding of these processes has been limited to small spatial scales and through sampling approaches that only provide plot-level information on habitat structure. For example, vegetative structure is typically collected at plots and the resultant data is used to evaluate microhabitat associations (e.g., stem density⁴) or averaged at the stand level to investigate coarser-scale influences (e.g., basal area⁵) on wildlife. However, these surveys do not provide a continuous and multi-dimensional map of the structural attributes within a forest. Although remotely-sensed products are useful for predicting forest cover types and even forest age at relatively high accuracy and resolution^{6,7} and provide important data for evaluating ecological relationships at broader spatial scales⁸, these products rarely capture microhabitat features that can greatly affect ecological processes^{9,10}. Thus, scaling up microhabitat features has been unachievable yet critical for understanding species-habitat dynamics and the conditions that lead to higher biodiversity¹¹.

A related challenge, and an important step to promote and maintain biodiversity, is to provide forest management recommendations based on understanding of microhabitat-species relationships. However, previous work has relied on plot-level level estimates of microhabitat that do not always translate into clear forest management outcomes for wildlife. For example, previous studies indicate that American martens select stands with basal area >18 m² /ha in Maine⁵ and large deciduous trees for resting and denning in Michigan¹². While this information

is useful, it does not provide a multi-dimensional understanding of how to accommodate these microhabitat requirements for martens in forest management plans. Mapping forests using high resolution LiDAR data provides a means to this end and the opportunity to bridge the gap between wildlife and forest managers. Although a technological solution does not ensure that research findings will be communicated effectively¹³, it does provide the opportunity for wildlife and forest ecologists to work in tandem to find a management solution that can be applied on the ground¹⁴. Our team includes a diversity of scientists from government agencies and universities with expertise in forest and wildlife ecology, remote sensing, and natural resource management. A shared goal is to connect with a variety of natural resource professionals that live and work in the Northern Forest to ensure our science is practical and useful.

Identifying factors that promote and sustain biodiversity is an NSRC priority and is a state and federal mandate for many large and private landowners^{15,16}. We see our study as a means to address long-standing interests in biodiversity research and umbrella species management. Our study spanned the range of climate, land use, and dominant forest cover types in the Northern Forest. We leveraged 7-year (2014–2020) datasets on vegetative characteristics (695 plots), snowshoe hare density and habitat use (16,572 observations), and wildlife occurrence data (>200,000 observations), including Species of Greatest Conservation Need (SGCN) such as martens, hares, and Canada lynx (*Lynx canadensis*). We also collected new information on mammal and avian species richness using remote cameras and acoustic recording units to test the assumption that co-occurrence of hares and martens results in higher biodiversity (Figure 1). Mapping the distribution of structural conditions associated with forest disturbance and succession and recording taxa and species other than hares and martens provides the opportunity to evaluate long-standing assumptions of biodiversity and the umbrella species concept to better inform management practices and endangered species conservation

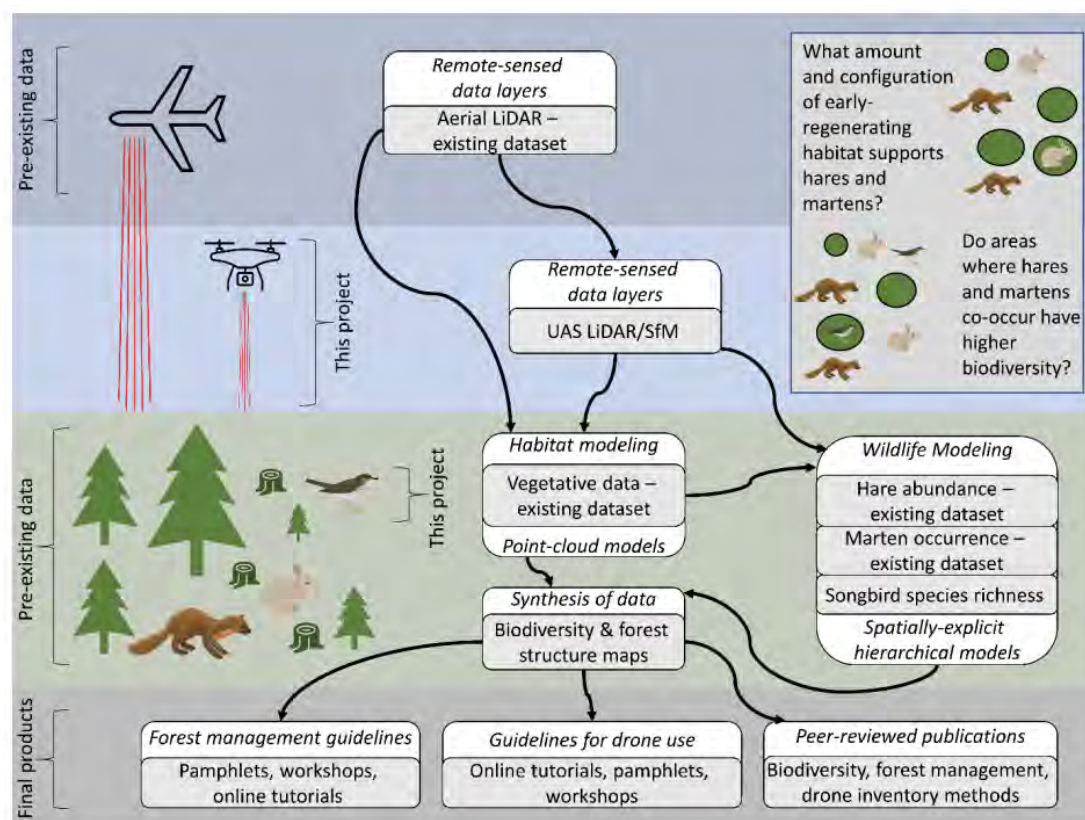


Figure 1. Schematic of our project outlining 1) existing data from aerial LiDAR, vegetative, and wildlife surveys, 2) LiDAR and mammal/songbird species richness data collected on this project, 3) workflow of analyses and synthesis of data, and 4) products and outputs. The inset illustrates our research questions of how microhabitat (green circles) influences co-occurrence of hares and martens and biodiversity.

Methods

Study Area

To evaluate the ability of drone-based LiDAR to map and predict forest structure important for wildlife, we conducted LiDAR surveys at 14 forested stands (each 20 ha) in the Nulhegan Basin (NB) of Vermont and the White Mountain National Forest (WMNF) of New Hampshire (Figure 2). These stands are representative of the forests, management regimes, and climatic conditions in the Northern Forest and are part of our long-term study evaluating the influence of abiotic and biotic factors on wildlife populations¹⁷. We used existing vegetative and wildlife data (2014–2020) and collected new wildlife data (2021–2023) from these stands using fecal pellet count, remote camera, and audio surveys to estimate relative hare density, mammal species richness, and avian species richness, respectively, during the leaf-off (16 October–15 May) and leaf-on (16 May–15 October) seasons. Each stand contained 1) 50 plots all spaced 50 m apart along 5 parallel transects (10 plots/transect), 2) 3 remote cameras spaced at least 150 m apart, and 3) 3 audio recorders that were collocated with the cameras (Figure 2).

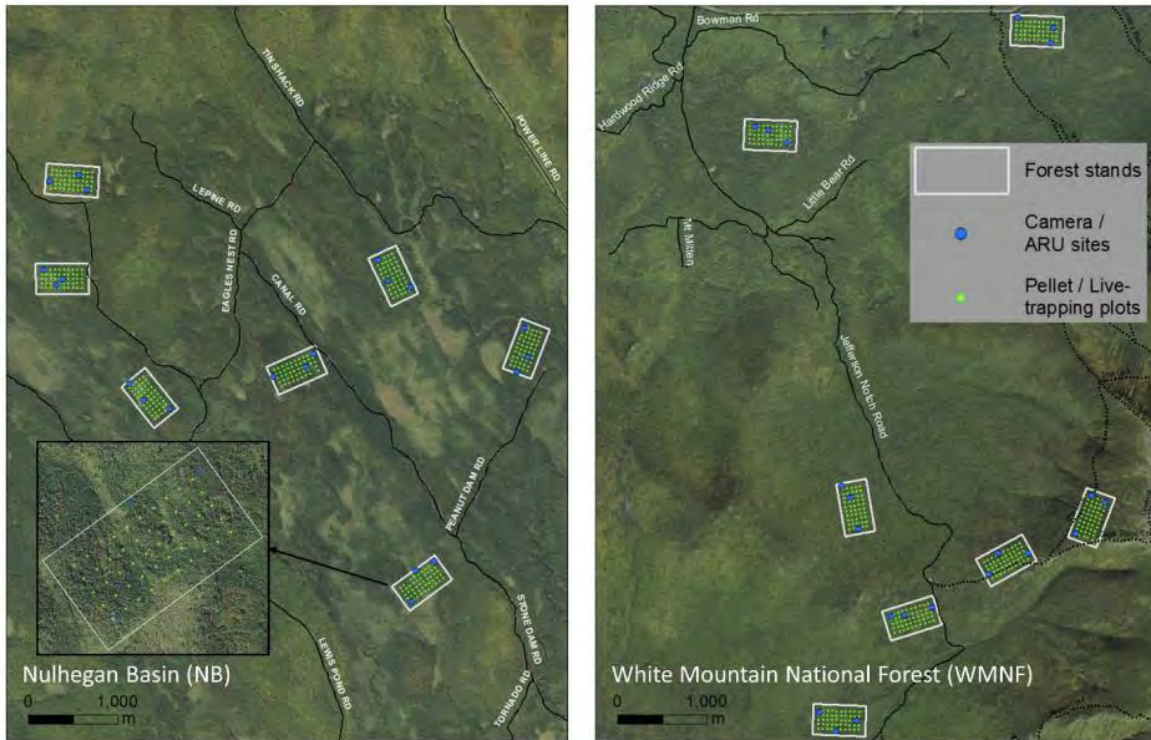


Figure 2. Study area in the NB (left panel) and WMNF (right panel) used for evaluating the influence of forest structure on wildlife populations and biodiversity. The left inset map is a zoomed in stand showing the plots and camera/audio sites used for collecting vegetative and wildlife data from 2014–2023.

LiDAR Surveys

We acquired very-high point density LiDAR data over 14 stands in the NB and WMNF during the spring leaf-off season of 2022. Data were acquired using a lightweight, low-cost LiDAR sensor (300 returns per square meter (Figure 3a, stand G179_SFF6). Following postprocessing to classify ground returns, LiDAR data from each stand were used to derive digital terrain models and canopy height models, along with a series of plot-scale height metrics and variables describing forest canopy light environments (Figure 3b–c).

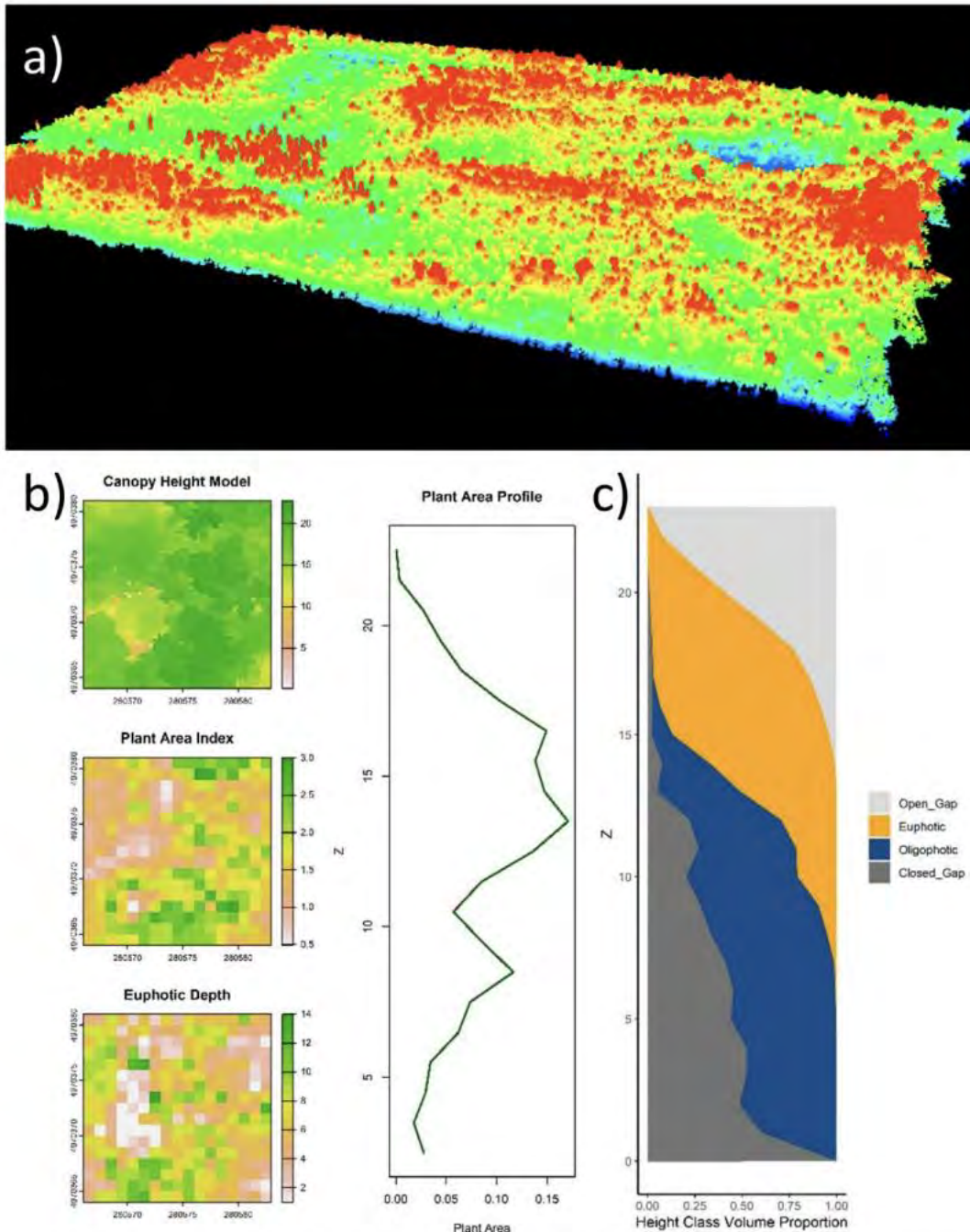


Figure 3. Point cloud data from one of the 14 stands (G179_SFF6) where high resolution LiDAR data was collected during the leaf-off period of 2022 (a). These data were used to calculate, among other metrics, canopy height (b) and forest canopy light environments (c) at the plot and stand level (plot G179_NHF2_34). Euphotic refers to the upper zone of the canopy that blocks the majority of available light and oligophotic is the zone directly beneath it.

Vegetation Surveys

We collected forest structure data at the 14 stands from during leaf-off in early spring and late fall of 2020 (Figure 2, 4b). Basal area, diameter at breast height (DBH), overhead canopy closure

and stem density were sampled at every plot within each of the 14 stands and coarse woody debris (CWD) was sampled along 3 randomly selected 200 m transects within each stand (Figure 4b)¹⁸. We measured canopy closure during the leaf-off season using a spherical densiometer and recorded four measurements in each cardinal direction with the densiometer centered 1 m above the ground and centered over each plot. We used 10 factor English prisms centered above each plot to calculate basal area of coniferous and deciduous trees, and a metric diameter tape to measure the DBH of trees ≥ 7.6 cm that were counted using the prism. We counted all woody stems ≤ 7.6 cm DBH within a 2 m radius at each plot and differentiated between coniferous, deciduous and shrub stems. We measured CWD on 3 randomly selected 200 m transects in each stand, using calipers to record the diameter of fallen logs at the point of intersection as we walked the transect.

