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Smart Data for Resilient Forests

NSF RII Track 2 FEC: Leveraging Intelligent Informatics and Smart Data for Improved Understanding of Northern Forest Ecosystem Resiliency (INSPIRES)

INSPIRES Year 4 Annual Progress Report

August 1, 2022-July 31, 2023

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Date Submitted: May 17, 2023

University of New Hampshire · The University of Maine · The University of Vermont · Alabama A&M University

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EXECUTIVE SUMMARY

Forests are an economically important and ecologically critical component of New England's working landscape. New England's forests are highly dynamic and diverse due to a wide variety of complex factors including changing environmental conditions, management regimes, and natural disturbances. This project leverages unique expertise from the University of Maine, University of New Hampshire, University of Vermont, and most recently, Alabama A&M University to construct a digital framework to better assess, understand, and forecast this complex forest at a resolution relevant to scientists, land managers, and policymakers.

Vision

The vision for the INSPIRES program is to harness the Northern Forest Region's complex landscape and digital information diversity to support hypothesis formulation and testing across various social-ecological dimensions.

Mission

INSPIRES will develop a regional Forest Ecosystems Research Consortium that facilitates analysis of ecosystem health and resilience in response to multiple agents of environmental change.

Project Goals

Maine, New Hampshire, and Vermont encompass major parts of the complex and highly interconnected Northern Forest Region (NFR), which has a long history of providing important environmental services to the region's rural communities. Although the economies and identities of local communities strongly depend on healthy ecosystems, forests across the region are increasingly threatened by complex and dynamically interacting stressors. The INSPIRES project aims to harness the region's complex landscape and digital information diversity through the creation of a Digital Forest resource, which is our Big Data Science approach to integrating contrasting forest information, ownership, management units, and underlying ecology into a "natural laboratory" that can be used to support hypothesis formulation and testing across the various social-ecological dimensions that comprise the highly complex NFR (Figure 1).

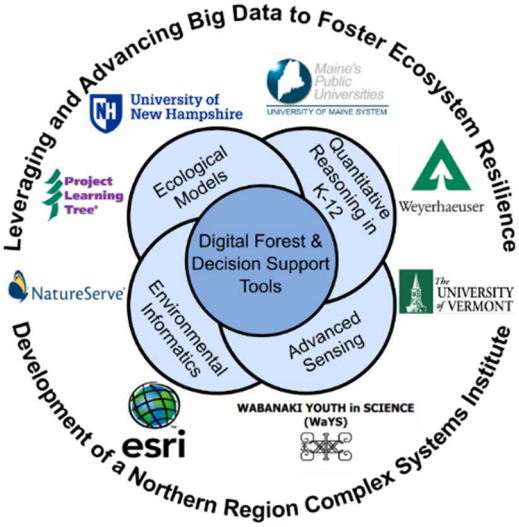


Figure 1. INSPIRES Digital Forest Research and Workforce Development Framework

Our efforts address the following overarching science questions:

1. How are spatio-temporal variation and uncertainty in forest extent, composition, health, and productivity driven by: (a) climate; (b) land use; (c) forest management; (d) regulatory policies; (e) invasive insects; (f) other biotic stressors like invasive plants; and (g) natural disturbances?
2. How will these changes affect ecosystem integrity and key services related to: (a) carbon storage/fiber production; (b) habitat/biodiversity; and (c) water quality/surface energy regulation?

These questions arise from our hypothesis that novel Big Data acquisition, integration, and analysis will allow us to address these issues in a way that informs how we approach challenges and opportunities related to the current and future integrity of forest ecosystems. Over the long-term, we hope to extend this framework beyond the region, particularly to other ecosystems of high interest.

Year 4 Goals

Undeterred by the constant challenges from the pandemic, the INSPIRES team continues to rally around collaborative efforts, strategies to enhance effective team building, and interjurisdictional research collaboration (details of Years 1 to 3 are available at https://bit.ly/InspiresForestResearch).

The primary goals for Year 4 were to complete installation of wireless sensors for climate data acquisition across the four jurisdictions, begin cataloging the various datasets generated by the multi-year effort, explore strategies for future sustainability of the collaborative efforts, and prioritize remaining focal activities and events. Project leadership continued to meet regularly to identify future opportunities for collaboration and strategize on how to effectively engage stakeholders and project partners to gain input and feedback on research objectives. In addition, an important milestone of Year 4 was organizing, preparing for, and completing a summative project assessment by an external expert review panel coordinated by the external evaluator. This evaluation focused on project outcomes and key project priorities, particularly potential synthesis outcomes. The panel provided feedback that was mostly centered around focused efforts on synthesis publications, future proposals, sustaining project capacity and impacts, and stakeholder engagement.

"Wow, Year 4 of INSPIRES has come and is nearly over, which is just remarkable. This has been a tremendous collaborative effort across four distinct EPSCoR jurisdictions that really came together to accomplish what we sought to do and more despite disruptions from a global pandemic. It has been a true honor to work with such a dedicated team of people and we will focus on finding ways to leverage these partnerships we have formed."

Dr. Aaron Weiskittel, INSPIRES PI

Institutional Roles

The participating institutions are the University of Maine (UM; lead), the University of New Hampshire (UNH; Co-PI), the University of Vermont (UVM; Co-PI), and Alabama A&M University (AAMU), which became part of the team in Year 3 through NSF Minority Serving Institution (MSI) supplemental funding. The PIs at these four institutions make up the Core Leadership Team (CLT; Table 1), a collaborative effort to continually reassess project goals and objectives, strengthen cross-institutional cooperation, and support team members. In addition, upper administrative officials at these institutions compose the Tri-Jurisdictional Institutional Advisory Board (IAB). The INSPIRES team also includes several scientists and researchers from three additional academic institutions (Dartmouth College, Unity College, University of Maine at Fort Kent) and two non-profit organizations (Schoodic Institute at Acadia National Park, Appalachian Mountain Club).

Project Summary, Year 4

The INSPIRES project started August 1, 2019 and began as an interjurisdictional partnership between research and higher educational institutions in Maine, New Hampshire, and Vermont. AAMU, an Historically Black College and University (HBCU), began its partnership with the INSPIRES team in 2021. This partnership has added a diversified perspective as well as specific scientific expertise and talent to the multi-institution, multi-state endeavor. In Year 4, the collaboration with AAMU has been mutually beneficial to both AAMU and the original INSPIRES partners through research collaboration opportunities, student exchange experiences (e.g., AAMU undergraduates traveled to Maine for hands-on learning experience building sensors and software programming). Cross-institutional collaboration has focused on AAMU's long-term ForestGeo plot at Paint Rock Valley and building a strong, integrated forest research program there. To further this effort, Theme 2's Peter Nelson (Schoodic Institute, ME) traveled there in May 2023 to provide ground and airborne spectroscopy demonstrations, while also conducting an extensive field campaign.

The addition of AAMU has resulted in new collaborations and tangible outcomes, including a joint UNH-AAMU project focusing on the ecological impacts of drought that was funded by NSF's Organismal Response to Climate Change program. Given AAMU joined INSPIRES at the project's midpoint and due to the various delays caused by the pandemic, a one-year no-cost extension will be formally requested to maximize potential outcomes from the effort and ensure complete spending out of the available funding. Priorities for a potential Year 5 of INSPIRES are further outlined in our detailed response to the external review (Appendix 6).

> "The INSPIRES Track-2 project is extremely strong and demonstrates a high-level of productivity in terms of the achievement of NSF-determined products, technical objectives, the pursuit and acquisition of follow-on funding, and the development of a collaborative spirit across the institutions and themes."
>
> ***External Review Panel Assessment Report***

As of Spring 2023 the INSPIRES team involves 130 individuals with the majority being faculty from the four states (43; ME = 21, NH = 11, VT = 7, AL = 4), bolstered by undergraduate students (24), graduate students (21), post-doctorate researchers (4), and professional staff (10). The team has remained diverse (57% female), has built strong linkages across jurisdictions, and many of the faculty remain early career; there has been a significant increase with the involvement of underrepresented minority students at AAMU during Year 4. The structure of the project remains centered around four core research themes, namely: (1) Advanced Sensing and Computing Technologies; (2) Smart Environmental Informatics; (3) Integrated Ecological Modeling; and (4) Quantitative Reasoning Skills in Context. These themes are building an understanding of current and future changes in the Northern & Southern Forest with a focus on key ecological and socioeconomic drivers.

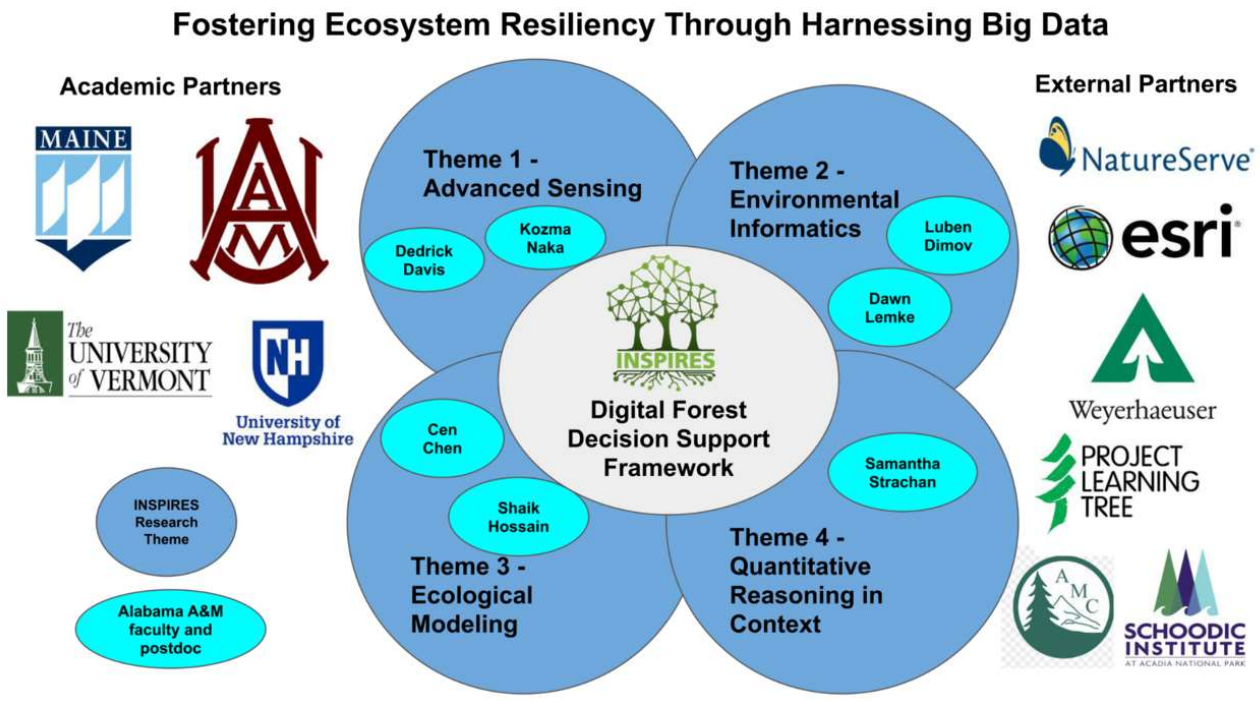


Figure 2. Integration of the AAMU team into the INSPIRES effort through the NSF MSI supplemental funding.

Table 1. Project Core Leadership Team (CLT)

Name	Role	Affiliation	Institution	Jurisdiction
Aaron Weiskittel	PI	Center for Research on Sustainable Forests	University of Maine	ME
Ali Abedi	Co-PI	Department of Electrical and Computer Engineering	University of Maine	ME
Kate Beard-Tisdale	Co-PI	School of Computing and Information Science	University of Maine	ME
Anthony D'Amato	Co-PI	Rubenstein School of Environment and Natural Resources	University of Vermont	VT
Scott Ollinger	Co-PI	Earth Systems Research Center	University of New Hampshire	NH
Dawn Lemke	Co-PI	Biological & Environmental Sciences	Alabama A&M University	AL

For Year 4, INSPIRES team members remained highly engaged and actively sought ways to enhance interjurisdictional research collaboration, particularly with AAMU. Quarterly all-team meetings remained the primary means of convening the broader team with strong participation, while monthly theme meetings continued and allowed the research to evolve and be fully implemented. Various in-person activities were arranged in conjunction with other ongoing events and additional events are planned for the coming summer months. Faculty and student interactions expanded, including cross institutional visits, especially with AAMU collaborators. Based on the summative recommendations provided by the external review panel, strategic adjustments were made and prioritized to include additional outreach efforts, continued emphasis on synthesis outcomes, and better showcasing the novelty of the scientific contributions. These efforts will be continued in the coming months to ensure successful project completion.

The CLT (Table 1) continues to meet at regular intervals to reassess priorities, discuss concerns, and plan future sustainability efforts, while quarterly all-team meetings primarily focus on project and research theme updates and discussion. Largely led by early-career scientists, individual research themes continue to regularly interact to complete strategic materials including collaborative research agendas, and outline key research milestones, which are essential to for successful project outcomes. Student-led meetings of INSPIRES graduate students in Year 4 helped strengthen cohort connections, provided professional networking opportunities, inaugurated a writing group, and built community and collaboration across disciplines and institutions. The Collaborative Research Committee (CRC) meets monthly to better align theme activities and explore sustainability opportunities. Likewise, the Mentoring, Engagement, and Education (MEE) committee developed a technical writing module and associated materials to help students. Both the CRC and MEE met regularly during Year 4 to review materials, discuss potential opportunities, and plan for project completion. The Data Sharing Committee also met regularly to update its materials, particularly their easy-to-use templates for uploading data and metadata to the Environmental Data Initiative, which were sent to all of the themes to encourage data archiving. As a result, several new datasets were successfully published on the Environmental Data Initiative in Year 4.

With fewer pandemic-related restrictions, the project team was able to travel more in Year 4, which helped with the completion of various field-based efforts, allowed the variety of INSPIRES outcomes to be showcased to a broader audience at national or international conferences, and better facilitated greater exchanges across the various jurisdictions involved, especially with AAMU team members. The Implementation Group (TIG; external evaluator on the project) continued to survey INSPIRES faculty and students as part of the evaluation process. The survey results were formally summarized and evaluated (see Evaluation section of this report). TIG also completed a project summative assessment with various external experts and provided specific recommendations. Important changes

based on these recommendations have now been implemented by project leadership. A few highlights as noted by the review panel include:

- Success in pursuing and securing additional resources in support of the efforts initiated by INSPIRES.
- Project collaborative coordinator's (Dr. Emily Uhrig) efforts to build collaboration across research themes, particularly the integration of AAMU researchers and students, and help mentor students with regular meetings.
- Lead site continues to prioritize reducing administrative burdens for INSPIRES faculty.

The TIG recommendations, general efforts by the CLT to address them, and overall project updates have been provided to the Inter-Jurisdictional Advisory Board (IAB). A key milestone of this project and an outcome of the IAB's direct involvement in Year 4 was securing supportive federal legislation for the expansion of the USDA NRCS SnoTel Network to New England. Several INSPIRES team members including Sarah Nelson, Alix Contosta, and Liz Burakowski, helped to make this legislation possible. The specific FY23 appropriations legislation provides "$1,000,000 for a study of the potential expansion of the SNOTEL automated mountain weather monitoring network to the northeastern United States," which will likely leverage INSPIRES-related research and partnerships. Current efforts are seeking to expand this language in FY24 and begin an actual pilot project at selected sites throughout the INSPIRES jurisdictions.

Overall, the INSPIRES effort made substantial forward progress in the last year and has largely accomplished what it had originally proposed despite the endless challenges of the pandemic. Because of the emphasis and support of collaborative team science, as elaborated in this report, the INSPIRES team remains engaged, productive, and excited about the potential of this research effort and its broader implications for the region's forest-based economy. The focus now has shifted from project execution to outcomes reporting and future sustainability of the effort, particularly maintaining the research infrastructure that has been built. Finally, several key INSPIRES team members including Jane Foster (UVM), Melissa Pastore (UVM), and Andrew Ouimette (UNH) secured permanent research scientist positions with the US Forest Service in Year 4.

Key Achievements

- New inter-jurisdictional research on cold-air pooling and managing for the cold supported by a multi-disciplinary network of team members from INSPIRES and beyond, including the University of Michigan; US Fish and Wildlife; Vermont Forests, Parks and Recreation; Vermont Fish and Wildlife Conservation, and Bartlett Experimental Forest (US Forest Service). This project is led by UVM post-doc Melissa Pastore and AMC project partner, Sarah Nelson.
- Federal budget provisions to the Natural Resources Conservation Service (USDA) for the Sno-Tel network of automated of 900 data collection sites in western states includes a $1M provision to study the expansion of Sno-Tel to the eastern U.S., because of appropriations requests from Maine, Vermont, and New Hampshire, initiated by INSPIRES leadership.
- A direct outcome of INSPIRES is an NSF EPSCoR RII Track-1 proposal in development by UMaine which, if awarded, would sustainably and effectively manage resilient forests in the face of financial challenges to this industry sector, grow a forest-based economy that enhances the utilization of renewable forest goods and services, use AI to provide better information on Maine's forest, and leverage the growing advanced bioproducts sector in Maine.
- This is the second year of a strategic partnership with the Alabama Agricultural & Mechanical University (AAMU), an Historically Black College and University (HBCU). AAMU's long-term research field site at Paint Rock is a key focal area of collaboration. Student and faculty exchanges between UMaine, UNH, and AAMU occurred throughout Year 4.
- Proposals have been submitted to sustain the collaboration with AAMU. An NSF ORCC grant for $670,495 was awarded to Co-PI Ollinger (UNH) to investigate drought and cold resilience of northeastern US trees to inform ecological modeling and forest management practices, in collaboration with Dawn Lemke (AAMU).

- A proposal to USDA NIFA for $260,590 submitted by Shaik Hossain, AAMU, would support work with INSPIRES post-doc Cen Chen (UMaine/AAMU), on patterns in natural regeneration of shortleaf pine across the southeastern United States facing climate change was awarded.
- Cross-disciplinary projects have developed, including one on tree species identification from aerial images taken with an imaging spectrometer involving Ken Bundy (UMaine) computer science, using machine learning, and Peter Nelson (Schoodic Institute) forest ecology, using an unmanned aerial vehicle to gather data. Nelson flew the UAV over AAMU's Paint Rock field site in May.

Figure 3. INSPIRES PI Weiskittel organized and led a special session on NSF Track 2 projects attended by NSF Program Officer JD Swanson at the November 2022 NSF EPSCoR National Meeting in Portland, Maine.

- The regional network of novel sensors has expanded to 11 sites, including multiple partners (Acadia National Park, Debouille Ecological Reserve, AMC Maine Woods Initiative, US Fish and Wildlife Service, US Forest Service, and three secondary schools across the region).
- New methods for outage minimization in wireless sensor nodes were developed and deployed.
- The map- and online-based INLeaf data sharing and staging system was created and expanded.
- An open-source R Package of functions for processing spectroradiometric and imaging spectrometer data with machine learning (ML) and parallel processing developed and released.
- Work advanced in integrating remote sensing time-series data and data from other qualitative and quantitative information sources via the Digital Forest framework, which was further expanded.
- Ontologies were created as semantic representations about forest types, tree species and environmental conditions by UMaine PhD student Kingsley Wiafe-Kwakye.
- Work is continuing to integrate the data from the sensor streams and data from remote sensing, ecological sensor networks, and qualitative information into ecological models to improve confidence in future projections of forest ecosystem processes and regional outcomes. Model development, parametrization, and refinement have resulted in implementation and results.
- The Functionally Assembled Terrestrial Ecosystem Simulator (FATES), coupled with the Energy Exascale Earth System Model (E3SM) land model (ELM), was used to model the forest ecosystem at Howland Forest.
- The Forest Vegetation Simulator (FVS) modeling and decision analysis tools highlighted the consequences and tradeoffs of salvage decisions in the context of alternative business-as-usual practices and different discount rates for carbon sequestration.
- Fourteen middle- and high-school teachers are engaged in the INSPIRES outreach programs for quantitative reasoning in the context of forestry. Four schools have become sites with Mayfly sensors and two more are in consideration. Teachers have incorporated modules on forestry data in their classrooms. A user-friendly website with forestry data has been established for teachers and students. A proposal for publication, entitled "Engaging Scientists, Teachers, And Students in Authentic Investigations With Forestry Data," was submitted to the New England Educational Research Organization.
- An on-site training last summer was attended by 13 teachers and the final training institute will take place in June in Vermont.
- Stakeholder outreach continued, with four more science/practice interactive webinars that typically draw 60-80 participants and are archived on YouTube for future use. Field tours at INSPIRES research sites in Vermont,

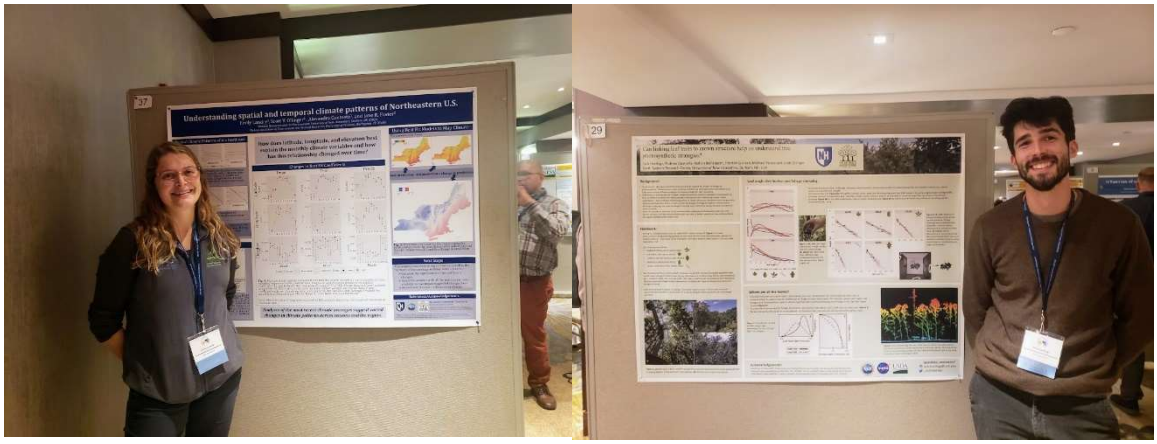


Figure 4. INSPIRES graduate students Emily Landry (MS, left) and Jack Hastings (PhD, right) presenting their research at the NSF EPSCoR National Meeting in Portland, Maine in November 2022.

New Hampshire, and Maine were attended by more than 170 foresters, scientists, conservationists and land managers. Topics included adaptation strategies to address invasive insects and climate change impacts and novel insights provided by advanced sensing technologies.

- Stakeholder engagement is supported by robust multi-media communications efforts, including the project website, 4 new INSPIRES-related videos on the YouTube channel, active social media accounts, e-newsletters and team profiles.
- PI Weiskittel organized and led a well-attended session on Track 2 projects at the National EPSCoR Conference in Portland, Maine (Figure 3). Several INSPIRES graduate students also presented posters at the event (Figure 4).
- Early-career scientists on the INSPIRES team have been hired for new jobs in federal agencies (4) or NGOs (2), while several graduate students have finished and also taken new permanent positions.
- The INSPIRES team currently involves 130 individuals with the majority being faculty from the four states (43; ME = 21, NH = 11, VT = 7, AL = 4), bolstered by undergraduate students (24), graduate students (21), post-doctorate researchers (4), and professional staff (10).
- Research outputs increased, 10 (8 published; 2 in press) peer-reviewed articles, 1 conference proceedings, 5 data/model/technology products, and 20 presentations.
- Summative external project assessment by evaluator and independent experts completed with highly positive outcomes and recommendations.
- In Year 4 (through April 2023), 20 research proposals requesting $19,990,175 were submitted with 12 awarded ($13,845,442) and 4 pending ($2,659,791).
- Project continued quarterly all-team and monthly theme/committee meetings.
- Strong number of potential and ongoing joint publications (Table 2) and proposals (Table 3) identified during 2023 all-team meeting.
- Data sharing document was further refined to guide the INSPIRES team on best practices for data sharing and to identify each theme's outputs and estimated schedule of when the data will be live and in use. Several datasets were published on the Environmental Data Initiative repository.
- Peter Nelson offered a one-day workshop at AAMU including faculty and students on ecological image-based reflectance spectra including the use of the developed R package and code (Figure 5).
- Continued recruitment and hiring of key project participants including several new graduate students across the four jurisdictions.
- Project faculty remain primarily early-career (55%).

Figure 5. Peter Nelson demonstrating the developed R package, Lecospec, and a custom UAV setup at a one-day workshop involving faculty and students at AAMU in May 2023.

- Team has remained diverse (57% female) with increased involvement of underrepresented minority students, particularly at AAMU.
- Ongoing updates to project jargon and acronym dictionary.
- Annual survey of project participants completed and analyzed.
- Monthly graduate student meetings led by Project Collaborative Coordinator Emily Uhrig with non-academic professionals to discuss future opportunities and ongoing research continued.
- Online technical writing module for undergraduate and graduate students developed by Project Collaborative Coordinator Emily Uhrig
- Ongoing development of INSPIRES team member profiles highlighting individual and project involvement.
- PI Weiskittel presented the ongoing research to over 100 middle school students across Maine through the Gulf of Maine Scientist To Go Series (Figure 6; https://youtu.be/mNecxltiUWc).
- Continued dissemination of a project e-newsletter.

Figure 6. PI Weiskittel presented INSPIRES research to several middle school students across Maine as part of the Gulf of Maine Research Institute's Scientist To Go webinar series.

Table 2. Identified ongoing and potential collaborative research publication proposals from the April 2023 all-team meeting.

Concepts for publications				
Paper subject	**Expertise needed**	**Potential lead authors**	**Target journals**	**Next steps**
Determination and delineation of novel regional climate zones	Ecology, modeling	Sam Roy, Xinyuan Wei, Daniel Hayes, Alix Contosta	Global Change Biology	Submitted to Ecosystems
Image processing for tree species using hyperspectral UAV data	remote sensing, ecology, ecosystem ecology	Peter Nelson and Ken Bundy	Remote Sensing	Revise draft manuscript
New HSI Semantic Segmentation Model (CE U-NET)	Machine Learning, Deep Learning, Remote Sensing	Salimeh Yasaei Sekeh and Nicholas Soucy	IEEE Remote Sensing	Submitted
Drivers of forest productivity	ecologists, modeling, data scientists	Andrew Ouimette, Scott Ollinger	Forest Ecology and Management	Outline draft
Spatial-temporal Patterns of Cold-Air Pooling in the Northeastern US From MODIS	remote sensing, ecology, ecosystem ecology	Jane Foster, Melissa Pastore, Tony D'Amato, Aimee Classen, Carol Adair, Dave King, etc.	Remote Sensing of Environment	Revise draft manuscript
Semantics of Forest Knowledge	ecology, modeling	Torsten Hahmann, Kingsley Wiafe-Kwakye, Kate Beard	Current Forestry Research; Forest Ecology and Management	Revise draft manuscript
Review: Sensitivity of forest models to minimum Temperatures	forest and ecological modeling	Jane Foster, Andrew Ouimette, Erin Simons-Legaard	Ecological Modeling	Revise draft manuscript
SBW & Decision-Making	Forest modeling	John Gunn	Ecosphere	Revise draft manuscript
Nutrient dynamics in forest dead wood	ecologists modeling	Andrew Ouimette, Jane Foster, Mark Ducey, Scott Ollinger, Tony D'Amato, Jack Hastings	Ecological Applications	Revise draft manuscript
Snow refugia: How the forest canopy affects winter conditions in the Northeast	ecologists modeling	Melissa Pastore, Sarah Nelson, Alix Contosta, Dave Lutz	Ecological Applications	Draft manuscript outlined and being written

Table 3. Identified potential collaborative research proposals from the April 2022 all-team meeting.

Concepts for proposals				
Topic/short title	**Expertise needed**	**Team members**	**Stakeholders**	**Next steps**
NSF AI	Open	All	Forest landowners	Declined; Being Revised
USDA SAS	Open	All	Forest landowners	Secured (UMaine)
NSF Track 1	Open	UMaine	Forest landowners	NOI submitted
NSF NRT	Open	All	Open	Outline concept
NSF Mid-Scale Infrastructure R1	Open	All	Open	Outline concept
NSF i-TEST	Open	All	Open	Outline concept
NSF Innovation for Undergraduate Teaching	Open	All	Open	Outline concept
Northeastern States Research Cooperative	Open	All	Open	Submit preproposal
NSF Partnerships for International Research	Open	Canadian partners?	Christian Messier of UQAL	Outline concept
NSF EAGER	Open	Melissa Pastore, Jane Foster,	Open	Outline concept
NSF CAREER	Open	All	Open	Outline concept
NSF MRI	Purchase remote sensing hyperspectral & LiDAR	P. Nelson, Hayes	Ecosystem modeling, forest inventory, crop health	Submit full proposal
NSF GeoInformatics	Remote sensing	All	Open	Outline concept
NSF Growing Convergence	Open	All	Open	Outline concept
NSF Climate Change DCL	Open	All	Open	Outline concept
NSF START	Open	All	White Mountains Community College	Outline concept
NSF INTERN	Open	Current grad students can spend 6 months at a private company	Open	Outline concept
NASA Ecological Forecasting	Remote sensing and modeling	All	Open	Outline concept
NASA Biodiversity	Remote sensing and ecology	All	Open	Outline concept
NSF Mid-Career Advancement	Associate-level faculty	All	Open	https://beta.nsf.gov/funding/opportunities/mid-career-advancement-mca

Intellectual Merit

The project's intellectual merit stems from our approach of integrating basic field measurements, novel environmental sensors, big-data analytics, and ecosystem models to improve understanding of ecosystem function and how forests are responding to environmental change. As highlighted in the project's outcomes, the INSPIRES effort has resulted in several important outcomes with high intellectual merit. With 2 months still to go in Year 4, this has included 11

proposals funded (3 multi-institutional), 8 peer-reviewed publications (6 inter-jurisdictional, 7 student-led, 3 early-career-led, and 3 female-led), and 20 presentations (3 inter-jurisdictional, 9 student-led, 6 early-career-led, and 9 female-led). The funded proposals include awards from NSF, USDA, NASA, and the Northeastern States Research Cooperative. Cumulatively to date, INSPIRES has generated a total of 46 peer-reviewed publications (28 multi-institutional, 19 early-career led, 21 student-led, and 15 female-led), 54 presentations (11 multi-institutional, 23 early-career led, 16 student-led, and 25 female-led), 33 funded projects (10 multi-institutional, 14 early-career led, 1 student-led, and 7 female-led), and 6 published data products (Figure 7). Overall, the strong intellectual merit outcomes highlight the level and strength of current collaborations within INSPIRES. As we approach the final year of the project, emphasis will continue to be placed on inter-jurisdictional outcomes, particularly publications. Support and professional development of students and early-career, female faculty members will remain a high priority, which are reflected in the high percentage of project outcomes from these groups (Figure 8). As identified from the Year 4 all-team meeting in April 2023, key synthesis products that assess the current state of knowledge and outline strategies for future research will be prioritized in the remainder of Year 4 and potentially Year 5 of the project.

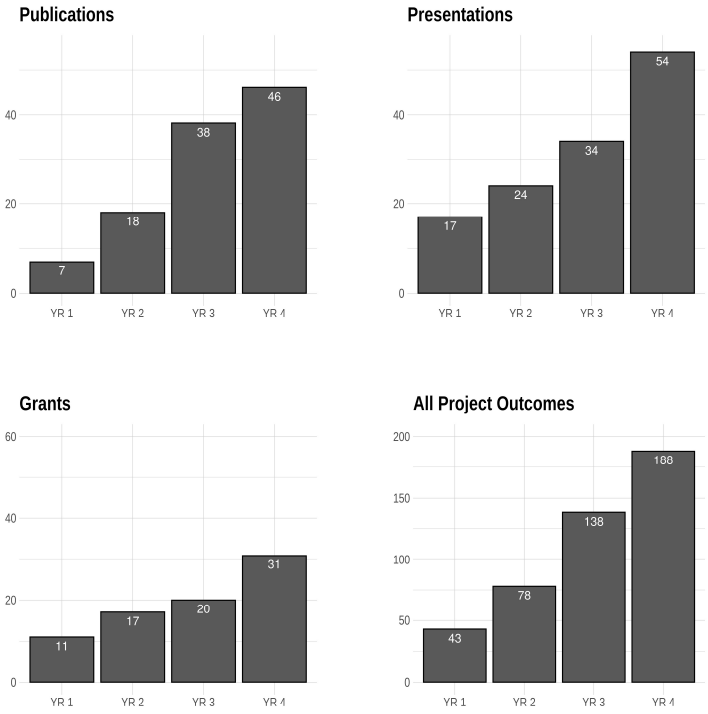


Figure 7. Cumulative publications, presentations, grants, and total project outcomes through April 2023.

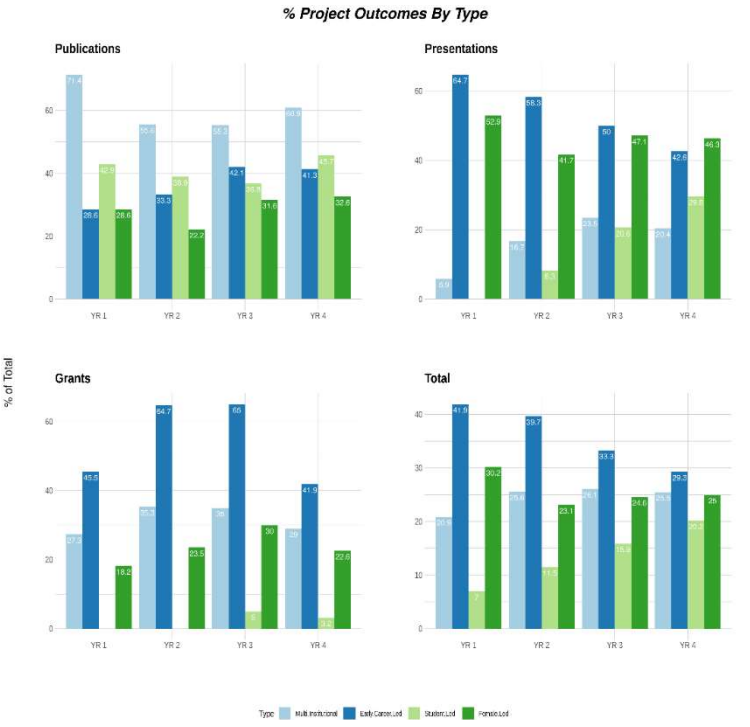


Figure 8. Percentage of publications, presentation, grants, and total project outcomes that are multi-institutional, early-career led, student-led, and female-led through April 2023.

Broader Impacts

Effective project outreach and stakeholder engagement remain a high priority for INSPIRES. In Year 4, virtual and in-person outreach events featured INSPIRES participants and highlighted ongoing research. In particular, Theme 4 continues to unite high school science teachers across the region with INSPIRES researchers to foster forest research and data acquisition partnerships. In June 2023, Theme 4 will host numerous high school science teachers

and researchers from around the region for a multi-day workshop in Vermont, which will include visiting a local INSPIRES sensor location. A public website for educators is maintained to support collaboration between teachers and researchers to work together to develop lessons for the classroom focused on forestry and Quantitative Reasoning in Context (QRC; https://www.mainestempartnership.org/ index.php/track-ii-inspires). Science and Practice webinars related to forest climate change in Maine (https://crsf.umaine.edu/fcci-webinars/) continued for a third year and were enhanced by field tours that provide opportunities for scientists, conservationists, land managers, and the public to learn and discuss climate change impacts on forest types found in Maine. The interactive webinars are very well attended (60-80 participants per webinar, attendees are primarily from the northeast), serve to highlight ongoing research efforts from INSPIRES, and are recorded for future viewing on the Science and Practice YouTube playlist, along with video highlights from each field tour. The May 2023 tour highlighted INSPIRES sensor locations on lands owned by project partner Appalachian Mountain Club in northern Maine (Figure 9). Similarly, workshops and field tours for over 150 foresters and other stakeholders have occurred at the Corinth, Second College Grant, and Nulhegan Basin INSPIRES sites in Vermont and New Hampshire over the past year to demonstrate adaptation strategies to address invasive insects and climate change impacts and the novel insights provided by advanced sensing technologies. The project's external website and social media (Instagram, Twitter) accounts, in conjunction with the Team Slack channel and INSPIRES website, continue to showcase the project's research successes (Appendix 5. Communications and Resources).

Figure 9. Team scientist Sarah Nelson leads a discussion on remote sensor data acquisition in northern Maine.

Project Problems and Mitigation Efforts

Although the project largely remains on schedule with strong participation across the institutions involved, problems have continued to be encountered with important mitigation efforts implemented. The primary challenge has been adjusting to life following the global pandemic, which has created numerous barriers, and additional demands on project participants. An April 2023 survey of the INSPIRES team revealed that participants (n=21) currently rate themselves on the Stress Continuum Scale as "Surviving" (62%; up from 55% in Year 3, while 33% reported that they are Excelling or Thriving (Figure 10). The majority of participants (76%) indicated that they continue to struggle with challenges related to the pandemic, including workload, isolation, work-family balance, and availability of time to

complete their workload. A variety of mitigation efforts have been implemented to address these challenges, such as shifting effort from extensive field data collection to computer-based activities such as modeling, shared resources for project success, regular meetings where the pandemic is acknowledged and discussed, efforts by CLT to reduce administrative burdens on team members, adaptation to virtual workspaces, and communication of potential impacts or implications to university administrators.

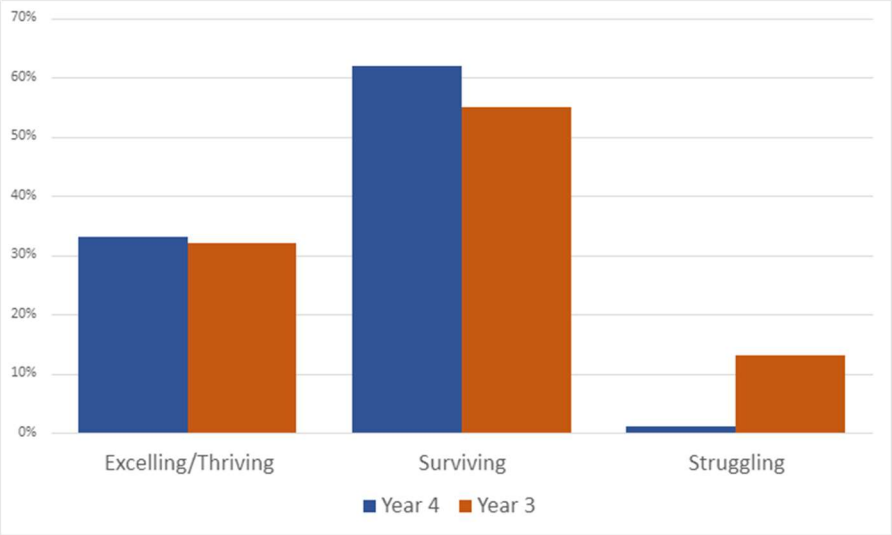


Figure 10. Survey during Spring 2023 all-team meeting shows improvement over Year 3 on self-reported rating on the stress continuum.

Novel Opportunities

With the supplemental funding received for AAMU joining INSPIRES, several important and highly unique opportunities continued to emerge in Year 4. AAMU faculty and students participated in numerous INSPIRES events and areas of potential collaboration were established across all project research themes. In particular, AAMU's long-term research field site at Paint Rock is a key focal area of collaboration and leverage numerous ongoing INSPIRES efforts and has already led to a successful collaborative proposal to NSF. For example, AAMU faculty and students have built additional wireless soil moisture sensors that will also be deployed at the Paint Rock field site. Theme 2 sent a researcher there in May to acquire unique high-resolution hyperspectral imagery for the Paint Rock field site, which will be aligned with foliar nitrogen samples simultaneously taken and used to create a map of canopy traits (Figure 11). Theme 3 has identified key input variables and developed a common framework for ecological modeling initialization with efforts to include Paint Rock as selected site for model evaluation and refinement. Finally, efforts are underway to recruit Alabama high school science teachers to participate in Theme 4 meetings and summer events.

Figure 11. Peter Nelson orienting AAMU students to hyperspectral data and instruments, May 2023.

The plan is to have high school teachers who are already part of the project mentor the incoming teachers to help facilitate collaboration and build teams across jurisdictions. These collaborative cross-institution and multi-jurisdictional efforts were highlighted prominently at the NSF National EPSCoR meeting in November organized and hosted by the Maine EPSCoR Office.

Changes in Strategy

Due to the ongoing challenges created by the pandemic and the difficulties of arranging in-person meetings, virtual meetings were kept to a minimum and teams encouraged to communicate directly via Slack or other means.

A new Collaborative Project Coordinator at the University of Maine, Dr. Emily Uhrig, was hired in Year 3 and she has made several key efforts to help facilitate team member participation and satisfaction. In particular, this has largely meant personalized one-on-one meetings with various team members, which led to follow-up meetings or identifying potential collaborative opportunities for the team. Through these meetings and reviewing project materials, she has developed a team collaborative network diagram (Figure 12), which was presented to the full team and used to facilitate additional collaboration, particularly across research themes and jurisdictions. Dr. Uhrig has also coordinated monthly INSPIRES student meetings where relevant guest speakers are identified and invited to discuss their professional journey. Finally, Dr. Uhrig has attended and helped facilitate the regular research theme as well as the Collaborative Research Committee monthly meetings, which has been helpful for identifying potential synergies between research themes and project participants. Dr. Uhrig will be an important project asset as INSPIRES moves into its final year and the focus shifts to sustaining ongoing collaborations.

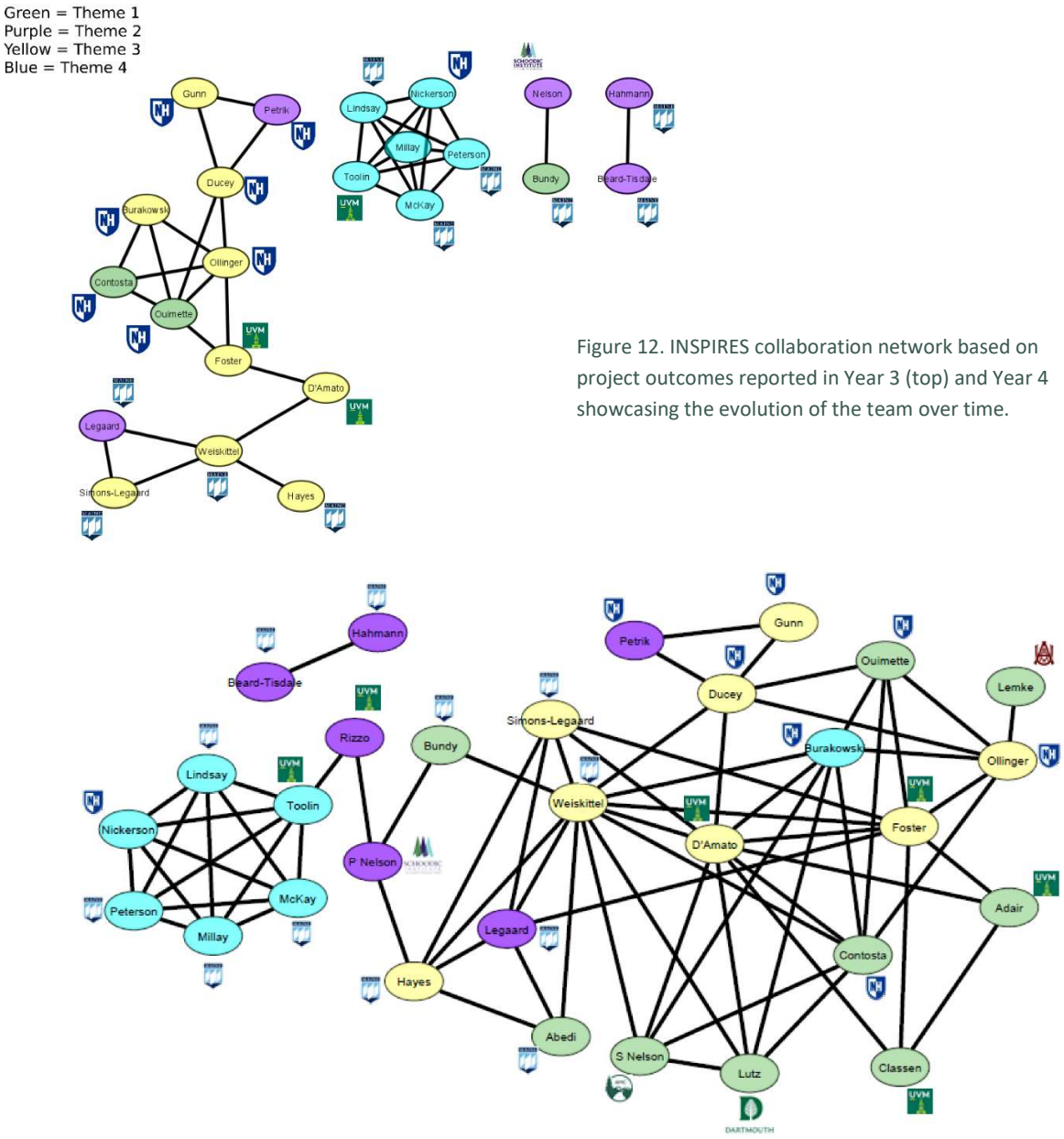


Figure 12. INSPIRES collaboration network based on project outcomes reported in Year 3 (top) and Year 4 showcasing the evolution of the team over time.

RESEARCH PROGRAM

Background

Societal demands on the Northern Forest and the ecosystem services they provide continue to expand at a time when key stressors, such as land use, invasive pests, and extreme abiotic events, are significantly on the rise. Maintaining the value and integrity of the Northern Forest for the communities that depend on them requires a better understanding of how these stressors affect this ecosystem. To address these challenges, the multi-jurisdictional INSPIRES faculty are collaborating on the development of a regional Complex Systems Research Consortium to facilitate analysis of forest ecosystem integrity and resilience from multiple scientific perspectives.

The overarching goal of the INSPIRES project is to integrate novel Big Data with ecological models to understand how climate change, land use, forest management, regulatory policies, invasive pests, and natural disturbances affect forest extent, composition, health, and productivity. To do this, INSPIRES aims to (1) overcome gaps in spatial and temporal data coverage; (2) improve capacity for quantifying and managing uncertainty; and (3) enhance linkages between ecological models and driving data.

The INSPIRES interdisciplinary effort is organized across four integrated themes (Table 4) that are essential to an innovative and flexible framework for harnessing Big Data across multiple spatio-temporal scales. Early career faculty lead each theme, supported by senior mentors. Each theme includes researchers and/or students from all three jurisdictions, as well as personnel cross-over to ensure sustainability and convergent approaches to problem solving. INSPIRES faculty and students are working across the four research-integrated themes to develop a novel and flexible Digital Forest framework for effectively harnessing Big Data to enhance our fundamental understanding of Northern Forest ecosystems across multiple spatio-temporal scales and under alternative scenarios of future environmental and management changes.

The CLT is responsible for achieving the project's objectives and providing guidance to team members. It is composed of the PI and co-PIs, representing the lead institutions. With themes and projects well underway in Year 4, the CLT now meets quarterly via videoconference to review research progress, develop team activities, and discuss issues relevant to project governance. For full transparency, CLT meetings are regularly scheduled, open to all team members, and meeting notes made available through the shared OneDrive folder.

Table 4. INSPIRES Research Approach and Goals by Theme

Theme	Research Approach	Research Goals
Theme 1. Advanced Sensing and Computing Technologies	Contribute valuable Big Data that, when combined with smart environmental informatics, advances ecological models & our knowledge of the NFR ecosystem.	Improve power and wireless spectrum efficiency for a large-scale network to enable a novel in-situ forest data collection and processing system that furthers our fundamental knowledge of advanced sensing and computing technologies, while reliably quantifying the spatial-temporal variability of key forest ecosystem integrity metrics. Use ML for link quality improvement and efficient resource utilization in addition to data mining.

Theme	Research Approach	Research Goals
Theme 2. Smart Environmental Informatics	Integrate remote sensing data, sensor data, and qualitative information (e.g., TEK) to better understand spatial-temporal variability of stressors. Semantically enriching data helps to identify future measurements to predict stress.	Develop and test how a theoretical model can (1) quantify spatial & temporal variability & uncertainty and (2) incorporate qualitative & other nontraditional sources of ecological knowledge. Identify where additional sensing leads to greatest increases in data quality and model accuracy to improve the efficacy of sparse sensor networks. Build a smart data framework that leverages semantic knowledge to extract and characterize high-level places/events. Gain knowledge about how forest stressors vary across places and inform modeling by identifying where more granular models are beneficial.
Theme 3. Integrated Ecological Models	Quantify the impact of stressors on ecosystem integrity indicators & predict change across NFR when refined and driven by links to Themes 1 and 2.	Integrating sensor data, remote sensing imagery, and semantically enriched information from Themes 1 and 2 to better enhance as well as complete an inverse parameterization of regional ecological models for projecting forest ecosystem integrity and its uncertainty under an array of alternative futures that include variation in climate, land use, regulatory policies, and natural disturbance scenarios.
Theme 4. Improving Quantitative Reasoning in Context	Connect teachers and students to locally relevant research and datasets, broadening and deepening STEM engagement.	(1) Develop/adapt materials for G6-12 that build QRC with opportunities to learn through data collection using sensors, asking & answering research questions about forests and the local environment & ecology using big data sets, and engaging in data visualization activities; (2) investigate the knowledge teachers need to support students in developing quantitative reasoning skills; (3) evaluate how students benefit from these opportunities.

Significance of Accomplishments

A key accomplishment in Year 4 was continuing to build collaborations with AAMU as a partner in the project under a supplemental grant, which has created new collaboration opportunities and research directions for the project. Primary Year 4 research activities of the INSPIRES project focused on the continued refinement and deployment of environmental sensors at strategic locations throughout the region (Theme 1), providing regional estimates of key forest canopy traits (e.g. foliar nitrogen, photosynthetic capacity) at high resolution (30-m) using field collected data and remote sensing platforms (Theme 2), initiating the construction of a general digital framework for a multi-model comparison to understand model strengths and weaknesses (Theme 3), and continuation of engagement as well as recruitment of high school science teachers to better integrate project elements into hands-on curricular activities (Theme 4). INSPIRES graduate student projects continue to progress with summer field seasons planned and new students being recruited. To enhance collaboration, researchers have actively participated in quarterly all-team discussions and team-building exercises with a project collaboration network diagram formulated and presented to the team.

"In February 2023, I had the opportunity to give an oral presentation at the Adaptive Silviculture for Climate Change (ASCC) Annual Meeting. I presented on the research I have conducted at the Second College Grant, NH in collaboration with Shawn Fraver at UMaine. Our study investigates the impact of adaptive management regimes on wood decomposition rates and nutrient dynamics. I am currently working on writing this study up and hope to pursue publication in the near future.

Our writing group has been going strong for two semesters now! A small group of students from multiple institutions within the INSPIRES network come together, virtually, once a week for two hours. During this time, we take the opportunity to catch up, discuss our goals, ask questions and provide each other feedback. We then spend the rest of the meeting working silently.

Overall, this group has really helped me to develop my daily writing practice and increased my productivity. Aside from writing, I've also had the chance to discuss other research- and academic-related topics like building R scripts for analyses or discussing professional development and careers. Lastly, and most importantly, it has allowed me to connect with my peers and build a network with them and others."

Paulina Murray
UVM Graduate Student

Ongoing science and planning meetings continue within and across jurisdictions to develop theme-specific research agendas with clearly defined research objectives and corresponding lead personnel and milestones. Logistical planning has begun for field research activities and analytical techniques for summer 2023, with additional wireless sensor deployment, remote sensing acquisitions, and model parameterization and calibration for predicting regional forest dynamics anticipated. Cross-theme coordination continues with Theme 4 team's Quantitative Reasoning in Context (QCR) teacher training with teachers from Vermont and Maine as well as researchers from all three jurisdictions. A Theme 4 teacher summer workshop is planned for Vermont in June 2023 and may include additional new participants from Alabama.

The INSPIRES team continues to engage project stakeholders and partners for input and feedback on research objectives, to secure access to research sites and identify potential new experimental sites, to identify opportunities for leveraging existing long-term data collections, and to develop collaborative relationships around the INSPIRES themes. Our key project stakeholders remain federal partners such as the US Forest Service, NGOs such as the Appalachian Mountain Club, Schoodic Institute, or Second College Grant, and private forest landowners such as The Nature Conservancy, Seven Islands Land Company, and Weyerhaeuser Company. As detailed in the following pages, the project has continued to make considerable progress despite three years of restrictions and challenges created by the global pandemic. Current momentum and partnerships position the project is well to effectively deliver on the key outputs originally identified in the proposal, and to sustain collaborative work in the future.

Theme 1. Advanced Sensing and Computing Technologies

Background

The primary research task in Theme 1 is to overcome gaps in spatial and temporal data coverage of key environmental data through the development and deployment of novel wireless sensors and existing low-cost sensors. Year 1 focused on determining where sensors could be deployed and what could be measured. Years 2 and 3 focused on deciding what ecosystem parameters would be measured at specific sites and how the system would be built, resulting in the splitting of theme members into two related subgroups: (1) UMaine completed the design phase of a wireless soil moisture probe and began field comparisons with more standard research-grade sensors and (2) Dartmouth/UNH/UVM team deployed a sensor suite (measuring Photosynthetically Active Radiation [PAR], snow depth, atmospheric temperature and relative humidity, soil temperature and volumetric water content, soil matric potential) with existing low-cost sensors at multiple sites in VT, NH, and ME. In Year 4, continued efforts were to deploy the developed sensors at a variety of locations, including sites in Alabama. Additional sensors were developed to measure soil CO_2 and tree radial growth.

Theme 1 continued to meet monthly to report progress and work through challenges and have regularly joined members of Theme 3 to work on cross-theme collaboration and data management planning. In particular, extraordinarily strong synergies have been identified with new collaborators from Alabama, particularly with Dr. Raziq Yaqub and his students. In January 2023, an AAMU faculty member and several undergraduate students visited the University of Maine to learn how to design, construct, and deploy wireless sensors, which was the basis of their senior capstone projects (Figure 13). Their findings were presented to the April 2023 all-team meeting. The Theme 1 team this year refined key research goals, questions, and motivating hypotheses from the proposal, particularly with respect to cold air pooling and managing for the cold.

Figure 13. AAMU electrical engineering undergraduate students visiting the University of Maine via the INSPIRES grant are mentored by UMaine INSPIRES team members Ken Bundy (L.) and Thayer Whitney (R) while learning how to build wireless sensors.

Highlights

- Established 7 new environmental monitoring sensor sites using technology developed by Theme 1 researchers (Figure 14).
- Environmental sensor suite at 11 sites throughout study area. Some sites feature multiple stations for comparison and within-site variability quantification.
- Open-source, low-cost CO_2 sensor field-tested in summer and fall of 2022 and will be further integrated into sensor suite in 2023.
- The IWiN system-designed modules developed under the leadership of Dr. Ali Abedi at UMaine Wireless Sensor Networks Laboratory (WiSe-Net Lab) were implemented and refined in Year 4.
- Comparison of low-cost CO_2 sensors with research grade instruments.
- Provided research opportunities for undergraduate interns with UNH's Hennecys Perez-Castro winning the best undergraduate student poster for this research at the LTER All Scientists Meeting in Monterey, CA, September 2022 (Figure 15).
- Compilation of beneath-canopy repeated images at select sensor sites has allowed dynamically tracking of vegetation phenology across the region (Figure 16).

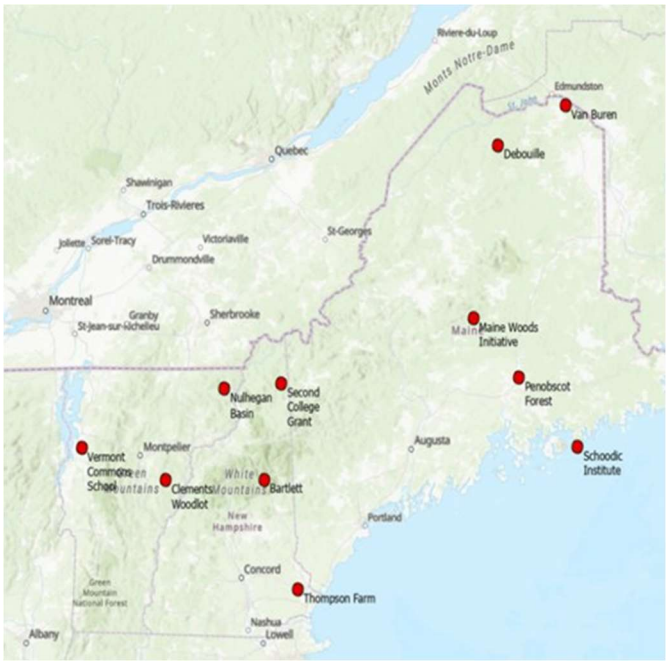


Figure 14. Map of current sensor network including the 9 new sensor stations in 6 new locations established in Year 4 of INSPIRES across the three New England jurisdictions.

- Doubled Cold Air Pooling Plots to a total of 100 and published a synthesis concept paper in *Ecology* based on the collected data (Figure 17).
- INSPIRES sensors and data helped catalyze additional climate monitoring by partners such as AMC (Figure 18), who deployed complementary climate monitoring for lake and stream temperature assessment including soil moisture sensor developed from the project (Figure 19).
- Deployed wireless sensor stations in conjunction with Theme 4 high schools in VT (Figure 20).
- INdendro second prototype: Redesigned the first version of the wireless dendrometer bands. This new, larger scale pilot study is more compact, higher precision, low power, and rugged design that is easier to install and maintain (Figure 21).

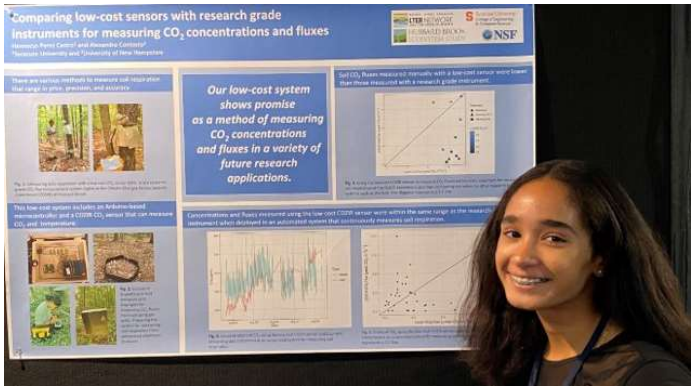
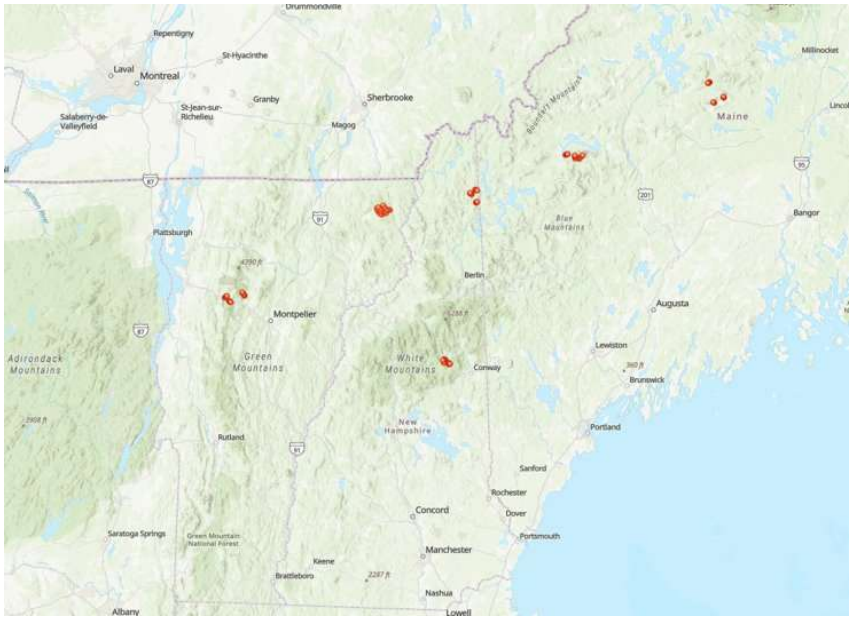


Figure 15. Hennecys Perez-Castro (UNH) won best undergraduate student poster for this research at the LTER All Scientists Meeting in Monterey, CA, September 2022.

Figure 16. Select images from a beneath-canopy camera taking time-lapse photos for tracking vegetation phenology. This camera is located at Bartlett Experimental Forest.



ECOLOGY

CONCEPTS & SYNTHESIS

Cold-air pools as microrefugia for ecosystem functions in the face of climate change

Melissa A. Pastore | Aimée T. Classen | Anthony W. D'Amato | Jane R. Foster | E. Carol Adair

Abstract

Cold-air pooling, a global phenomenon that describes static low temperatures in sheltered, low lying depressions and valleys and drives other key environmental conditions, such as soil temperature, soil moisture, vapor pressure deficit, frost frequency, and nursery dynamics, local climatic patterns in areas prone to cold-air pooling are partly decoupled from regional climates and thus may be buffered from macroscale climate change. There is remarkable evidence from studies across the globe that cold-air pooling impacts plant communities and ecosystem functions, making these decoupled systems areas potentially important microrefugia for species under climate warming. Despite interest in the potential for cold-air pools to enable species persistence under warming, studies investigating the effects of cold air pooling on ecosystem processes are scarce. Because local temperatures and vegetation composition are critical drivers of ecosystem processes like carbon cycling and storage, cold-air pooling may also act to preserve ecosystem functions. We review research exploring the ecological impacts of cold air pooling with a focus on vegetation, and then present a new conceptual framework in which cold-air pooling creates feedbacks between species and ecosystem properties that generate unique hotspots for carbon storage. In some systems relative to areas more vulnerable to regional climate change impacts. Finally, we describe key steps to motivate future research investigating the potential for cold-air pools to serve as microrefugia for ecosystem functions under climate change.

KEYWORDS

carbon, climate change, cold air drainage, cold air pooling, complex terrain, ecosystem

INTRODUCTION

Figure 17. Map of current Cold Air Pooling Plots, which doubled in size in Year 4 to a total of 100 plots, and the synthesis publication lead by INSPIRES post-doc Melissa Pastore.