Camera Surveys

We established remote cameras (SiMPL magnet method, Clark et al. In Review) on trees ~1–1.5 m high at 42 sites in the NB and WMNF (Figures 2, 4c). The sites were baited (~10 grams of peanuts) and checked approximately every 3 months to swap SD cards and batteries (when needed) and rebaited for continuous monitoring from November 2021–June 2023¹⁹. Camera data were uploaded and stored in a database (AMMonitor20). The identity of animals in pictures were tagged by undergraduate interns and graduate students at the University of Massachusetts¹⁹.

Acoustic Recorder Surveys

We established acoustic recording units (28 Song Meter Micro and 14 Audio Moths) at 42 sites in the NB and WMNF and collocated with remote cameras (Figures 2, 4c). The sites were established in the spring and pulled in the fall of 2022 and 2023. The recording schedule was set to maximize detection of birds and amphibians (one minute every 10 minutes between 05:00 – 10:00 and one minute every 30 minutes between 16:30–23:00). We also conducted point count surveys at each site using a standard protocol of resurveying each site up to 3 times.

Fecal Pellet Surveys

We counted and cleared snowshoe hare fecal pellets biannually within a 56 cm radius circular plot (50 plots/stand) to index leaf-off and leaf-on relative density and habitat use (Figures 2, 4d). We originally conducted surveys from 2014–2018 in the WMNF and 2015–2019 in the NB¹⁷ and conducted new surveys at both study sites from 2021–2023. Additionally, during the spring of 2023, we surveyed ruffed grouse (*Bonasa umbellus*) and spruce grouse (*Falcipennis canadensis*) using a fecal pellet survey method to evaluate occupancy and habitat use²¹. We searched for fecal pellets of these species along four 200 m transects (800 m total) spaced 150 m apart within each stand, using the snowshoe hare pellet plots as starting and end points (Figure 2). We used

a GPS and compass to maintain a straight bearing while walking along the transects and counted and measured the distance pellet groupings were detected from the centerline of the transect. We also recorded a GPS waypoint of the location of pellet groupings. Pellets from spruce grouse are long, thin, dark green and frequently lack uric acid wash. Pellets from ruffed grouse are short, thick, yellow-brown, and typically have a uric acid wash²¹.



Figure 4. Field methods used to evaluate the influence of forest structure on wildlife populations and biodiversity, including (a) LiDAR-based UAV surveys, (b) vegetative surveys, (c) camera and audio surveys (red circle is an audio recorder; blue oval is a remote camera, and yellow oval is a SiMPL magnet), and (d) fecal pellet surveys. People in photos include (a) Franklin Sullivan (Co-PI) and Jahiya Clark (MSc Student at UMass) conducting UAV-based LiDAR surveys and (b) Katelyn Courtot (MSc Student at Plymouth State University) collecting vegetation data at a plot. All photos were taken by Alexej Sirén.

Results

We met several times each year during the project to plan fieldwork and field trips, analyze data, write reports, pursue grants, and work on peer-reviewed publications. Most of our planning was done online due to the pandemic (2020–2021) but also due to geographic isolation (Figure 5). We held two in-person field meetings – one at the NB during the summer of 2022 and one at the Umbagog NWR during the fall of 2023. Our first meeting was to tour the study area and observe the LiDAR flights. Our recent meeting at Umbagog Refuge was to discuss research progress and to plan for new grants that build on research findings from this project.

LiDAR Surveys

In total, we acquired ~420 ha of LiDAR data from 14 stands over 3 survey dates (~1.5 hours/stand) during May 2022 (Figure 4a). To our knowledge, this is one of the most extensive UAV LiDAR surveys of northern New England Figure 5. Screenshot of part of our group from an online meeting in 2022 to discuss research progress during our first year and planning for the upcoming year (top left to bottom right include R. Cliché, A Sirén, L. Prout, J. Clark, M. Palace, F.



Figure 5. Screenshot of part of our group from an online meeting in 2022 to discuss research progress during our first year and planning for the upcoming year (top left to bottom right include R. Cliché, A Sirén, L. Prout, J. Clark, M. Palace, F. Sullivan, and S. Agius).

Sullivan, and S. Agius). Forest stands and represents a baseline for documenting forest change and management practices at these two sites. Each of these LiDAR data sets will be published in the SAD Remote Sensing group's Harvard Dataverse catalog.

The derivation of meaningful LiDAR metrics from the standpoint of vegetation structure and from the standpoint of habitat characterization are continually evolving. For this study, we have developed new workflows to ingest and summarize very-high density LiDAR data sets in the statistical programming language R, leveraging existing libraries for handling LiDAR and spatial data. Specifically, we developed efficient functions to classify canopy space in three dimensions using existing definitions of “photic zones” (i.e., canopy light environments, see Figure 3b,c). Additionally, we have transcribed in R an iterative tree detection routine previously published and developed in the IDL programming language. Together, these and other metrics (e.g., stem density) are being used to understand how LiDAR can be used to rapidly assess forest and habitat conditions in the context of conservation. Three analyses and publications are currently being prepared using these LiDAR data sets and the derived metrics (Sullivan et al. In Prep, Sirén et al. In Prep.[a], Sirén et al. In Prep.[b]). An example of some derived metrics used for the analyses are canopy closure, stem density, and shrub density (Figure 6).

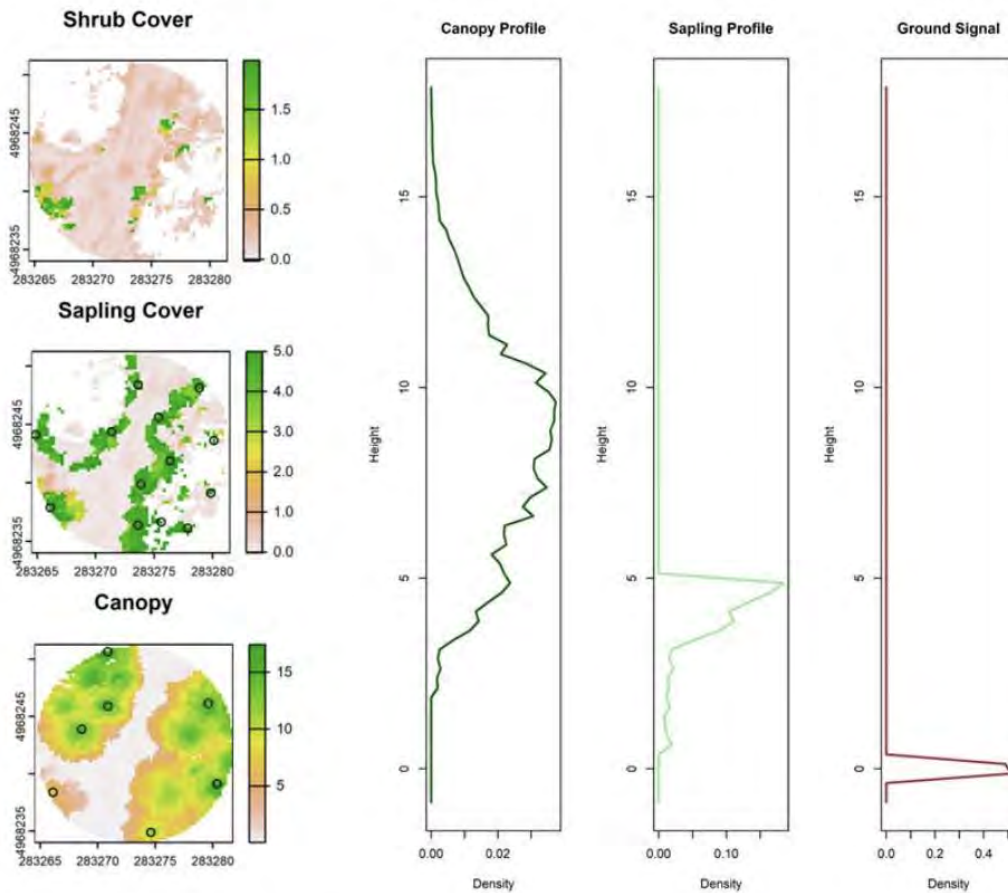


Figure 6. Shrub cover, sapling cover, and canopy closure derived from UAV-based LiDAR (left panel) and the height profiles of the canopy and sapling profiles and ground signal (right panel) from 1 of our 695 plots (8.5 m radius). These derived metrics were used in the analyses of wildlife habitat use and animal species richness.

Vegetation Surveys

The following is a summary from Courtot (2022)18: A total of 60,420 stems were counted in the NB (18,188 coniferous stems, 1,828 deciduous stems, and 20,724 shrub stems) and the WMNF (12,921 coniferous stems, 5,511 deciduous stems and 1,248 shrub stems) stands. Canopy closure averaged 70% in the NB and 75% in the WMNF during the leaf-off season. The average DBH for coniferous trees was 17.8 cm in the NB and 21.2 cm in the WMNF; deciduous trees were 22.5 cm and 24.5 cm, respectively. Coniferous basal area averaged 18 m² /ha in the NB, however, it was much higher (25.2 m² /ha) in the WMNF. Deciduous basal area was comparable in both study areas, averaging 11 m² /ha in the NB and 11.2 m² /ha in the WMNF. CWD was twice as high in the WMNF (n = 791 intersections) than in the NB (n = 383 intersects), yet the diameters were nearly identical (14.6 cm, and 14.5 cm, respectively). Overall, the NB was characterized by high shrub stem counts and the WMNF was characterized by deciduous stems, higher canopy closure,

and higher coniferous basal area. Both study regions had a high number of coniferous stems, with less in the WMNF.

Camera Surveys

We collected photo data from 42 camera sites in the NB and WMNF, recording 411,594 photos from November 2021–June 2023. We recorded >12 mammal and >13 bird species (some animals were unidentifiable at the species level). Red squirrels were the most commonly detected species (513 weekly detections), followed by American marten (280 weekly detections), species of the Cricetidae family (e.g., mice, voles; 211 detections), moose (110 weekly detections), species of the flying squirrel genus (104 weekly detections), white-tailed deer (36 weekly detections), fisher (21 weekly detections), black bear (11 weekly detections), weasel spp. (4 weekly detections), coyote (2 weekly detections), bobcat (2 weekly detections), and red fox (1 weekly detection). These detection data were used to model species-habitat relationships such as the positive influence of canopy closure (derived from LiDAR) on American marten occupancy (Figure 7). These findings are similar to Courtot (2022)¹⁸ who used traditional plot-based forest metrics to evaluate marten habitat use. More details of these surveys are summarized in Clark (2023)¹⁹.

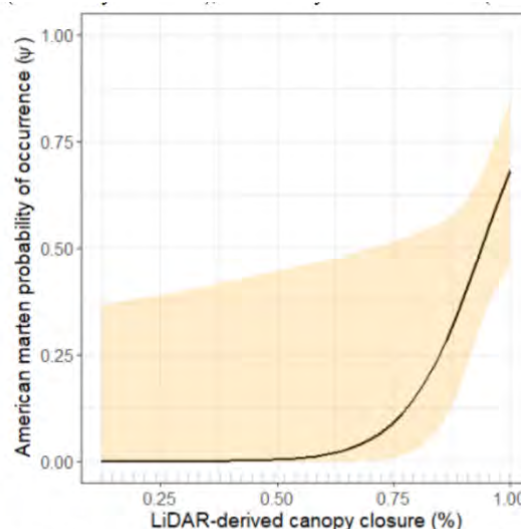


Figure 7. Predicted relationship between canopy closure (derived from UAV- LiDAR) and American marten probability of occurrence using 42 remote cameras established in 14 stands in the NB and WMNF, operating from November 2021–June 2023. Martens were more likely to occur in (use) stands with higher canopy closure.

Acoustic Recorder Surveys

We collected audio data from 42 audio recorders in the NB and WMNF over two spring–fall periods (2022 and 2023). We did not experience any data loss and recorded >250,000 audio files, that exceeded >600 GB of data. A qualitative screening of the data indicates that numerous songbird and amphibian species were recorded. These data will continue to be analyzed to evaluate the influence of forest structure on avian and amphibian species richness.

Fecal Pellet Surveys

During leaf-off and leaf-on surveys from 2015–2019 and 2021–2023, we counted and cleared 345 pellet plots in 7 stands in the NB and 350 plots in 7 stands in the WMNF to index snowshoe hare relative density and habitat use. We evaluated the influence of several forest metrics derived from LiDAR data on snowshoe hare habitat use. Of the forest metrics we evaluated, the proportion of saplings and shrubs within a plot had a stronger effect on pellet density than canopy closure; this pattern was consistent for the leaf-off and leaf-on seasons and highlight that stem and shrub density is a strong driver of snowshoe hare habitat use (Figure 8). These results

Figure 8. Influence of structural habitat (proportion of shrubs, proportion of saplings, and canopy closure) derived from UAV-based LiDAR on fine scale snowshoe hare habitat use. Hares were more likely to use locations that had a higher proportion of saplings and shrubs with high canopy closure. The effects were stronger during the leaf-off season (a–c) than the leaf-on season (d–e). are consistent with models that included forest inventory data collected by Courtot (2022)¹⁸ at the same plots (see Vegetation Surveys) and provide confidence that LiDAR-derived metrics are consistent with those derived from plot-based vegetation sampling. We also conducted fecal pellet surveys to evaluate the presence and habitat use of ruffed and spruce grouse during the spring of 2023. We only recorded one grouping of spruce grouse pellets (off-transect) in the NB and 6 groupings of ruffed grouse pellets in the NB. Future work will focus on sampling earlier in the spring just before the snow has melted as the pellet groupings are more visible then and less prone to decomposition (personal communication, K. Courtot).

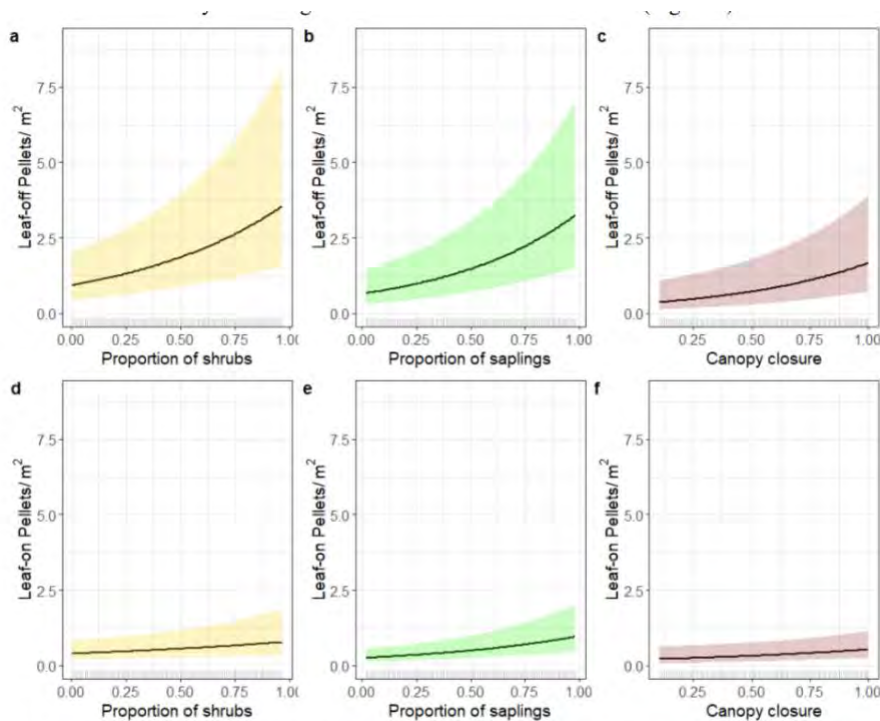


Figure 8. Influence of structural habitat (proportion of shrubs, proportion of saplings, and canopy closure) derived from UAV-based LiDAR on fine scale snowshoe hare habitat use. Hares were more likely to use locations that had a higher proportion of saplings and shrubs with high canopy closure. The effects were stronger during the leaf-off season (a–c) than the leaf-on season (d–e).