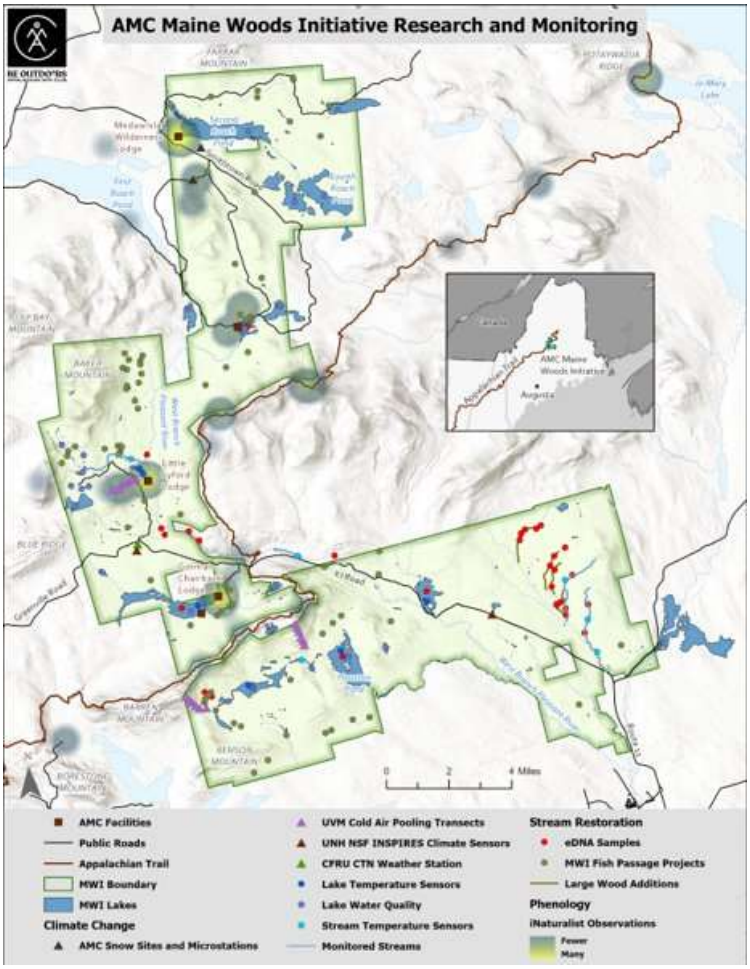


Figure 18. Draft of map depicting proposed network of environmental sensors for comprehensive climate change monitoring at INSPIRES project partner AMC's Maine Woods Initiative.

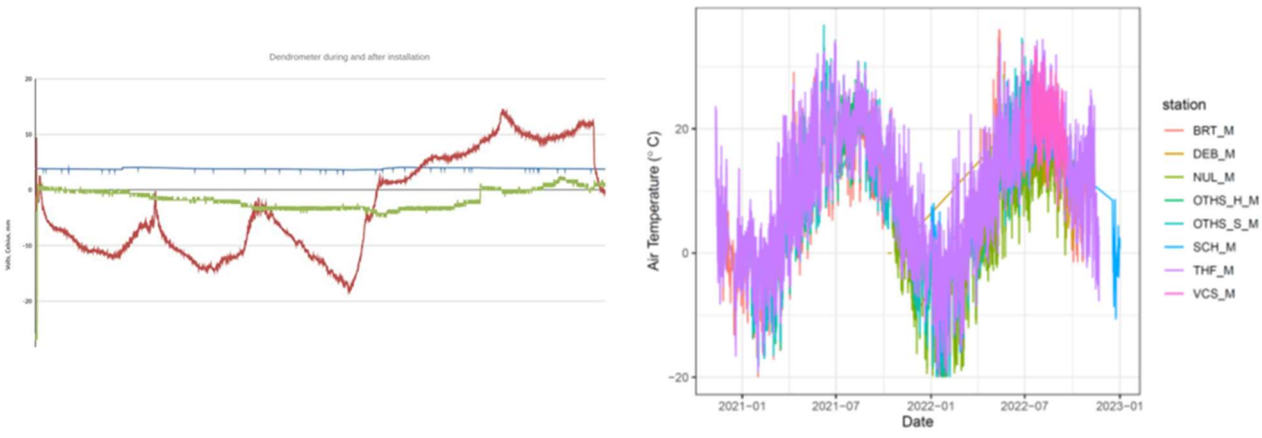


Figure 19. Example time series of data collected to date across regional sensor network. Tree radial growth patterns (left) and air temperature at 1.5 m above the surface (right) over time at selected locations in INSPIRES.

Figure 20. Deployment of environmental sensor networks in collaboration with Theme 4 high schools at Vermont Common School and Van Buren High School.

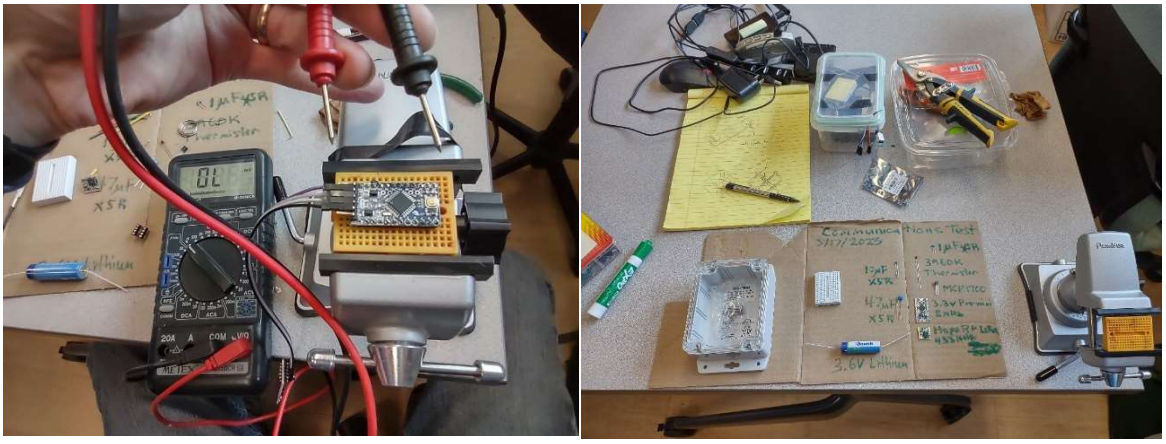


Figure 21. Build out of the INdendro second prototype for the Nutting Preserve pilot study.

Team Members

12 faculty (9 early career), 4 research technicians, 1 post-doc, 6 graduate students, and 4 undergraduate students; 11 VT, 7 ME, 4
NH

Name	Affiliation	Jurisdiction	Institution	Early Career	Role
Aimee Classen	Gund Institute for Environment/ Rubenstein School of Environment and Natural Resources	VT	UVM/ UMichigan	N	Faculty
Ali Abedi	Department of Electrical and Computer Engineering	ME	UMO	N	Faculty
Alix Contosta	Earth Systems Research Center	NH	UNH	Y	Faculty
Andrew Ouimette	Earth Systems Research Center	NH	UNH	Y	Research Staff
Apryl Perry	Earth Systems Research Center	NH	UNH	N	Research Technician
Bruce Segee	Advanced Computing Group	ME	UMO	N	Faculty
Carol Adair	Rubenstein School of Environment and Natural Resources	VT	UVM	Y	Faculty
Dave Lutz	Environmental Studies	NH	Dartmouth	Y	Faculty
Dawn Lemke	Department of Biological and Environmental Sciences	AL	AAMU	N	Faculty
Dedrick Davis	Department of Biological and Environmental Sciences	AL	AAMU	N	Faculty
Grace Smith	Rubenstein School of Environment and Natural Resources	VT	UVM	N	Grad Student
Helen Czech	Department of Biological and Environmental Sciences	AL	AAMU	N	Research Technician
Emma Hazard	Environmental Studies	NH	Dartmouth	N	Grad Student
Karin Rand	Rubenstein School of Environment and Natural Resources	VT	UVM	N	Research Technician
Kenneth Bundy	Department of Mathematics	ME	UMAB	Y	Faculty
Kindrea Gibbons	Department of Biological and Environmental Sciences	AL	AAMU	N	Research Technician
Lindsay Barbieri	Rubenstein School of Environment and Natural Resources	VT	UVM	N	Grad Student
Marie English	Rubenstein School of Environment and Natural Resources	VT	UVM	N	Research Technician
Mersedeh Naji	Dept. of Electrical & Computer Engineering	ME	UMO	N	Grad Student
Melissa Pastore	Rubenstein School of Environment and Natural Resources	VT	UVM	Y	Post-Doc

Name	Affiliation	Jurisdiction	Institution	Early Career	Role
Paulina Murray	Rubenstein School of Environment and Natural Resources	VT	UVM	N	Grad Student
Raziq Yaqub	Department of Biological and Environmental Sciences	AL	AAMU	N	Faculty
Sarah Nelson	School of Forest Resources (former), AMC (Current)	ME	AMC (Current) UMO (Former)	N	Faculty
Samantha Aali	Dept. of Electrical & Computer Engineering	ME	UMO	N	Undergrad
Thayer Whitney	Dept. of Electrical & Computer Engineering	ME	UMO	N	Grad Student

Research Milestones Progress

Objective	Projects	Project responsible parties	Year 4 Milestones	Milestone Progress
1.1	1.1a Wireless sensor research and development	Abedi, Contosta, Adair, Naderi	Continue strategic expansion of regional sensor network based on available data	Developed low-cost soil moisture sensor at University of Maine and published findings in Springer Nature journal. Deployed Arduino data loggers for monitoring soil moisture, temperature, PAR, microclimate, snow depth, and phenology. CO_2 sensor development and deployment (Contosta). Analyzing sensor data to understand how forest structure, composition, and management affect forest microclimate (Contosta, Lutz, Rand, Adair, Nelson, Pastore). Refined development of a wireless dendrometer for non-invasively measuring tree radial growth.
1.2	1.2a Wireless sensor network design	Abedi, Contosta, Adair, Lutz, Whitney	Regionally implement sensor networks	Deployed 8 new stations in 6 new locations across the region (Contosta, Lutz, Rand). Deployed stations in partnership with local high schools. New optimization algorithms have been developed that minimizes the outage probability. New results created design paradigms to suggest battery

Objective	Projects	Project responsible parties	Year 4 Milestones	Milestone Progress
				requirements based on solar radiation data in Maine. Several iterations of wireless sensor nodes were designed and tested in both lab and field environment; soil moisture was measured wirelessly side by side with a wired precision system; started expanding the nodes to include more sensors (soil and air temperature).
1.3	1.3a Cyber-based big data harmonization, ML & interface	Abedi, Bundy	Process, summarize, and synthesize available regional ecological sensor data collected by this project and develop online interface	These data have been published on EDI and in a journal article. The map-based INLeaf data sharing and staging system created. Networked sensors send real-time data to INLeaf. INLeaf is available inside INSPIRES and for outside stakeholders.
1.4	Implications of cold-air pooling to forest vegetation composition and soil carbon storage across the northeastern US	Pastore, Adair, Classen, D'Amato, Foster, Rand, Engish	Complete a synthesis publication using the available data Analyze sensor data to better understand canopy interactions with snow depth dynamics and longevity	Expansion of monitoring network to 100 locations. Continual monitoring at all locations. Publication of a synthesis journal article on the topic. Outlined a conceptual framework for better understanding snow dynamics under forest canopies and started a synthesis manuscript.

Significant Problems/Unexpected Results/Novel Opportunities

- Supply chain issues causing equipment shortages and delays as well as increases in costs

Future Plans

- Continued deployment of wireless environmental sensors in Alabama
- Refinement and of training materials for sensor construction and deployment
- Expansion of co-deployment of sensors for measuring key forest ecosystem attributes such tree growth linked with microclimate
- Modifications, refinements and additional deployment of INdendro sensors
- Continual monitoring of wireless sensors at specific study locations throughout the region
- Synthesis of key trends and integration with Themes 2 & 3
- Completion of online interface for data access and trend assessment

Theme 1 Project Report

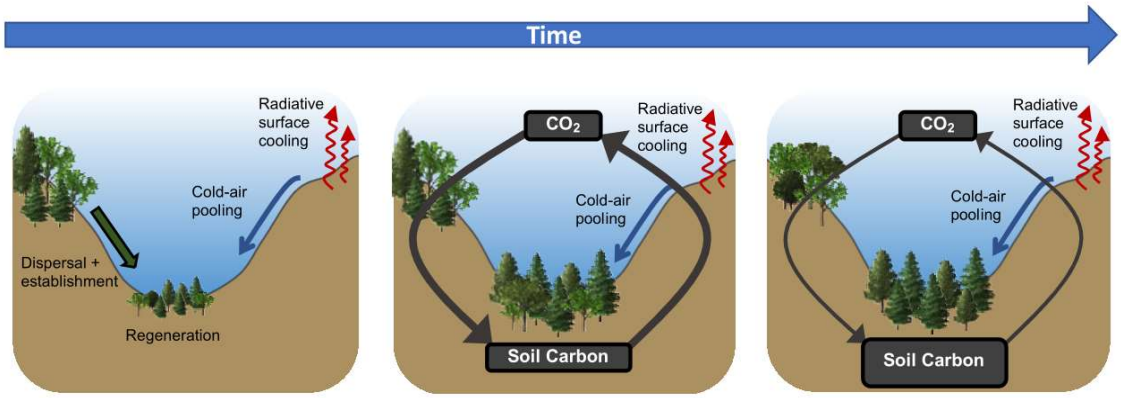
Determining the Implications of Cold-Air Pooling to Forest Vegetation Composition and Soil Carbon Storage Across the Northeastern US

The Cold-Air Pooling team continued to establish monitoring plots along key elevational gradients to better understand key ecological dynamics (Figure 22). Key concepts (Figure 23) outlined in the synthesis paper published in Ecology in August 2022 can now be better understood through this data. Among the important concepts that are emerging is that sites with more temperature inversions display inverted forest composition patterns across elevation. Approximately 50% of the timesteps monitored showed an inversion with an average and maximum inversion temperature differential of 2.3 and 16.2°C, respectively (Figure 24). A structural equation model indicated that conifer abundance was driven by a complex interaction between microclimate mean annual temperature and soil moisture, which are further mediated by aspect, elevation, and topographic position (Figure 25). Fine scale monitoring of soil moisture showcase the importance of forest canopy both with and without foliage (Figure 26), which is likely due to the complex interaction with snowcover dynamics that are further explored below.

Figure 22. Continued establishment of cold-air pooling sites along key elevational gradients throughout the region to better understand important ecological relationships.

On November 28-29, 2022, members of the INSPIRES team plus colleagues working on related research met for an overnight retreat at the Appalachian Mountain Club (AMC)'s Pinkham Notch/Joe Dodge Lodge facility in the White Mountains of New Hampshire to work collaboratively on a manuscript (led by M. Pastore and S. Nelson) regarding snow refugia in the Northeast, which would be a follow-up to the recently published synthesis paper on cold air drainage in Ecology. We defined objectives, worked with data from INSPIRES and other sources, discussed implications for wildlife and approaches to stakeholder interests, and even fit in a hike in wintry conditions on a lunch break. The intensive meeting was the first time some members of our team had met in person, despite collaborating online for over two years. Attendees were: Alix Contosta, Dave Lutz, Toni Lyn Morelli, Alexej Sirén, Grace Smith, Melissa Pastore, Sarah Garlick, Aaron Weiskittel, Sarah Nelson; Tony D'Amato is a member of the team working on this project as well. Since the retreat, four virtual team meetings and sub-group working sessions have advanced the manuscript, working on hypotheses and conceptual figures, data syntheses, and writing tasks. Regular meetings are scheduled to continue progress on the paper.

Key concepts that are emerging from the group discussions are motivating hypotheses of how differences in forest



a) Strong disturbance and system reset. After a strong disturbance, species re-sorting occurs as species regenerate and disperse downslope. Because of cold extremes and frost, there may be greater survival of cold-adapted evergreen seedlings and greater mortality of deciduous seedlings. Some deciduous seedlings may persist via cold acclimation and/or because they are good competitors. Climate-plant-soil feedbacks initiated by cold-air pooling may promote evergreen dominance over time.

b) Climate-plant-soil feedback. Cold-air pooling favors cold-adapted evergreens with conservative functional traits, slowing carbon cycling and reducing soil nutrient availability. Over time, lower soil nutrient availability and pH, low temperatures, shade, and early/late frosts increasingly exclude deciduous species, reducing competitive pressure for evergreens.

c) Change-resistant conservative system. After decades, cold-air pools maintain cold-adapted evergreen species with conservative traits that promote slow carbon cycling. Low soil nutrient availability, pH, and light prevent deciduous intrusion. Evergreen abundance in the surrounding region may decline as climate change continues, while the cold-air pooling area continues to harbor evergreens and promote carbon accrual.

Figure 23. Key concepts outlined in the cold-air synthesis publication in Ecology. Cold-air pool events are characterized by a temperature inversion, with cooler temperatures at lower levels. Climate-plant-soil feedbacks in cold-air pools could promote carbon storage.

canopy characteristics affect snowpack depth and duration during the snow season. Snowpack depth is the difference between (b) cumulative snowpack gain and (c) cumulative snowpack loss at any point in time (Figure 27) with the primary mechanisms driving differences in snowpack and soil temperature along a continuous gradient of dormant season canopy complexity (Figure 28). Differences in cumulative gain among levels of canopy complexity are driven by differences in snow throughfall and sublimation/evaporation from intercepted canopy snow. Differences in

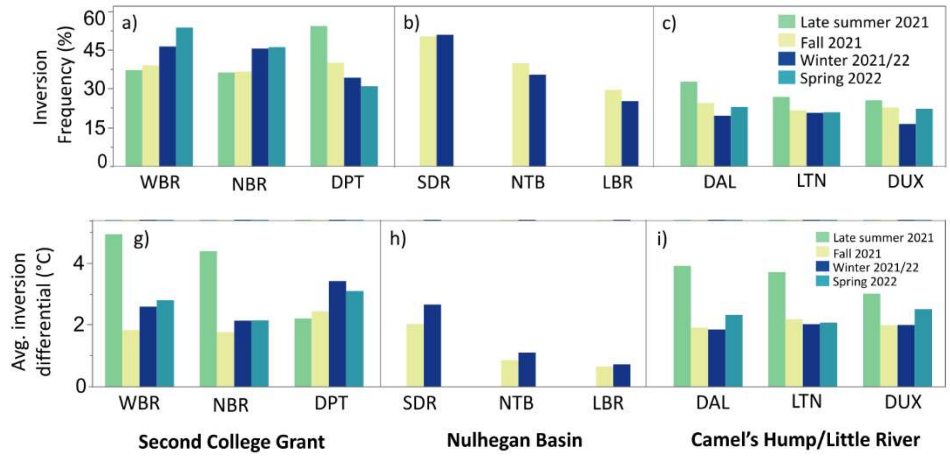


Figure 24. Proportion of timesteps with a cold-air inversion (top) and average inversion temperature differential (°C) across different years and seasons at key locations along three elevational gradiental transects in Vermont and New Hampshire.

cumulative loss among levels of canopy complexity are driven by differences in snowpack melt, sublimation, and evaporation. We use dormant season canopy complexity as an umbrella term encompassing various inter-related forest characteristics that affect snow dynamics (e.g., forest type/species composition, stem and tree density, canopy cover, leaf area, vertical structure, gap distributions/sizes, age, spatial arrangement).

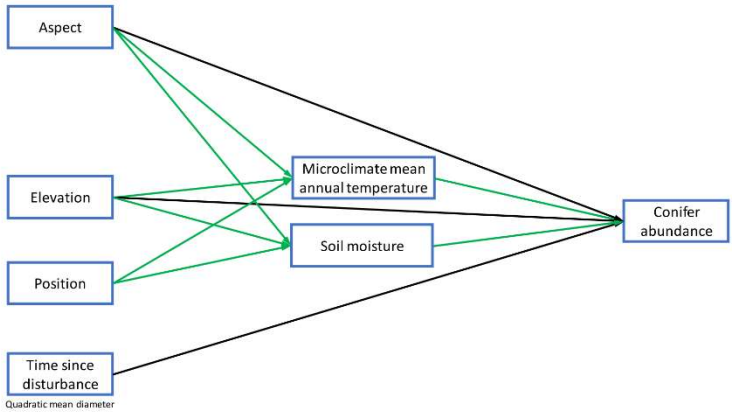


Figure 25. Structural equation model linking various physiographic measures with microclimate and soil moisture effects on conifer abundance across different elevational transects in Vermont and New Hampshire.

Canopy complexity is illustrated with discrete categories here for simplification, but is a continuous gradient. We hypothesize that there is a 'goldilocks zone' where peak snowpack depth and snowcover duration will be highest; here this is illustrated as medium dormant season canopy complexity, which could represent a vertically stratified mixed forest, for example. Low dormant season canopy complexity could represent a recently disturbed area with even-aged regenerating seedlings/saplings and little to no dormant season leaf area, while high dormant season canopy complexity could represent a dense coniferous forest with multiple age classes. For snow dynamics under forest canopies, the macrofilter (i.e., regional climate and topographical characteristics like elevation, slope, and aspect) determines base conditions, which are then modified by the interrelated vegetation mesofilter characteristics that determine canopy complexity (e.g., forest type/species composition, stem and tree density, canopy cover, leaf area, vertical structure, age, spatial arrangement, gap distributions/sizes). Red arrows indicate processes that lead to shallower snowpack and blue arrows represent processes that lead to deeper snowpack; arrow sizes represent relative strength.

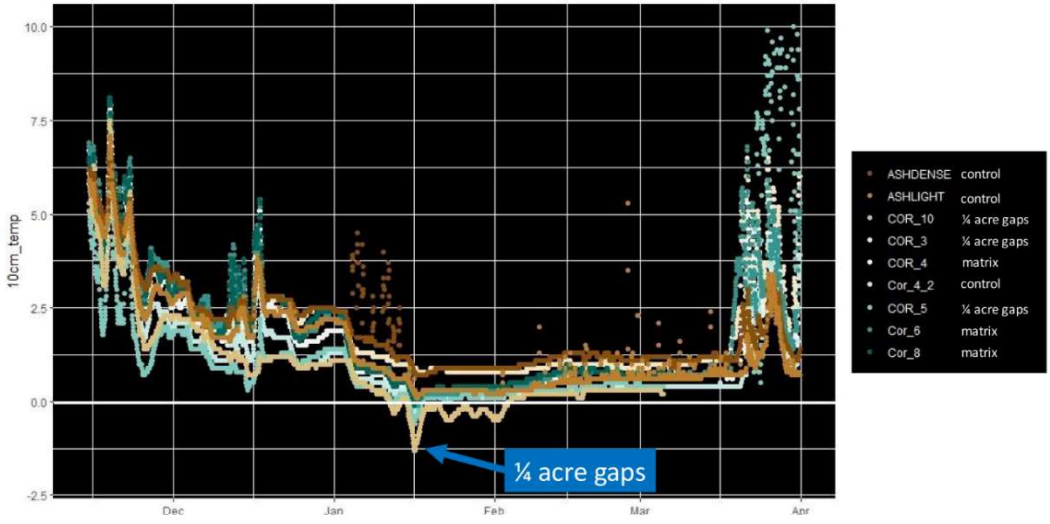


Figure 26. High resolution soil temperature at a site in Vermont with varying levels of canopy cover throughout the winter, which highlights the importance of snowcover depth and duration.

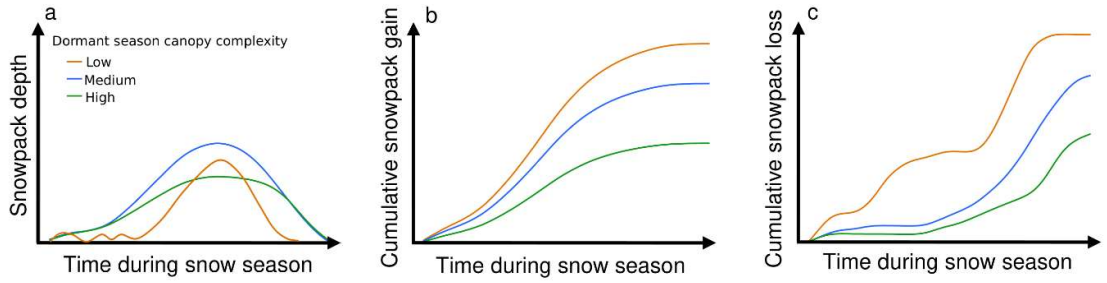


Figure 27. Contrasting hypotheses about the interaction between snowpack (a), cumulative snowpack gain (b) and cumulative snowpack loss (c) that show mechanisms corresponding to each of the three levels of canopy complexity.

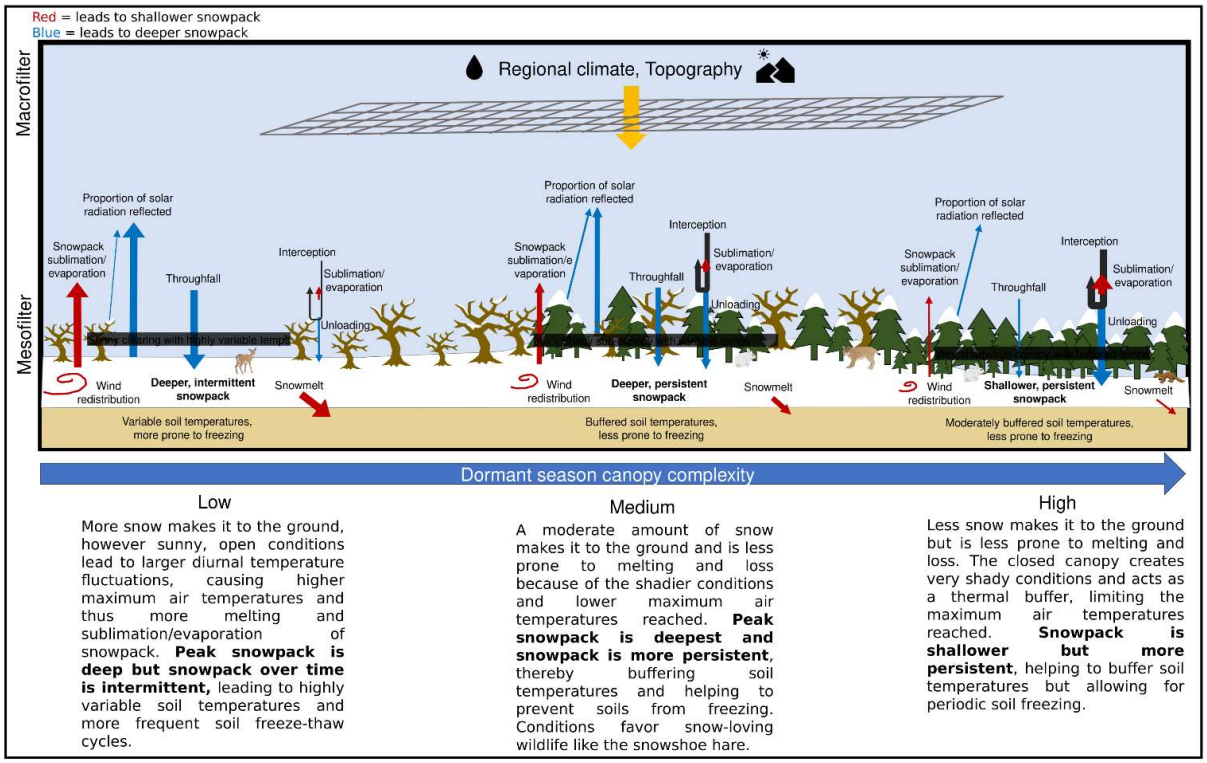


Figure 28. Conceptual diagram of the mechanisms driving differences in snowpack depth among forest types over time.

Theme 2. Environmental Informatics and Analytics

Background

Theme 2 focuses on integrating various data such as those available from remote sensing, ecological sensor networks, and qualitative information (e.g., Traditional Ecological Knowledge (TEK)) to better understand spatial-temporal variability of stressors. In Year 2, the team completed preliminary 20 m tree species occurrence and abundance maps for 4 million ha in northern Maine and New Hampshire using Sentinnel-2 imagery and a cloud-based machine-learning algorithm, identified new regional climatic zones based on project future conditions (which show significant departures from the USDA plant hardiness zones), refined machine learning classifier algorithms to detect individual tree crowns from high-resolution remote sensing images, and developed a streamlined and novel workflow for querying of multiple available spatial datasets to be deployed in the Digital Forest framework. The emphasis for Year 3 efforts was to continue evaluating key relationships between remote sensing variables and various ecosystem attributes, harmonizing various regional spatial layers within a unified digital framework for assessing key spatiotemporal trends, and understanding the primary drivers of forest productivity that can be leveraged in Theme 3 for future ecological forecasting. For Year 4, focus shifted toward identifying and designing suitable ontologies for formal representation, interpretation, and integration of forest data to devise novel approaches that leverage synergies between these ontologies and machine learning approaches to improve integrated forestry data analysis (Figure 29). In addition, further refinement of remote sensing and machine learning cloud computing capabilities was completed, which will enable large-scale state- or even region-wide mapping. Ultimately, the goal is to outline and develop a smart data framework that leverages semantic knowledge to extract and characterize high-level places/events, which will allow managers and scientists to gain knowledge about how forest stressors vary across places and inform modeling by identifying where more granular models are beneficial.

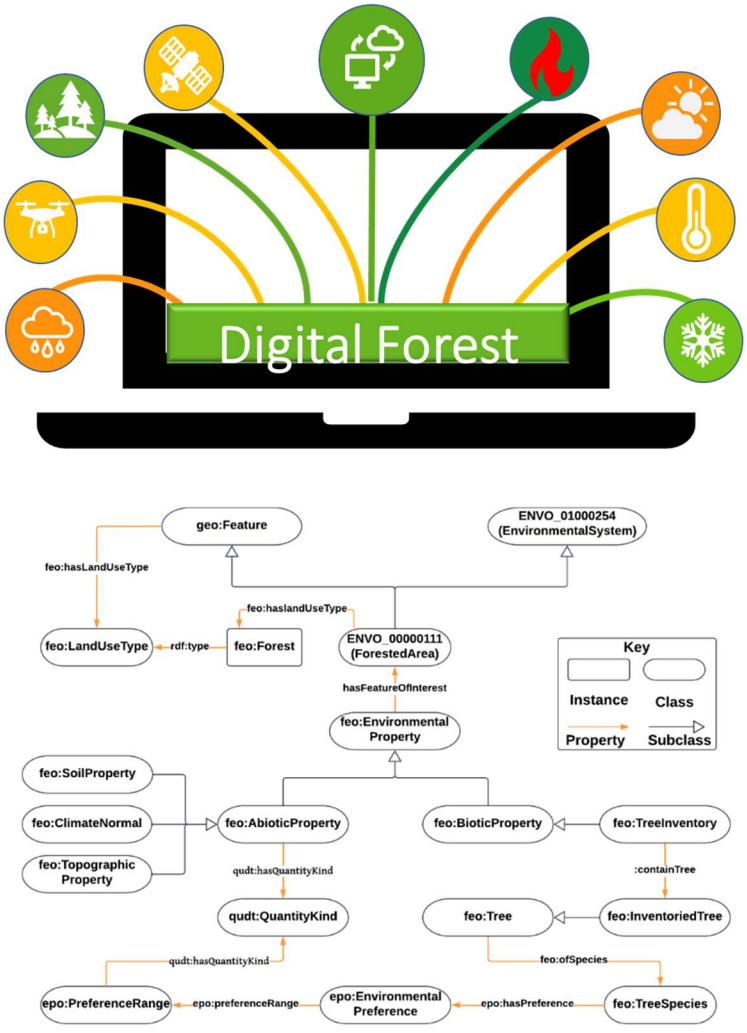


Figure 29. Use of the Digital Forest to integrate various datasets created through INSPIRES with the developed forest ecology ontology being led by Co-PI Beard-Tisdale, Senior Personnel Hahmann, and graduate student Kingsley Wiafe-Kwakye at the University of Maine.

Highlights

- Updates and significant refinement to the software system for processing remote sensing data, lecospec (https://github.com/nelsopet/lecospec), happened through collaborations across themes.

- A R package (lecospectR) for hyperspectral and geospatial machine learning inference was further developed in Year 4, which increased used to assess reflectance data across contrasting species (Figure 30).