Implications and Applications in the Northern Forest Region

Our project, although still ongoing, has several implications and applications for the Northern Forest region. First, we have demonstrated that UAV-LiDAR can be used to derive high resolution (>300 returns/m²) forest metrics that are correlated with traditional plot-based metrics. Second, we were able to efficiently survey at relatively large spatial scales, mapping 30 ha (~75 acre)

stands on average within 2 hours. Next, we were able to find strong wildlife-habitat associations using forest metrics derived from UAV-LiDAR. These results have clear applications for mapping forest structure and predicting wildlife habitat and biodiversity hotspots across landscapes. For example, UAVs equipped with LiDAR sensors can be used by small and large landowners to conduct forest inventories and map wildlife habitat. Most parcels owned by small landowners in the Northern Forest are <30 ha¹⁶ and could be efficiently sampled using our protocol within 2 hours. Further, the post-processing of the data for a parcel of this size takes 6– 10 hours on a standard laptop with significantly faster computing times using cloud-based services (e.g., AWS). For larger landowners, a stratified random sampling approach could be adopted using transects across a gradient of stand and forest types across a region to evaluate wildlife habitat at regional scales. Our research team includes cooperators from the private (e.g., Weyerhaeuser) and public sector (e.g., Natural Resources Conservation Service, Vermont Coverts) that work directly with landowners and forest managers. We plan to continue to work with these collaborators and cooperators in 2024 to determine practical and cost-effective approaches for mapping forests and wildlife habitat at broad spatial scales. Finally, our research can be used to efficiently identify and predict landscapes that are biologically diverse or require management to bolster habitat and connectivity for SGCN species (e.g., spruce grouse, Baybreasted warbler [Setophaga castanea]). Our ongoing research using data from this project (e.g., Figure 9) will focus on these topics and can be used by a variety of landowners in the Northern Forest to balance the needs of wildlife and people.

Future Directions

The majority of the objectives have been completed on this project, including the collection and processing of LiDAR, snowshoe hare abundance, and camera data. We are currently working on 3 papers using these data (see List of Products section) that we plan to submit to peer-reviewed journals in 2024. The first paper (Sullivan et al. In Prep) is a comparison of forest metrics derived from LiDAR vs. traditional plot-based sampling collected in the spring of 2020/18. The second paper (Siren et al. In Prep[a]) is an evaluation of forest metrics that best explain snowshoe hare habitat use during the leaf-off and leaf-on seasons. This paper will also include a retrospective analysis of fecal pellet data from 2014–2022 to evaluate the frequency that LiDAR surveys should be conducted to monitor hare populations. A third paper (Siren et al. In Prep[b]) will investigate the habitat conditions associated with the co-occurrence of hares and martens and to test whether biodiversity is higher in these areas.

We collected acoustic recorder data during the spring–fall of 2022 and 2023 and will be processing and analyzing it during 2024. Additionally, we plan to continue analyzing the snowshoe hare abundance and camera data using various forest, patch, and landscape metrics derived from LiDAR data (e.g., patch configuration of optimal snowshoe hare habitat). We were

hoping to have these analyses done earlier but the COVID pandemic delayed fieldwork and the ability to collaborate on these analyses. Further, we spent considerable time field testing the UAV surveys during 2021 to facilitate efficient sampling during the spring of 2022. We plan on including a PhD student (D. Farris) from the University of Massachusetts to analyze the audio data. Finally, we also plan to evaluate alternative approaches for mapping wildlife habitat by comparing LiDAR and Structure from motion (SfM) data collected at two stands.

Because of delays brought on by the pandemic, we were not able to hold an in-person meeting to share our research findings. We are excited to host a workshop later during the fall of 2024 to highlight our work using UAVs to map forest structure and wildlife habitat. We will demonstrate a flight at a new site that is both accessible and can be used to evaluate the predictive abilities of the mapping technology developed on this project. We plan to map a small (10 ha) parcel (using a UAV equipped with a LiDAR camera) with participants and also collect snowshoe hare fecal pellet data. These activities can be coordinated within a 4-hour period with a small group and the post-processing can be done in a relatively short timeframe (e.g., 2 hours) allowing for a start-to-finish demonstration of the process and a way for us to validate our model at a new location.

We are pursuing two new research projects that would use several of the technologies developed on this project. The first is an evaluation of the response of boreal forest wildlife, with a focus on snowshoe hares, to ecological silviculture practices designed to accelerate stand growth and diversity in the Northern Forest. We are particularly excited about this project as we can efficiently inventory stand pre- and post-treatment to quantify structural differences and evaluate wildlife responses to these changes over time. The second project has more of a fundamental focus and would evaluate the structural attributes of high elevation spruce-fir waves²² and how changes in climate affects the disturbance frequency of these rare ecosystems. We would use UAVs equipped with LiDAR sensors to map several candidate waves in the Northern Forest and conduct retrospective analyses using time series data from LANDSAT. An additional component of this work would be to evaluate the responses of snowshoe hares to the disturbance regimes of these systems as we have hare abundance data dating back to 2014, yet the mechanisms behind their stable populations in these high elevation forests are still unknown¹⁷.

Quantifying the Genetic Impacts of Forest Management Strategies on Sugar Maple in the Northern Forest

Principal Investigator: Danilo D. Fernando, Department of Environmental Biology, SUNY-ESF

Co- Principal Investigator: Diane H. Kiernan, Department of Sustainable Resource Management, SUNY-ESF

Completion date: October 31, 2023

The key findings from this research are: managed stands have lower genetic diversity than unmanaged stands, and seedlings in the unmanaged and shelterwood stands have higher genetic diversity than poles and mature trees in the shelterwood stands, and in all size classes in the selection stands

Project Summary

Forest tree harvesting practices that enhance genetic diversity are essential for the long-term sustainability of our forests. Using genetic markers for potentially adaptive genes, we quantified the effects of selection (SE) and shelterwood (SW) management systems in comparison to unmanaged (UM) stands on the genetic diversity of sugar maples across the Northern Forest.

Our results show that compared to UM stands, SE and SW stands both have lower allelic richness (AR), while only SE stands have lower expected heterozygosity (*HE*). Lower AR indicates limited allele diversity and potentially reduced adaptive potentials. While there is no statistically significant difference between SE and SW irrespective of size classes and states, this lower genetic diversity is more concerning for the SE stands. This concern is based on its lower *HE* compared to UM stands, given that this genetic index is related to fitness, which has clear ecological implications.

Comparison of size classes only and analysis of the interactions between management types and size classes point to the high genetic diversity of seedlings in UM and SW stands, which is responsible for most of the genetic variations detected in this study.

The lower genetic diversity of SE stands seedlings and SW poles and mature trees are the two indications of genetic erosion due to management identified by our study.

Difference in seedling genetic diversity between SE and SW stands may be attributed to the number of seed trees retained, their spatial distribution in the stands, and management goals, which may have influenced gene flow from pollen and seed. Interestingly, the more intense harvesting in SW compared to SE is associated with genetically diverse seedlings indicating enhanced outcrossing and immigration rates.

The difference in the genetic diversity between SW seedlings and its poles and mature trees may have been an impact of past harvesting intensity and phenotypic criteria used in selecting the residual trees.

Opting for a longer cutting cycle, which results in a lower level of residual basal area, will allow for more open stand structure in the SE stands. This may be key to reducing its genetic impact by allowing greater gene flow from outside of the stands. While there will be fewer mature trees in the stands, the opportunity for increased outside pollination and seed influx may provide the necessary alleles to adapt to changing environment. For SW, leaving a few more mature seed trees may not significantly decrease genetic diversity while it still keeps a more open stand structure.

This study increases our awareness of the potential genetic impacts of forest harvesting practices and provides informed decisions in promoting the health, resilience, and sustainable use of our forests.

Background and Justification

Importance of Sugar Maple (*Acer saccharum*)

- It is an integral component of the ecology, history, economic and cultural development of the Northern Forest, as well as much of the entire northeastern United States.
- As the dominant tree species of the Northern Hardwood Forests, it is a key component of the Northern Forest region's biodiversity, forest structure and function, and ecosystem integrity. Thus, many faunal and floral associations depend on its existence and the environment it creates.
- It is imperative that significant research efforts be devoted to the protection of its health and long-term persistence considering the threats emanating from anthropological and natural disturbances (Ratnam et al. 2014, Bishop et al. 2015).

Genetic Impact of Forest Tree Harvesting Practices

- Harvesting is one of the major anthropogenic forest disturbances that may affect genetic diversity and evolutionary potential of tree species (Buchert et al. 1997, Fageria and Rajora 2013, Ratnam et al. 2014, Stojnic et al. 2019).
- Studies on genetic impacts of silviculture methods on sugar maple stands are limited and focused on effects of intensive logging in the Great Smoky Mountains (Baucom et al., 2005) and selection cutting in New York (Motege, 2000) and Quebec (Simon et al., 1995; Gaignic et al., 2016).

- Baucom et al. (1995) and Graignic et al. (2016) found lower genetic diversity in younger ages classes than in mature trees of managed stands.
- Simon et al. (1995) and Moteği (2000) reported that clearcutting and selection systems did not significantly affect the genetic diversity and genetic structure of sugar maple stands.
- The conflicting results necessitate a more comprehensive analysis of silvicultural methods examined across multiple generations and regional scale to better understand the genetic impact on sugar maple stands, particularly for the Northern Forest.

Nature of the Genetic Markers

- Molecular markers are commonly used to quantify genetic diversity.
- All previous genetic analysis on sugar maple used neutral genetic markers which provide information on population processes such as gene flow, migration or dispersal. However, they have a very limited ability to predict adaptive or evolutionary potential of a population or species.
- In the current study, we used non-neutral markers which occur in the transcribed regions of the nuclear genome and specifically from sugar maple as developed by Harmon et al. (2017).
- In particular, we used expressed sequence tag-derived simple sequence repeat (eSSR) markers, which unlike neutral markers, have the potential to link genotypes with fitness across a range of environmental conditions, and thus, they are subjected to natural selection and ideal in the analysis of adaptive genetic variation and local adaptations (Harmon et al. 2017; Alcaide et al. 2019).

Methods

Study Sites

- Northern Forest of New York, Vermont, New Hampshire, and Maine
- Two replicate study sites per state
- Each site has an unmanaged stand (which serves as experimental control), as well as selection and shelterwood stands

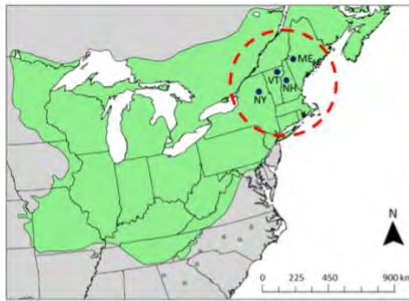


Fig. 1. Natural range of sugar maple (green) and locations of the four study sites (encircled).

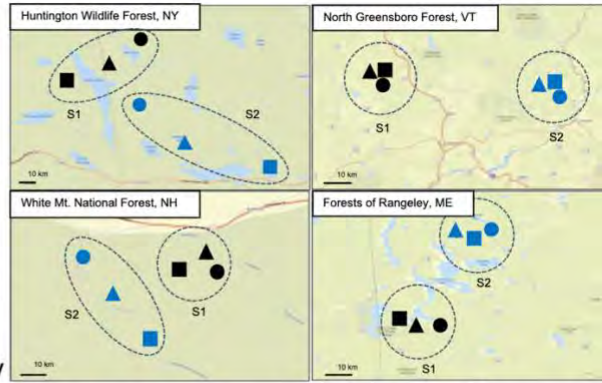


Fig. 2. Locations of two study sites per management type per state.

□ Unmanaged stand
△ Shelterwood stand
○ Selection stand



Figure 3. On site photos taken during data collection illustrating the three management types: B) unmanaged stand, C) selection system, and D) shelterwood system.

Physiognomy of Silvicultural Systems

Sampling

- 3 size classes (seedling, pole-timber & mature trees) and 3 management types
- 10 samples/size class/mngt ($10 \times 3 \times 3 = 90$)/stand ($90 \times 2 = 180$)/state ($180 \times 4 = 720$)
- Genetic diversity indices based on 11 eSSR markers:
 - Total alleles (AT) & Allelic richness (AR): # of all & mean # of unique alleles/locus

- Heterozygosity (HO & HE): Actual & HWE proportion of heterozygous locus
- Inbreeding coefficient (FIS): probability that 2 alleles/locus are identical by descent
- Number of private alleles (PA): alleles exclusive to a single variable

Key Findings

Genetic diversity indices

- Genetic diversity indices that showed significant mean differences among the management types, irrespective of size class and state, were total number of alleles (AT) ($p = 0.001$), allelic richness (AR) ($p < 0.001$) and expected heterozygosity (HE) ($p = 0.028$).
- Considering that AR and HE were calculated from AT and both regarded as the more sensitive indicators of genetic diversity, only results from these two indices were described in this report.
- Mean differences in observed heterozygosity (HO), inbreeding coefficient (FIS), and number of private alleles (PA) were not statistically significant ($p > 0.05$) between any of the three variables.
- Observed heterozygosity is the actual proportion of heterozygous locus, while expected heterozygosity is proportion of heterozygous locus calculated under Hardy-Weinberg Equilibrium, which takes into account sample size.

Genetic diversity between management types

- Comparison between means of management types showed that both SE and SW stands had significantly lower AR (SE $p < 0.001$; SW $p = 0.004$) than UM stands.
- Only SE stands had significantly lower HE ($p = 0.024$) compared to UM stands.

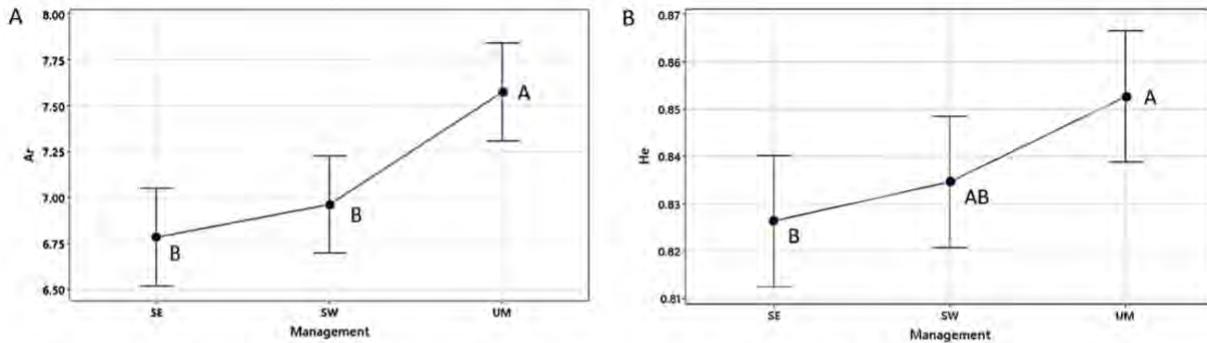


Fig. 5. One-way ANOVA showing genetic diversity between management types (SE, Selection; SW, Shelterwood; UM, Unmanaged) based on: A) Mean allelic richness (A_R) and B) Mean expected heterozygosity (H_E). Error bars indicate standard errors of the means. Treatments that share the same letter are not significantly different ($p > 0.05$).