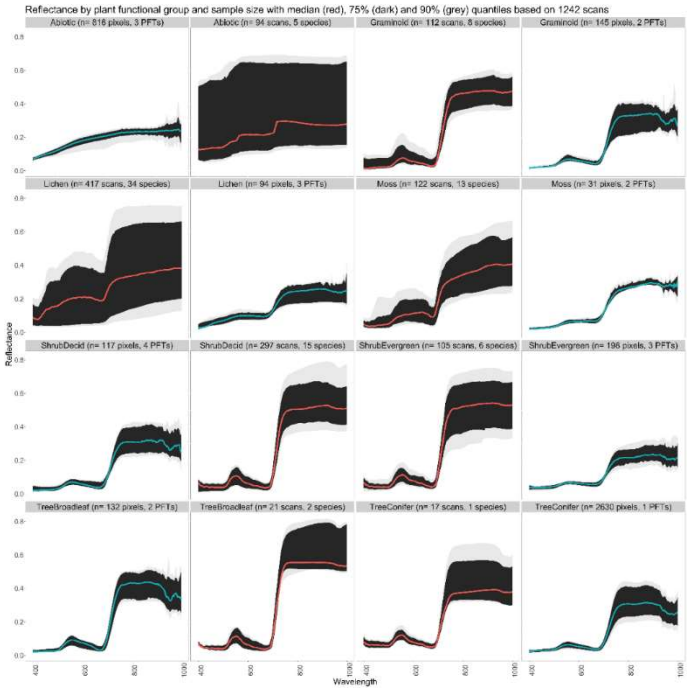


Figure 30. Reflectance data summarized and visualized by the lecospec R package available at GitHub (https://github.com/nelsopet/lecospec). The accuracy summary of the median and interquartile ranges of reflectance (75% black & 95% grey) with the sample size in number of scans distributed across a number of scans (ground measured) or pixels (airborne).

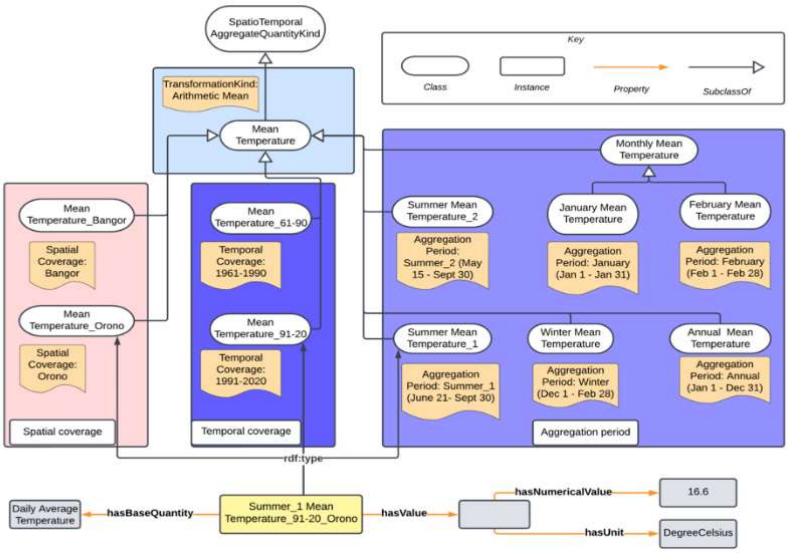


Figure 31. Use of ontology design pattern for Spatial and Temporal Aggregate Data (STAD) to describe a specific kind of summer mean temperature (Summer_1 MeanTemperature_91-20_Orono shown at the bottom) as the arithmetic mean of daily mean temperature data for over the summers as presented in Wiafe-Kwakye et al. (2022; https://ceur-ws.org/Vol-3352/pattern4.pdf).

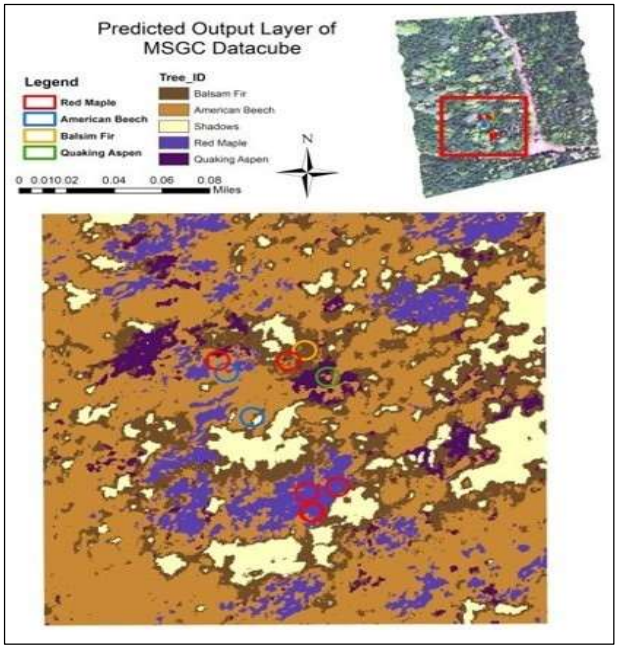


Figure 32. High-resolution species composition map for a forest in Maine based acquired hyperspectral imagery and developed processing workflows developed by Peter Nelson.

- ❖ Machine learning classifiers used to identify tree species characteristics based on hyperspectral imagery were developed and published.
- ❖ A ontology design pattern for Spatial and Temporal Aggregate Data (STAD) used to better understand variation in environmental factors like air temperature, was published (Figure 31).
- ❖ NSF NRT Science Intern partnered with Peter Nelson to generate high geometric accuracy ground validation data from hyperspectral images and preliminary forest composition products generated (Figure 32).
- ❖ A beta prototype for a Digital Forest Web Interface was further developed to query the database (Figure 33).
- ❖ Understanding of the response of temperate forest tree species to climate change was refined by measuring their response to drought using sensors developed in Theme 1.
- ❖ Developed and published an Adversarial Discriminator Ensemble Network (ADE-Net) to better deal with various kinds of noise in hyperspectral images (Figure 34).
- ❖ Developed regional climatic zones refined and projected into the future using different RCP models (Figure 35). A GitHub repository was created to house the developed code, model output, and map (https://github.com/xinyuanwylb19/ClimateZone).
- ❖ Climate zones used to better understand regional patterns in forest type, land cover, biomass, and species diversity (Figure 36).
- ❖ Peter Nelson completed a multi-day field acquisition in May 2023 to acquire hyperspectral imagery for Paint Rock field site in Alabama (Figure 37, left photo).

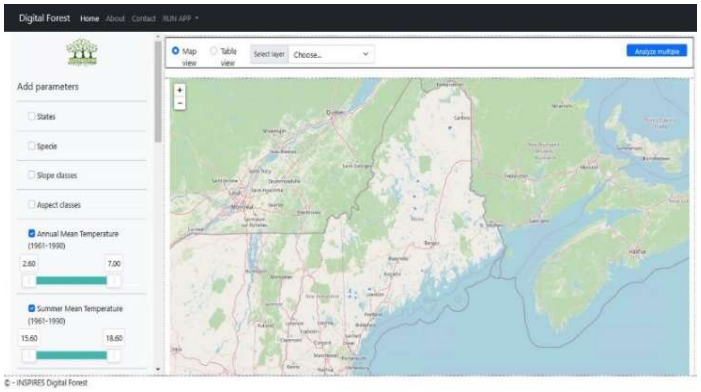


Figure 33. Beta prototype online version of the Digital Forest used for ontology-driven data exploration, visualization and analysis developed by PhD candidate, Kingsley Wiafe-Kwakye.

- ❖ An undergraduate student from AAMU (Casey Mills) was hosted by UNH for a week over the summer. During the host period, the student was involved in several field projects, including foliar sampling on cold-air pooling transects at the Bartlett Experimental Forest (Figure 37).

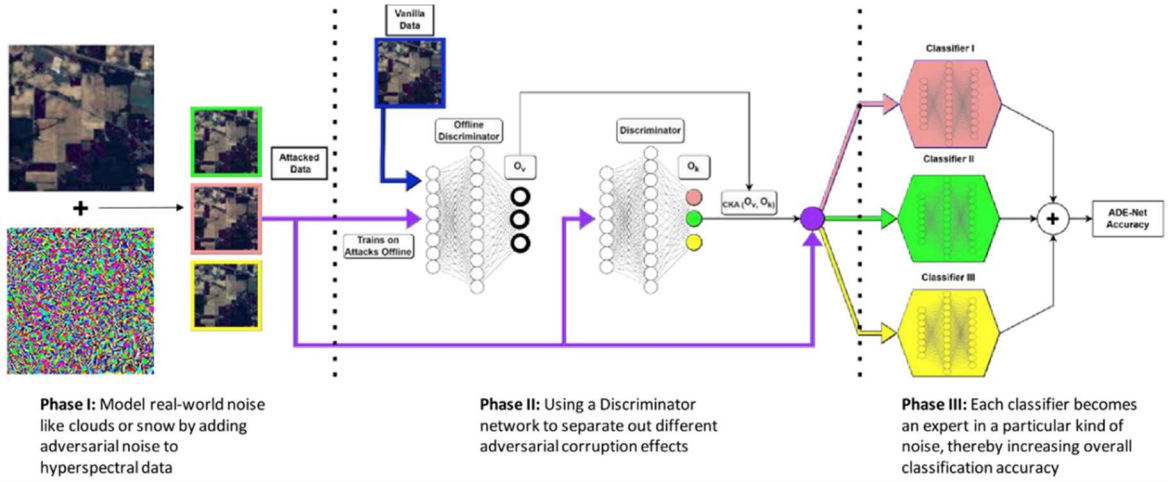


Figure 34. An Adversarial Discriminator Ensemble Network (ADE-Net) was developed to better deal with various kinds of noise in hyperspectral images.

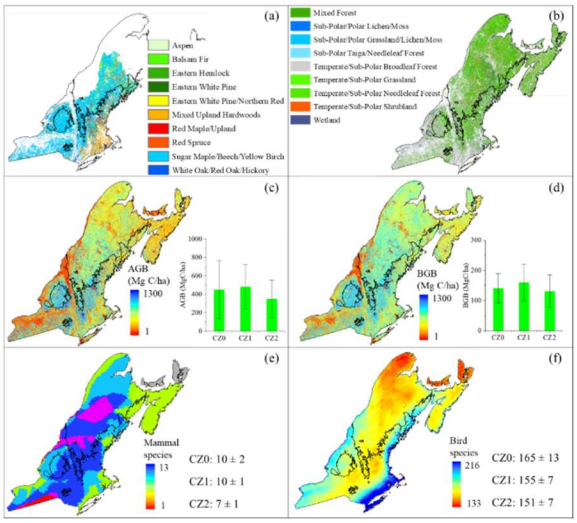


Figure 35. Relationship between regional climate zones with forest type map for the northeastern United States (a), the land cover map (b), the aboveground biomass (AGB) density (c), belowground biomass (BGB) density (d), mammal species richness (e), and bird species richness for the entire study area zones.

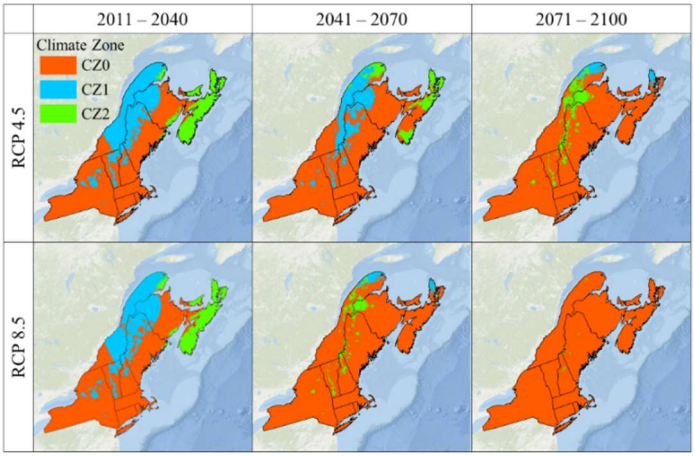


Figure 36. Climate zones delineated by using predicted climate normals for the three periods of 2011-2040, 2041-2070, and 2071-2100 under RCP 4.5 and 8.5 scenarios.

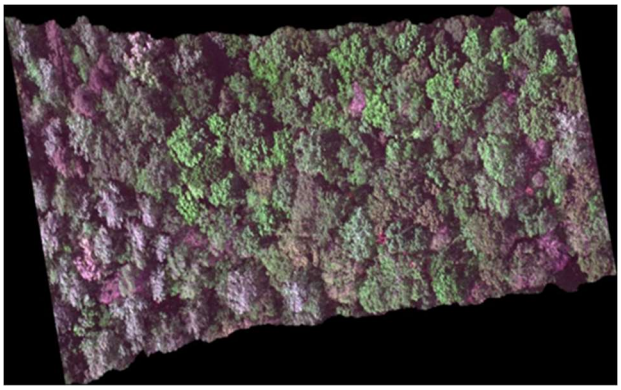


Figure 37. *[LEFT]* Relationship between regional climate zones with forest type map for the northeastern United States (a), the land cover map (b), the aboveground biomass (AGB) density (c), belowground biomass (BGB) density (d), mammal species richness (e), and bird species richness for the entire study area zones. *[RIGHT]* An undergraduate student from AAMU (Casey Mills) spent a week in New Hampshire over the summer. During the host period, the student was involved in several field projects, including foliar sampling on cold-air pooling transects at the Bartlett Experimental Forest.

Team Members

12 Faculty (7 Early-Career), 2 Professional Staff, 5 Graduate Students, and 1 Undergraduate Student; 15 ME, 4 NH, 1 VT, and 2 AL

Name	Affiliation	Jurisdiction	Institution	Early Career	Role
Abigail Forcier	Earth Systems Research Center	NH	UNH	N	Grad Student
Andrew Ouimette	Earth Systems Research Center	NH	UNH	Y	Faculty
Casey Mills	Department of Biological and Environmental Sciences	AL	AAMU	N	Undergrad
Christopher Jones	Department of Biological and Environmental Sciences	AL	AAMU	N	Grad Student
Darren Ranco	Department of Anthropology	ME	UMO	N	Faculty
Donna Rizzo	Department of Civil & Environmental Engineering	VT	UVM	N	Faculty
Emily Landry	Earth Systems Research Center	NH	UNH	N	Grad Student
Jane Pettit	Center for Research on Sustainable Forests	ME	UMO	N	Prof staff
John Hastings	Earth Systems Research Center	NH	UNH	N	Grad student
Kasey Legaard	Center for Research on Sustainable Forests	ME	UMO	Y	Faculty
Kate Beard-Tisdale	School of Computing and Information Science	ME	UMO	N	Faculty
Kingsley Wiafe-Kwakye	Department of Spatial Information Sciences and Engineering	ME	UMO	N	Grad student

Name	Affiliation	Jurisdiction	Institution	Early Career	Role
Leo Edmiston-Cyr	Center for Research on Sustainable Forests	ME	UMO	N	Prof staff
Marek Petrik	Department of Computer Science	NH	UNH	Y	Faculty
Mary Martin	Earth Systems Research Center	NH	UNH	N	Faculty
Nick Soucy	Department of Computer Science	ME	UMO	N	Grad student
Peter Nelson	Forest Ecology	ME	Schoodic Institute	Y	Faculty
Salimeh Yasaei Sekeh	School of Computing and Information Science	ME	UMO	Y	Faculty
Sam Roy	Mitchell Center for Sustainability Sciences	ME	UMO	Y	Faculty
Silvia Nittel	School of Computing and Information Science	ME	UMO	N	Faculty
Torsten Hahmann	School of Computing and Information Science	ME	UMO	Y	Faculty

Research Milestones Progress

Objective	Project	Project responsible parties	Year 4 Milestones	Milestone Progress
2.1	2.1a Extension of field model beyond in-situ sensors	Nittel, Petrik, Ranco	Extend methods for producing regional-scale spatial and better quantify uncertainty	Applied and tested multi-objective machine learning and automated geoprocessing algorithms to generate regional, high resolution tree species, forest type, and forest disturbance maps (Legaard)
2.2	2.2a Hybrid Semantic-statistical representation of forest places	Hahmann, Beard, Legaard, & Martin	Formalize select semantics (land use/land cover, forest type, maturity, water availability) in an ontology using input from Theme 3 to seed the semantically-enabled representation	Developed an NLP-based workflow to extract ecological preferences of species from existing text sources. (Hahmann)
	2.2b Provide spatial datasets for Theme 3 objectives	Hahmann, Beard, Martin	Test AI/ML methods to produce necessary spatial layers at scale and incorporate uncertainty	Expanded the "Digital Forest" framework for linking and querying various spatial datasets (Hahmann & Beard) Developed STAD ontology design pattern for capturing spatial and temporal uncertainty and precision (Hahmann & Beard)
	2.2c. Develop and evaluate alternative ML	Legaard, Roy, Yasaei	Compare existing and newly developed ML algorithms on	Developed Forest Ecology Ontology and tested their use with clustering

Objective	Project	Project responsible parties	Year 4 Milestones	Milestone Progress
	algorithms for analyzing spatio-temporal datasets		similar spatiotemporal datasets	methods to associate forest types with abiotic factors (Hahmann & Beard) Designed an ontology-driven user interface for exploring, reasoning and analyzing the data sets in the Digital Forest (Hahmann & Beard)
2.3	2.3a Analysis of forest place correlations and similarities	Beard, Legaard, Petrik, Hahmann, McGill, Roy, Ranco	Refine existing layers of regional climatic, forest type, disturbance, and potential productivity based on forecasted changes produced by Theme 3	Developed UAV data collection and processing pipeline for ground-truth validation of tree crown segmentation from high-resolution hyperspectral imaging (Nelson) Designed an adversial ensemble network to for more robust forest classification from hyperspectral images (Yasaei Sekeh)

Significant Problems/Unexpected Results/Novel Opportunities

- Availability of research equipment supplies
- Availability of cloud- or haze-free remote sensing imagery for New England

Future Plans

- Refinements and necessary bug fixes needed to finalize the lecospectR's API and functionality.
- Joint field season with AAMU graduate and undergraduate students planned.
- Regional expansion of tree species, forest type, and forest disturbance maps.
- Enhanced testing of the Digital Forest for its ability and usability to answer novel Forest-related questions.
- Ontology-based Machine Learning: Connecting the Digital Forest's Knowledge Graph with ML. algorithms to improve analytics capabilities and produce interpretable summaries of tree species, habitats and locations.
- Refinement of machine learning classifiers for tree crown segmentation.
- Strengthening cross-theme connections through use of remote sensing products and Digital Forest.

Theme 2 Project Report
UNH's Terrestrial Ecosystems Analysis Lab (TEAL)

TEAL accomplishments in Year 4 are highlighted by student-led efforts with active involvement of several UNH faculty including Co-PI Ollinger. Two major field campaigns were conducted this past year, primarily to support the research of PhD student, Jack Hastings. The first campaign was a Northeast region-wide foliar nitrogen sampling campaign to help improve satellite-based estimates of canopy nitrogen content. Sunlit foliage of dominant trees in plots spanning wide elevational, latitudinal, and longitudinal gradients were collected (Figure 38). This work also

Figure 38. UNH PhD student, Jack Hastings, collecting foliage samples for chemistry analysis.

served to provide canopy chemistry measurements for a UVM collaborative cold-air pooling project.

The second campaign focused on measuring through-the-canopy structural, chemical, and physiological traits for tree species at the Thompson Farm Earth Systems Observatory in Durham, NH. This data is being used to understand how species-level differences in canopy structure and foliage arrangement influence light capture and light use, influence canopy thermal regulation, and relate to foliar chemistry and physiological success. We combined detailed field sampling conducted from a mobile canopy lift with structural measurements derived from high-density UAV LiDAR (Figure 39).

MS student Emily Landry has been examining how climate patterns are changing across the Northeast US. She is analyzing how NOAA climate normal (min and max temp, precipitation) have changed in recent decades, and its implications for forest productivity across the region (Figure 40). In particular, the preliminary results both minimum and maximum temperatures to be increasing across region in all seasons, especially at higher elevations, while precipitation is also mostly increasing across region, except for higher elevations where it is decreasing in the winter. Both Emily and Jack presented results from their work at the NSF EPSCoR National Conference, the American Geophysical Union Conference, and multiple local meetings.

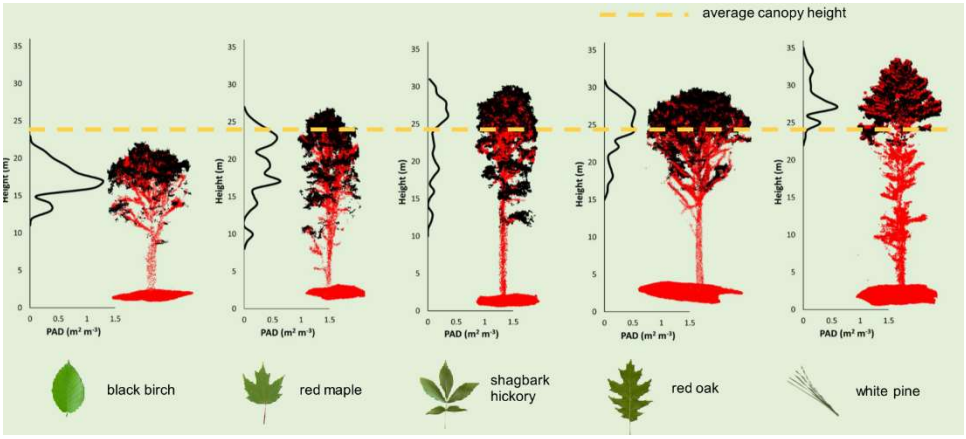


Figure 39. Use of high-resolution LiDAR data to examine species differences in 3D foliage distributions.

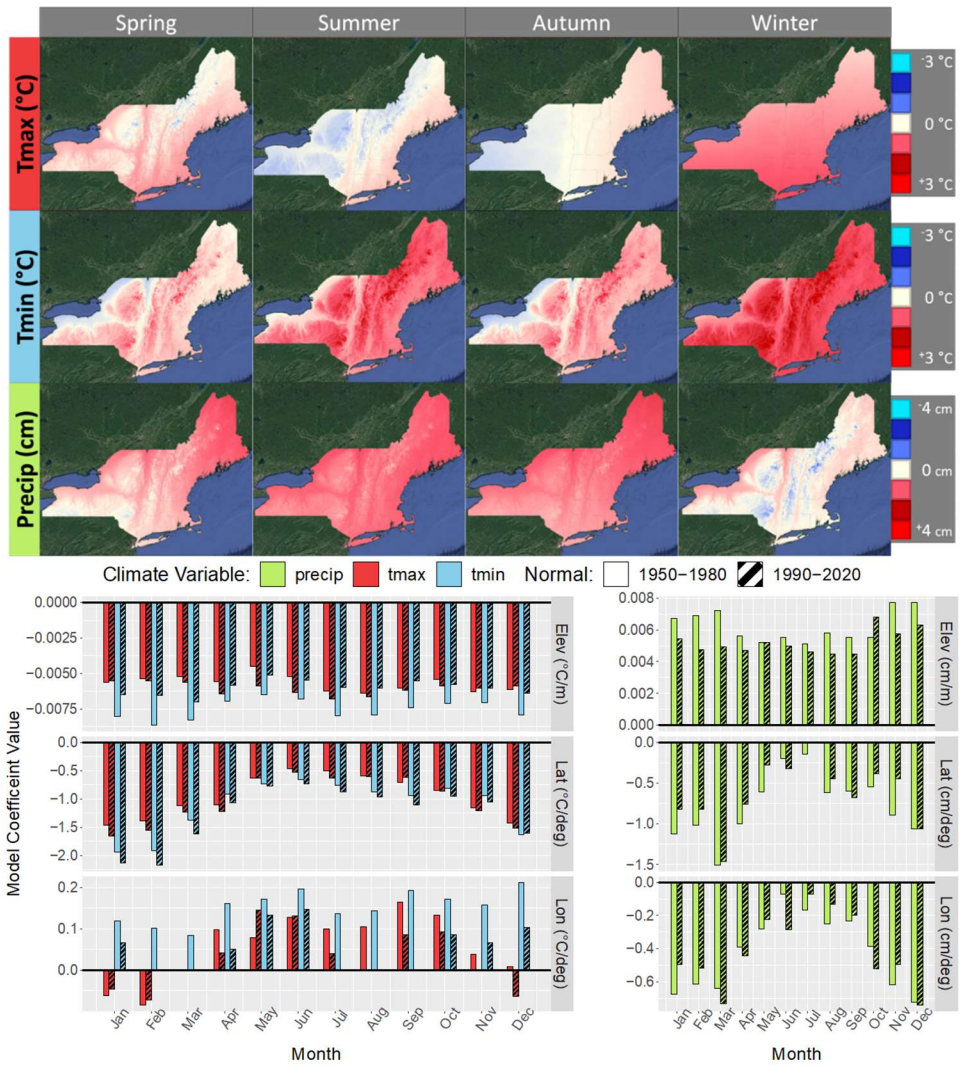


Figure 40. Regional changes in maximum/minimum temperature from 1950 to 2020 across New England (top) and the empirical relationship with elevation, latitude, and longitude (bottom).

Integrating/Building Synergies Among Jurisdictions & Themes

- Collaborated with Theme 1 members from UVM to collect foliar chemistry on cold-air pooling transects across Vermont, New Hampshire, and Maine (Figure 41Figure).
- Hosted an undergraduate student from AAMU for a week over the summer. During the host period, the student was involved in several field projects, including foliar sampling on cold-air pooling transects at the Bartlett Experimental Forest.
- Awarded an NSF ORCC grant to study the regions response to drought and the work will be in collaboration with AAMU (INSPIRES collaborators) and Smith College (Gersony former INSPIRES post-doc).

Broader Impacts

Figure 41. Theme 2 collaboration with Theme 1 members on cold-air plot sampling in New Hampshire.

- M.S. student Emily Landry and Ph.D. student Jack Hastings gave talks to third-grade classes at Moharimet Elementary School, in Madbury, NH, about their research and what it is like to be a scientist. Emily's talk focused on explaining the differences between weather and climate, and how scientists study climate patterns in the Northeast. Jack's talk focused on the different examples of remote sensing tools used by scientists to study changes in forests, including satellites, drones, and tower mounted cameras.
- Staff scientist Andrew Ouimette, Ph.D. student Jack Hastings, and Research Assistant Kaitlyn Baillargeon led two field tours of the Thompson Farm Earth Systems Observatory, in Durham, NH, for high school environmental science classes from Philips Exeter Academy. The field tour included discussion of the eddy flux tower instrumentation operating on site, and the ways we can use the data to study ecosystem responses to environmental stressors.
- Andrew Ouimette took a permanent research scientist position with the US Forest Service, Northern Research Station in Durham, NH.

Theme 3. Integrated Ecological Modeling

Background

The primary goal of this research theme is to integrate several complementary ecological models with information gained in Themes 1 and 2 to improve confidence in future projections of forest ecosystem processes and answer the overarching science questions our research is designed to address. The modeling framework will provide the means for organizing and scaling both the high spatio-temporal resolution data collected by this project's new sensor networks from Theme 1 and remote sensing data products developed by Theme 2. The focus of Theme 3 in Year 4 was continuing to (1) identify gaps in model representations of key ecological processes in PnET-II and LANDIS-II, particularly as they relate to carbon and nitrogen cycling and (2) evaluate as well as harmonize available model initialization data, particularly related to regional and local climate data that could be collected or modeled by Theme 1 or 2. By expanding LANDIS-II code base for LANDIS-II PnET-Succession module to incorporate nitrogen cycling routines, model improvements now provide for more realistic simulation of tree growth and species competition for light, water, and nitrogen. Collaborative interaction with Theme 1 to collect temperature sensor data along topographic gradients has filled important knowledge and data gaps. Canopy-level measurements to observe species differences in the optimum temperature range for photosynthesis and sun vs. leaf temperature demonstrated that leaf temperature can be substantially higher, which has important implications for growth predictions. In addition, working with undergraduate computer science capstone students, additional decision-support tools within the Forest Ecosystem Status and Trends (ForEST) web application were developed.

In Year 3, the primary focus was in constructing a common model initialization dataset for a variety of study locations in the region. This data and code will allow for effective model intercomparison assessments, which can help with future model refinement and integration plans. Currently, this model intercomparison is focused on three primary student locations including the Penobscot Experimental Forest in Maine, the Bartlett Experimental Forest in New Hampshire, and Victory State Forest in Vermont. This work has also involved researchers from each of the three jurisdictions including Drs. Erin Simons-Legaard (Maine), Jane Foster (Vermont), and Andrew Ouimette (New Hampshire). Through a shared website and code base, substantial progress has been made and was finalized in Year 4. In addition, Year 4 also saw the continued integration of AAMU researchers into Theme 3 with plans for using the Paint Rock study site in Alabama as a potential addition to the model intercomparison effort.

Theme 3 primarily consists of researchers who are developing a modeling framework that provides a means for organizing and scaling the high spatio-temporal resolution data collected by this project's new sensor networks from Theme 1 and remote sensing data products developed by Theme 2. The primary goal of Theme 3 is to advance a suite of ecosystem models and improve future projections of forest composition, productivity, and the capacity of forests to continue to provide critical ecosystem services to residents of the Northern Forest Region. To meet this overarching goal, researchers in Theme 3 have focused on five specific objectives including:

1) Integration of several unique models that vary in their ability to capture a range of drivers (e.g. climate, geology, management, and disturbance) and responses (e.g. forest composition and products, wildlife habitat, impact on climate, and water and nitrogen cycle effects).
2) Increasing model accessibility to students, researchers, and the forestry community through development of front-end code to standardize and simplify model parameterization and initialization.
3) Identification of model weaknesses and data gaps (including highlighting geographic regions where input data have high uncertainty).
4) Improving the representation of key ecological processes within models.
5) Application of updated models to quantify the impact of various stressors on ecosystem integrity indicators and predict change across Northern Forest Region under future scenarios.

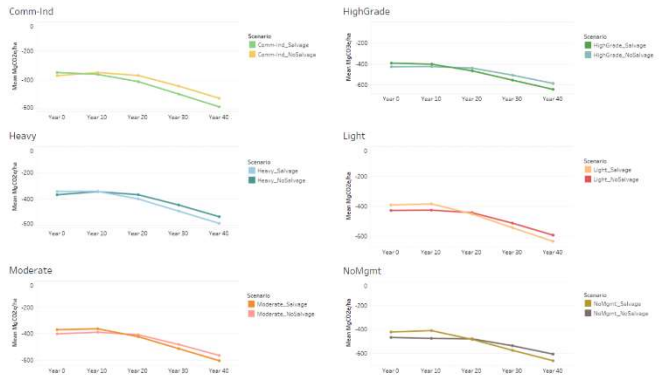


Figure 42. INSPIRES UNH Graduate student, Lisa Scott, projected influence on forest carbon with various levels of spruce budworm outbreak and salvage scenarios.

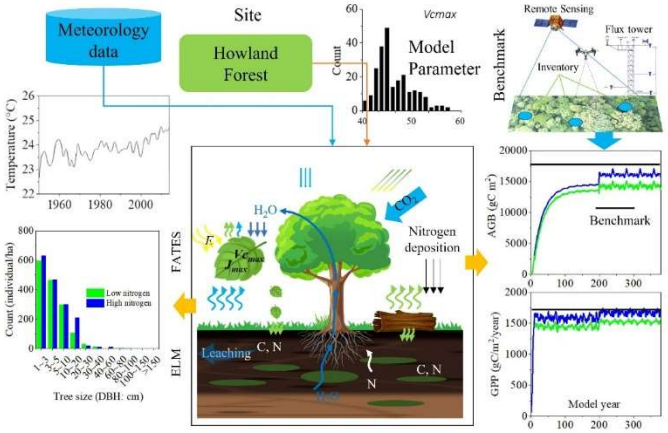


Figure 43. Benchmark performance of the parameterized ELM-FATES model and comparison with observations (flux tower, remote sensing data, and forest inventory) collected at Howland Forest in Maine.