Genetic diversity by size classes

- Comparison between means of size classes showed that seedlings had significantly higher AR ($p < 0.001$) and H_E ($p = 0.003$) than poles and mature trees.
- No significant difference between poles and mature trees for both genetic diversity indices ($p > 0.05$).

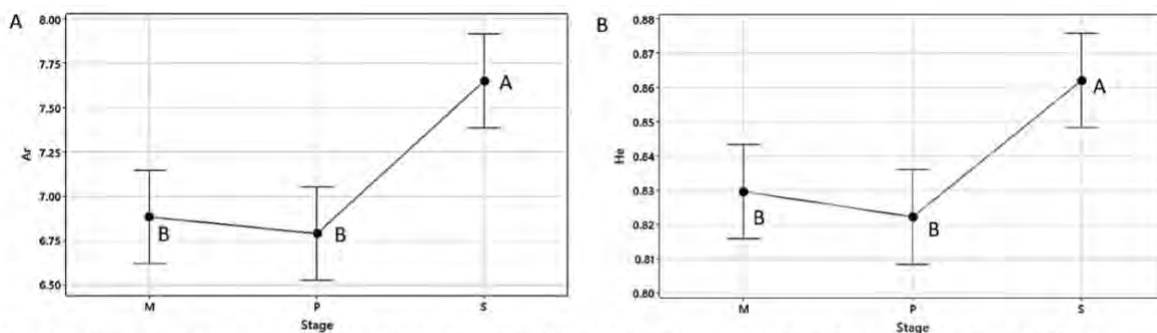


Fig. 6. One-way ANOVA showing genetic diversity between the three size classes (M, Mature; P, Pole; S, Seedling) based on: A) Mean allelic richness (A_R) and B) Mean expected heterozygosity (H_E). Error bars indicate standard errors of the means. Treatments that share the same letter are not significantly different ($p > 0.05$).

Genetic diversity by state

- Two-ANOVA showed no significant difference between the four states, irrespective of management or size classes, on all the 6 genetic diversity indices.

Management and size class interaction

- Seedlings in UM and SW stands had significantly higher AR compared to all size classes in the SE stands and poles and mature trees in the SW stands.
- No significant difference in HE between seedlings in all management types.
- Seedlings in SW had higher HE than its poles and mature trees, and poles and mature trees of SE stands.
 - No significant differences between poles and mature trees across the management types for AR and HE .

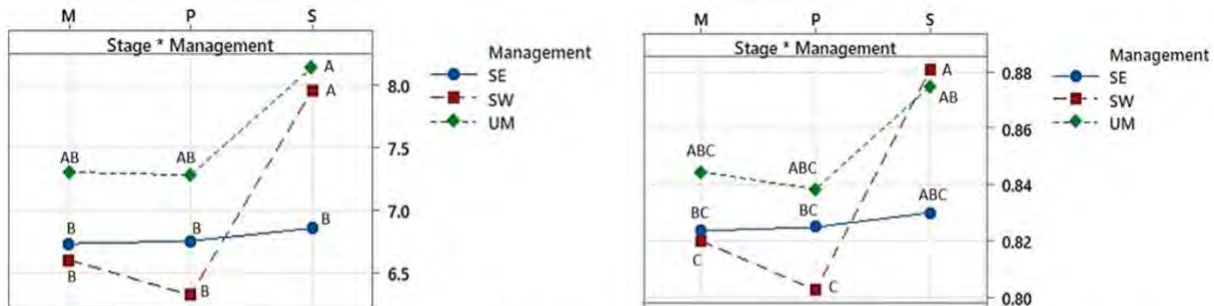


Fig. 7. Two-way ANOVA for means of A_R (left) and H_E (right) across the three size classes (stage) for the three different management types (SE, Selection; SW, Shelterwood; UM, Unmanaged). Treatments that share the same letter are not significantly different ($p > 0.05$).

State and size class interaction

- No significant interaction for AR between the four states and the three size classes.
- However, based on simple effects, seedlings had a significantly higher AR compared to the poles and mature trees, which were not significantly different from each other.
- Seedlings in NY, NH & ME along with mature trees in NY had significantly higher HE than poles in NH and mature trees in ME.
- In ME, NY, and VT, there was no significant difference in HE between their seedlings and poles, and between seedlings and mature trees in NY, NH, and VT.
- All size classes in NY and VT were statistically similar.

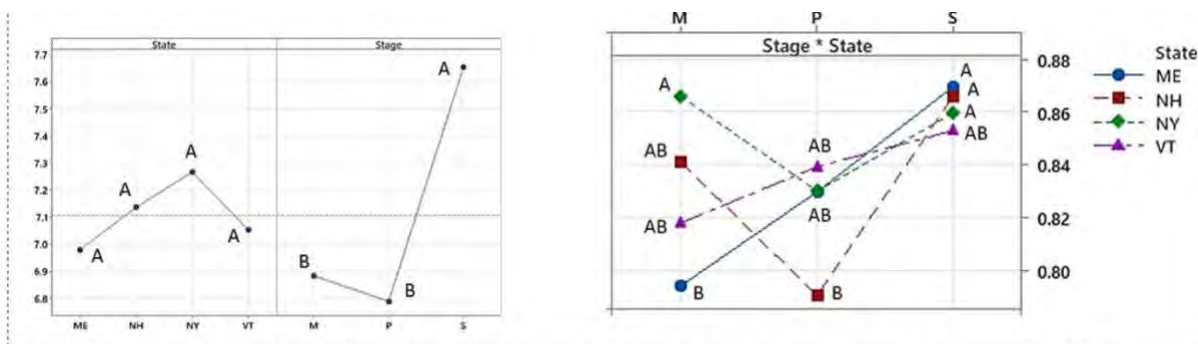


Fig. 9. Main effects for A_R (left) and H_E (right) for the four states (ME, Maine; NH, New Hampshire; NY, New York; VT, Vermont) and three size classes (M, Mature; P, Pole; S, Seedling). Treatments that share the same letter are not significantly different ($p > 0.05$).

Implications and Applications in the Northern Forest Region

Importance of Unmanaged Stands

- The high genetic diversity of unmanaged stands contributes to the increased gene pool in their respective and neighboring stands, as well as to the Northern Forest as a whole, sustaining a high level of genetic diversity for generations to come.

Selection and Shelterwood Systems

- The generally lower genetic diversity of seedlings in SE stands and poles and mature trees in SW stands are the early indications of genetic erosion due to management identified by the study.
- The higher seedling genetic diversity in SW stands is likely due to their more open stand structure that facilitates pollen capture and seed influx from outside of the stands.
- When using the selection system, a longer cutting cycle paired with a lower level of residual basal area is recommended. This approach allows for more open stand structure which may increase the capture of pollen and seed flow from outside of the stands, improving the level of genetic diversity within the stands.
- In both management systems, leaving high-quality growing stocks will allow enhancement of their genetic variation and ensures their sustainability.

Genetic Resource Monitoring

- This study is the first to examine the genetic diversity of sugar maple in all four states comprising the Northern Forest of the United States of America in relation to forest management types.
- The study is a snapshot in time, allowing a glimpse of the current level of genetic diversity in relation to management types.

- While the results of the study needs to be substantiated, the data presented serves as a baseline information on the level of sugar maple genetic diversity in the representative stands. It will be invaluable for future genetic analysis of sugar maple in the region.
- This study paves the way for genetic resource monitoring in the region to detect potentially harmful changes to forest adaptability.
- An early detection system will enable implementation of management and site-specific actions to protect forest ecosystem functioning and sustainability.

Future Directions

Several interesting results were reported in this study, but they need to be substantiated to be more meaningful. Future research should address the following:

1. Strengthen genetic analysis by increasing the number of adaptive genetic markers including the incorporation of neutral markers as they provide additional insights on random evolutionary processes such as genetic drift, bottlenecks, and dispersal patterns. Such will allow testing of the relevance of spatial indices, particularly landscape connectivity. The use of both types of genetic markers will provide stronger insights on plant responses to short- and long-term environmental and anthropogenic impacts.
2. Establish the correlation between stand structures and genetic diversity in SE and SW systems including number of residual trees and their spatial distribution.
3. Examine more samples and study sites including differentiating the potential genetic impacts between regular vs irregular shelterwood systems, individual vs group selection system, and other management types used in the region.
4. Integrate genetic diversity data with more detailed management history such as specific prescriptions employed within and between management types and impacts of anthropogenic disturbances such forest fires, die back disease, etc.

The State of the Northeastern Forest Carbon Cycle: High-Resolution Carbon Accounting for the Regional Forest Sector

Principal Investigator: Daniel J. Hayes, University of Maine School of Forest Resources

Co-Principal Investigator

Adam Daigneault, University of Maine School of Forest Resources

Completion date: May 2025

This project developed a comprehensive carbon accounting framework for the forest sector of the Northeastern States Research Cooperative (NSRC) region, integrating remote sensing data with forest inventory data analysis to provide requisite information for regional greenhouse gas measurement, monitoring, reporting, and verification (MMRV).

The results demonstrate that the Maine forest sector, as a case study for the broader NSRC region, offsets approximately 90% of the state's gross emissions, highlighting the significant role that forest ecosystems and wood products play in regional climate mitigation efforts.

Project Summary

The northeastern forest represents an important natural climate solution by taking up carbon from the atmosphere and storing it in its biomass, soils, and wood products. However, precise accounting of this carbon sink at high spatial and temporal resolution has been lacking, which limits applications for management. Our project addressed this gap by developing a detailed carbon accounting framework for the NSRC region, with a specific application to Maine as a demonstration case.

Our research used a bookkeeping approach based on remote sensing and forest inventory data to track carbon stocks and fluxes. We integrated US Forest Service Forest Inventory and Analysis (FIA) plot data, airborne LiDAR, and Landsat time-series to map forest biomass at high resolution (30m) across the region. We used Landsat-derived disturbance mapping implemented on the Google Earth Engine to track forest changes over time. We developed new models to account for key carbon budget components, including a wood products model to calculate the contribution of forest harvesting and a lateral aquatic flux model to estimate carbon transfer to oceans.

The direct results of our project work included the completion of "Version 2" of the Maine carbon budget, demonstrating that the forest sector offsets approximately 90% of the state's gross emissions. This work directly informed Maine's official Greenhouse Gas Emissions reporting and provides a scientific framework that can be applied across the entire NSRC region. The methodologies and tools developed represent significant advances in forest carbon accounting

that can support regional climate mitigation policies and sustainable forest management practices.

Background and Justification for the project

Forests in the Northeastern United States represent a significant carbon sink that plays a crucial role in regional and national climate mitigation strategies. However, quantifying this sink at scales relevant for decision-making has been challenging due to the complexity of forest ecosystems, diverse ownership patterns, and varied management practices across the region.

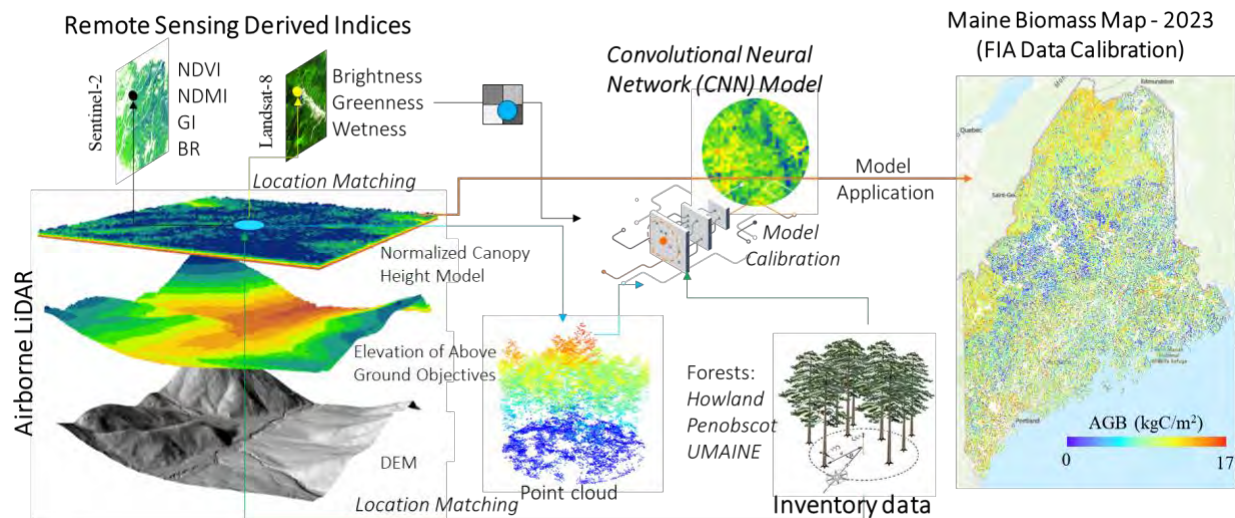
Traditional carbon accounting methods often rely on broad spatial averages from forest inventory data, lacking the spatial resolution needed to inform localized management decisions. Meanwhile, reporting requirements for greenhouse gas emissions at state and regional levels have become increasingly important as jurisdictions set ambitious climate goals. Maine, for example, has established a net-zero emissions target that requires accurate accounting of forest carbon sequestration.

This project was designed to address these challenges by developing a comprehensive, high-resolution carbon accounting framework that integrates advanced remote sensing technologies with forest inventory data. The approach allows for more spatially explicit tracking of forest carbon stocks and fluxes, including tracking the fate of harvested wood products (Li et al., 2022) and lateral aquatic transfers (Casas-Ruiz et al., 2023). The resulting framework provides policymakers, forest managers, and stakeholders with the detailed information needed to develop effective climate mitigation strategies and sustainable forest management practices tailored to the unique characteristics of the Northeastern forest.

Methods

Our project led to the development of a comprehensive "bookkeeping" approach to carbon accounting that tracks initial carbon stocks based on forest type groups and subsequent changes through time based on forest disturbances. This method balances scientific rigor with practical applicability, making it suitable for both research and policy applications.

We began by developing high-resolution maps of forest biomass across the NSRC region at 30m resolution. This process involved integrating multiple remote sensing data sources, including airborne LiDAR combined with Landsat time-series metrics. For tracking forest changes over time, we used Landsat-based disturbance algorithms on the Google Earth Engine platform. We used these data with the US Forest Service Land Change Monitoring System (LCMS) products to map forest disturbances across the region from 1985-2022.



The model-data integration workflow for developing the statewide forest biomass map for the state of Maine.

We developed an open-source Python tool to calculate plot-based carbon pools from the FIA database. Based on the NSVB data, we created models relating stand age to aboveground biomass in northeastern forest types. The growth curves were applied to track changes over time within the bookkeeping framework for annually-updated, pixel-level carbon accounting. This tool also allows regional extrapolation of carbon estimates using spatial data on forest type, stand age or time since disturbance, and environmental variables.

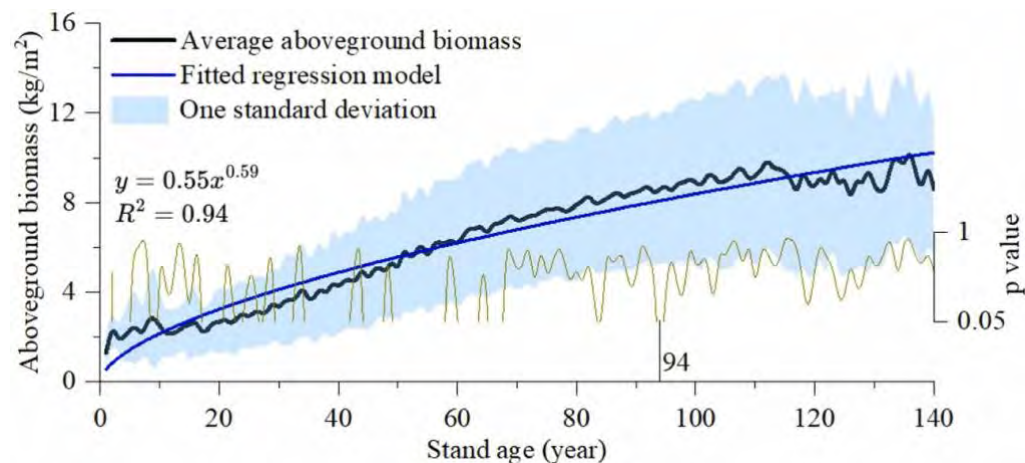


Figure 2.
Relationship between stand age and aboveground biomass in northeastern United States forests (from Wei et al., 2025).

We have developed two new models in this project for the purpose of including additional carbon budget components that are often not included in such assessments. First, we developed and released an open-source tool for life cycle and product type-based estimation to quantify the carbon stored in wood products, which allowed us to track the fate of carbon post-harvest. Second, we published a lateral aquatic flux model to estimate dissolved organic carbon export to

oceans, addressing an important carbon transfer pathway that typically represents a large gap in terrestrial carbon modeling.

We employed a careful testing and verification approach throughout the project. Initially, we developed and verified the accounting framework on a set of forest research properties as test sites. This allowed us to refine our methods before scaling to the entire state of Maine and subsequently to the broader NSRC region. Working with the University's Office of Sustainability, we incorporated our forest carbon accounting into the campus carbon footprint assessment, providing a practical demonstration of how our methods could be applied to local management decisions.

Key Findings

- Successfully developed ["Version 2" of the Maine carbon budget](#), which was incorporated into the state's [Tenth Biennial Greenhouse Gas Emissions Report](#). The results show that the forest sector offset approximately 90% of the state's gross emissions over the 2017 to 2021 period, an increase from the 75% offset estimated in the previous assessment ("Version 1").
- Created a comprehensive [technical document](#) detailing the data and methodological approach used to generate the state carbon budget, providing transparency and facilitating adaptation of the framework to other states.
- Developed two innovative models to account for key components of the forest carbon budget:
 - A life cycle and product type-based estimator for quantifying carbon stored in harvested wood products.
 - A model to estimate the fate of terrigenous dissolved organic carbon in coastal systems.
- Produced high-resolution (30m) maps of forest biomass and disturbances across the NSRC region, providing the spatial detail on forest carbon dynamics required for management decisions.
- Identified potential climate change impacts on forest carbon sequestration, including findings that potential shifts of dominant tree species under climate change could reduce aboveground biomass in northeastern forests.
- Integrated the aquatic system in our assessment, demonstrating the importance of considering lateral carbon fluxes in regional carbon budgets.

- Hosted annual "Maine Forest Carbon" workshops (2022, 2023) with 40+ participants each year to demonstrate data products to stakeholders and gather feedback on their utility and applications.

Implications and Applications in the Northern Forest Region

This project has significant implications for forest management and climate policy across the Northern Forest region:

- **Policy Support:** Our carbon accounting framework provides the scientific foundation needed for states to track progress toward climate goals. The Maine case study demonstrates how forest carbon sequestration can be incorporated into state greenhouse gas inventories, allowing for calculation of "net emissions" that account for natural climate solutions.
- **Management Decision Support:** The high-resolution maps and models developed enable forest managers to understand carbon dynamics at scales relevant to management decisions. This can inform practices that optimize both timber production and carbon sequestration among other management goals.
- **Climate Adaptation Planning:** Our research on climate-induced shifts in forest composition and potential impacts on carbon sequestration provides valuable information for long-term forest planning and climate adaptation strategies.
- **Wood Products Value:** The wood products carbon model highlights the importance of considering the full life cycle of harvested wood in carbon accounting, supporting the priority on markets for long-lived wood products that store carbon for extended periods.
- **Partnerships and Collaborations:** This project established strong working relationships with key stakeholders:
 - Maine Department of Environmental Protection for state GHG reporting
 - US Forest Service for alignment with federal carbon accounting approaches
 - University of Maine's Office of Sustainability for campus carbon footprint assessment
 - NASA Carbon Monitoring System science team
- **Transferable Framework:** While demonstrated for Maine, the carbon accounting approach developed is applicable across the entire Northern Forest region and could be adapted by other states for their climate reporting needs.

Future directions

Building on the foundation established by this project, several promising directions for future work include:

- **Expansion to Additional States:** Applying the full carbon accounting framework to other states within the NSRC region, helping them develop state-specific carbon budgets and integrate forest carbon into their climate policies.
- **Scenario Modeling:** Developing the capability to model alternative forest management and climate scenarios, allowing stakeholders to explore how different strategies might affect forest carbon sequestration in the future.
- **Integration with Economic Models:** Connecting the carbon accounting framework with economic models to assess the financial implications of different carbon management strategies, potentially supporting the development of carbon markets in the region.
- **Climate Change Vulnerability Assessment:** Further investigating how shifting climate patterns may affect forest carbon sequestration capacity across the region, with particular attention to species composition changes and disturbance regime shifts.
- **Enhanced Disturbance Mapping:** Improving the classification of disturbance types (harvest, insect, fire, etc.) and severities to better understand their differential impacts on carbon cycling.
- **Integration with Operational Forest Management Systems:** Working with large landowners and managers to incorporate carbon accounting into their operational planning and reporting systems.

10. Partners/Stakeholders/Collaborators

- US Forest Service (Chris Woodall)
- Maine Department of Environmental Protection (Stacy Knapp)
- University of Maine's Office of Sustainability (Daniel Dixon)
- NASA Carbon Monitoring System science team

Town Forest Census: Carbon, COVID, and Capacity-Building

Principal Investigator: Cecilia Danks, Ph.D. Associate Professor, Rubenstein School of Environment and Natural Resources, University of Vermont

Completion date: March 31, 2025

This census captures the perspectives of community volunteers and staff who steward forests owned by municipalities, which were found to vary greatly in terms of their size, age, governance structures, use levels, and expressed needs for assistance and information.

Providing accessibility, protecting ecological values, and managing trail networks were among the top challenges named by local forest stewards, who also emphasized the many benefits to humans, wildlife, ecological functions, and community life provided by these forests.

Project Summary

Rationale: Town forests contribute to forest integrity, ecosystem services, recreational opportunities, wildlife habitat, the wood products industry, education and human health. They are well-loved and growing throughout the Northern Forest region. Many communities, however, encounter challenges as they seek to provide for diverse public demands with limited resources. State and private initiatives in Vermont have sought to build the capacity of communities to steward their forests. These efforts have identified several constraints to this work, including the lack of a complete inventory of town forests with key contacts for each, outdated public maps, and uneven knowledge of community needs and strengths.

Methods: To address these gaps, we conducted a census in two stages: 1) outreach to every municipality in VT to create an inventory including number, name, size and best contact for each forest, and 2) deployment of a 24 question census through the Qualtrics survey platform, developed with Advisory Committee input, asking for descriptive information, challenges and support needs of each forest. In addition, mapping options were evaluated and initiated using census responses and new VT parcel maps. An economic analysis was conducted using an ecosystem services framework to calculate statewide economic benefits and to create an interactive tool for communities. A project website was created to host resources for towns as well as census information and products. Finally, an operational manual was created to facilitate replication of this census in the future.

Outcomes: Outreach and census responses reveal the marked growth and variety of forests owned by municipalities statewide. Governance structures vary considerably, with volunteers playing major roles in most communities. Respondents clearly treasure their forests and want to

share their successes. Yet, they are keenly aware of potential threats, which for some are overuse and for others are neglect. Top challenges include providing access for all abilities, constructing and managing trail networks, protecting ecological integrity, and securing funding. Respondents expressed most interest in receiving assistance for managing invasive species, protecting ecologically sensitive areas, and monitoring impacts.

Implications: Town forests have an outsized influence, not only because they provide local public access (which many private and state lands do) but they also engage community members as stewards of forests for public benefit. Given the mix of needs and strengths among the forests, we see great opportunities and potential benefits from peer learning to help address the main issues they are encountering.

Background and Justification

Town forests are uniquely valuable for what they provide to their surrounding communities, the regional forested landscape, and the forest economy. In Vermont, over 67,000 acres of forestland are owned by at least 168 municipalities. The public values of these town forests are diverse, from watershed protection, wildlife habitat, and forest products to outdoor classrooms and gathering places for neighbors. These publicly owned forests also have the potential to serve as models of exemplary forestry and recreational practices, thus influencing management on Vermont's private forestlands. For these reasons and more, town forests have been identified in the current Vermont Forest Action Plan as a priority landscape, and this project aligns with goals and strategies in the plan to support, promote, and advance use and management of town forests as public lands (ANR FPR 2017)

During the current COVID 19 pandemic, the importance of town forests to public health has become increasingly clear as Vermonters have sought local, outdoor recreational spaces to sustain mind, body and community. Moreover, legislation and state programs to address forest fragmentation and bolster Vermont's forest-based outdoor recreation industry have focused renewed attention on town-owned forest lands. Despite this enormous potential, the stewardship of town forests varies greatly, due in part to differences in governance, use, and community resources. In some communities, growing demands on town forests to be 'everything for everyone,' combined with a lack of capacity for community planning, has challenged the health of the forest and contributed to conflict and fractures within local communities.

The Vermont Urban and Community Forestry (UCF) Program of FPR, working with public and private sector partners, has long supported capacity-building efforts to help towns to steward their forests. However, a lack of comprehensive information about community needs was found to hamper outreach and potentially lead to uneven support in which the well-known or well-resourced town forests would be most successful in accessing additional resources. While there are published case studies of town forests (e.g. Lyman, Danks & McDonough 2013) and excellent historical accounts of their development (McCullough 1995), there is not a comprehensive dataset that supports either additional scholarship or community outreach efforts.

The idea of a census, a 100 percent survey of all Vermont town forests, emerged as a way to address these information needs and catalyze efforts to improve stewardship of town forests.

This project updates and expands research previously funded by the NSRC: one in 2007 to conduct an initial town forest inventory, and again in 2015 to update that map for Vermont's town forest centennial year. Those mapping projects acknowledged errors of omission and commission, and the numbers and sizes of town forests have expanded since federal funding in the Community Forestry Program became available in the mid-2010s. While one census will not provide all of the answers, it will provide comprehensive baseline data and analysis to help form the right questions and guide future initiatives.

Methods

Step 1: Creation of Advisory Committee. We invited over twenty experts and community members from across the state to guide development, deployment and interpretation of the census. The names and affiliations of the 15 Advisory Committee members and 6 ad hoc advisors can be found on the website and in #10 below. We also solicited input on the census when presenting the project in several VT forums (listed in #8 below), and developed a listserv of stakeholders and others who expressed interest in the project.

Step 2: Develop Inventory of Forests owned by Municipalities

A list of all forest areas owned by municipalities in Vermont, along with a key contact for each one, was pursued in three phases: a detailed town-by-town online research to develop list of town officials (clerk or equivalent town administrator) of every municipality in Vermont, and two phases of outreach to those officials. Outreach 1 was conducted by email, and consisted of a short online survey sent to each town asking how many forest areas they owned, if any, and the contact information for the best person to fill out the census form for each forest. After 6 reminders over a two month period, Outreach 1 received responses from 131 towns yielding contact information for 185 forests, with 44 towns responding that they had no forests. The second round, Outreach 2, blended intensive, town-by-town online research followed up by direct contact (email or phone) with town officials or volunteers for each municipality that did not respond to the Outreach 1 survey. Outreach 2 is ongoing with undergraduate research assistance that will extend through summer 2025. Results from both rounds of outreach were checked against the 2015 list of town forests and information on town websites. Any discrepancies were cleared up in consultation with town representatives.

Step 3: Town Forest Census development, deployment and analysis. The questions to be included in this first census of Vermont town forests was developed and pretested with iterative input from the Advisory Committee and other stakeholders. The census form was constructed in the Qualtrics survey platform, which enabled excellent tracking of responses and automatic reminders. A PDF of the census can be found [on the website](#). These census forms were sent to the contact person for each of the 185 forests in Fall-Winter 2025 with 5 follow-up reminders, yielding 112 usable responses. These responses constitute Cohort 1, the results of which are summarized in the first technical report.

For every topic, there were both fixed-choice and open-ended questions to allow for quantification of results while capturing the nuance and broad range of forest conditions,

objectives, activities and concerns. Initial data analysis for the first technical report consists of summary descriptive statistics by question, and the categorization and basic coding of open-ended responses. Additional analysis comparing responses between questions and incorporating socio-economic data by community is on-going. The full data set, with some confidential variable removed, will be made publicly available through the project website and the Forest Ecosystem Monitoring Cooperative to enable analysis by other agencies, organizations and communities, as well as UVM students and faculty.

Step 4. Economic value of forest benefits

The potential economic value of town forest benefits was calculated by UVM students in the senior capstone service learning class NR 4060 under the guidance of the project PI. An ecosystems services framework was used to identify key provisioning, regulating and cultural benefits of Vermont forests. Multiple sources and key informants were used to estimate the value of benefits on a per acre basis which were then used to calculate benefits statewide. These estimates were also used to create an online, form-based tool which community members could use to calculate economic value of benefits for their own forests.

Step 5. Mapping.

Initially, the mapping effort was anticipated to precede and inform the census, contributing substantially to identifying forests owned by municipalities. However, because of technical issues with matching layers and the decision to wait until the latest VT parcel map was available, creating and deploying the census was prioritized. Moreover, even if the forests were first identified on the map, we would still need to reach out to each town to find the principal steward fill out the census form. We are moving ahead with two mapping efforts: 1) using an open source map (MyMap in Google) to create a point location for each forest that responds to the census on the map and pair it with a spreadsheet containing basic descriptions of the forest (e.g. size, year established, website for more information), and 2) to create a fresh town forest layer using the most recent VT parcel map as the base and adding forests town by town based on their census responses and own plans. Both maps will be member-checked for accuracy. Some forests have asked not to be included in public data such as an online map because they did not want to attract more visitors when they were having trouble managing the current visitors. This GIS map will be created in consultation with the Vermont Center for Geographic Information and eventually be made available on their site.

Key Findings

Their size, age, governance structures, use levels, and interest in assistance and information vary greatly across the state. Recreation was the most frequently reported management objectives, followed by “protection of forest connectivity, sensitive ecological features, habitats and species.” “Ensuring access for all abilities”, “constructing and managing trail networks”, “balancing public access and ecological integrity”, and “securing funding” were among the top challenges named by forest stewards. A wide variety of actions and rules are employed to balance recreation and ecological protection on these forests. Nearly a quarter of forests harvested wood products

within the last 15 years. Many forests noted a sustained increase in visitors and maintenance issues since the covid lockdown in 2020, while others report that the visitation rate has returned to normal. The many anecdotes and detailed information added throughout the census's open-ended comments attest to the importance of these forests that many communities hold dear.