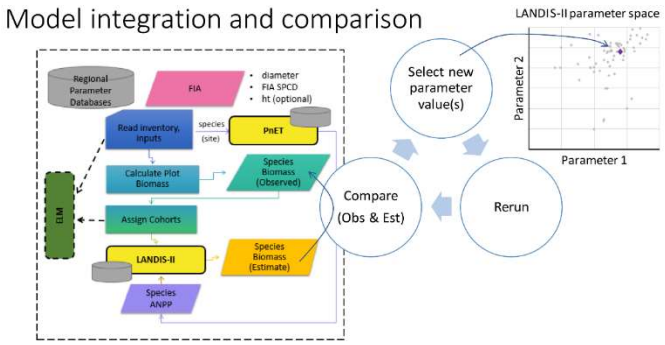


Figure 44. Bayesian inverse parameterization of the LANDIS-II using regional USFS FIA data.

Highlights

- ❖ Completion of new LANDIS-II extension that integrates the PnET-CN model and the LANDIS-II PnET-Succession model. This new extension allows users to model the effects of nutrient availability and tree species competition for nitrogen on forest succession.
- ❖ Completion of a new stand-alone model in Python in to assess the importance of various parameters on predicting nitrogen and carbon cycling in coarse dead wood. Model testing at long-term research site demonstrated the importance of correctly parameterizing the stoichiometric demands of the wood decay microbial community and accounting for time since disturbance in model inputs.
- ❖ Completion of a new study using FVS to evaluate the effects of alternative forest management strategies and salvage, in response to eastern spruce budworm, on future forest carbon.
- ❖ Graduate student-led development of INLeaf tool for outreach to agency practitioners regarding identification of sensitive habitat areas to inform tradeoffs associated with risk management associated with spruce budworm. (Figure 42).
- ❖ Cross-jurisdictional model intercomparison (MIC) working group completed prototype workflow (and code base) for initializing LANDIS-II from USFS FIA plot data and simulating site-level aboveground biomass. Additional code is being developed to generalize the framework to include initialization using inventory data from a range of sources, including NEON and LTER sites. This work has been led by researchers from each of the three jurisdictions including Drs. Erin Simons-Legaard (Maine), Jane Foster (Vermont), and Andrew Ouimette (New Hampshire).
- ❖ Initial site-level simulation with ELM-FATES model was completed and compared with observations (flux tower, remote sensing data, and forest inventory) collected at Howland Forest. Future work by the MIC working group will include framework extension to include ELM-FATES to allow comparison of site simulations to LANDIS-II (Figure 43).
- ❖ Cross-theme (Themes 2 and 3) working group completed changes in inverse parameterization of key LANDIS-II parameters for modeling future forest growth for USFS FIA inventory plots (Figure 44).

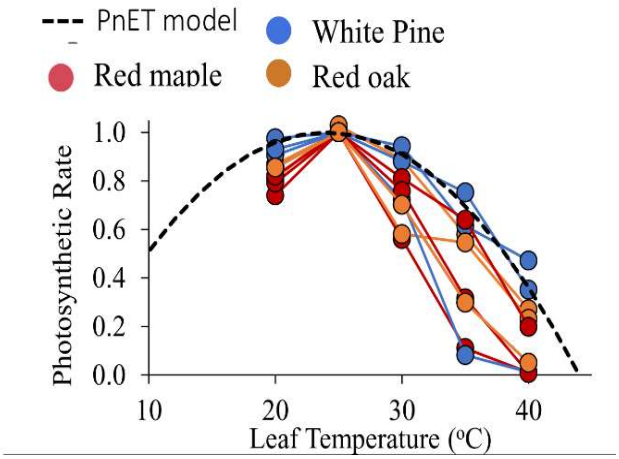


Figure 45. Theme 2 collection of canopy leaf temperatures during the growing season (left) and comparison to PnET model predictions by Theme 3 based on this data (right).

- Worked with early-career computer programmers to develop new interactive tools for ForEST, allowing users to upload existing boundary files of landowner properties or on-screen digitization of areas of interest for providing a summary of risk and ecosystem services.
- Canopy leaf temperatures collected by Theme 2 were compared with PnET model projections (Figure 45).
- Harmonized code-based workflow to initialize LANDIS-II model for additional long-term forest inventory plot data that includes NEON, USFS FIA, LTER, and other additional regional CFI plots.
- Refined how the cohort concept is derived for LANDIS-II and evaluate effects on model/biomass dynamics (Figure 46).
- Model intercomparison has highlighted key differences between approaches (Figure 47).
- Continued integration of AAMU researchers into Theme 3 with plans for using the Paint Rock study site in Alabama as a potential addition to the model intercomparison effort.
- Report qualitatively assessing model capabilities for modeling forest carbon was released (Figure 48).
- Report comparing long-term outcomes of alternative forest management regimes in northern Maine was released (Figure 49Figure).
- Acadian Variant of FVS was benchmarked against regional FIA data (Figure 50).

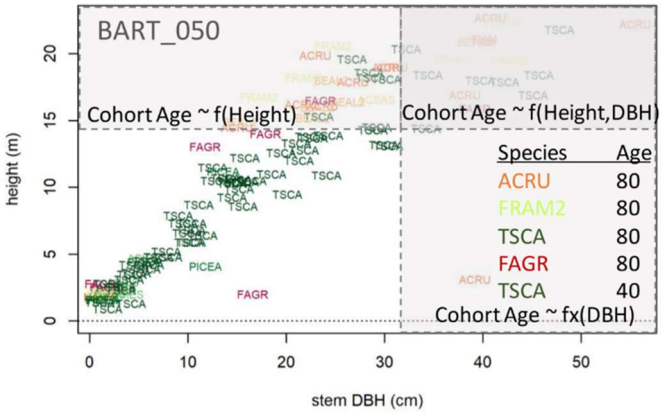


Figure 46. Refinement of cohort concept that relates tree height and diameter to age for common species in New England, which is important for the LANDIS-II model.

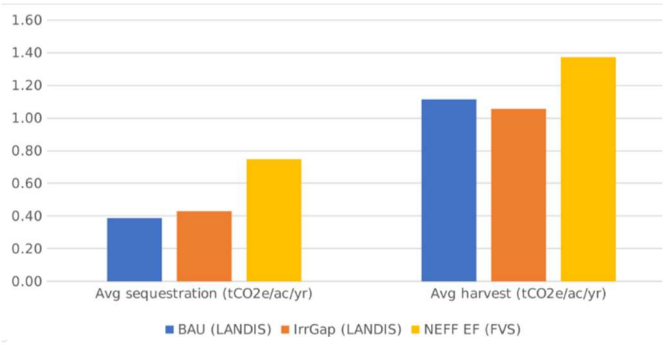


Figure 47. Comparison of average projected carbon sequestration and harvested in t CO_2 e per acre per year using LANDIS-II and Forest Vegetation Simulator in Maine under different management scenarios like business as usual (BAU), irregular gap (IrrGap), and exemplary forestry (EF).

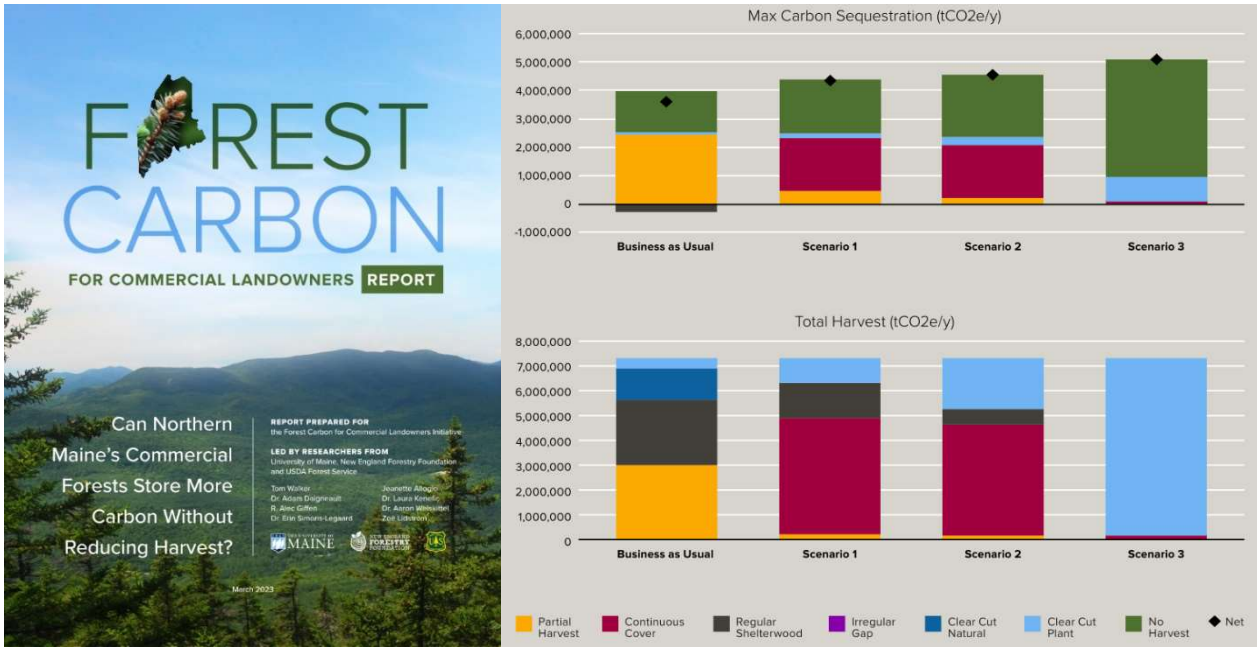
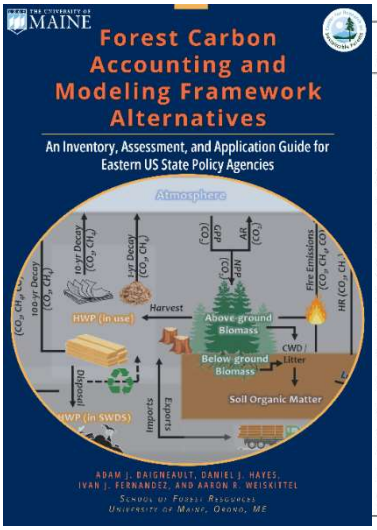


Figure 48. Large-scale projections of forest carbon sequestration potential in northern Maine under alternative management scenarios outlined by stakeholders.



Model Name	Usability Score	Complexity Score	Analytical Capability Score	Total Score
FVS	7.0	9.6	8.6	**8.4**
LANDIS-II	6.0	9.6	8.1	**7.9**
ForGATE	10.0	7.6	5.7	**7.8**
GTM	5.0	8.0	10.0	**7.7**
TEM6	6.7	8.0	8.3	**7.7**
CBM-CFS3	5.3	9.0	8.6	**7.6**
Open Stand Model	6.7	8.9	6.7	**7.4**
FASOM	3.3	8.0	10.0	**7.1**
Ecosystem Demography (ED2)	8.3	7.0	3.9	**6.4**
PnET	8.3	6.5	4.0	**6.3**
Biome-BGC	8.3	6.3	4.0	**6.2**
3PG	6.7	6.0	5.4	**6.0**
CLM5 / CLM-FATES	6.7	5.6	5.4	**5.9**
LURA	3.3	7.3	6.7	**5.8**
Woodstock / REMSOFT	0.3	7.9	6.7	**5.0**

Figure 49. Forest carbon modeling report that qualitatively assessed model suitability.

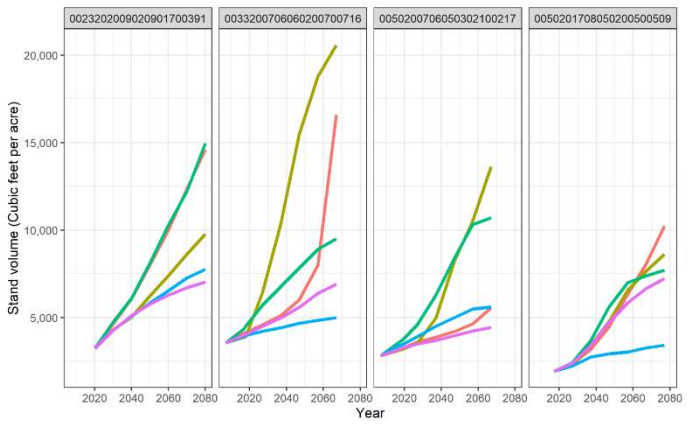


Figure 50. Comparison of long-term projections of stand total volume using alternative versions of the Acadian Variant of the Forest Vegetation Simulator (FVS-ACD) compared to the Northeast Variant of FVS (FVS-NE).

Team Members

12 faculty (8 early-career), 2 post-docs, 1 graduate student, 2 Research Staff; 7 ME, 3 VT, 7 NH, and 2 AL

Name	Affiliation	Jurisdiction	Institution	Early Career	Role
Aaron Weiskittel	Center for Research on Sustainable Forests	ME	UMO	N	Faculty
Andrew Ouimette	Northern Research Station	NH	US Forest Service	Y	Research Scientist
Anthony D'Amato	Rubenstein School of Environment and Natural Resources	VT	UVM	N	Faculty
Cen Chen	Department of Biological and Environmental Sciences	AL	AAMU	Y	Post-doc
Daniel Hayes	School of Forest Resources	ME	UMO	Y	Faculty
Elizabeth Burakowski	Institute for the Study of Earth Oceans and Space	NH	UNH	Y	Faculty
Erin Simons-Legaard	School of Forest Resources	ME	UMO	Y	Faculty
Jane Foster	Southern Research Station/Rubenstein School of Environment and Natural Resources	TN/VT	US Forest Service/ UVM	Y	Faculty
John Gunn	Department of Natural Resources and the Environment	NH	UNH	Y	Faculty
Kathy Crowley	Unity College	ME	Unity	Y	Faculty
Lisa Scott	Department of Natural Resources and the Environment	NH	UNH	N	Grad Student
Luben Dimov	Rubenstein School of Environment and Natural Resources	VT	UVM	N	Faculty
Mark Ducey	Department of Natural Resources and the Environment	NH	UNH	N	Faculty
Shaik Hossain	Department of Biological and Environmental Sciences	AL	AAMU	Y	Faculty
Scott Ollinger	Earth Systems Research Center	NH	UNH	N	Faculty
Xinyuan Wei	School of Forest Resources	ME	UMO	Y	Post-doc
Zaixing Zhou	Earth Systems Research Center	NH	UNH	Y	Research Staff

Research Milestones Progress

Objective	Projects	Project responsible parties	Year 3 Milestones	Milestone Progress
3.1	3.1a Inverse parameterization of ecological models	Foster, Simons-Legaard	Complete model inverse parameterization using regional landscapes and evaluate model uncertainty at broad spatial or temporal scales	Finalized code for completing a model inverse parameterization and has been initialized using regional FIA data Model intercomparison has continued at several key study sites throughout the region and highlighted key model differences
3.2	3.2a Model integration and application	Hayes, Burakowski, Ollinger	Complete model integration and evaluate performance on test landscapes Apply integrated model to broader region	Finalized Integration of PnET and LANDIS-II models with v5 officially release and code made publicly available via GitHub Continued refinement of nutrient cycling dynamics under alternative climates
3.3	3.3a Scenario assessment & trend analysis	Weiskittel, D'Amato, Ducey, Gunn	Refine and finalize scenarios Complete model projections and evaluation outcomes Present to stakeholders for input and feedback	Climate change scenario projections finalized in Maine Alternative management scenarios and outcomes in Maine published and presented to a variety of stakeholders Decision-support tool for spruce budworm management being finalized

Significant Problems/Unexpected Results/Novel Opportunities

- Instability of US Forest Service, Forest Inventory and Analysis' FIA DataMart, which has delayed access to core files needed for analysis.
- Early withdrawal of a grad student focusing on Theme 3 work resulting from COVID-related challenges.
- Availability of new data from Paint Rock study site in Alabama.
- Integration of data preparation and modeling approaches from multiple research groups that span multiple scripting languages (e.g. C++, Matlab, Python, R, etc.).

Future Plans

- Complete multi-model integration that links alternative model frameworks (Figure 51).
- Complete inverse parameterization of select LANDIS-II parameters from FIA plot data.
- Conduct multi-model comparison of biomass estimation.
- Finalize ELM-FATES model development for the Northern Forest Region.
- Complete regional initialization data from Theme 2 data products.

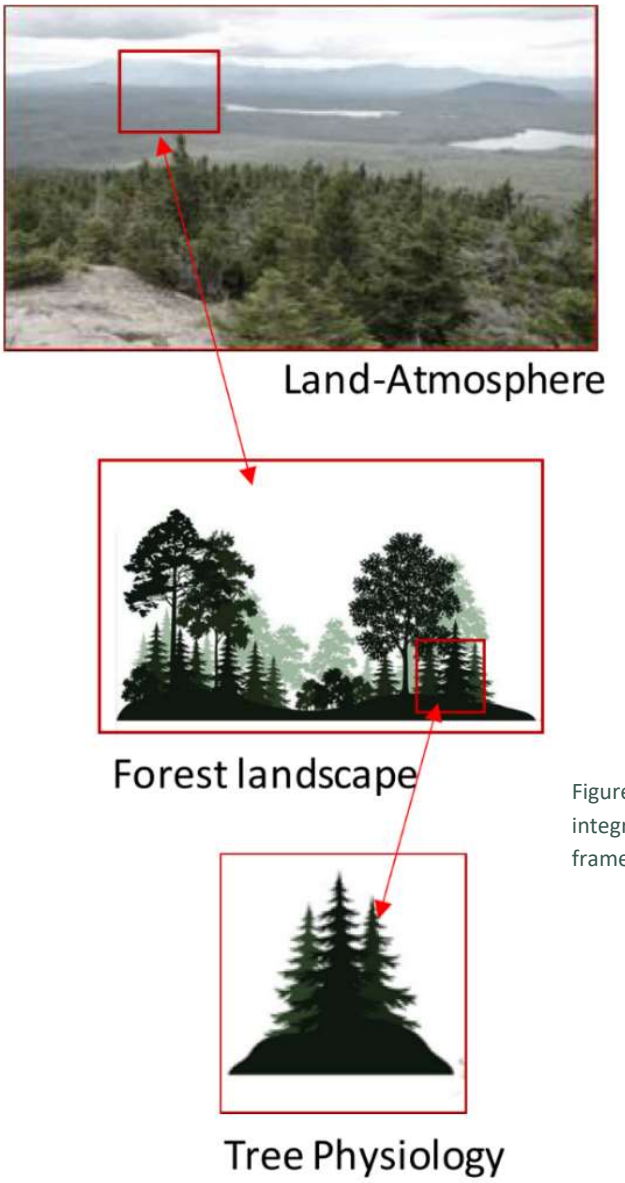


Figure 51. Multi-model integration linking model frameworks.

Theme 4. Quantitative Reasoning in Context

Background

Theme 4 is focused on building a collaborative three-state team and putting into place strategies for connecting classroom teachers with the work of INSPIRES. Progress in the first few years of the project included collaboration across the project themes by attending through monthly meetings, developing collaborative research across the three northern states, recruiting teachers from VT, ME, and NH into the project, and working with members of the other project themes to design professional learning opportunities for teachers that will support lesson development for classrooms in ME, NH, and VT. In Year 3, Theme 4 conducted a professional learning workshop focused on Quantitative Reasoning in Context (QRC) with regional teachers and INSPIRES researchers, while UVM faculty Dr. Regina Toolin designed and teaches a graduate-level course to support STEM teachers to incorporate QRC, forestry topics, Big Data and TEK into their classroom activities.

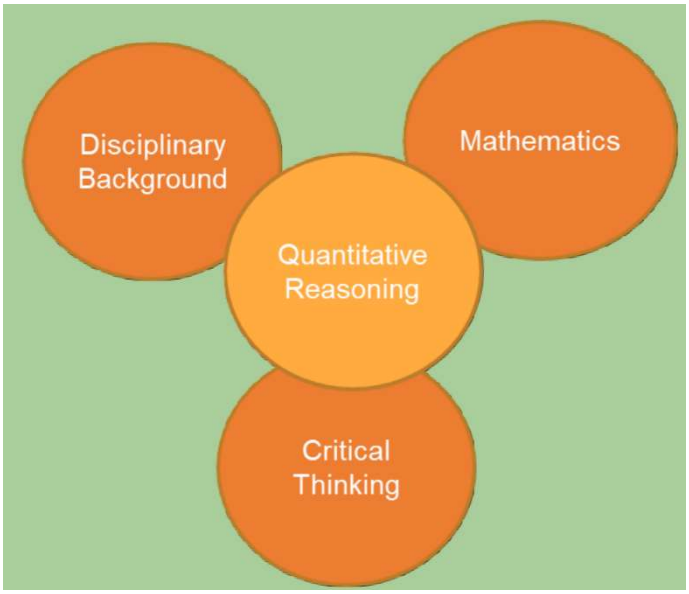


Figure 52. Conceptual linkages to key student's skills accomplished through quantitative reason in context (QRC).

In Year 4, a number of small working group meetings included invited researchers from Themes 1-3 to discuss INSPIRES-related publications that might offer teachers more context and background information about the broader project's research outcomes. Theme 4 members continued to work with teachers from ME (5 high school teachers) and VT (8 middle and high school teachers) on lesson development, piloting, and refinement. The research team has also developed interview protocols for both teachers and scientists who have worked with Theme 4 over the course of the project. These interviews are currently taking place and will be used to inform future manuscripts. The team is currently gearing up for a final in-person team meeting with Theme 4 and teachers in Vermont in June 2023.

Highlights

- A second professional learning workshop led by the Theme 4 team members Sara Lindsay, Marina Van der Eb, Regina Toolin, and Susan McKay was held in July 2022 in Old Town, ME. Workshop content included learning about components of Quantitative Reasoning in Context, placing forest sensors and gathering data, and group work and planning for classroom activities (Figure 52).
- The workshop involved scientists from other INSPIRES themes including Alix Contosta (UNH).
- Strong network of teachers across the region formed and remain interested in continuing to interact after the project ends (Table 5).
- Over 14 INSPIRES project participants outside of Theme 4 have engaged with the teachers.
- Teachers are now piloting lessons learned over the past 2 years in their classrooms.
- Cross theme working group collaborations have developed with scientists Alix Contosta, Liz Burakowski, and Melissa Pastore.
- Regina Toolin is leading second year of the UVM graduate course with all VT teachers enrolled.
- Small working groups met asynchronously during fall focused on learning experiences.
- Continued regular whole group meetings.

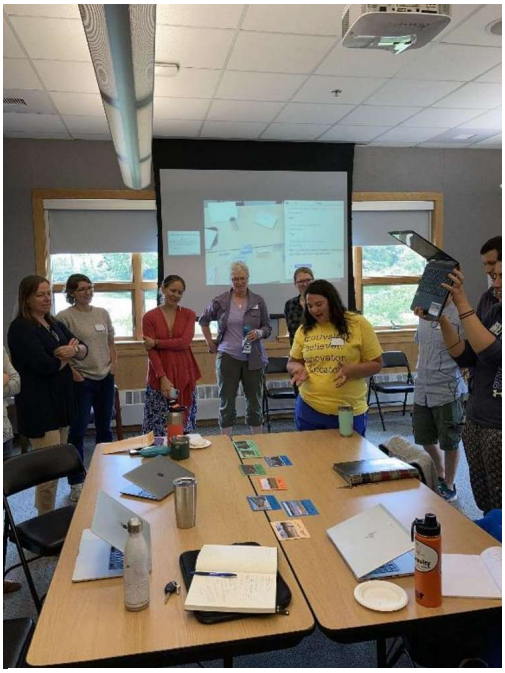


Figure 53. Participants in the INSPIRES Teacher Graduate Course offered at the University of Vermont, which explored pedagogical approaches, including place and project-based learning and culturally relevant pedagogy.

- ❖ Continue to interview teachers—learning experience development, QRC and how it may have changed during this project, reflect on being part of the research practice partnership.
- ❖ Feedback sessions were organized and conducted on: (1) content and flow of the different learning objectives; (2) details for publication dissemination.
- ❖ Chrissy Siddons is interviewing INSPIRES scientists from across the themes to reflect on the current partnership and how to make future collaborations and partnerships between teachers and scientists successful.
- ❖ An INSPIRES Teacher Graduate Course was offered; it is designed to continue to foster a professional learning community that engages in critical dialogue and reflection about the nature of science and scientific research, forest ecology, natural communities, traditional ecological knowledge, big data, and quantitative reasoning in context (Figure 53).
- ❖ A NEERO proposal was developed and accepted to help sustain future efforts of this research theme.
- ❖ New sensor suites were established at Vermont Commons School and Van Buren High Schools with mentorship from Theme 1 scientists.
- ❖ Forest data website is being curated to translate theme data to make them teacher and student friendly (Figure 54).
- ❖ INSPIRES scientists helped high school teachers and students measure and predict forest carbon using established protocols, including how to measure canopy density with low cost densiometers (Figure 55).
- ❖ Spring teacher working groups will look at climate and environmental science (high school) and sensors and math integration into science (middle school).
- ❖ Poster on integrating QRC skills in the context of forest research was presented at annual Maine STEM educators conference (Figure 56).
- ❖ Established 4 additional sensor sites at or near schools with 2 more planned.
- ❖ Building awareness of Traditional Ecological Knowledge with connections to Wabanaki Youth in Science (WaYS) Coordinator tish carr.

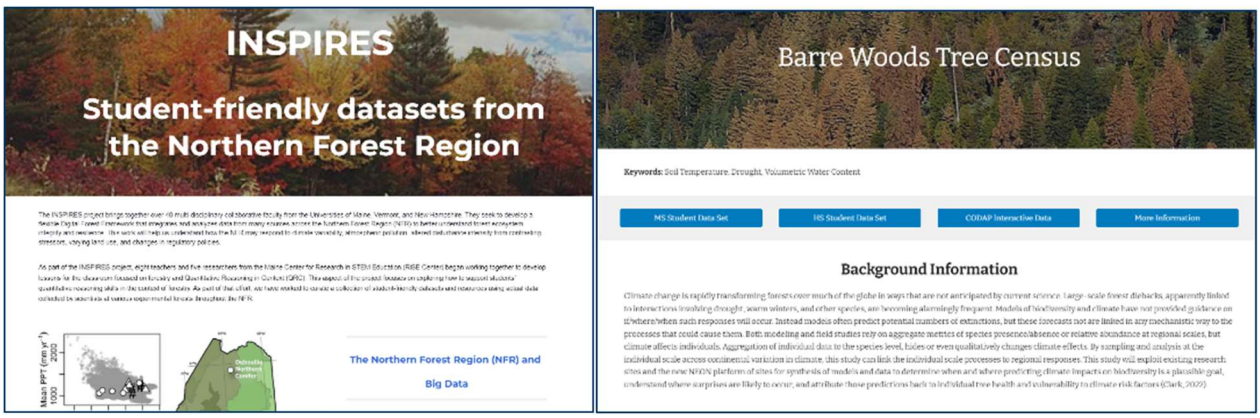


Figure 54. Theme 4 is developing websites to be used by high school students and teachers across the region for sharing data.

Figure 55. INSPIRES high school science teachers visit the Old Town, ME sensor site in July 2022.

Table 5. Network of Teachers and INSPIRES Project Researchers

Teachers	Project Collaborators External to Theme 4
Maine (6) • Dylan Harry • Ruth Poland • Amy Sidell • Laurie Spooner • Betsy Trenckmann • Ed Lindsey *Vermont (8)* • Meagan Denardo • Dave Cutler • Peter Goff • Bryn Keenhold • Morgan LaPointe • Andrew Malaby • Dave McNally • Erin Wysolmerski	*Maine (8)* • Aaron Weiskittel • Peter Nelson • Emily Uhrig • Torsten Hahmann • Tony Guay • tish carr • Leo Edmiston-Cyr • Meg Ferguson *Vermont (3)* • Jane Foster • Melissa Pastore • Karin Rand *New Hampshire (4)* • Andrew Ouimette • Alix Contosta • Liz Burakowski • Jack Hastings *Alabama (1)* • Dawn Lemke

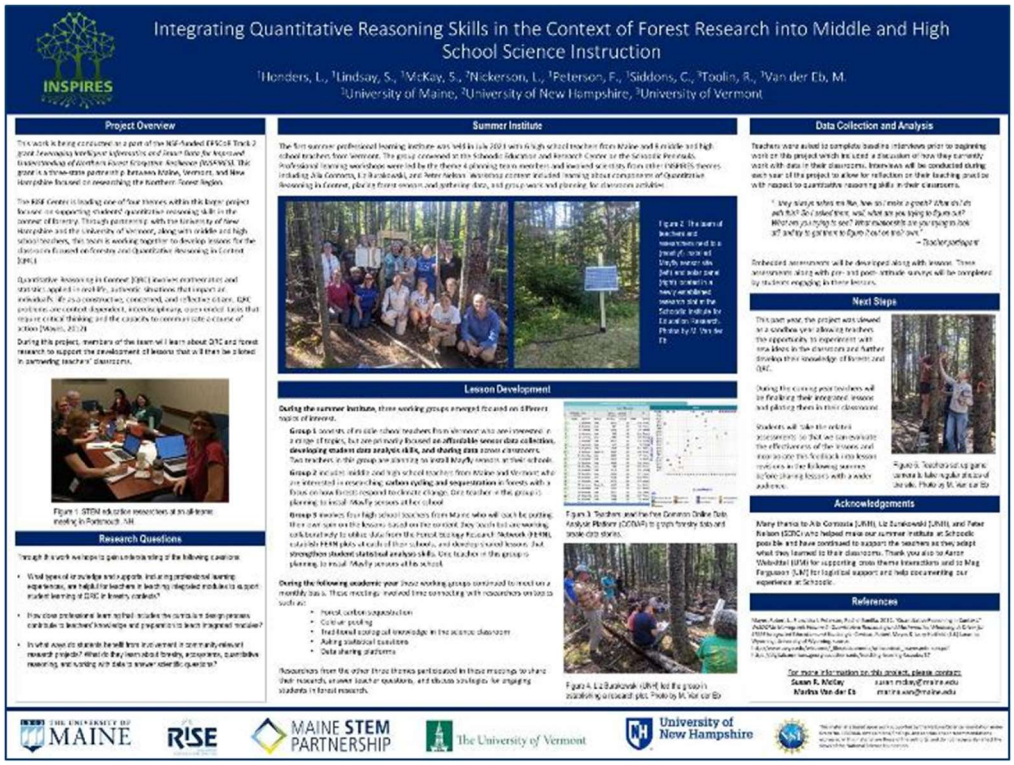


Figure 56. Theme 4 conference poster presented at the annual Maine STEM Educators conference in October 2022.

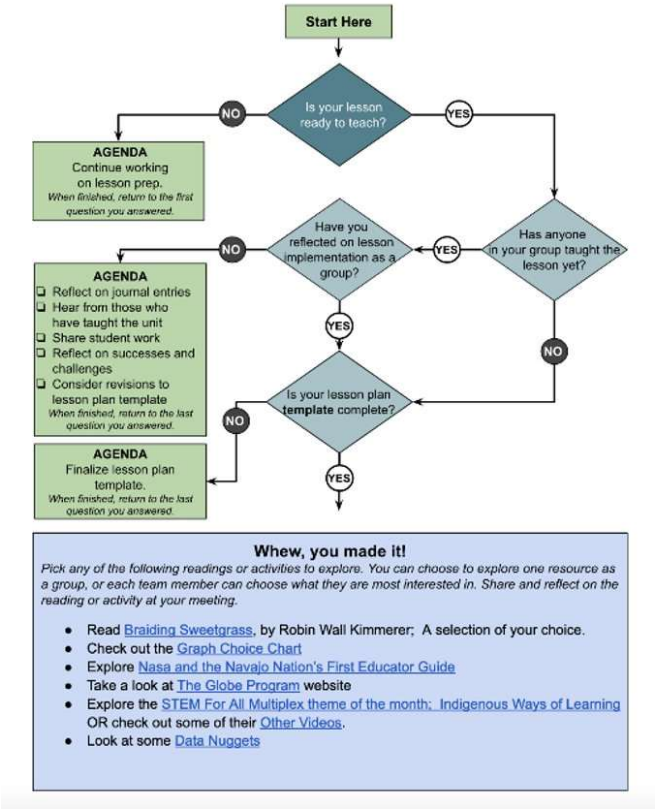


Figure 57. A meeting planner to help Theme 4 high school teachers organize their work and curriculum development.