Implications and Applications in the Northern Forest Region

Town forests contribute to the Northern Forest landscape by keeping productive forestlands in timber management, protecting physical and biological diversity, and maintaining connectivity between larger patches of forest. They yield many of the ecological and economic benefits of larger tracts of protected land owned by the state or federal government. Moreover, they excel in providing local recreational, educational, and cultural opportunities that contribute to human health and community well-being. However they face many of the same challenges of balancing management objectives, user conflicts and ecological changes wrought by climate change and invasive species – without the professional expertise, labor force, and budget that state and federal lands may have. This census has revealed that stewards of some forests may excel in one set of challenges, while other those of forests excel in different issues. Many are keen to learn from their peers. State efforts that seek to foster peer-learning may be an efficient and effective way to support these vital local public forests, especially during times of uncertain government funding. The public data set created by this project will facilitate peer learning while providing research opportunities for students of all levels as well as academics and agency researchers.

Future directions

Future work in this area includes:

- Continued collection of data to get to full 100 percent of Vermont Town Forests.
- The census was designed to be conducted on a periodic basic, perhaps timed to provide data to the Vermont Forest Action Plan, which is updated about every 10 years.
- Continue to engage the Advisory Committee and listserv to promote information sharing regarding best management practices (e.g. for invasive species, trail construction), options for monitoring wildlife and human use, funding opportunities and other areas of interest identified in the census.
- Pursue a dual mapping approach: 1) public facing google map supported by UVM undergrad research interns, and 2) a new GIS layer (undergraduate honors student is working on this). Continue to respect wishes of towns that prefer to remain unlisted in public-facing maps.
- Follow up on the issue of accessibility, a top ranked concern expressed by census respondents. UVM undergrad will be studying this issue for her honors thesis in 2025-2026.

- Explore potential for the Town Forest Stewardship Team of UVM undergrad students who can provide outreach to municipal forest stewards during an era of constrained budgets both in state agencies and federal research institutions. Apply for funds (e.g. Leahy Center for Community Partnerships) to initiate this effort.
- Collaborate with new UVM Community News Service to work with specific towns on community engagement and more generally to increase the profile of town forests in Vermont.

Haudenosaunee Forest Principles

Principal Investigator: Robin Kimmerer (SUNY ESF) rkimmer@esf.edu Neil Patterson Jr. (SUNY ESF) nvpatter@esf.edu

December 31, 2024

In partnership with the Haudenosaunee Environmental Task Force, we conducted three Forest Forums to draft Haudenosaunee Forest Caretaking Principles, developed youth forest education programs, and conducted numerous community outreach efforts in response to community needs and goals. This resulted in new research efforts to support Haudenosaunee forest caretaking on over 15,000 acres of their traditional lands in upstate New York, and new partnerships with Indigenous Nations for culturally significant plant research and restoration projects.

Project Summary

Haudenosaunee people are the traditional caretakers of over twenty million acres of forests in what is now called New York State. The goal of this project was to bring together Indigenous community leaders, knowledge holders, and practitioners to consider the ways that Haudenosaunee forest protocols and traditions can be applied to contemporary forest management practices.

In close partnership with the Haudenosaunee Environmental Task Force (HETF) and Indigenous Partners, we convened three Forest Forums with community leaders and practitioners to identify community research and education priorities related to forested lands and to develop forest ecology and stewardship curriculum for Native Earth. We then began to also gather and assess several methods for applying Indigenous drafted principles might apply to contemporary forest management practices.

Through our partnerships with the HETF and other Indigenous Knowledge holders across Haudenosaunee territory, we drafted Haudenosaunee Forest Caretaking Principles through shared dialogue and field experiences with leadership and knowledge holders from at least six different Indigenous Nations and communities. We also conducted several extensive outreach experiences for communities and native youth to pilot and learn from traditional access and care principles.

Several implications resulting from this project include: the creation of, and continued support for, a community of Indigenous knowledge holders and practitioners seeking to advance Haudenosaunee access and care of traditional lands; a clearer understanding of the values underlying traditional caretaking principles; hundreds of Indigenous students and community members educated about western forest management approaches and techniques; new research efforts to support Haudenosaunee forest caretaking plans on over 15,000 acres in upstate New York; and new partnerships with Indigenous Nations for culturally significant plant research and restoration.

Background and Justification for the project

A growing number of forest managers today are required by state policies or certification programs to integrate Indigenous stewardship and access into their management plans. The goal of this project was to bring together Indigenous community leaders, knowledge holders and practitioners to consider the ways that Haudenosaunee forest protocols and traditions can be applied to contemporary forest management practices. The Center continues to receive a growing number of requests from private and public forest owners interested in how Indigenous knowledge and access should be part of land management plans, including the New York State Department of Environmental Conservation, (NYSDEC) the New York State Office of Parks, Recreation and Historic Preservation, The Nature Conservancy and numerous land trusts and non-profit conservation organizations.

The project gathers and invites participation from Indigenous Nations addressing forest research priorities, and builds on CNPE's cross-cultural programs with the NYSDEC and TNC exploring models of forest stewardship. Currently, there are structural inequities built into lands now under non-Indigenous jurisdiction and ownership, and we seek to enhance Indigenous access and care of traditional territories.

Methods

Our methods include working with representatives of the Haudenosaunee Environmental Task Force (HETF) to co-produce three forums convening Indigenous knowledge holders and practitioners at the Onondaga Nation (2021), the Akwesasne Mohawk Nation (2022), and the Tonawanda Seneca Nation (2024). We drafted a set of commonly-shared Haudenosaunee Forest Caretaking Principles following the second forum and presented them for review in the third.

Draft Haudenosaunee Forest Caretaking Principles are still in review due to potentially sensitive information and all such materials developed or recorded for this project are under the sole guardianship of the Haudenosaunee Environmental Task Force and subject to the Akwesasne Task force on the Environment's Research Policy.

We conducted three 7–10-day long forest education experiences in the Northern Forest during our annual Native Earth Environmental Youth Program for high school students. Students engaged in (re)learning traditional forest knowledge and practices on the land and witnesses several examples of non-Indigenous contemporary forest management.

Methods responded to direct feedback from HETF and Indigenous participants. We included additional research-based and outreach efforts at the request of our partners to promote dialogue about forest caretaking principles. We also began collecting data to support the application of draft Haudenosaunee Forest Caretaking Principles on currently-recognized Indigenous and State Forest Lands, including community forest tours this period for Haudenosaunee leaders to better understand how their ancestral forests are cared for by currently recognized owners and managers.

Key Findings/Accomplishments

- We drafted a set of Haudenosaunee Forest Caretaking Principles through several community forums and outreach events over the last four years.
- We identified and disseminated a number of unpublished work by Haudenosaunee authors describing traditional tree and forest caretaking principles that shaped the principles drafted.
- We spent time in contemporary forests with Haudenosaunee leaders, practitioners and youth to better understand non-Indigenous contemporary forest management.
- We developed new research efforts to support Haudenosaunee forest caretaking plans for the Onondaga Nation and at over 14,000 acres of protected lands in the Adirondack Park.
- We began and funded new partnerships with Indigenous Nations for culturally significant plant research and restoration, and for cultural provisioning on private forest lands in NYS.

Implications and Applications in the Northern Forest Region

Forum participants identified several culturally-significant species as potential indicators of forest well-being that are now included in state-wide forest inventories conducted by the NY Natural Heritage Program.

A key application of the project is forest inventory and management data newly made available to Indigenous communities. Our efforts developed methods for communities to access and apply this data, particularly for the protection and restoration of culturally-significant species in the Northern Forest.

Structural inequities of current forest management and access were reviewed and assessed by Indigenous Nations, including New York State Department of Environmental Conservation regulations requiring revocable permits or voluntary stewardship agreements, and were found to be supported for some applications of Haudenosaunee forest care, but not all.

Support for the application of drafted Haudenosaunee Forest Caretaking Principles was made possible this year on 1000 acres on land in Central New York returned to the Onondaga Nation and over 14,600 acres of the Northern Forest at Follensby Pond, where a new conservation easement provides “opportunities for restoring Indigenous Peoples’ access to, and caretaking of, their ancestral homelands.”

Future directions

There is great support by our Indigenous Partners for continued dialogue in Forest Forums. We plan to continue the Forums through 2025 to continue advance Haudenosaunee Forest Caretaking Principles in partnership with Indigenous Nations. We will continue partnerships established during this effort to address the cultural plant research and restoration projects identified by Indigenous Nations.

NEBI (Water): Connecting N'dakinna (Land), Bilowagizegad (Climate), and Alnobak (People)

Project Summary

Vital to life in N'dakinna (present-day Northeastern United States) is access to clean and safe surface water. For the indigenous people of N'dakinna, the Abenaki and Pennacook, nebi (Abenaki for water) provides the interconnected web that organizes life. The relationship to water throughout contemporary New Hampshire maintains these relationships including access to food and clean water and supporting agriculture. One contemporary challenge for indigenous communities and water resource management alike is the uncertain effects of global change.

Project Nebi provides students (undergraduate and graduate) opportunities to integrate indigenous knowledge with western science.

Objectives & Approach

Provide UNH undergraduate and graduate students exposure to and experience with indigenous knowledge and ways of thinking.

Provide educational and research opportunities for university students to consider the sustainability of forested watersheds (and ecosystems more generally) from both indigenous perspectives as well as western scientific perspectives.

Explore interactions between indigenous knowledge and western science especially as it pertains to climate change and water resources. The project explored two fundamental indigenous concepts: reciprocity and two-eyed seeing.

Highlights and Key Findings

We developed and explored two critical frameworks that integrated indigenous knowledge/ways of knowing with western scientific knowledge. Our first effort applied the concept of reciprocity with contemporary scientific methods and the second applied the concept of two-eyed seeing to partnerships between Native Tribes and Federal Agencies.

The Environmental Responsibility Framework was inspired by the indigenous concept of reciprocity which recognizes fundamental and bidirectional relationships between people and other living organisms. With this concept in mind, our team developed the Five R's of environmental conscious research which provides a framework for scientific researchers to interrogate scientific protocols to reduce the environmental impact of the research itself. This project also drew inspiration from IRB (Institutional Review Board) and IACUC (Institutional Animal Care and Use Committee) protocols which

are frameworks aimed to protect human and animal subjects during research. No such framework exists to protect the environment and ecosystems. Our five R's include: recognition, refinement, reduction, replacement, and restoration. We published this framework as a Commentary in the international journal *Earth's Future*. This effort was led by PhD student Deni Murray and included 2 undergraduates, three additional PhD students, and one post-doctoral researcher.

Second, we explored the concept of two-eyed seeing through the integration of maps that describe different perspectives of land management. The core principle to two-eyed seeing is that Indigenous Knowledge and conventional Western science don't have to validate each other to both be useful to policymaking. The goal of two-eyed seeing is to gain benefits from both perspectives rather than trying to integrate into a single framework. For example, tribal maps may differ from those developed via western (and Federal) mapping techniques in conceptions of borders, time, and perspective. For many indigenous communities, meaningful connections exist across boundaries and over vast time scales which are difficult to place on maps. The framework developed here (and presented at last year's AGU meeting by PhD student Kristin Green) is designed to bring the notion that certain mapping techniques represent specific perspectives and leave others out to light

Outcomes (i.e., personal, professional, workforce development; advancing partnerships; innovation & growth)

This project provided opportunities for professional development for many of its participants. Two PhD students were provided with the opportunity to present their work at an international conference. This included PhD student Deni Murray and her presentation on the Environmental Responsibility Framework and Kristin Green to present her cartography-based work and the principle of two-eyed seeing. Both of these students also had the opportunity to present and discuss their research at other institutions (Murray at the University of Puerto Rico) and with the press (Green and her interview published in *Eos*).

Undergraduate researcher Isabel Cole also had the opportunity to present her research on the Environmental Responsibility Framework at the University of New Hampshire Undergraduate Research Conference.

New partnerships were also established throughout the project including new collaborations between Dr. Teresa Cohn and Dr. Adam Wymore at the University of New Hampshire. This resulted in a proposal to the National Science Foundation and the AISL (Advancing Informal STEM Learning) entitled "Re-Storying Disturbance: Integrating Informal STEM Learning through Participatory Narratives". While this proposal was unsuccessful, we are planning to revise and resubmit. Cohn is also now collaborating with Abenaki leadership resulting in multiple collaboration between UNH faculty and students and indigenous leadership.

Significant Challenges

The project was significantly affected by the COVID 19 pandemic. This limited the amount and frequency of interactions between team members. Work was also slowed due to additional obligation of team members due to COVID and increased responsibilities at home. This was the primary reason for the initial no cost extension request. However, over these past 12 months much was accomplished supporting a set of meaningful product outputs.

Future Plans

We are now identifying opportunities to expand upon the two major outcomes of this project. We plan to work with the University of New Hampshire Sustainability Center to identify mechanisms to integrate the Environmental Responsibility Framework into the larger research program at the University of New Hampshire. We have shared our paper (Murray et al. 2023) with UNH leadership (e.g., Deans in both the College of Life Science and Agriculture and the College of Engineering and Physical Science) and plan to discuss with the UNH research office opportunities to implement the framework at UNH as an initial test bed.

We are also planning to share the Environmental Responsibility Framework with the leadership at the US National Science Foundation to discuss ways for such a framework to be included in the proposal development and review process. We firmly believe that without formal institutional support of such a framework that progress cannot be made to lower the environmental impact of scientific research. We had initial discussions with former NSF program officers at last year's American Geophysical Union meeting that were highly encouraging.

PhD student Kristin Green will also develop a manuscript for peer-review based on her application of two- eyed seeing to cartography and Native-Federal partnerships and land management. This work will also be included in her dissertation with an expected graduation date of May 2025.

We will continue to partner with the INHCC (Indigenous New Hampshire Collaborative Collection) to share our work and disseminate out outputs.

Figures, Tables, And Photos

Attachment 1: Conceptual figure from Murray et al. 2023 that outlines the Five-R's of the Environmental Responsibility Framework. See citation above.