- Sub-teams of Theme 4 researchers and high school teachers were formed: (1) Climate; (2) Environmental Science; (3) Sensors; and (4) Math Integration.
- Meeting planner was developed to help curriculum content development (Figure 57).
- High school science teacher and student posters were presented at symposium that included INSPIRES researchers (Figure 58).
- Location and contact information for all participating high school science teachers incorporated into the INSPIRES's online collaborative tool INLeaf to increase potential interactions between researchers and science teachers.

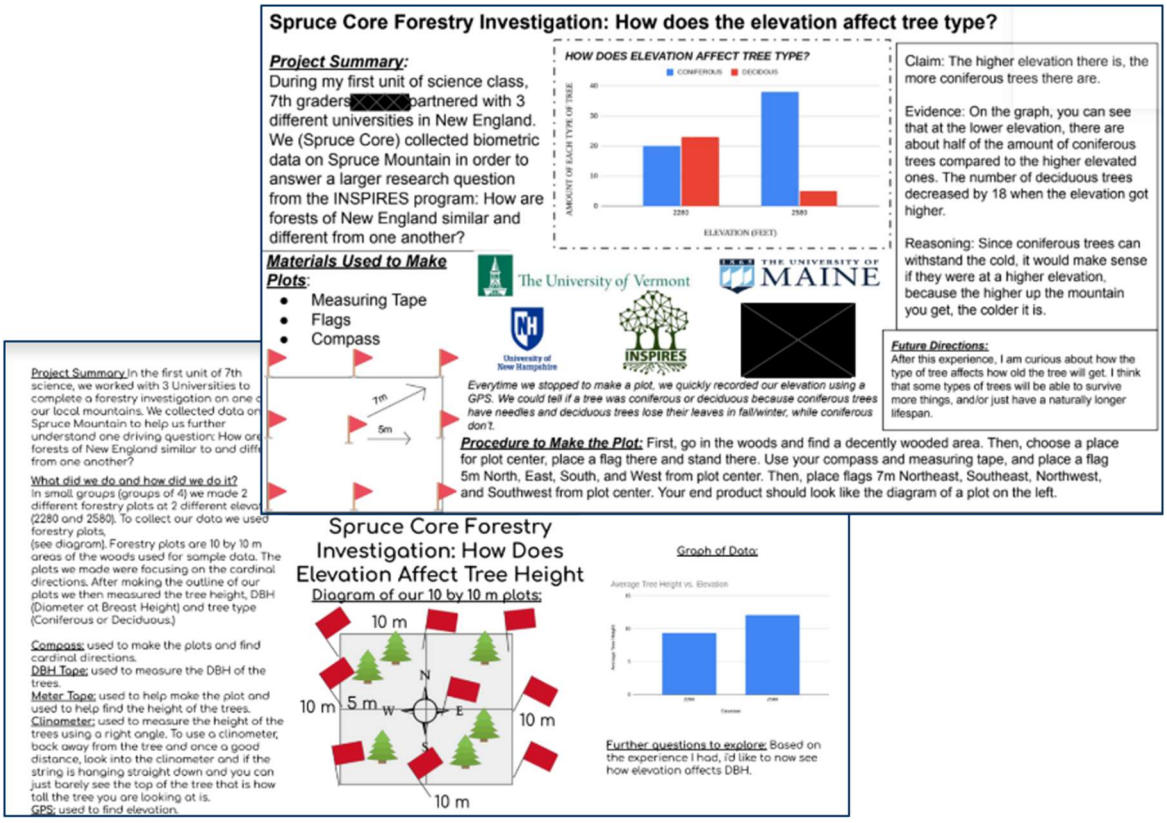


Figure 58. Teacher and student posters presented at regional science symposiums that included INSPIRES researchers.

Team Members

- 5 Faculty (2 Early-Career), 3 Professional Staff, and 1 Graduate Students; 7 ME, 1 VT, and 1 NH.

Name	Affiliation	Jurisdiction	Institution	Early Career	Role
Chrissy Siddons	Maine Center for Research in STEM Education	ME	UMO	N	Professional Staff
Franziska Peterson	Maine Center for Research in STEM Education	ME	UMO	Y	Faculty
Gabby Holt	Maine Center for Research in STEM Education	ME	UMO	N	Professional Staff
Liz Burakowski	Earth Systems Research Center	NH	UNH	Y	Faculty
Kelsey Davis	Maine Center for Research in STEM Education	ME	UMO	N	Grad Student
Marina Van der Eb	Maine Center for Research in STEM Education	ME	UMO	N	Professional Staff
Regina Toolin	College of Education and Social Services	VT	UVM	N	Faculty
Sara Lindsay	School of Marine Sciences	ME	UMO	N	Faculty
Susan McKay	Maine Center for Research in STEM Education	ME	UMO	N	Faculty

Research Milestones Progress

Objective	Project responsible parties	Year 4 Milestones	Milestone Progress
4.1 Design and implementation of Big Data modules integrated into G6-12 curricular material	Peterson, Toolin, Millay, Lindsay, McKay, Shulman, Nickerson	Curricular materials and lessons learned are disseminated across the education networks of ME, NH, and VT Region's workforce continues to benefit from the educational skills developed by project personnel, as well as from the enhanced skills of students impacted through middle and high school instruction	Curriculum materials developed and used in the classroom across the region Regular network meetings with teachers to discuss science and potential curriculum content Student surveys and classroom assessment of developed curriculum materials are being administered and analyzed for effectiveness

Objective	Project responsible parties	Year 4 Milestones	Milestone Progress
4.2. Use local Big Data to answer student- and community-relevant science questions	Peterson, Toolin, Millay, Lindsay, McKay, Shulman, Nickerson	Education research contributes to understanding of the knowledge and supports teachers need to support quantitative reasoning in context in their classrooms	Interviews with both high school science teachers and researchers being conducted to identify potential participation and implementation barriers
4.3. Use of local Big Data to answer student- and community-relevant science questions	Peterson, Toolin, Millay, Lindsay, McKay, Shulman, Nickerson	Teachers develop an understanding of the integration of big data, forestry, and quantitative reasoning in context; interviews provide evidence of learning for project research	Websites created for housing available data and showcasing examples of using the data Teacher posters highlighting alternative research using local data presented at a regional conference

Significant Problems/Unexpected Results/Novel Opportunities

- Trying to catch up with workshops meetings that were delayed due to COVID.
- Recruitment of teachers in Alabama and New Hampshire remains a challenge, but efforts are underway.

Future Plans

- Teachers continue to pilot and refine lessons they designed in their classrooms and administer student surveys/classroom assessments.
- Continue holding Theme 4 meetings monthly throughout the academic year.
- Host a third summer learning professional learning workshop in Burlington, Vermont in June 2023 with teachers, Theme 4 team members, and Theme 1-3 collaborators.
- Complete interviews with interested teachers to reflect on project implementation and lesson development.
- Complete reflective interviews with some researchers across all four themes who have worked with Theme 4 teachers in a more involved capacity.
- Finalize and disseminate lesson documents via the Maine STEM Partnership website for other teachers to access and use.
- Present research at NEERO conference in May.
- Disseminate lessons through workshops at annual RiSE Center (ME) conference in June.
- Submit publications to teaching journals that share lesson development process and provide access to lessons.
- Continue to build out the data website.
- Develop and submit additional manuscripts with INSPIRES cross-theme collaborators.
- Future work/proposal: incorporate measures of student impacts.

PROJECT OUTCOMES

Inter-jurisdictional and multi-institutional research collaborations are a key focus of the NSF EPSCoR RII Track-2 program. The INSPIRES project promotes such collaborations by enabling its participants to work across four integrated research themes. Responses from the external review committee recognized this as a unique strength of the INSPIRES effort and the majority of participants noted new collaborations as a result of the project (see Evaluation section).

Project participants are encouraged to work on or across more than one theme or research project, and this has resulted in several important project outcomes, including 2 intra- and 7 inter-jurisdictional publications, respectively, in Year 4. In addition, the NSF EPSCoR RII Track-2 program is intended to enhance research competitiveness and develop research capacity by increasing access to knowledge, expertise, equipment, and collaborators through the participation in collaborative research networks. This has not only happened between jurisdictions but has also occurred within jurisdictions. For example, INSPIRES has resulted in 32 intra- (5 awarded) and 19 inter- (3 awarded) jurisdictional proposals through Year 4.

In Year 4, research products included 11 (8 published; 3 in press) peer-reviewed articles, 21 presentations, 5 data/model/technology products, and 19 proposals (11 funded) (Appendix 1. Products Year 4). The publications were in top tier ecological and remote sensing journals including *Ecology* (IF = 4.7), *Forest Ecology and Management* (IF = 4.4), *Journal of Big Data* (IF = 1.12), and Frontiers in *Forests and Global Change Forest Management* (IF = 4.0). Several of the publications were multi-author and interjurisdictional (4) that included INSPIRES trainees, early-career, and senior faculty as co-authors. Overall, INSPIRES has resulted in 46 peer-reviewed publications through Year 4 with the majority (28) being interjurisdictional with either early-career, female, and/or student involvement (46%). Although the number of presentations has increased in the last two years (Year 3 = 10 and Year 4 = 20), the total number for the project is relatively low (54), reflecting the lack of regional or national conferences due to the pandemic. As outlined earlier, the INSPIRES team has identified several new potential publications and this will be a primary focus in the remainder of Year 4 and potential no-cost extension. In addition, the Year 4 presentations were primarily by INSPIRES early-career faculty or professional staff (6) and trainees (9) at regional (4), national (6), and international (2) meetings.

The number and size of proposals submitted in Year 4 was much higher than Year 3 as the focus has continued to shift to larger competitive grants. As of May 2023, INSPIRES researchers have submitted a total of 19 proposals with $19,970,765 in requested funding (compared to 8 proposals requesting $23,733,100 in Year 3). Based on these submissions, 12 projects were awarded ($13,845,442) and 4 pending ($2,659,791). Several Year 4 proposals were led primarily by early-career faculty (6) and were submitted to a variety of sources including the National Science Foundation (4) and other Federal agencies (9). Four of the awarded proposals were inter-jurisdictional and totaled $12,250,602 in funding. Details on the specific research proposals and Year 4 awards are provided in Table 6.

Table 6. Year 4 Proposals and Funding Status

PI/CO-PIs	Proposal Title	Funding Organization	Amount Requested	Status	Amount Awarded
Ollinger, S. Gersony, J., Lemke, D. [+]	Collaborative Research: ORCC: Investigating drought and cold resilience of northeastern US trees to inform ecological modeling and forest management practices	NSF	$1,252,547	Awarded	$1,252,547

PI/CO-PIs	Proposal Title	Funding Organization	Amount Requested	Status	Amount Awarded
Hayes, D. *	Citizens to Satellites: Developing an Earth-surface to Space-based Monitoring Framework for Maine's Natural Resources	NASA	$11,279	Awarded	$11,279
Weiskittel, A., Varahramyan, K., De Urioste-Stone, S.M., Moeykens, S. and Whitney, B	Maine EPSCoR RII Track-1 Planning Grant.	NSF EPSCoR	$100,000	Awarded	$100,000
Wason, J., Fraver, S., Hayes, D. *, Rogers, N., and Nelson, P. *	Management and conservation of coastal spruce forests for resilience to rapid warming	USDA-NIFA Agriculture and Food Research Initiative	$643,848	Awarded	$643,848
Hayes, D.	NAIP-EFI: Investigating the use of new 3-D canopy surface model data sets from the National Agricultural Imagery Program in developing Enhanced Forest Inventory products in Maine	Cooperative Forestry Research Unit	$104,444	Awarded	$104,444
Weiskittel, A., Premer, M. *, Daigneault, A., and Hayes, D.	Evaluation of model differences for forest carbon projections: A synthesis and assessment of current state of the knowledge	NCASI	$30,000	Awarded	$30,000
Short, J., Reynolds, J.W., McGowan, C., Watson, E., Bowman, B., O'Neill, S.R., D'Amato, A.W., Ducey, M., Fast, A., Weiskittel, A. +	Coalition of Northern Forest Innovation and Research (CONFIR).	NSF Regional Innovation Engine Type-1	$998,055	Awarded	$998,055
Lutz, D. *, Nelson, S., Contosta, A. * +	Managing for the cold: Examining the linkage between adaptive harvest and sub-canopy snow retention at Maine Adaptive Silvicultural Network research sites	Cooperative Forestry Research Unit	$142,408	Declined	-
Fei, S., Weiskittel, A., Bettinger, P.	Promoting Economic Resilience and Sustainability of the Eastern US Forests (PERSEUS)	USDA Sustainable Agriculture Systems	$10,000,000	Awarded	$10,000,000
Wei, X. * and Hayes, D.*	Enhancing forest adaptation, carbon stock, and timber production under drought stress in Maine, USA	Cooperative Forestry Research Unit	$22,750	Declined	-
Ward, J., O'Neill, S., Beaupre, J., Hart, D., Silka, L. Crawley, A., Bailey, M., Weiskittel,	Forest Bioeconomy Cluster Coordination & Acceleration	EDA BBBRC Component Project Cluster Managment	$9,618,966	Declined	-

PI/CO-PIs	Proposal Title	Funding Organization	Amount Requested	Status	Amount Awarded
A., Daigneault, A., and Simons-Legaard, E.*					
Sekeh, S. *	AI-Carb: An AI-based High-Resolution Carbon Flux Monitoring and Simulation Platform	NASA	$25,000	Pending	-
Sekeh, S. *	DSFAS: Advancing AI Technology for Sustainable and Climate-Smart Agriculture	USDA	$799,990	Declined	-
Hahmann, T.*	SEI: An Innovative Research Practice Partnership to Integrate Computer Science and Technology with Authentic Science Learning in Grades 6-8: A Model for State-Wide Scaling	NSF	$3,500,000	Declined	-
Ranco, D.	Partnerships for Climate Smart Commodities	USDA	$635,559	Pending	-
Ranco, D.	Wabanaki Climate Change Adaptation	NSF	$50,000	Awarded	$50,000
Ranco, D.	Building a community of interest and response to the Emerald Ash Borer threatening Maine's ash trees and Wabanaki lifeways	USDA	$300,000	Awarded	$300,000
Ranco, D.	Building Stewardship Capacity: Protecting the Brown Ash of the Northern Forest	USDA	$94,679	Awarded	$94,679
Hayes, D.*	Impacts of winter climate extremes on carbon sequestration and productivity of ecosystems in the Northeast	DOE	$999,616	Pending	-
Hossain, S.*, Chen, C.*	Patterns in natural regeneration of shortleaf pine (*Pinus echinata* Mill.) across the southeastern United States facing climate change	USDA	$260,590	Awarded	-
	Total Submitted (19)		**$19,970,765**		
	Total Pending (4)		**$2,659,791**		
	Total Awarded (12)		**$13,845,442**		

*Early-career faculty

[+]Inter-jurisdictional proposal

Inter-jurisdictional Collaboration

A key tenet of the INSPIRES effort is to ensure and enhance successful inter-jurisdictional collaboration across the primary institutions, which has been a significant challenge created by the ongoing global pandemic. In Year 1, the Core Leadership Team strategically focused on developing a detailed project implementation plan including governance, communications, and detailed theme research milestones, which was hoped to foster innovation and cross-theme, inter-jurisdictional collaboration. Year 2 of INSPIRES focused on continuing to build cross-theme, inter-jurisdictional collaboration in the face of the ongoing pandemic. New cross-theme, inter-jurisdictional ideas emerged, such as cold-air drainage, managing for the cold, regional site evaluation methodologies, and shifting climatic zones, which each lends itself to the integrative and synthetic publications that were recommended by the external review panel. In Year 3, specific efforts were made to encourage cross-theme and inter-jurisdictional collaboration, particularly with the involvement of new project partners at AAMU. In particular, AAMU PI Dawn Lemke spent several weeks in Maine to meet with project participants and external stakeholders to better understand potential collaborative opportunities in Year 3, which resulted in highly successful faculty/student exchanges in Year 4. Within New Hampshire, a portion of the funds originally allocated to the University of New Hampshire were redirected to Dartmouth College to increase undergraduate student involvement in INSPIRES and support an early-career, soft-money faculty member there. In Year 4, continued efforts to engage with AAMU were the focus and with several meaningful collaborative exchanges happening. This included AAMU undergraduate students and faculty traveling to Maine in January 2023 to learn about wireless sensor development, which was the focus of their senior capstone project. Recently, Peter Nelson from Maine traveled to Alabama in May 2023 to do a one-day, hands-on workshop on hyperspectral data processing and analysis, while completing a multi-day field campaign at Paint Rock where high-resolution imagery was flown and over 300 foliage samples from over 30 different species processed. Future analysis of this data will involve AAMU faculty and students. This data will become part of the open-source package available on GitHub and a critical new addition to a tree spectral library that is being constructed (https://github.com/nelsopet/Tree_Spectral_Library).

Inter-jurisdictional collaborations were constrained during the first three years of the project by the global pandemic. Once the danger of contagion diminished, team members in Year 4 felt more comfortable gathering in person and working on concepts for proposals and publications. We held a three-day team retreat in New Hampshire May 24-25, 2022, in Bartlett, NH, attended by over 30 team members from across the involved jurisdictions. Research presentations on the first day provided updates and gave students a chance to highlight their work. The second day was devoted to a field trip to the Bartlett Experimental Forest (BEF), a 2,600-acre tract established as a field laboratory in 1932 and maintained by the US Forest Service's Northern Research Station. It is a National Ecological Observatory Network (NEON) site. USFS and staff of the White Mountains National Forest gave talks during the field tour on the ecology, history and long-term research at BEF, and the linkages of BEF with the stewardship mission for the National Forest. The field tour also included demonstrations of environmental sensor research at BEF, including an INSPIRES sensor station (Alix Contosta and Sarah Nelson) an eddy flux tower and NEON activities at BEF (Scott Ollinger). The retreat wrapped up on the third day with theme discussions and breakout sessions stakeholder engagement, project sustainability, proposals and publications, and STEM education.

A collaborative research project on cold-air pooling, initiated by Melissa Pastore, post-doctoral associate at UVM, with a publication in Ecology in April 2022 (https://doi.org/10.1002/ecy.3717), has developed into a new multi-disciplinary network to continue this work, with members from UVM, UNH, UMaine, the University of Michigan, AMC, BEF, US Fish and Wildlife Service, VT Forests, Parks and Recreation, VT Fish and Wildlife, Dartmouth College. This effort led to the November 2022 workshop at AMC properties in New Hampshire to discuss a follow-up on managing for the cold. A current collaborative synthesis project is being led by Melissa Pastore with AMC collaborator, Sarah Nelson, leading this effort. Similar to the cold-air pooling publication, this collaboration involves the primary jurisdictions and several INSPIRES early-career faculty members.

In addition, the inter-jurisdictional collaborations initiated with the addition of AAMU in Year 3 have continued to grow. During the past year, AAMU undergraduate engineering students in a senior design class focused on sensor development

received assistance from Ken Bundy, a machine learning research scientist at UMaine, on the project code for the wireless sensors. Peter Nelson from the Schoodic Institute in Maine planned to visit Alabama in May 2023 to give students field demonstrations on using drones. Cen Chen, a UMaine post-doc on assignment at AAMU, taught Applications of Geostatistics as a part of his career development training of the INSPIRES program. Four publications are in development between AAMU and UMaine or UVM as well as the recently funded NSF ORCC grant between UNH and AAMU, which should help to further extended this partnership into the future.

The work of Collaborative Project Coordinator Dr. Emily Uhrig has continued to support key inter-jurisdictional collaborative opportunities for project participants. Dr. Uhrig has met with numerous INSPIRES researchers including new faculty at AAMU and has worked to support both early-career faculty and students. She facilitates research theme meetings and convenes monthly meetings of the Collaborative Research Committee, while also working very closely with the INSPIRES students. She updated the social network analysis in January and it shows significant increases in inter-jurisdictional collaborations since the last iteration in Year 3. She has also developed an online technical writing module that has been tested with several INSPIRES students with strong support and will continue to be refined.

Workforce Development

Research Capacity

The NSF EPSCoR RII Track-2 program is intended to enhance research competitiveness and develop research capacity by increasing access to knowledge, expertise, equipment, and collaborators through the participation in collaborative research networks. A key aspect of enhancing research capacity at the project and individual researcher levels is improved access to knowledge, expertise, equipment, and collaborators through the participation in collaborative research networks. Building research capacity, a primary focus of this project in Years 1 and 2, was completed via ensuring successful inter-jurisdictional collaborations and providing significant workforce development opportunities. Year 3 saw the onboarding of several new project participants, which has helped to broaden and diversify participation. In Year 4, INSPIRES continued to enhance research capacity across the institutions involved by significantly leveraging the investment being made by NSF. INSPIRES researchers have been very active with proposal development and submission as 19 proposals have been submitted with 12 of them awarded and 4 are still pending. This has generated $13.8 million in available new funding, particularly 4 new inter-jurisdictional projects to help sustain INSPIRES collaborations. In total, INSPIRES has secured $27,656,128 in external funding after 4 years, which represents a current ratio of 4.6 for funding generated to amount of funding awarded by the NSF EPSCoR RII Track-2 grant. Although these additional research awards have been obtained primarily through other NSF programs in past years, most of the Year 4 funding is from other Federal programs (90%). This suggests that INSPIRES researchers are being very effective and successful in their proposal development efforts despite the highly competitive nature of both NSF and other Federal funding programs. The Core Leadership attributes this success to the greater research capacity created by INSPIRES and the improved collaborations created by an expanded regional collaborative research network.

Student Training and Support

Student training through research and mentorship, along with a strong STEM education component, provides a pathway to career development. The INSPIRES project also provided many opportunities in Year 4 for interjurisdictional training, welcoming Alabama students to Maine and New Hampshire and sending Maine scientist Peter Nelson with remote sensing technology to conduct a hands-on workshop with AAMU students. Over the past year, AAMU students were engaged in a summer training program on field instrumentation, covering the principles of operation, design, and implementation of instrumentation used in plant, soil, environmental, and atmospheric science studies. Graduate students from all four institutions meet monthly for mentorship with program scientists and writing workshops. Undergraduate experiences include field-based research data collection and sensor building. Students are encouraged to present their work at workshops and conferences (Figure 59).

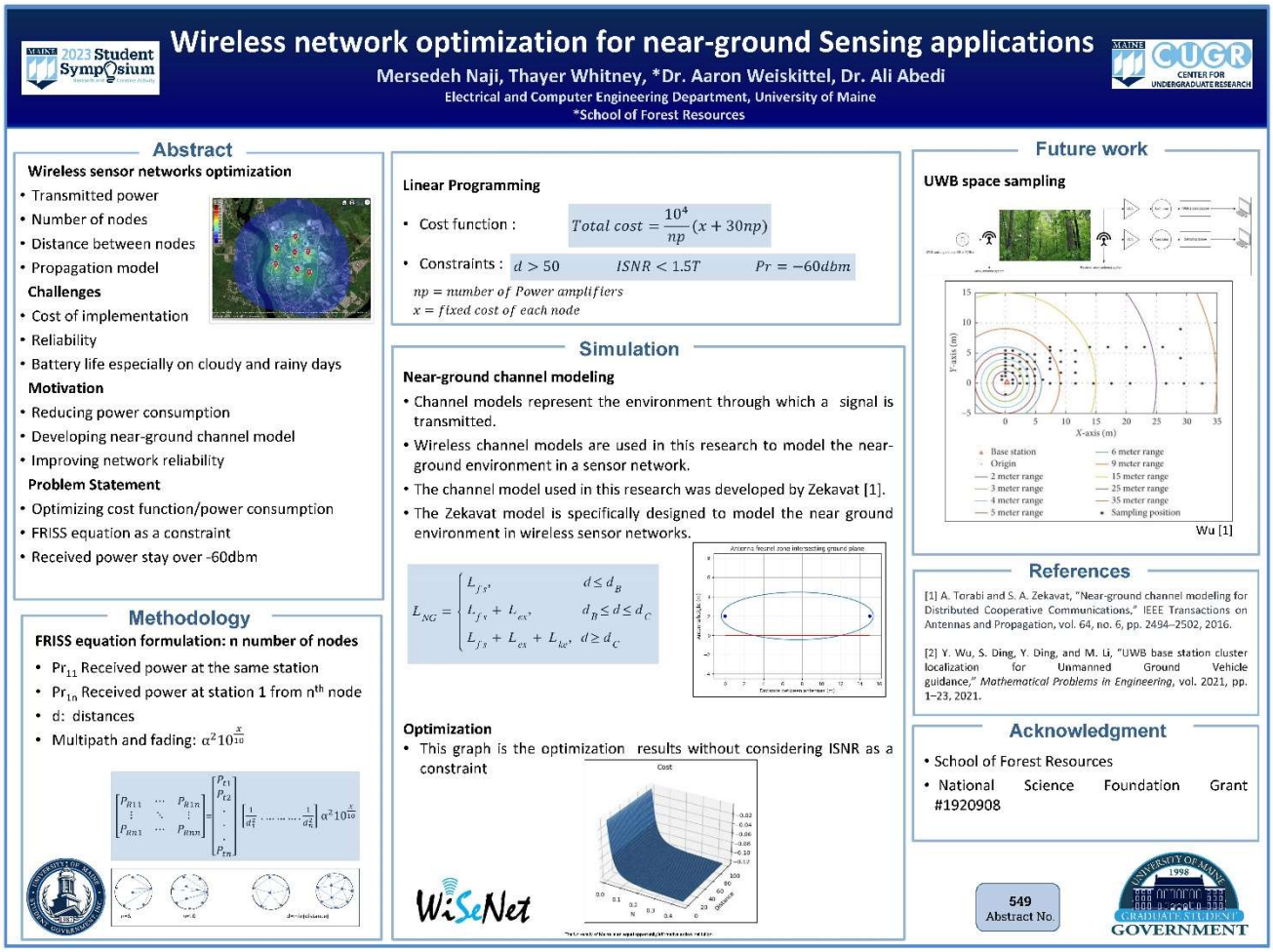


Figure 59. Poster by UMaine graduate students Mersedeh Naji and Thayer Whitney presented at the 2023 UMaine student symposium.

Jurisdictional Impacts

Maine

The INSPIRES effort continues to be primarily led and supported by the University of Maine with involvement of numerous support staff including an Outreach and Communications Specialist (Meg Fergusson), Project Financial Manager (Leslee Canty-Noyes), Administrative Coordinator (Stefania Marthakis) and a Collaborative Project Coordinator (Emily Uhrig). An important focus in Year 4 at the University of Maine was supporting key communications and outreach efforts, coordinating the project team for the external review panel in January 2023, and providing direct support to several graduate students on the projects. Nicholas Soucy (MS) and Sonia Naderi (PhD) both completed their degrees and secured positions at private technology companies. Nicholas is working for a company within Maine, while Sonia is employed by one external to Maine. Other UMaine graduate students continue to make progress on their degrees as Kingsley Wiafe-Kwakye passed his PhD comprehensive exam and both Thayer Whitney and Mersedeh Naji worked with AAMU collaborators on refining their wireless sensor technology. Due to his efforts on INSPIRES and several other projects, Co-PI Abedi was given the UMaine Presidential Award for research. PI Weiskittel was also awarded an NSF EPSCoR Track 1 planning grant, which builds on numerous key outcomes from INSPIRES, and is actively developing an NSFF EPSCoR Track 1 proposal, which will

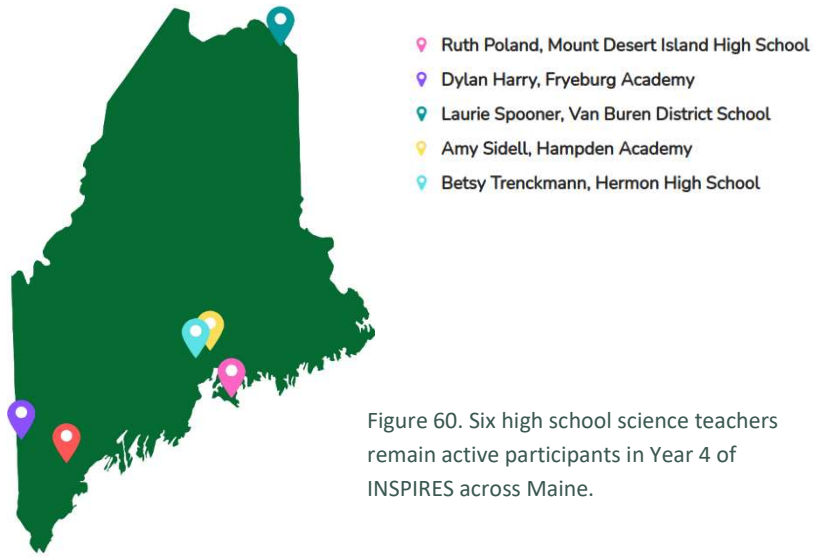


Figure 60. Six high school science teachers remain active participants in Year 4 of INSPIRES across Maine.

be submitted in August 2023. High school teachers throughout Maine remain actively engaged with INSPIRES (Figure 60). Most of these teachers have successfully incorporated elements of INSPIRES into their curriculums and plan to continue to support the environmental sensor sites following the completion of the grant. INSPIRES research continues to be prominently featured in the Climate Change Science and Practice webinar/field tour series. In May, 53 attendees participated in a one-hour webinar given by INSPIRES project partner, AMC, while 28 people joined the one-day field tour of the North Maine Woods Initiative (Figure 61). Both the webinar and field tour showcased specific research and outcomes from INSPRIES, particularly the developed environmental sensors and long-term monitoring opportunities that they provide. AMC plans to maintain and expand their environmental sensor networks even after the completion of INSPIRES. Many of the UMaine INSPIRES team will also continue collaborations our the newly funded USDA Sustainable Agricultural Systems grant with Purdue University and University of Georgia, which will help maintain current momentum and building on the prior investment from NSF. The team continues to pursue additional funding opportunities through NASA, NSF, and USDA.

Figure 61. Attendees gather on AMC lands in northern Maine for a field tour in May 2023.

New Hampshire

The University of New Hampshire team consists of 8 faculty (4 early career), 4 research staff (2 early career), and 3 graduate students. In Year 4, UNH team members focused on building research infrastructure and strengthening external collaborations. Over the past year, led by early career faculty, Alix Contosta, researchers from UNH deployed low-cost sensor prototypes at field sites at numerous locations across the 3 states. This included an interjurisdictional collaboration with UVM and UMaine to establish a set of over 100 monitoring plots aimed at understanding the effects of cold-air pooling on local species composition and climate. PhD student Jack Hastings continued the construction of a lab-based goniometer setup, allowing for the quantification of leaf to branch scale reflectance. This infrastructure is being used to understand how forest canopies interact with light to improve both remote sensing techniques as well as modeling forest carbon uptake. Early career research scientist Andrew Ouimette developed a new model to simulate carbon and nitrogen dynamics during wood decay while Zaixing Zhou is leading an effort to formally integrate a landscape successional model (LANDIS) with a biogeochemical model (PnET-CN). PnET has also been re-coded from the C++ to Python to make model development accessible to students and other researchers. Ouimette, Hastings, Zhou, and Kaitlyn Baillargeon are also collaborating with UVM and UMaine to develop a regional parameter database (including a regional remotely sensed map of foliar traits) and front-end code to make application of LANDIS and PnET streamlined and easier for students and stakeholders. C0-PI Ollinger secured a $1.25M proposal in collaboration with AAMU's Dawn Lemke awarded by NSF's Organismal Response to Climate Change program. The project focuses on forest sensitivity to drought using contrasting sites New Hampshire and Alabama. The UNH-AAMU team is a new collaboration that was made possible by the addition of AAMU to the INSPIRES project.

Plans for the no-cost extension include expansion of the cold-air pooling sensor network across all jurisdictions. In addition to additional meteorological sensor deployment, this will include field campaigns to quantify plant physiological traits related to drought and temperature tolerance as well as forest productivity. UNH members from Themes 1, 2, and 3 will also attempt to develop ultra-low-cost radiation sensors to deploy within tree crowns that will allow quantification tree species-specific interactions with light. UNH team members also plan to continue model development with the goal of publicly releasing new model versions, and will continue to build a regional input parameter database to increase model accessibility.

Vermont

The team based out of the University of Vermont represents a team of 7 faculty, 1 post-doc, 2 graduate students and 1 research technician. These participants span 3 academic units within the University of Vermont. Dave Lutz and his student Emma Hazard and new student Laurella Marin, from Dartmouth College, also remain an integral part of our UVM based team. UVM team members continued to focus efforts on inter-jurisdictional collaborations across each theme, with an emphasis on attending project-wide monthly theme meetings and participating in field site visits and sampling tied to INSPIRES sensor sites in Corinth and Brunswick, VT (Nulhegan Basin) and the Second College Grant, NH. In addition, the UVM team organized and several field tours and workshops for 150 forest managers and other stakeholders at the

Figure 62. Forest managers and wildlife biologists on field tour of INSPIRES sensor site on Nulhegan Basin portion of the Silvio O. Conte National Wildlife Refuge in Brunswick, VT in December 2022.

Figure 63. Teachers getting familiar with the sensor array at the Corinth site in Vermont.

Nulhegan, Corinth, and Second College Grant INSPIRES sites in June, July, and December 2022 to demonstrate adaptation strategies for addressing the impacts of climate change and non-native insects and diseases. These workshops and tours included demonstrations of the sensor networks installed at each site and their applications to guiding strategies to address global change impacts on forests in the region (Figure x).

Considerable effort in Year 4 was put into leveraging the regional network of advanced sensoring to ask specific questions around the influence of forest conditions on cold air pooling and winter snowpack dynamics. To this end, an early career scientist (Pastore) and graduate student (Smith) at UVM led field sampling efforts at INSPIRES sensor sites and a regional field campaign for a cold-air pooling assessment to synthesize climate data for investigating winter and cold air dynamics. This work was in collaboration with early career scientists from the other two jurisdictions (Contosta-UNH; Nelson-UMaine), as well as external partners with the USGS and Hubbard Brook Foundation. This work resulted in a collaborative synthesis paper currently in the final stages of preparation, as well as expansion of snow sampling sensors to new INSPIRES sites through interjurisdictional collaborations with Alix Contosta. Theme 4 continued teacher training with the 9 teachers recruited in 2021, including a UVM seminar course that contained guest lectures from researchers on the INSPIRES team. These teachers toured the Corinth INSPIRES site in April 2022 to learn about forest inventory methods and the application of environmental sensors to understand the impacts of the invasive emerald ash borer on northern hardwood forests. In addition, UVM and UNH investigators on Theme 1 continued to maintain an INSPIRES sensor network installed at a high school in Vermont. Finally, INSPIRES-supported early career scientists, Melissa Pastore and Jane Foster, both took permanent USFS Scientist positions in 2022-2023.

Alabama

Due to processing delays at all institutions, the NSF supplemental grant funding was not finalized until February 2022, which disrupted certain paperwork and planned expenditures. Regardless, faculty members at AAMU have continued to attend virtual meetings and have effectively built new collaborations with the broader INSPIRES team, which rapidly accelerated in Year 4. This second year of collaboration has had numerous challenges, but long-lasting collaborations have already been formed. For example, Dr. Dedrick Davis is now working with Theme 1 researchers to bring new wireless environmental sensor technology developed under INSPIRES to AAMU. He will also be running a summer field instrumentation course for students at AAMU this summer that will be directly supported through this supplemental grant (Figure 64). Dr. Raziq Yaqub has connected with Dr. Ali Abedi at UMaine and collaborated on wireless sensor designs, which was a focus of an undergraduate senior capstone project at AAMU in Year 4. Dr. Lemke has continued to build new and strategic partnerships across the INSPIRES jurisdictions on a range of potential applications, including the environmental sensor efforts and the educational components of the project. Dr. Lemke has been mentored by several faculty across the INSPIRES institutions with guidance in building out her base 20 ha forest plot. She has also participated in two collaborative proposals with INSPIRES faculty. Graduate students have been involved with INSPIRES graduate meetings,

Figure 64. AAMU field crew of undergraduates that will work to complete research related to INSPIRES.

giving them a depth of interactions, which have been difficult during covid. Over the summer there will be a full engagement of faculty, students and technicians in integrating sensors into both education and forest research at Alabama A&M. With the post-doc, Dr Chen, the research components of the supplement should ramp up. Full student research and education opportunities facilitated through this grant should be in place by the fall. A new team of undergraduate student technicians who will complete fieldwork at Paint Rock this summer has been recruited and trained.

Overall Project Integration

As noted in the External Evaluator's report, robust research collaboration among project participants is currently happening and there is now an equal number of both intra- and inter-jurisdictional research collaborations. This is critical as the project nears completion with an important recognition that the team needs to better identify and prioritize how the connections established because of the INSPIRES project might be sustained or expanded in the long-term. Consequently, overall project integration has continued to be a primary focus in Year 4 with several specific initiatives including cross-theme meetings, improved coordination with involved students, and strategic identification of priority publications as well as proposals. Open-ended discussions at the Year 4 all-team meetings helped to generate new ideas and potential collaboration opportunities. In addition, better project integration was achieved with the involvement of Dr. Emily Uhrig who serves as the project's collaboration coordinator and started in the fall of 2021. She has been vital for directly connecting with various team members, identifying potential collaboration opportunities, and helping to provide better project integration support. The success of these various efforts has been demonstrated with continued strong involvement of project participants across all research themes as well as jurisdictions, increased involvement and interactions between students on the project, and focus on collaborative publications or proposals.

Despite only being involved in the project since Year 3, the partnership with AAMU has been quite strong and they have been very well integrated into the project. This has led to additional collaborative opportunities and new proposals, which have been quite productive for all project participants. Year 4 was particularly important for this new partnership as several faculty/student exchanges were completed with plans for future exchanges too. Going into the final stages of the project, overall project integration will remain the highest priority and significant effort will be made to ensure the completion of numerous collaborative outcomes. This will be done in conjunction with improved stakeholder engagement and outreach to ensure the future sustainability of this effort.

BROADENING PARTICIPATION

Team Demographics

Significant focus in Year 4 was the continued successful integration of the AAMU team into INSPIRES. A summary of current team member composition across the four jurisdictions as of Spring 2023 is provided in Table 7, while a detailed list of all personnel is provided in Appendix 2. Based on the compiled demographics report, INSPIRES faculty composition still has strong representation of early-career investigators (54%) composed of a high percentage of those identifying as female (42%). In terms of race, 10%, 5%, and 36% of the early-career researchers, senior researchers, and trainees were from a non-white race with one individual Native American on the team. In addition, INSPIRES faculty are also highly diverse in terms of academic rank and the number of disciplines (20) represented remains relatively high for current team size (45 faculty). Current representation of early-career investigators and involved disciplines are well balanced across the four research themes with 7-12 disciplines and 14-78% early-career investigator composition on the themes. There are currently 120 active project participants across the four jurisdictions with 21 senior researchers (24%), 26 early career researchers (30%), 2 post-docs (2%), 19 graduate students (23%), 38 undergraduate students (31%), and 14 other participants (17%). Diversity is relatively balanced for a large project with 55% identify as female and 13% of the project participants identifying as an underrepresented minority (Table 8). Including AAMU in the project helped to diversify the team where 54% of their participants are an underrepresented minority. Since the project started, 2, 4, and 7 post-doc, undergraduate, and graduate trainees have graduated. who have graduated.

Table 7. Summary of INSPIRES team personnel by role and jurisdiction

Role	Jurisdiction				Total
	Maine	New Hampshire	Vermont	Alabama	
Faculty (Early-career)	22 (10)	12 (9)	8 (3)	5 (4)	**47 (26)**
Staff (Professional/ Support)	8	2	2	3	**14**
Trainees (Undergraduate/ graduates)	8 (1/7)	6 (1/5)	5 (0/5)	38 (36/2)	**57 (38/19)**
Post-doc	1	-	1	-	**2**
Total	**39**	**20**	**15**	**46**	**120**

Table 8. Summary of INSPIRES team personnel by role, gender (F=Female), and underrepresented status (URM = underrepresented minority).

Role	Jurisdiction				Total
	Maine	New Hampshire	Vermont	Alabama	
Early- Career Faculty	33% F; 7% URM	33% F; 0% URM	80% F; 0% URM	25% F; 25% URM	**42% F; 6% URM**
Senior Faculty	50% F; 10% URM	33% F; 0% URM	75% F; 0% URM	50% F; 0% URM	**50% F; 6% URM**
Staff (Professional/ Support)	86% F; 0% URM	100% F; 0% URM	100% F; 0% URM	100% F; 33% URM	**92% F; 8% URM**

Graduate Students	50% F; 50% URM	50% F; 0% URM	100% F; 0% URM	50% F; 100% URM	**56% F; 33% URM**
Undergraduate Students	100% F; 0% URM	-	-	33% F; 100% URM	**40% F; 60% URM**
Post-doc	0% F; 0% URM	-	100% F; 0% URM	0% F; 0% URM	**50% F; 0% URM**
Total	**51% F; 9% URM**	**47% F; 0% URM**	**82% F; 0% URM**	**46% F; 54% URM**	**55% F; 13% URM**

Development/Recruitment of Diverse Early Career Faculty

A continued focus in Year 4 was on encouraging early-career faculty to lead high-impact synthesis publications. The benefits for early-career faculty throughout the project have primarily stemmed from theme and institutional cross-collaborations, which are enhancing research and analytical skills for team members. The results of these efforts were again quite successful in Year 4 as highlighted above. In particular, INSPIRES UVM post-doc, Melissa Pastore, teamed with other INSPIRES faculty there to write a synthesis publication in top-tier ecological journal (Ecology; Impact Factor = 5.49) on a topic that emerged from Theme 1 discussions. The publication is available was published in August (https://doi.org/10.1002/ecy.3717) and several additional ones are planned for future years as outlined in the potential publication table near the beginning of this annual report. Similar efforts will also be made on proposal development.

There have been multiple opportunities for early career faculty, particularly with helping to lead or co-lead within the specific research themes. Currently, there are 25 early-career faculty in INSPIRES with a nearly equal representation in gender with continual recruitment of faculty ongoing. The four research themes are all being led or co-led by early-career faculty with direct support from senior faculty members, which is helping build leadership and organizational skills. Support for undergraduate and graduate students, equipment, and travel support have all been provided to early-career faculty members. This has also had direct benefits for the early-career faculty members. For example, Elizabeth Burakowski, an early-career research assistant professor at UNH, spearheaded the successful effort in New Hampshire to submit a Federal appropriations request for the expansion of the snowpack data collection network, SnoTel, which is maintained by the USDA Natural Resources Conservation Service. SnoTel has over 900 sites in the mountainous regions of the west and northwest. The request, approved and funded in the federal budget, appropriates $7 million to expand SnoTel, and $1 million for a study of potential sites in the Northeastern states. Burakowski, whose research interests include impact of climate change on snowpack, reached out to her colleagues in NRCS to support this request. Sarah Nelson, director of research for the Appalachian Mountain Club in Gorham, NH (formerly an associate research professor at UMaine), led a coalition of INSPIRES states (Maine, Vermont, New Hampshire) in a series of briefings about the SnoTel request for eight members of the House and Senate. In additional Andrew Ouimette, formerly a research scientist at UNH whose work focused on carbon cycling and climate change, left the university in 2022 for a position as ecologist for the USDA US Forest Service. At UVM, Jane Foster and Melissa Pastore also secured permanent research scientist positions with the US Forest Service yet maintain strong ties to the INSPIRES project.

At each institution, the Core Leadership Team has continued to regularly check-in with all team members, particularly early-career faculty, to ensure they have the resources needed to successfully participate in the project. This has ranged from converting part-time graduate assistantships to full-time, hiring additional undergraduate student employees for project support, and covering workshop costs for early-career faculty. This has been particularly important during this project and Year 4 especially given the potential unintended consequences and impacts of the ongoing pandemic. For several early-career faculty members, PI Weiskittel has written reference letters of support describing their involvement with the effort and nature of these collaboration for their annual evaluations, which have highlighted the significant impacts of the pandemic on the project. In addition, the inter-jurisdictional advisory board

will continue to work to support early-career faculty on this project at each institution by potentially offering additional seed grants, acknowledging their involvement in multi-institution EPSCoR grant, and ensuring they have the necessary resources for being productive despite the ongoing pandemic. To ensure successful outcomes of this project for early-career faculty, the Core Leadership Team plans to provide additional funds the summer of Year 4 to support collaboration, particularly those involving AAMU.

Development/Recruitment of Diverse Students

Currently, there are 1 female post-doc, 2 undergraduate (1 female) and 19 (11 female) graduate students across the four institutions that are involved with the project. Student diversity significantly increased with the involvement of AAMU as most of them are female and from underrepresented groups. Overall, 20% and 57% of the projects trainees currently identify as a member of an underrepresented minority group, respectively. Since the project started, 1 (100%), 6 (86%), and 3 (75%) post-doc, graduate, and undergraduate trainees, respectively, were female. The CLT has continued to endeavor to welcome all students on the INSPIRES project, introducing them to the full team and encouraging cross institutional or jurisdictional connections. With the coordination and guidance provided by project collaboration coordinator Dr. Emily Uhrig, INSPIRES students have continued to organize and utilize regular monthly check-in virtual meetings across institutions and jurisdictions in Year 4. These sessions have included student-led discussion on their research as we as guest speakers (mostly female and early-career) from the US Forest Service, National Park Service, Appalachian Mountain Club, and AAMU. These individuals have joined the student meetings to present their research interests as well as discuss their specific organizations and career paths.

Additional opportunities have been provided for students to present findings during both all-team and theme virtual meetings. Graduate students have been encouraged to give flash talks about their research at the external review panel assessment and the all-team meeting in April as well as to reach out and interact with other INSPIRES team members over the coming field season. In addition, INSPIRES graduate students have actively contributed to the project's social media accounts, which has helped to build collaboration and networking across jurisdictions. Ongoing mentoring and recruitment for the remainder of Year 4 will continue, particularly for undergraduates, and going forward there will be a specific focus on underrepresented groups, particularly racial minorities, and Native Americans. This is especially important for AAMU and will be a high priority for Year 4 and beyond.

The pandemic, which was particularly onerous for grad students and researchers throughout the first three years of the project, has lessened but lingering effects remain due to limited in-person support and high isolation. The Core Leadership Team continues to recognize these challenges and strives to work hard to resolve hardships for both mentors and mentees. Efforts in Year 4 have focused on refining MEE materials and ensuring students have every opportunity to gain new professional experiences. In July 2022, students from Alabama traveled to New Hampshire to learn about ongoing field data collection efforts happening as part of INSPIRES, which provided invaluable in-person time to connect with fellow students and mentors in the northeast. Overall, the current students remain highly engaged and enthusiastic about the project, particularly the involvement of underrepresented from AAMU.

Leadership and Governance

After the first 2 years of meeting monthly to assess project progress, potential issues, and team needs, the Core Leadership Team (CLT) has stepped back a notch to organically allow team faculty and graduate students to lead and organize research projects. As pandemic-related adjustments are becoming less onerous and core research efforts are becoming well established, along with the potential for more in-person and interactive project management, project and theme leads have become proactive and continue to help guide the research. The role of the CLT has become more focused on ensuring successful outcomes from the research such as synthesis of key research to overall project goals and student retention, while focusing on continued collaboration and long-term research capacity needs. Project engagement and overall team fatigue remain high concerns for the CLT. The high uncertainty created by the pandemic

and general team disappointment over the lack of in-person events was redirected towards a retreat in May of 2022, which lead into a collaborative and exciting field season. This has provided a strong boost to overall team morale, particularly with trainees, with another field retreat planned in June of 2023 in Vermont.

As outlined in the original proposal and our current governance document, an additional key project element was the formation of several important committees including a Tri-Jurisdictional Institutional Advisory Board (IAB), and two project committees: Collaborative Research Committee (CRC) and Mentoring, Education, & Engagement (MEE) Committee. The IAB is from a range of disciplines and institutional contexts across jurisdictions that have: (1) helped INSPIRES achieve its research and education goals and outcomes; (2) respond to external assessment; (3) identify potential jurisdictional barriers to minimize their potential impact on the project; (4) help promote the relevance of INSPIRES to key university stakeholders such as industry, NGOs, and other sectors; and (5) assist with sustainability by helping to identify related research opportunities. The MEE Committee (led by Co-PI D'Amato) has shared mentorship and effective advising across the project and lead educational and professional development activities, including potential course development, writing retreats, and field trips to promote cross-project learning and research advancement. The MEE works closely with the CRC (led by Co-PI Ollinger) to ensure strong cross-institutional and jurisdictional collaborative opportunities. Using a Science of Team Science approach, the CRC will establish an ongoing research program to study and inform the development of the organization, promote interdisciplinary research efforts, and strengthen relationships with stakeholders. CRC has continued to host monthly cross-theme collaboration meetings where project participants discuss ongoing research and areas of potentially high synergy. Both MEE and CRC have been greatly assisted with the addition of project collaborative coordinator Dr. Emily Uhrig who has assisted with committee key functions, organization, and implementation. She will have a key role in the final year of the project by helping to build and sustain the ongoing synergistic activities that both MEE and CRC have initiated.

In Year 4, the CLT continued to support these various committees including the CRC, MEE, and IAB as specifically described above, but continued to feel the ongoing impacts of the global pandemic have made it too difficult to form an EAB. Consequently, the CLT continues to feel well connected with stakeholders and it is believed that a formal EAB would potentially be redundant at this stage of the project, particularly given the input provided by the external evaluator and the recent review panel. Regardless, INSPIRES faculty and the CLT have continued to maintain a list of potential EAB members and will work on connecting with these individuals directly given the future shift to project sustainability and outreach efforts.

To help sustain this positive and significant momentum of INSPIRES, the CLT continued to revise and update the project implementation plan, particularly the overall project and theme-specific research milestones. In addition, the preparation and presentation of key project briefing materials for the IAB helped to identify key project strengths and potential opportunities that will were further explored in Year 4 and will be a primary focus in the remainder of the effort. In particular, the CLT and IAB continued to feel the key strengths were: (1) successfully interactions and collaboration among applied ecologists and data science experts; (2) the exceptional integration of education and outreach efforts into specific activities and objectives that enhance inter-institutional collaboration; (3) the focus and support for developing an integrated entity that can produce convergent outcomes and products (e.g., the Digital Forest Framework); and (4) the successful integration of a new partner (I.e., AAMU) into the project during an ongoing pandemic. These specific core strengths have been clearly expressed to the IAB and will be sought to be fully leveraged by the CLT in the final year of the project. The perspective and input from the AMMU PI (Dawn Lemke) have been sought and included in all CLT discussions. She already feels like INSPIRES has been a tremendous help for her to build linkages to both researchers at her own institution as well as externally. PI Weiskittel and Co-PI Lemke have continued ongoing discussions to help leverage and sustain these collaborations, particularly with INSPIRES post-doc Cen Chen now transitioning from full-time employment at the University of Maine to AAMU.

Table 9. INSPIRES Benchmarks and Accomplishments

Program Area	Output/Outcome/ Impact Indicators	Annual Project Benchmarks	Year 4 Accomplishments
Research Capacity	Interdisciplinary and convergent research collaborations; post-docs recruited; graduate students enrolled; new regional Complex Systems Research Consortium	3 post-docs and 8 graduate students, 3 research assistants, strategic plan presented to internal/external advisory boards	2 post-doc, 20 graduate students, 5 research assistants; Strategic plan updated & refined, inclusion of AAMU; Potential publications and proposals identified
Research Productivity	Peer-reviewed publications; submitted (awarded) grants (by funding source); patents, licenses and commercialization opportunities; amount and resolution of data generated	6 publications (50% multi-institution), 10 presentations, 4 proposals submitted (50% multi-institution), 1 cross-jurisdictional grant funded, 5 data products publicly available (25% being integrated)	28 publications (18 multi-institution), 12 presen-tations (5 student-led), 4 proposals submitted or pending (3 multi-institutional), 5 grants funded (3 cross-jurisdictional), 6 data products publicly available
Education and Diversity	Student participation in project research activities; student participation in project professional and career development training events; student research and career development outcomes; diversity (participation of students from populations underrepresented in STEM; i.e. WaYS)	10 undergraduates involved, 5 undergraduate & graduate students enrolled in certificate programs, 3 training events, 35% of project participants from underrepresented groups, 1 inter- institutional graduate course	Undergraduates involved (6), 47% female trainees, and trainee participation from underrepresented backgrounds (4), collaborative project coordinator supported, monthly student meetings, development of a scientific technical writing online module; Faculty and student exchanges with AAMU
Workforce Development	Undergraduate/graduate student education and career outcomes (next steps); early career faculty development outcomes (progress toward research independence, tenure, teaching, mentoring, and leadership skills development); integration of big data modules into K-12 curricula	5 early career faculty involved, curricular materials for grades 6- 12 created/ improved (Yrs 2-4), annual teacher's workshop held (Yrs 2-4), 1000 students impacted (Yrs 2-4), 20 involved (Yrs 2-4), post-docs/ graduate/undergraduate students gain experience in K-12 education, perspectives from WaYS reflected in curricular materials	55% of faculty involved are early career (25); 17 high school science teachers actively involved in Maine (8) and Vermont (9); Summer hands-on teacher's workshop planned in Vermont in June 2023; Project participants have presented and collaborated with K-12 educators on a regular basis; A 3-credit INSPIRES Teacher Professional Learning graduate course offered by UVM

Program Area	Output/Outcome/ Impact Indicators	Annual Project Benchmarks	Year 4 Accomplishments
Stakeholder Engagement	Collaborations and partnerships with local organizations, industry, and other academic institutions; benefits to participants in collaborative networks	5 involved partnerships, 3 outreach events, 5 media features, 25 event participants	New partnership created; 6 outreach events across the primary jurisdictions; 10+ recent media features; Active social media presence; Connections to Maine tribal councils strengthened with collaboration planned

EVALUATION Year 4

Overview

On January 9-11, 2023, TIG conducted and led a summative assessment of the INSPIRES project to evaluate project outcomes, provide guidance on priorities for the final six months of the award period, and make recommendations for sustaining the capacity built and impact generated from the collaboration. The panel was composed of the same experts who participated in the strategic assessment in March 2021. Both events consisted of a series of virtual meetings with the INSPIRES leadership team, participating researchers and trainees, and project coordination and administrative support staff.

Panel members were: Dr. Jennifer Allen (Portland State University), Dr. Ragan Callaway (University of Montana), and Dr. Christian Messier (University of Quebec in Montreal and in Outaouais). Dr. Heather McInnis, an evaluation expert with experience assessing large-scale, multi-institutional and multi-disciplinary STEM initiatives, led the assessment and development of a report, which has been emailed to our program officer. The specific charge to the panel was to: (1) Assess progress toward goals and what remains to be done during this last year of the project; (2) Assess sustainability planning and what aspects of INSPIRES are relevant to the UMaine Track-1 proposal; (3) Assess early-career researcher development; (4) Assess student outcomes; and (5) Assess stakeholder engagement.

The final external assessment found that the INSPIRES Track-2 project was extremely strong and demonstrates a high-level of productivity in terms of the achievement of NSF-determined products, technical objectives, the pursuit and acquisition of follow-on funding, and the development of a collaborative spirit across the institutions and themes. The team from AAMU has been successfully integrated into the project, despite only having finalized the subaward and received funding in January 2022. The report also indicated that PI and CLT have done an excellent job of minimizing the administrative burden on those engaged directly in the on-the-ground work. Early Career researchers have been productive and successful, with several of them advancing into new careers in INSPIRES-related fields and positions within the partnering jurisdictions. Importantly, the CLT has wisely given a great deal of intellectual freedom to Early Career researchers and graduate students for problem solving and developing novel and sustainable ideas for expanding the research accomplishments of INSPIRES. Accordingly, research results are strong across Themes 1-3, and there have been significant broader impacts to the community through the efforts under Theme 4 to engage teachers and other community partners. There was strong participation in the TIG review panel's virtual site visit and review discussions from a suite of stakeholders, including staff from several non-profits as well as teachers engaged in Theme 4. The TIG review panel was also impressed with project's strong communications team and the efforts and strategies focused on effectively informing the broader public about INSPIRES work.

The report also noted that partnerships and collaborations that have been developed through INSPIRES are even more impressive in the context of the challenges posed by the COVID pandemic. While the pandemic was at some level a shared experience, its impacts were greater for those team members either at a vulnerable moment in their careers (e.g., early in their academic careers) or experiencing difficult personal circumstances. Navigating the isolation and disruptions to work and home environments has placed additional and continuing stress on many participants, including tensions related to work-life balance, maintaining productivity, and the challenges of developing and maintaining relationships with colleagues in the absence of in-person interactions. Again, the collaborative spirit that was evident to the TIG review panel through interactions with numerous team member during the virtual site visit as well as assessment of the work produced through the project is particularly remarkable given these pressures. The TIG review panel noted that while teams collaborating under each of the four research themes have made significant progress toward their research and engagement goals, they have not yet had time to explore many of the potential linkages between the themes. While the activities under each theme offer very important contributions, the overall

impacts of this work could be elevated if the infrastructure, data, and research findings are integrated across the overall INSPIRES project.

Outcomes

Next Steps

In response to the TIG panel suggestions, we have developed a framework for the fifth year of the project during the requested no-cost extension. Note that we have endeavored to spend the award on schedule, with the exception of pandemic-related impacts causing delays and the additional funds from the supplement in Year 2 to add AAMU. Therefore, we do not have funds available to support a wide range of research activities beyond what was anticipated when the implementation plan was developed in Year 1. However, we anticipate carrying forward the following research and education activities in the no-cost extension year and several address the panel's suggestions (see Future Plans section).

The primary recommendations of the external assessment panel were: (1) highlight the outcomes of project management and communication strategies in the final reports to the NSF; (2) pursue opportunities for sustainability such as new funding with AAMU that will keep the new cross-institutional and cross-jurisdictional relationships going; (3) leadership and senior faculty should engage with early career faculty as the project winds down to advise and mentor them towards their career goals after INSPIRE ends and to explore how their engagement in the INSPIRES work might be emphasized or leveraged for their future success; (4) use the next 12 months to complete and publish findings from the work being done under Theme 3, as well as further develop the connections between Themes 1 and 2 and Theme 3; (5) work closely with partners to identify where and how they might incorporate findings from the research to improve their practices; (6) identify what aspects of the project activities and findings might inform and support ongoing relationship-building with regional Tribes and advance the integration of traditional ecological knowledge in research and forestry management practices; (7) leverage connections with industrial partners to disseminate novel information coming out of the Track-2; (8) continue efforts to develop cross-theme papers and products over the next 6 to 12 months; (9) extend interjurisdictional collaboration, specifically with AAMU, through the NCE; (10) the final report to the NSF should explicitly describe how the project will sustain the regional research capacity built from INSPIRES; and (11) the Final Report to the NSF should include a section that communicates products that may not be completed by the end of the project but that are highly likely to be completed during several years after INSPIRES ends.

The CLT drafted a detailed response to these recommendations and believe they can all be effectively addressed with a granted one-year no-cost extension. The primary focal areas will be: (1) integration of science across the themes; (2) continued strategic deployment and use of sensors with linkages to remote sensing; (3) increased engagement with both graduate student and early-career faculty activities; (4) expanded stakeholder engagement; (5) refinement and release of several online tools; and (6) seeking of additional funding for long-term sustainability. These ideas are further outlined in the Future Plans section below.

PROGRESS ON SPECIFIC PROGRAM ELEMENTS

Committees & Subcommittees

Mentoring, Education, and Engagement (MEE)

The Mentoring, Education, and Engagement (MEE) committee led by Co-PI D'Amato. In Year 4, the guidelines for effective collaboration for student mentors and mentees have been updated and revised by this committee with input from all INSPIRES team members. The MEE provides students with the space to openly discuss challenges they are facing, network with fellow students, and hear from the other INSPIRES team members about their research as well as professional development. This committee has been especially important during this project given the ongoing and evolving nature of the current pandemic, which has been particularly challenging for graduate students starting new programs. Project collaborative coordinator Dr. Emily Uhrig has been vital for keeping the students engaged and helping to support the ongoing efforts of this committee. For reminder of Year 4 and beyond, the committee hopes to better document and learn from the students and many of them wrap up their studies and plan for next steps.

Collaborative Research Committee (CRC)

The Collaborative Research Committee (CRC) led by Co-PI Ollinger has continued to meet regularly to discuss cross-theme and inter-jurisdictional research collaborations. The CRC took the lead on a key discussion focused on joint publications and proposals at the April 2023 all-team meeting. An outcome of this is a cross-jurisdictional/cross-theme shared table of potential publications and proposals that is accessible to the full team and allows team members to contribute ideas and connect with possible collaborators. In addition, the CRC led to the creation of INLeaf, which is an online platform for geospatial data sharing and visualization (Figure 65). In Year 4, INLeaf has been continued to be refined, updated, and expanded by INSPIRES team member Leo Edmiston-Cyr, and it was recently presented to the Theme 4 high school teachers as a potential tool for their QRC curriculum activities and was well received. The CRC has also identified key regional research infrastructure needs in Year 4, which has led INSPIRES partner Appalachian Mountain Club to develop a briefing paper that has been shared and presented to Federal delegations of the three northeast jurisdictions. This brief paper focuses on the changing winters in New England (a key research topic in Theme 1) and the need for better monitoring through an integrated network of snow monitoring stations, similar to SnoTel in the western US. The Appalachian Mountain Club has also connected and presented this to the USDA SnoTel leadership. All parties have recognized the clear need for SnoTel-East and it is currently being prioritized for potential Federal funding, which would be a direct result of the CRC and the partnerships that INSPIRES has helped to foster. In the remainder of Year 4 and beyond, CRC will focus on outlining and planning the Complex Systems Regional Consortium, which will help to leverage and sustain the momentum created by INSPIRES.