Publication DOI: 10.1029/2022EF002964

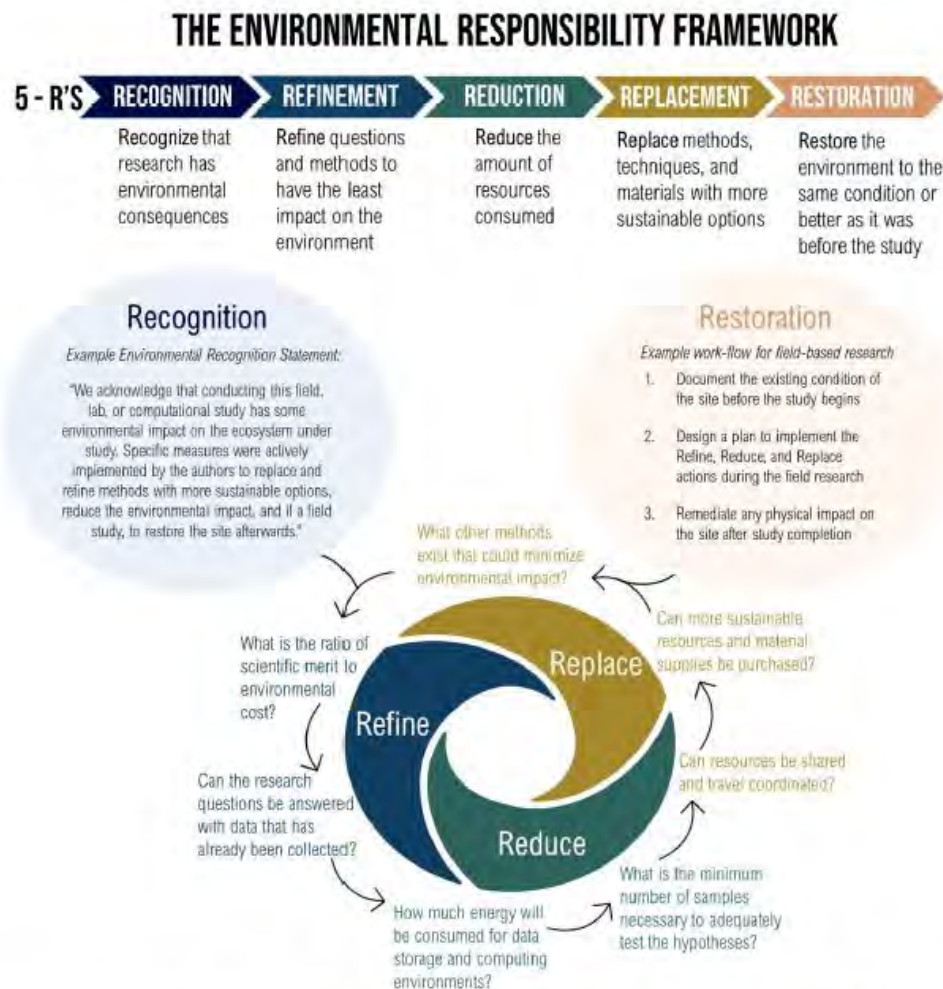
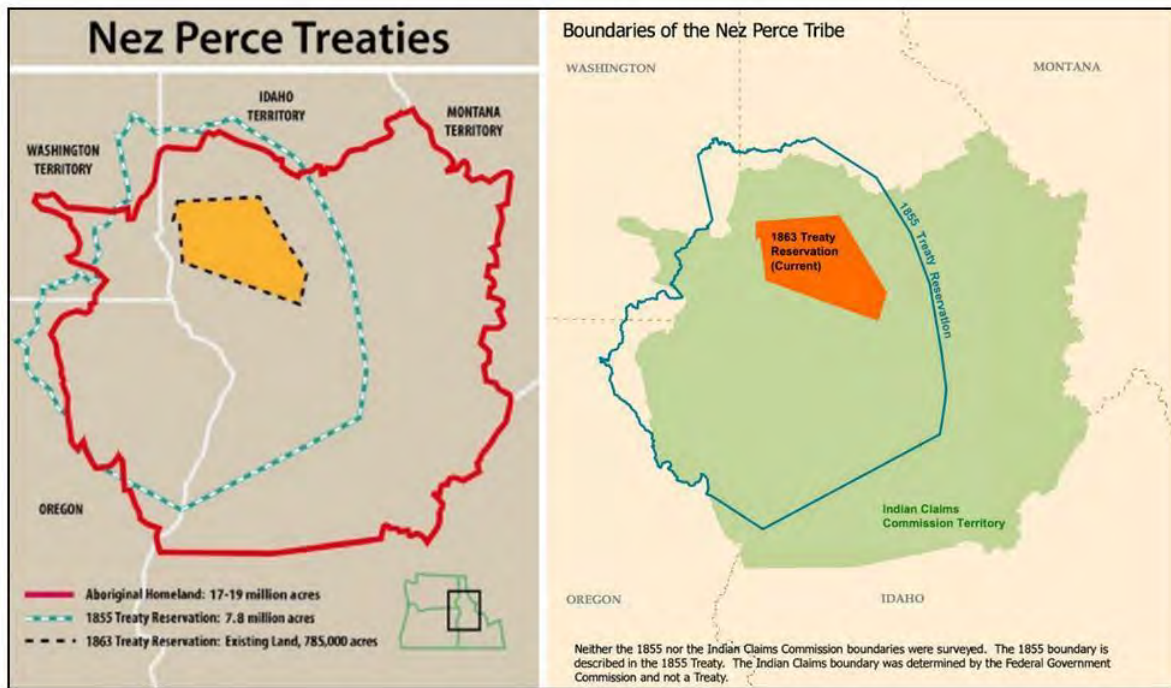


Figure 1. The Environmental Responsibility 5-R Framework (ER²F) can be applied to all types of scientific research activities (field, lab, or computer data-based analysis projects) and promotes the Recognition of the research's environmental impact through statements that can be included in grant proposals or manuscripts. Researchers can also leverage the actionable goals- Refine, Reduce, and Replace-through a series of iterative self-reflecting prompts that encourage researchers to Refine methods, Reduce resources consumed, and Replace single-use and non-biodegradable materials. If the research is field-based, efforts to Restore the environment at the study site can be initiated throughout the project or at its conclusion.

Attachment 2: Figure from Eos article (cited above) highlighting the research and presentation of Kristin Green (PhD student at UNH) at the American Geophysical Union conference. Eos picked up Kristin’s work and interviewed her and other experts in the field to highlight her research, the concept of two-eyed seeing, and the importance of maps to merge indigenous perspectives with federal agencies in the management of federal lands. See full article at: <https://eos.org/articles/maps-strengthen-collaboration-between-tribes-and-federal-agencies>



A 2016 map (left) created by the U.S. Forest Service names a large, off-reservation area as "Aboriginal Homeland." A 2019 map (right) created by the Nez Perce Tribe, updated for this article, names the larger, off-reservation area as "Indian Claims Commission Territory." Click image for larger version. Credit: (left) [USDA Forest Service](#), (right) [Nez Perce Tribe GIS Program](#)

Appendix A: Products

Peer reviewed papers

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11. Wei, X., Hayes, D. J., Li, D., Butman, D. E., & Brewin, R. J. (2024). [Fates of Terrigenous Dissolved Organic Carbon in the Gulf of Maine](#). *Environmental Science & Technology*, doi:10.1021/acs.est.3c08218.
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13. Wei, X., J. Zhao, D.J. Hayes, L. Li, A. Daigneault, and H. Zhu (2023) [A life cycle and product type based estimator for quantifying the carbon stored in wood products](#), *Carbon Balance and Management*, 18, 1, doi.org/10.1186/s13021-022-00220-y.

In preparation

1. Drasher, C.E., S. McKay, P. Tate, S. Webb, K. Royar, B. Mosher, A. Strong, S.L. Vanderzwan, B.N. Sacks, and J.D. Murdoch. *In prep.* Landscape genetics of terrestrial mammals in the northeastern United States. Target journal: Molecular Ecology.
2. Drasher, C.E., S. McKay, B. Mosher, A. Strong, S. Gifford, S. Wixsom, S.L. Vanderzwan, B.N. Sacks, and J.D. Murdoch. *In prep.* Integrating ecological and genetic data using circuit theory to model terrestrial mammal movement and connectivity across the northeastern United States. Target journal: Landscape Ecology.
3. Fernando DD, Yun S, Heo N and Kiernan D. 2023. Impact of forest management practices on genetic diversity of sugar maple in the Northern Forest, USA. Submitted to Forest Ecology and Management, October 31, 2023.
4. Frost, J., C. Danks, R. McCullough and K. Coleman. *In prep.* “What is a “town forest”? Variety, patterns, importance and trends found in Vermont, USA.” Journal manuscript in preparation.
5. Kelly, L.C, A.T. Morzillo, and A. Feldpausch-Parker. Site use patterns based on parking behavior at high-use outdoor recreation areas. *Journal of Outdoor Recreation and Tourism*. Submitted 15-May 2025
6. Sirén, A.P.K., Sullivan, F., K. Courtot, R. Cliché, L. Prout, J. Kilborn, A.W. D’Amato, M. Palace. In Preparation[a]. Mapping and monitoring habitat use of snowshoe hares (*Lepus americanus*) at several spatial and temporal scales with drone-based LiDAR. Target Journal: Forest Ecology and Management.
7. Sirén, A.P.K., Sullivan, F., K. Courtot, R. Cliché, L. Prout, J. Kilborn, A.W. D’Amato, M. Palace. In Preparation[b]. Does co-occurrence of early- and late-successional species translate into higher biodiversity? A test of the Intermediate Disturbance Hypothesis. Target Journal: Ecology.
8. Sullivan, F., K. Courtot, M. Palace, A.P.K. Sirén. In Preparation. Inventorying forests from the ground and air – How do they compare? Target Journal: Forest Ecology and Management.

Presentations

1. Browntail Moth. Sponsored by the Maine Audubon. May 2024. 30 participants.
2. Browntail Moth Management. Sponsored by the University of Maine Cooperative Extension and the Maine Board of Pesticides Control. March 2023. 125 participants.
3. Cole, I, HM Fazekas, A Herreid, A Lowien, D Murray, N Nunez, E Parker, AS Wymore. The Five R's of Environmental Responsibility. Poster Presentation. University of New Hampshire, Undergraduate Research Conference. April 2023.
4. Crosby, S.*, Fanning, P., and Mech, A. The Bane of Maine: reducing browntail moth's itchy impacts in Vacationland. *2022 Joint Entomological Society of America (ESA), Entomological Society of Canada (ESC), and the Entomological Society of British Columbia (ESBC) Annual Meeting*. November 2022. Vancouver, BC
5. Danks, C. and J. Frost, J. "Vermont Town Forests Census: Update." Presented at Forest Ecosystem Management Conference, Burlington, VT, December 2024.
<https://www.uvm.edu/femc/CI4/cooperative/conference/2024>
6. Danks, C. L. Edling and J. Frost. 2023 VT Town Forest Census. Presented at VT Urban and Community Forestry Council meeting, June 14, 2023.
7. Drasher, C.E. 2022. Scoring Transportation structures for wildlife connectivity using an omnidirectional circuit theory approach. Research presented at The Wildlife Society Annual Conference, 10 November 2022, Spokane, Washington, USA.
8. Drasher, C.E. 2022. Modeling landscape connectivity for terrestrial mammals using electrical circuit theory across the northeastern U.S. Presentation at the Northeast Furbearer Resources Technical Committee Annual Meeting, Blue Mountain Lake, NY.
9. Drasher, C.E. 2022. Modeling landscape connectivity for terrestrial mammals using electrical circuit theory. Presentation at Vermont Coverts Annual Meeting, Castleton, VT.
10. Fernando DD and Kiernan DH (co-presenters). Impact of forest management practices on genetic diversity of sugar maple in the Northern Forest. Presented to research collaborators cooperators via zoom presentation. September 28, 2023.
11. Frost, J. and C. Danks. "Vermont Town Forests Census: Carbon, COVID, and Capacity". Presented at Forest Ecosystem Management Conference, Burlington, VT, December 2023.
<https://www.uvm.edu/femc/CI4/cooperative/conference/2023>
12. Frost, J. and C. Danks. "The Vermont Town Forests Census: Carbon, COVID, and Capacity ." Presented at VT Urban and Community Forestry Program Annual Conference, Randolph, VT, May 2024. <https://vtcommunityforestry.org/events/vermont-urban-community-forestry-conference>
13. Frost, J. and C. Danks. 2024. " The Vermont Town Forests Census: Carbon, COVID, and Capacity ." Presented at Association of Vermont Conservation Commissions Annual Meeting, virtual, September 2024.
14. Green, K, T Cohn, AS Wymore. Conceptions of Space in United States National Forest Governance. Poster Presentation. Annual Meeting for the American Geophysical Union. San Francisco, CA. December 2023.

15. Hayes, D.J. " Demonstrating a Carbon MMRV Prototype for Maine's Working Forests: Results from a Stakeholder-driven, Landscape Model-data Framework" American Geophysical Union Fall Meeting, December 2024.
16. Hayes, D.J. "High-resolution forest carbon accounting for the Northeastern United States." American Geophysical Union Fall Meeting, December 2023.
17. History & Ecology of Browntail Moth. Sponsored by the Maine Arborists Association. December 2023. 100 participants.
18. Irvine, E.* and Mech, A. Flight capabilities and host selection of female browntail moth. *87th Northeastern Forest Pest Council Annual Meeting*. March 2025.
19. Irvine, E.* and Mech, A. Flight capabilities of female browntail moth. *86th Northeastern Forest Pest Council Annual Meeting*. March 2024.
20. Kelly, L., and A.T. Morzillo. 2024. Social carrying capacity of trail users in high-use recreation areas. University of Connecticut College of Agriculture, Health, and Natural Resources Graduate Research Forum, Storrs, CT
21. Kelly, L., and A.T. Morzillo. 2024. Social carrying capacity of trail users in high-use recreation areas. National Environment and Recreation Research Symposium, Annapolis, MD
22. Kelly, L., and A.T. Morzillo. 2023. Social carrying capacity among trail users in high-use recreation areas. Connecticut Trail Symposium. Torrington, CT.
23. Kelly, L., A.T. Morzillo, and A.M. Feldpausch-Parker. 2023. Social carrying capacity among trail users in high-use recreation areas. University of Connecticut College of Agriculture, Health, and Natural Resources Graduate Research Forum, Storrs, CT
24. Kelly, L. and A. Morzillo. 2024. Social Carrying Capacity Among Trail Users in High-Use Recreation Areas. Connecticut Trail Symposium, 4 Oct. 2024, Manchester Community College, Manchester, CT.
25. Kenefic, L.S., R.S. Seymour, N.S. Rogers, C. Ziegra, K. Kanoti. 2022. A Working Session on the New Silvicultural Guide for Spruce-Fir. New England Society of American Foresters Annual Meeting, 23 March 2022, South Portland, ME. Oral presentation.
26. Kenefic, L.S., R.S. Seymour, C. Ziegra, N.S. Rogers, K. Kanoti. 2023. Northern Conifer Silviculture Guide. New England Society of American Foresters Annual Meeting, 15 March 2023. Oral presentation.
27. Kenefic, L.S.; Rogers, N.S. 2023. Spruce – Fir Silviculture Guide: Spruce Budworm.
28. Maine Society of American Foresters Meeting, 10 October 2023, Orono, ME. Oral presentation.
29. Kenefic, L.S., R.S. Seymour, N.S. Rogers, C. Ziegra, K. Kanoti. 2022. Northern Conifer Silviculture Guide: Co-Production Webinar. 2 March 2022. Virtual presentation and facilitated discussion.
30. Kenefic, L.S., N.S. Rogers. New Density Management Tools for Northern Conifers. Cooperative Forestry Research Unit Annual Field Tour, October 2022, ME. In-field presentation.

31. Kiernan DH (presenter), Yun S, Heo N, and Fernando DD. Impact of silvicultural practices on the functional genetic diversity of sugar maple in the Northern Forest region. Presented to Northern Hardwood Conference, Fredericton Convention Centre, Fredericton, New Brunswick August 1-2, 2023.
32. "Maine Forest Carbon Workshop," University of Maine, September 2023. (40+ participants)
33. "Maine Forest Carbon Workshop," University of Maine, September 2022. (40+ participants)
34. Mech, A. The menacing moth of Maine: Understanding browntail moth and their outbreaks. Senator George J. Mitchell Center for Sustainability Solutions – Sustainability Talk Series. Seminar Speaker; April 2024. Orono, ME
35. Mech, A. Forest entomology research at the University of Maine. Northeast-Midwest State Foresters Alliance Annual Meeting. Keynote Speaker; March 2024. Bangor, ME
36. Mech, A. A one-health approach to addressing the browntail moth problem in Maine. One Health and the Environment Fall Retreat. Honorary Lecture Speaker; September 2023. Orono, ME
37. Mech, A., Crosby, S., and Rowe, D. The Bane of Maine: Trying to reduce the itchy impacts of browntail moth (*Euproctis chrysorrhoea*). *Entomological Society of America Annual Meeting*. November, 2023. National Harbor, MD.
38. Mech, A. Moths, Myths, and Maine: Understanding browntail moth and their outbreaks. *32nd USDA Interagency Research Forum on Invasive Species*. January, 2024. Annapolis, MD.
39. Morse, L. Presentation. Annual Meeting of the [New England Society of American Foresters](#) in 2023.
40. Murray, D, I Cole, N Nuñez, E Parker, A Lowien, AM Herreid, M Donovan, HM Fazekas, and AS Wymore. 2023. The environmental responsibility framework: a toolbox for recognizing and evaluating ecologically conscious research. Poster Presentation. Annual Meeting for the American Geophysical Union. San Francisco, CA. December 2023.
41. Murray, D. The environmental responsibility framework: a toolbox for recognizing and evaluating ecologically conscious research. Virtual Presentation. Department of Environmental Science, University of Puerto Rico, Rio Piedras – San Juan, Graduate Seminar. December 2023.
42. Murray D, I Cole, N Nuñez, E Parker, A Lowien, AM Herreid, M Donovan, HM Fazekas, and AS Wymore. The environmental responsibility framework: a toolbox for recognizing and evaluating ecologically conscious research. Oral Presentation. Department of Natural Resources and the Environment, University of New Hampshire. NREN Graduate Student Seminar Series. Spring 2023.
43. Roach, S.; Kenefic, L.S.; Kanoti, K., 2025. Silviculture and Site Influence Blowdown Damage During Extreme Weather Events in Northern Conifers. New England Society of American Foresters Annual Winter Meeting, 26 March 2025, Devens, MA. Poster presentation. (Published Abstract)

44. Rowe, D.*, and Mech, A. Monitoring browntail moth populations in Maine. *85th Northeastern Forest Pest Council Annual Meeting*. March 2023.
45. Rowe, D.*, and Mech, A. Browntail moth monitoring in Maine using pheromone traps. *87th Northeastern Forest Pest Council Annual Meeting*. March 2025.
46. *Songbirds in the Sugarwoods: Assessing Forest Structure and Bird Diversity in Vermont Sugarbushes*. Liza Morse, Steven D. Faccio, Steve Hagenbuch, Anthony W. D'Amato, Rachelle K. Gould, Brendan Fisher. Poster at the 2022 annual meeting of the Forest Ecosystem Monitoring Cooperative.
47. Sirén, A.P.K. 2023. Collaborative approaches to addressing pressing management and conservation challenges. United States Forest Service. Invited Speaker
48. Sirén, A.P.K. 2023. More than wildlife: Collaborative approaches to addressing pressing management and conservation challenges. University of New Hampshire. Invited Seminar Speaker
49. *Songbirds in the Sugarwoods: Assessing the Impacts of Forest Structure and Diversity on Bird Communities in Vermont Sugarbushes*. Liza Morse (presenter), Steven D. Faccio, Steve Hagenbuch, Anthony W. D'Amato, Rachelle K. Gould, Brendan Fisher. Invited paper, at the 2023 Annual Meeting of the New England Society of American Foresters.
50. Tackling Environmental Challenges in Your Community: Best practices for managing emerald ash borer & browntail moth. Sponsored by the Maine Municipal Association. February 2022. 54 participants.
51. The Biology and Management of Browntail Moth. Sponsored by the Maine Golf Course Superintendents Association. January 2022. 60 participants.
52. Vadeboncoeur MA, Zuckerman S, Ton K, Wajenberg H, Lish G, Asbjornsen H. All about the seedlings: three regeneration-focused NSRC projects at UNH. Invited talk at the Forest Ecosystem Monitoring Conference, Burlington VT, December 2023.
53. Yun S and Heo N (co-presenters). Effects of silvicultural practices on the genetic diversity of sugar maple in the Northern Forest. EcoLunch Seminar, Department of Environmental Biology, SUNY-ESF, December 7, 2023.
54. Zuckerman, S. Assisted migration and drought in the Northeast. Poster presented at: Univ. of New Hampshire Macfarlane Greenhouses Open House. Durham, NH. Apr. 6, 2024.
55. Zuckerman S. Testing assisted migration candidate species. Poster presented at: Univ. of New Hampshire Macfarlane Greenhouses Open House. Apr. 1, 2023.
56. Zuckerman S. "Tree responses to drought in the Northeast—updated" Univ. of New Hampshire NREN spring seminar series. Mar. 2023.
57. Zuckerman, S., Asbjornsen, H., Vadeboncoeur, M., McIntire, C., Wason J., D'Amato, A. Assisted migration: A Viable Silvicultural Technique for Facilitating Adaptation of Northern Forest Tree Species to a Warmer and Drier Future World? Talk presented at New England Society of American Foresters Annual Meeting. Devens, MA. March 27, 2025.

58. Zuckerman, S. "Assisted migration: a phenotypic evaluation of species, ecotypes, and drought responses". Forest Ecosystem Monitoring Coalition Conference. Burlington, VT. Dec. 2024.
59. Zuckerman, S., Asbjornsen H., Vadeboncoeur M., McIntire C., Wason J., D'Amato, A. Assisted migration and drought in the Northeast: a greenhouse common garden experiment. Talk presented at the Ecological Society of America Annual Meeting. Long Beach, CA. Aug. 4–9, 2024.
60. Zuckerman, S., Asbjornsen H., Vadeboncoeur M., McIntire C., Wason J., D'Amato, A. Species, ecotype, and drought: seedling growth and physiology data to support assisted migration decision-making in the Northeast U.S. Poster presented at Gordon Research Seminar. South Portland, ME. June 8–9, 2024.
61. Zuckerman, S. Assisted migration and drought in the Northeast. Talk presented at UNH Graduate Research Conference. Durham, NH. Apr. 15, 2024.
62. Zuckerman, S., Asbjornsen, H., McIntire, C., D'Amato, A., Wason, J., Vadeboncoeur, M. Assisted migration and drought in the Northeast. Poster presented at: New England Society of American Foresters annual conference. Burlington, VT. Mar. 27–28, 2024
63. Zuckerman S, Asbjornsen H, Vadeboncoeur M, McIntire C, Wason J, D'Amato A, Ehmet J. Identifying species and ecotypes suitable for assisted migration in the Northeast U.S. Poster presented at: Forest Ecosystem Monitoring Coalition. Burlington, VT. Dec. 2022.
64. Zuckerman S, Asbjornsen H, D'Amato A, Vadeboncoeur M, McIntire C, Wason J, Frost T. Assisted Migration and Drought in New England: Lessons Learned and Future Directions. Poster presented at: New England Society of American Foresters Annual Meeting; South Portland, ME. Mar. 2022.

Other products

1. Canadell, J.G., Poulter, B., Bastos, A., Ciais, P., Hayes, D.J., Thompson, R.L. and Villalobos, Y., (2022). [Balancing greenhouse gas sources and sinks: Inventories, budgets, and climate policy](#). In *Balancing Greenhouse Gas Budgets* (pp. 3-28). Elsevier.
2. Open-source Python tool for calculating plot-based carbon pools from the FIA database and regional expansion using NSVB growth curves and map data.
3. Brave Little State "How Vermont got so many town forests."
<https://www.vermontpublic.org/podcast/brave-little-state/2025-02-06/how-vermont-got-so-many-town-forests>
4. High-resolution (30m) forest biomass maps for the NSRC region
5. 30m resolution forest disturbance maps for the NSRC region based on Landsat time-series analysis
6. Web resource: [Maine Carbon Budget](#)
7. Hayes, D.J. et al. (2024). [The State of Maine Carbon Budget, ca. 2021](#). Technical Report. University of Maine, Center for Research on Sustainable Forests.

8. Maine's Tenth Biennial Greenhouse Gas Emissions Report (2024), Maine Department of Environmental Protection.
9. Maine's Ninth Biennial Greenhouse Gas Emissions Report (2022), Maine Department of Environmental Protection.
10. Frost, J., C. Danks, M. Fischetti, M. Jones, J. Gray. *In prep.* (August 2025). Vermont Town Forest Census 2025: Summary of Responses from Cohort 1. University of Vermont.
11. Frost, J. and C. Danks. *In prep* (August 2025). Operations Manual for the VT Town Forest Census. A technical guide for implementing future town forest censuses.
12. Danks C., J. Frost, and M. Fischetti. *In prep.* Inventory of Vermont Town Forests: Summary Data from Outreach Initiative. University of Vermont.
13. Muzzy, K., R. Munroe, G. Dowd, C. May, E. Stuhlman. 2024. Vermont Town Forest Economic Evaluation. Poster and NR 4060 report. University of Vermont.
14. Daigneault, A. J., **Hayes, D. J.**, Fernandez, I. J., & Weiskittel, A. R. (2022). [Forest Carbon Accounting and Modeling Framework Alternatives: An Inventory, Assessment, and Application Guide for Eastern US State Policy Agencies](#). Center for Research on Sustainable Forests Final Report. DOI:10.13140/RG.2.2.24014.33603.
15. Clark, J. 2023. Adaptive silviculture for wildlife: Supporting forest biodiversity through climate adaptation. University of Massachusetts. MSc. Thesis. 53 pp.
16. Courtot, K. 2022. Co-occurrence and habitat use overlap of snowshoe hares (*Lepus americanus*) and American martens (*Martes americana*) in the boreal–temperate ecotone of the northeastern U.S. Plymouth State University. MSc. Thesis. 97 pp.
17. Gokee, A. Aug. 6, 2021. “Assisted migration aims to help forests – and people – adapt to a swiftly changing climate. <https://newhampshirebulletin.com/2021/08/06/scientists-look-to-aid-migrating-trees-moving-slower-than-a-swiftly-changing-climate/>
18. Carsey School of Public Policy [@carseyschoolunh]. (2023, November 1). Northern Forest Migration [Video File]. Retrieved from <https://www.instagram.com/reel/CzHAI5pLtqa/?igshid=MzRIODBiNWFIZA==>
19. [Hardy S., N. Sharp, M. Veit, and S.D. Faccio. 2023. Pilot Study of Wild Bees in Working Sugar Maple Stands. Version 1.5. Vermont Center for Ecostudies. Sampling event dataset https://doi.org/10.15468/6xcj6z accessed via GBIF.org on 2023-06-07. https://www.gbif.org/dataset/22ba1903-ed9d-4ae2-9edb-dcab0dc3b220.](#)
20. Thelen, Brett. 2022. Bird-friendly Maple and the efficacy study. [Northern Woodlands](#).
21. Steve Faccio and Liza Morse co-lead a public field trip to a study site in July 2023 to discuss the project.
22. Steve Faccio and Liza Morse were interviewed on-camera about the project by documentary film-maker, Ian Sweet, of [Vermont Productions](#).
23. Kelly, L.C. 2025. Site Use Patterns and Social Carrying Capacity of Connecticut Outdoor Recreation Areas. [Thesis] Department of Natural Resources & the Environment, University of Connecticut.

24. Seymour, R.S. Silviculture of Acadian Spruce – Fir Forests. 2024-2025. University of Maine, Center for Research on Sustainable Forests. Series of Technical Reports.
https://digitalcommons.library.umaine.edu/crsf_acadian_forests/
25. Zukswert, Jenna; Kenefic, Laura. 2025. Stand Density Management Charts for Eastern Spruce-Fir Forests. Rooted in Research Issue 46, January 2025. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 2 p.
<https://research.fs.usda.gov/treesearch/68854>
26. <https://research.fs.usda.gov/nrs/articles/stand-density-management-charts-eastern-spruce-fir-forests>
27. Browntail moth (*Euproctis chrysorrhoea*) integrated pest management program: evaluation of monitoring traps and biopesticides. Sadia Crosby. University of Maine Master's Thesis. May 2023
28. Flight capabilities and host selection of female browntail moth (*Euproctis chrysorrhoea*). Emma Irvine. University of Maine Master's Thesis. May 2025.
29. (forthcoming) Browntail moth (*Euproctis chrysorrhoea*) monitoring and control in Maine. Devin Rowe. University of Maine Ph.D. Dissertation. May 2026 (expected)
30. Scientists want to try confusing browntail moths with arousing chemicals to end future outbreaks. By Sam Schipani. 6/30/2021 Bangor Daily News
<https://bangordailynews.com/2021/06/30/homestead/researchers-hope-to-prevent-future-browntail-moth-outbreaks-by-tricking-them/>
31. UMaine's Pilot Study on the Browntail Moth Could Be A Game Changer. By Sarah Nickerson. 7/2/2021 Z107.3 <https://z1073.com/umaines-pilot-study-on-the-browntail-moth-could-be-a-game-changer/>
32. Browntail moths returning, but scientists are working to limit their spread. By Rose Lundy. 5/8/2022 The Maine Monitor <https://www.themainemonitor.org/browntail-moths-returning-but-scientists-are-working-to-limit-their-spread/>
33. Browntail moth research. By Devin Daigneault. 2/16/23 Fox 22 WFVX Bangor/ABC7.
https://www.foxbangor.com/news/local/browntail-moth-research/article_7f90b128-ae46-11ed-bb09-8f0e1e17f39d.html
34. Promising research at UMaine may help curtail browntail moths. By Joe Lawlor. 7/4/2023. Portland Press Herald <https://www.pressherald.com/2023/07/04/promising-research-at-umaine-may-help-curtail-browntail-moth-populations/>
35. Browntail Moth in Maine. By Tim King. September 2023 Maine Organic Farmer and Gardener (Fall 2023 issue) <https://www.mofga.org/our-community/publications/the-maine-organic-farmer-gardener/>
36. Ph.D. student, Devin Rowe, entered the Dance Your Ph.D. competition sponsored by Science.
<https://www.youtube.com/watch?v=SFwRMZKODbc>
37. CNPE Blog <https://cnpe.home.blog/2021/11/04/haudenosaunee-forest-forum/>
38. "HETF & CNPE: Indigenous Forestry Principles" Tsadeyohdi. Ononda'geh Ongwawenna', November 2021.

39. “What Trees Tell Us Through the Year,” Skarure Monthly, February 2022.
<https://tuscaroraenvironment.org/newsletter>
40. Roberts-McMichael, A. “Sharing the River: Haudenosaunee Relationship With Ancestral Lands and New York State Public Forest Management. MS Thesis. (2022).
[https://experts.esf.edu/esploro/outputs/graduate/Sharing-the-River-Haudenosaunee-Relationship-](https://experts.esf.edu/esploro/outputs/graduate/Sharing-the-River-Haudenosaunee-Relationship-With/99892882504826?institution=01SUNY_ESF)
41. [With/99892882504826?institution=01SUNY_ESF](https://experts.esf.edu/esploro/outputs/graduate/Sharing-the-River-Haudenosaunee-Relationship-With/99892882504826?institution=01SUNY_ESF)
42. “Native Earth” <https://cnpe.home.blog/2022/09/19/native-earth-2022-back-in-action/>
43. “Indigenous-led Restoration and Stewardship of Culturally Significant Plants for Climate Change Adaptation in the Northeast.”
44. <https://necasc.umass.edu/news/ne-casc-launches-seven-new-projects-0>
45. “Follensby Pond Transforms Conservation—Again” <https://www.nature.org/en-us/about-us/where-we-work/united-states/new-york/stories-in-new-york/follensby-pond-raquette-river/?vu=follensby>
46. Little, J. Assessing Biocultural Restoration Pathways for Land Being Returned to the Onondaga Nation in Tully Valley, New York: A Historical Ecology and Plant Community Approach. MS Thesis (2024) https://experts.esf.edu/esploro/outputs/graduate/Assessing-Biocultural-Restoration-Pathways-for-Land/99953582004826?institution=01SUNY_ESF
47. “Restoring nature: The return of 1,000 acres to Onondaga Nation”
<https://www.thenewshouse.com/off-campus/restoring-nature-the-return-of-1000-acres-to-onondaga-nation/>
48. “In Upstate New York, Native Efforts to Protect Flora and Fauna Are Flourishing”:
<https://www.cntraveler.com/story/in-upstate-new-york-native-efforts-to-protect-flora-and-fauna-are-flourishing>