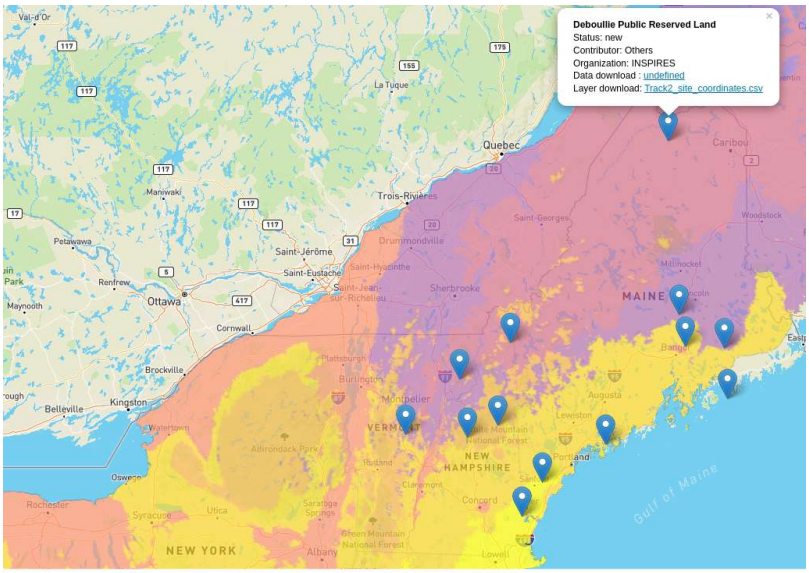


Figure 65. INLeaf online platform created by team member Leo Edmiston-Cyr (UMaine) showcasing INSPIRES research locations across the three primary jurisdictions and the climate zones developed and finalized by Theme 2 in Year 4. The tool is available at: http://INLeaf.inspires.acg.maine.edu/.

Data Sharing Subcommittee (DSS)

A cross-theme/cross-institutional subcommittee finalized and updated a concise document that would provide a foundational data sharing implementation plan in Year 3 (see Appendix 4). The DSS is co-led by Leo Edmiston-Cyr (UMaine) and Mary Martin (UNH) with active participation from across the different themes. In Year 4, the DSS continued to maintain the necessary cyberinfrastructure for effective data sharing and provided additional data standards as well as templates to maintain consistency across themes. These templates are currently being refined to encourage and ease data sharing via the Environmental Data Initiative, which is the long-term repository for all data created by the INSPIRES effort. To accomplish this, the DSS has provided Excel-based templates for both the raw data and metadata, while R code is currently being developed to further simplify the process. The DSS is currently working with several INSPIRES researchers to prepare and upload their data to the Environmental Data Initiative's online repository, which resulted in 5 data publications in Year 4. In the remainder of Year 4 and beyond, the DSS will continue to encourage data submissions and sharing, particularly following the project completion.

Inter-jurisdictional Advisory Board (IAB)

The Inter-jurisdictional Advisory Board (IAB) was formed in Year 2, formally met in Year 3 (August 2021), and received email updates in Year 4. The IAB consists of Jason Charland (UMaine), Director of the Office of Research Development; Shane Moeykens (UMaine), State EPSCoR Director; Anthony Davis (UNH), Dean of College of Life Sciences and Agriculture; Mark Milutinovich (UNH), Director of Research and Large Center Development; Nancy Mathews (UVM), Dean of Rubenstein School of Environment and Natural Resources; and Arne Bomblies, State Director of Vermont EPSCoR. The IAB updates in Year 4 discussed project progress to date, particularly items raised by the external review panel. Specific topics included cross-jurisdictional collaboration opportunities, sustainability of Northern Forest Digital Forest, potential availability of seed funding, creation of Regional Complex Systems Consortium, broader value of INSPIRES to each institution and the larger region, potential international collaborations (e.g., Finland MOU, Arctic Initiative) and finally, linkages to the region's tribal nations. Specific outcomes of the meeting were a focus on cross-jurisdictional collaboration issues at the next National EPSCoR meeting in November 2022, linking the INSPIRES Theme 4 education and outreach efforts to key EPSCoR representatives, importance of supporting institutional Indigenous Knowledge research, and the importance of common regional environmental monitoring infrastructure, which led to the SnoTel-East briefing paper. Each IAB member was planning to communicate the INSPIRES effort and plans for the future with key university administrators such as Provosts and Vice Presidents of Research at each of the primary institutions. A copy of the Year 4 annual report, external assessment report, and plans for the no-cost extension will be made available to them in the coming weeks. A key focal item of the IAB in the remainder of Year 4 and beyond will be leveraging the current collaborations with AAMU and sustaining INSPIRES following the project's completion with NSF.

Collaborative Research Development

The INSPIRES project started August 1, 2019 and is a relatively large multi-jurisdictional, multi-disciplinary effort with over 80 team members now. Over the last three years, the project has focused on team building to organize the project effectively to produce optimum, synergistic outcomes over the long-term, particularly with the ongoing challenges created by the current pandemic. The CLT has relied heavily on the effective team-building strategies outlined in *Strategies for Team Science Success* (edited by Hall et al., 2019) and continued to conduct facilitated team-building exercises with the full team in January 2022. The team also had its first in-person collaboration with cross-institutional, cross-theme team building event at the multi-day retreat in May 2022. Despite pandemic-imposed difficulties, the CLT has successfully incorporated highly interactive virtual team meetings with a mixed format approach, use of cloud-based collaborative tools such as Slack and OneDrive, and regular electronic team updates including a planned summer e-newsletter that will go to both the team and external project collaborators. Online

documents and resources to help foster team collaboration are regularly reviewed and updated. The team website, shared project calendar, project jargon or acronym dictionary, summary of project resources, anonymous feedback form, social media sites, and YouTube channel continue to highlight a multitude of team successes.

A primary focus during Year 2 was on the initiation of cross-theme, inter-jurisdictional research efforts as outlined in this annual report with team building still ongoing, particularly with a new project partner (AAMU). The project implementation plan developed in Year 1 provided the necessary structure, governance, strategic assessment, and plans for research, communications, and evaluation, which has continued to be updated and refined to help guide project strategic activities. A major success in Year 2 was the development and implementation of a detailed data sharing implementation plan. In Year 3, collaborative research developed has been primarily supported and enhanced by the new collaborative project coordinator (Dr. Emily Uhrig) who has helped to facilitate synergistic connections, particularly with our new team members at AAMU. In addition, a new subaward with Dartmouth College was established in Year 3 using reallocated funding from UNH and will now support an early-career faculty member (David Lutz) as well as his undergraduate research assistants who have been involved with the effort since Year 1. This should help facilitate additional collaboration opportunities and capacity, particularly given the potential linkages to AAMU. Year 4 continued to refine these efforts and think strategically about project wind-down in the next 12 months.

Finally, collaborative research development has been facilitated by identifying key topics that resonate across themes. Some of the most important key topics have been team collaboration platforms, knowledge to action, and K-12 education, which will receive more attention and focus at future team meetings. Team members have already started forming working groups to work on these additional topics. Collaborative research development has also been enhanced with the online tool INLeaf, which allows researchers to openly share and visualize data from INSPIRES across the involved themes and jurisdictions. INLeaf and the Digital Forest will likely be the primary online platforms for sustaining future INSPIRES efforts and sharing the outcomes with a broader audience. As Year 4 winds down and the team begins considering project wrap-up, ensuring continued collaborative research development will take priority and the CLT will engage with team members to ensure successful outcomes from the effort.

FUTURE PLANS

In response to the TIG panel suggestions (see Evaluation Section), we have developed a detailed and prioritized framework for the potential final and fifth year of the project during the requested no-cost extension. Key efforts include:

- Integration of science across the themes: This will be accomplished primarily through publication of synthesis papers and integration of data and models. One example is a working group led by Sarah Nelson, AMC, looking at the changes in winter, integrating sensors with remote sensing, connecting Themes 1 and 3. At our next all-team meeting, we will review the status of manuscripts under development with an eye toward theme integration, as well as proposals for funding.
- Deployment and use of sensors: Plans are underway to install sensors in new research sites in Vermont, including in the USFWS Nulhegan Basin Refuge, and to maintain them after the end of the project. The Appalachian Mountain Club has also committed to maintaining sensors on research sites, and sensors in use by teachers in Old Town, ME, will be maintained by UMaine personnel. Sensors are being built by the AAMU team and will be installed at Paint Rock in Alabama. In addition, Peter Nelson has flown Paint Rock with a UAV and hyperspectral imaging, which could be linked with sensors. He will work on processing and analyzing the data with AAMU faculty and students.
- Review documents: Data sharing plan and authorship agreement have been reviewed and, if necessary, they will be updated and adopted by the team.
- Graduate student activities: Several students will be completing their projects during the fifth year. Project coordinator Emily Uhrig will continue to convene meetings of the graduate students. She has developed an online module for technical writing which will be put into use with student groups.
- Early-career researchers: As the TIG panel noted, early-career researchers face a number of unique challenges, which were exacerbated by the pandemic. For early-career members of INSPIRES whose research activities and associated expenditures were delayed by, for example, the need to provide homeschooling for children, the no-cost extension year will provide them with a much-needed opportunity to catch up and complete the goals they originally laid out.
- Stakeholder engagement: We will conduct a survey of partners from industry and non-profit organizations to gather feedback on the project's key achievements. We will continue the successful public webinar series, Science and Practice, with a session on cold-air pooling research. A workshop will be held this summer for teachers involved in Theme 4 and will include a field trip to research sites in Vermont for the INSPIRES team and the teachers. In addition, the research team will share results with foresters and other partners during two field tours of a Vermont research installation (Nulhegan Refuge) in September and October, with these events coordinated by the Green Mountain Division of SAF and Forest Stewards Guild, respectively.
- Online tools: INLeaf and ForEST have been launched and work will continue to refine these tools; real-time sensor data will be incorporated this summer. Software for completing the inverse parameterization of Landis-II has been developed. Work will continue on the Digital Forest.
- Follow-on funding: Two proposals have been awarded to continue cross-jurisdictional and cross-institutional work (USDA/NIFA: AAMU and UMO) (NSF ORCC: UNH and AAMU). In addition, a NSF

Track 1 Regional Innovation Engine involving UMaine, UNH, and UVM along with several other partner organizations across the region, has also been approved for funding. This effort will focus on continuing to support and expand some of the precision forestry that INSPIRES has helped to foster.

- Integrate traditional ecological knowledge: UMO will continue to support relationship-building with regional Tribes and advance the integration of traditional ecological knowledge in research and forestry management practices, through the proposed new EPSCoR Track-1 project.
- Communication and outreach: Successful external communication efforts will be continued (website, social media) to spotlight the impact and significance of research efforts and the novel technology of inexpensive and easy-to-use sensors, including through field tours and webinars for foresters and other practitioners.

EXPENDITURES AND UNOBLIGATED FUNDS

Year 4 Financial Plan

The pandemic created significant challenges with spending the available funding over the past four years. This was caused by hiring delays, reduced travel opportunities, and continued limited availability of critical equipment/supplies due to supply issues. Also, significant delays with processing the subawards with AAMU and Dartmouth College, which had increased yet limited expenditures from those two institutions in Year 4. Despite these continued challenges, the project will have spent than 85% of the obligated funding for Year 4 (Table X), but additional funding remains unspent and a one-year no-cost extension has been formally requested, which would take the project to July 2024. This available funding following Year 4 is projected to be $274,131.82, which is primarily at AAMU ($108,913.31), University of New Hampshire ($75,439.28), University of Maine ($58,361.51), and Dartmouth College ($31,417.72).

Across the institutions involved in Year 4, the funds have primarily been used to support salaries and fringe benefits (40.5%) of professional staff such as research assistants and post-docs as well as graduate students followed by materials & supplies (6.0%), travel (2.8%), and professional services (1%). These trends will likely continue in the coming year under a no-cost extension with the AAMU post-doc being fully hired and several new graduate students and research assistants there. It is also an expected increase in travel expenditures going forward with the return of in-person workshops and conferences.

Table 10. Summary of Year 4 expenditures, allocations, and variance by budget line items across individual jurisdictions and the overall project.

Item	Spent	Allocated	Variance	% Variance
University of Maine (Project Lead)				
Salary	$104,811.34	$263,702.00	$158,890.66	60.25%
Fringe Benefits	$22,913.01	$49,120.00	$26,206.99	53.35%
Travel	$10,229.24	$19,849.00	$9,619.76	48.46%
Materials and Supplies	$70,466.00	$1,708.00	$(68,758.00)	-4025.64%
Professional Services	$1,193.00	$16,540.00	$15,347.00	92.79%
Computer Services	$248.48	$19,849.00	$19,600.52	98.75%
Other costs	$209,612.59	$101,810.00	$(107,802.59)	-105.89%
Indirect	$186,282.83	$191,540.00	$5,257.17	2.74%
Total	$605,756.49	$664,118.00	$58,361.51	91.21%
New Hampshire (University of New Hampshire & Dartmouth)				
Salary	$110,830.00	$149,442.44	$38,612.44	25.84%
Fringe Benefits	$30,359.00	$36,479.98	$6,120.98	16.78%
Travel	$3,570.00	$8,766.00	$5,196.00	59.27%
Materials and Supplies	$1,729.00	$1,528.17	$(200.83)	-13.14%
Professional Services	$-	$-	$-	-
Computer Services	$-	$1,477.79	$1,477.79	100.00%
Other costs	$78,275.00	$34,089.99	$34,089.99	100.00%
Indirect	$21,560.63	$99,835.63	$21,560.63	21.60%

Item	Spent	Allocated	Variance	% Variance
Total	$224,763.00	$331,620.00	$106,857.00	67.78%
University of Vermont				
Salary	$170,115.00	$170,115.00	$-	0.00%
Fringe Benefits	$56,452.00	$56,452.00	$-	0.00%
Travel	$22,079.00	$22,079.00	$-	0.00%
Materials and Supplies	$15,000.00	$15,000.00	$-	0.00%
Professional Services	$-	-	$-	-
Computer Services	$4,060.00	$4,060.00	$-	0.00%
Other costs	$39,511.00	$39,511.00	$-	0.00%
Indirect	$149,915.00	$149,915.00	$-	0.00%
Total	$457,132.00	$457,132.00	$-	0.00%
Alabama A&M University				
Salary	$87,506.00	$82,554.00	$(4,952.00)	106.00%
Fringe Benefits	$22,505.26	$28,894.00	$6,388.74	77.89%
Travel	$5,456.96	$30,000.00	$24,543.04	18.19%
Materials and Supplies	$2,600.76	$18,214.00	$15,613.24	14.28%
Professional Services	$-	$-	$-	-
Computer Services	$-	$-	$-	-
Other costs	$27,312.56	$60,500.00	$33,187.44	45.14%
Indirect	$43,705.15	$77,838.00	$34,132.85	56.15%
Total	$189,086.69	$298,000.00	$108,913.31	63.45%
Overall Project				
Item	**Spent**	**Allocated**	**Variance**	**% Variance**
Salary	$473,262.34	$665,813.44	$192,551.10	71.08%
Fringe Benefits	$132,229.27	$170,945.98	$38,716.71	77.35%
Travel	$41,335.20	$80,694.00	$39,358.80	51.22%
Materials and Supplies	$89,795.76	$36,450.17	$(53,345.59)	246.35%
Professional Services	$1,193.00	$16,540.00	$15,347.00	7.21%
Computer Services	$248.48	$25,386.79	$25,138.31	0.98%
Other costs	$354,711.15	$235,910.99	$(118,800.16)	150.36%
Indirect	$401,463.61	$519,128.63	$117,665.02	77.33%
Total	**$1,476,738.18**	**$1,750,870.00**	**$274,131.82**	**84.34%**

Table 11. Proposed allocation of funding by budget line item and jurisdiction/institution for a one-year no-cost extension.

Item	UM	UNH/Dartmouth	UVM	AAMU	Total
Salary	$10,098.03	$38,612.44	$-	$-	$48,710.47
Fringe Benefits	$2,207.55	$6,120.98	$-	$6,388.74	$14,717.27
Travel	$985.53	$5,196.00	$-	$24,543.04	$30,724.57
Materials and Supplies	$6,789.04	$-	$-	$15,613.24	$22,402.28
Professional Services	$114.94	$-	$-	$-	$114.94
Computer Services	$23.94	$1,477.79	$-	$-	$1,501.73
Other costs	$20,195.09	$34,089.99	$-	$33,187.44	$87,472.52
Indirect	$17,947.39	$21,560.63	$-	$34,132.85	$73,640.87
Total	**$58,361.51**	**$106,857.00**	**$-**	**$108,913.31**	**$274,131.82**

APPENDICES

Appendix 1. Products Year 4

Journal or Juried Conference Papers (9 published; 2 in press)
Presentations (20)
Video Outreach (3)
Database/Model/Technology Products (5)

Publications

Bishnu, Hari Wagle, Aaron R. Weiskittel, Anil R. Kizha, John-Pascal Berrill, Anthony W. D'Amato, David Marshall. 2022. Long-term influence of commercial thinning on stand structure and yield with/without pre-commercial thinning of spruce-fir in northern Maine, USA. Forest Ecology and Management, vol. 522, no. 15. https://doi.org/10.1016/j.foreco.2022.120453

Chen, C.; Kershaw Jr., J.; Weiskittel, A.; McGarrigle, E. 2023. Can a multistage approach improve individual tree mortality predictions across the complex mixed-species and managed forests of eastern North America? Forest Ecology. https://doi.org/10.1016/j.fecs.2023.100086

Clark, Peter, Tony D'Amato, Chris Woodall. 2022. Restoring a keystone tree species for the future: American chestnut assisted migration plantings in an adaptive silviculture experiment. Forest Ecology and Management, vol 523, no. 1. https://doi.org/10.1016/j.foreco.2022.120505

Clark, Peter; A.W. D'Amato. 2022. Seedbed not rescue effect buffer the role of extreme precipitation on temperate forest regeneration. Ecology. https://doi.org/10.1002/ecy.3926

Kuehne, Christian; Aaron Weiskittel; John A. Kershaw Jr. 2022. Development and evaluation of refined annualized individual tree diameter and height increment equations for the Acadian Variant of the Forest Vegetation Simulator: Implication for forest carbon estimates. Mathematical and Computational Forestry & Natural-Resource Sciences. http://mcfns.net/index.php/Journal/article/view/14.5

Naderi, Sonia; Bundy, Kenneth; Whitney, Thayer; Abedi, Ali; Weiskittel, Aaron; Contosta, Alexandra. 2022. Sharing Wireless Spectrum in the Forest Ecosystems Using Artificial Intelligence and Machine Learning. Int J Wireless Inf Networks. https://doi-org.wv-o-ursus-proxy02.ursus.maine.edu/10.1007/s10776-022-00572-9

Pastore, Melissa A.; Aimée T. Classen; Anthony W. D'Amato; Jane R. Foster; E. Carol Adair. 2022. Cold-air pools as microrefugia for ecosystem functions in the face of climate change. Ecology. https://doi.org/10.1002/ecy.3717

Scott, Lisa; Sean Smith; John Gunn; Marek Petrik; Mark Ducey; Thomas Buchholz; Ethan Belair. 2023. Salvage decision-making based on carbon following an eastern spruce budworm outbreak. Frontiers in Forests and Global Change Forest Management. https://www.frontiersin.org/articles/10.3389/ffgc.2023.1062176/abstract

Soucy, Nicholas; Salimeh Yasaei Sekeh. 2023. CEU-Net: Ensemble Semantic Segmentation of Hyperspectral Images Using Clustering. Journal of Big Data. In press.

Soucy, Nicholas; Salimeh Yasaei Sekeh. 2023. Improving Hyperspectral Adversarial Robustness Under Multiple Attacks, International Conference on Learning Representation (ICLR). Tiny Papers. In press.

Wiafe-Kwakye, Kingsley; Torsten Hahmann; Kate Beard. 2022. An Ontology Design Pattern for Spatial and Temporal Aggregate Data (STAD)Proceedings of the 13th Workshop on Ontology Design and Patterns (WOP 2022). https://ceur-ws.org/Vol-3352/pattern4.pdf

Presentations

Abedi, Ali. Sept 30 - Oct 2, 2022. Digital Radio Intelligent Forest Twin (DRIFT). MIT URTC. Conference Talk. Cambridge, MA

Chen, C., Kershaw Jr., J., Weiskittel, A., McGarrigle, E. April 06, 2023. Can a multistage approach improve individual tree mortality predictions across the complex mixed-species and managed forests of eastern North America? 2023 GMUG Conference. Conference Talk. Vancouver, Canada

D'Amato, A.W. June 2022. Outcomes of Adaptive Silviculture in Northern Hardwood and Spruce-Fir Forests in Northern New England. Granite State Division of Society of American Foresters Winter Meeting. Conference Talk. Bartlett, NH

Forcier, A. April 2023. Comparing Crown Plasticity in Open Grown Needleleaf and Broadleaf Trees. University of New Hampshire Undergraduate Research Conference. Conference Poster. Durham NH

Foster, J.R., Pastore, M., Rand, K., English, M., Finnerty, C., Adair, C., Classen, A., King, D., Lutz, D., Nelson, S., D'Amato, A.W. March 19-23, 2023. Climatology of cold-air pooling for montane watersheds and forests of the Northeastern US from MODIS data. International Association of Landscape Ecology (IALE) North America Annual Meeting. Conference Talk. Riverside, CA, USA

Hastings, J.H. Feb 2023. How does structure covary across scales within tree crowns? Natural Resources and the Environment Seminar Series. Conference Talk. Durham NH

Hastings, J.H. Jan 4-5, 2023. Structure covaries across multiple scales within individual tree crowns. Hubbard Brook LTER Quarterly Project Meeting. Conference Talk. Poughkeepsie NY

Hastings, J.H., Ouimette, A., Baillargeon, K., Sullivan, F., Palace, M.W., Ollinger, S.V. April 2023. Characterizing within crown traits to better understand tree strategies. University of New Hampshire Graduate Research Conference. Durham, NH. Conference Poster. Durham NH

Hastings, J.H., Ouimette, A., Baillargeon, K., Sullivan, F., Palace, M.W., Ollinger, S.V. Dec 12-16, 2022. Characterizing within crown traits to better understand tree strategies. American Geophysical Union Fall Meeting. Conference Poster. Chicago IL

Hastings, J.H., Ouimette, A., Baillargeon, K., Sullivan, F., Palace, M.W., Ollinger, S.V. Nov 13-16, 2023. Can linking leaf traits to crown structure help us understand tree photosynthetic strategies? NSF EPSCoR National Conference. Conference Poster. Portland ME

Landry, E., Contosta, A., Foster, J. Ollinger, S. April 2023. Understanding the spatial and temporal climate patterns of Northeastern US. University of New Hampshire Graduate Research Conference. Durham, NH. Conference Poster. Durham NH

Landry, E., Contosta, A., Foster, J., and Ollinger, S. Dec 12-16, 2023. Understanding the spatial and temporal climate patterns of Northeastern US. American Geophysical Union Fall Meeting. Conference Poster. Chicago IL

Landry, E., Contosta, A., Foster, J., and Ollinger, S. Feb 2023. Understanding the spatial and temporal climate patterns of Northeastern US. Natural Resources and the Environment Seminar Series. Conference Talk. Durham NH

Video Outreach

Guts of Climate Model: **S**hort educational video by Liz Burakowski for local school district for their Coding and Cocoa for Hour of Code week celebration in December 2021

INSPIRES Teacher Tour: Workshop Intro: INSPIRES Theme 4 hosted teachers from around the northeast for a field visit at the Schoodic Institute in Maine to support integration of Quantitative Reasoning in Context using forestry science and research.

INSPIRES Teach Workshop: Research Goals: INSPIRES Theme 3 researchers worked with teachers Maine, Vermont & New Hampshire to install climate data instrumentation with the goal of setting up data collection stations at regional schools.

Datasets

Baillargeon, K.A., A.P. Ouimette, J.H. Hastings, R. Sanders-DeMott, and S.V. Ollinger. Published Dataset. Regional and local variation in chemical, structural, and physical leaf traits for tree species in the northeastern United States ver 1. https://doi.org/10.6073/pasta/067108e9983d30d9149c14fc649f75c1. intra. Early-career and student involved. published in Environmental Data Initiative. "

Gustafson, Eric J., Brian R. Miranda, Brian R. Sturtevant, Zaixing Zhou. Model. PnET-Succession v 5.0: Comprehensive description of an ecophysiological succession extension within the LANDIS-II forest landscape model. intra. Early-career and student involved. Model

Hastings, J.H., K. Baillargeon, A.P. Ouimette, and S.V. Ollinger.. Published Dataset. Leaf angle measurements for temperate tree species in northeastern USA ver 1. https://doi.org/10.6073/pasta/faa03b13e5eab16a5e46a4ba0c2123e5. intra. Early-career and student involved. published in Environmental Data Initiative.

Ouimette, A.P., J.H. Hastings, S. Zuckerman, M.A. Vadeboncoeur, K. Baillargeon, S.V. Ollinger, and H. Asbjornsen.. Published Dataset. Leaf temperature of northeastern US tree species ver 1. https://doi.org/10.6073/pasta/964891a1931f6b562ffa8ce538f29b7f . intra. Early-career and student involved. published in Environmental Data Initiative. Data: Leaf temperature measurements were collected during the summer of 2020 within forested areas at the Thompson Farm Earth Systems Observatory in Durham, New Hampshire, USA.

Pastore, M.A., A.T. Classen, M.E. English, S.D. Frey, M.A. Knorr, K. Rand, and E.C. Adair. Published Dataset. Leaf angle measurements for temperate tree species in northeastern USA ver 1. https://doi.org/10.6073/pasta/faa03b13e5eab16a5e46a4ba0c2123e5. intra. Early-career and student involved. published in Environmental Data Initiative.

Appendix 2. Team Roster Year 4

Name	Theme	Institution	Role
Sama Aali	1	UMO	Undergraduate Student
Ali Abedi	1	UMO	Faculty
Carol Adair	1	UVM	Faculty
Kaitlyn Baillargeon	2	UNH	Professional Staff
Kate Beard-Tisdale	2	UMO	Faculty
Olivia Buchanan	3	AAMU	Trainee
Ken Bundy	1	UMO	Faculty
Elizabeth Burakowski	3	UNH	Faculty
Greg Bushey	3	AAMU	Trainee
Tanichia Campbell	4	AAMU	Undergraduate Student
Leslee Canty-Noyes	ALL	UMO	Professional Staff
Lorra Carter	3	AAMU	Trainee
Cen Chen	3	AAMU	Post-doc
Aimee Classen	1	UVM	Faculty
Alix Contosta	1	UNH	Faculty
Kathy Crowley	3	Unity	Faculty
Katie Cummings	4	AAMU	Professional Staff
Helen Czech	1	AAMU	Professional Staff
Anthony D'Amato	3	UVM	Faculty
Dedrick Davis	1	AAMU	Faculty
Jhanelle Davy	1	AAMU	Graduate Student
Luben Dimov	3	UVM	Faculty
Mark Ducey	3	UNH	Faculty
Alexus Dunn	4	AAMU	Undergraduate Student
Leo Edmiston-Cyr	2	UMO	Professional Staff
Emily Landry	2	UNH	Graduate Student
Sidnee Everhart	3	AAMU	Trainee
Meg Fergusson	ALL	UMO	Professional Staff
Sammie Finch	3	AAMU	Trainee
Jane Foster	3	UVM	Faculty
Kiara Gamble	4	AAMU	Undergraduate Student
Jessica Gersony	2	Smith	Post-doc
Kindrea Gibbons	1	AAMU	Graduate Student
Breona Grace	4	AAMU	Undergraduate Student
Marissa Gray	1	AAMU	Graduate Student
Zane Green	3	AAMU	Trainee
Michelle Gregoire	ALL	UNH	Professional Staff
Torsten Hahmann	2	UMO	Faculty
Howard Harris	1	AAMU	Undergraduate Student
John Hastings	2	UNH	Graduate Student
Daniel Hayes	3	UMO	Faculty
Christopher Holden	3	AAMU	Trainee
Gabrielle Holt	4	UMO	Professional Staff
Shaik Hossain	3	AAMU	Faculty
James Jackson	3	AAMU	Undergraduate Student
Austen Johnson	3	AAMU	Undergraduate Student
Andreana Jones	4	AAMU	Undergraduate Student
Christopher Jones	2	AAMU	Graduate Student
Maria Kimpe		AAMU	Professional Staff
Patience Knight		AAMU	Professional Staff
Kasey Legaard	2	UMO	Faculty
Dawn Lemke	1	AAMU	Faculty
Sara Lindsay	4	UMO	Faculty

Dave Lutz	1	Dartmouth	Faculty
Sophia Madison	1	AAMU	Graduate Student
Stefania Marthakis	ALL	UMO	Professional Staff
Mary Martin	2	UNH	Faculty
Annie McBride	4	AAMU	Undergraduate Student
Heather McInnis	All		Evaluator
Trinity McIntosh	4	AAMU	Undergraduate Student
Susan McKay	4	UMO	Faculty
Casey Mills	3	AAMU	Undergraduate Student
Hannah O. Millsap	4	AAMU	Undergraduate Student
Karman Morgan	1	AAMU	Graduate Student
Marley Muhammad	4	AAMU	Undergraduate Student
Paulina Murray	1 and 2	UVM	Graduate Student
Mersedeh Naji	1	UMO	Graduate Student
Peter Nelson	2	UMO	Faculty
Sarah Nelson	1	UMO	Faculty
Tucker Nugent	2	UNH	Undergraduate Student
Emmanuel Oko	1	AAMU	Graduate Student
Adefemi Olateru	1	AAMU	Undergraduate Student
Scott Ollinger	3	UNH	Faculty
Andrew Ouimette	1	UNH	Faculty
Melissa Pastore	1	UVM	Post-doc
LaQuanda Peagler	4	AAMU	Undergraduate Student
Apryl Perry	1	UNH	Professional Staff
Franziska Peterson	4	UMO	Faculty
Marek Petrik	2	UNH	Faculty
Jane Pettit	2	UMO	Professional Staff
Taylor Petty	3	AAMU	Trainee
Mphande Phiri	1	AAMU	Undergraduate Student
Anupam Raj	4	UMO	Graduate Student
Darren Ranco	2	UMO	Faculty
Karin Rand	1,2,3	UVM	Professional Staff
Donna Rizzo	2	UVM	Faculty
Sam Roy	2	UMO	Faculty
Lisa Scott	3	UNH	Graduate Student
Bruce Segee	1	UMO	Faculty
Christina Siddons	4	UMO	Graduate Student
Erin Simons-Legaard	3	UMO	Faculty
Grace Smith	2	UVM	Graduate Student
McKenzie Smith	3	AAMU	Undergraduate Student
Nicholas Soucy	1	UMO	Graduate Student
Kyla Tillman	4	AAMU	Undergraduate Student
Regina Toolin	4	UVM	Faculty
Emily Uhrig	All	UMO	Professional Staff
Marina Van der Eb	4	UMO	Faculty
Jeffrey Wansley	1	UNH	Graduate Student
Xinyuan Wei	3	UMO	Post-doc
Aaron Weiskittel	3	UMO	Faculty
Thayer Whitney	1	UMO	Graduate Student
Larry Whitsel	2	UMO	Faculty
Kingsley Wiafe-Kwakye	2	UMO	Graduate Student
Matheu Woodall	3	AAMU	Undergraduate Student
Troy Wright	1	AAMU	Graduate Student
Raziq Yaqub	1	AAMU	Faculty
Salimeh Yasaei Sekeh	1	UMO	Faculty
Zaixing Zhou	3	UNH	Faculty

Appendix 3. Team Profiles

Profiles by Stefania Irene Marthakis

THE UNIVERSITY OF MAINE

Maine EPSCoR

INSPIRES Profile:

Anupam Raj

INSPIRES Graduate Student Spotlight: Anupam Raj

August 22, 2022 General, News

By Stefania Irene Marthakis

Anupam Raj is a third-year graduate student as well as a research assistant in the Master of Science in Teaching (MST) program through the Maine Center for Research in STEM Education (RiSE Center) at the University of Maine (UMaine).

Raj is advised by Michael Wittmann (Professor of Physics) as well as Franziska Peterson (Assistant Professor of Mathematics and RiSE Center Graduate Coordinator) and Asli Barrie (Associate Professor of Curriculum, Assessment, and Instruction), collectively forming his graduate committee.

With a B.Sc. and M.Sc. in Physics from his home country of India, Raj found the best of both worlds in terms of research and teaching through the RiSE Center's MST program. Raj taught at Aakash Institute in Kashmir and participated in a research project at the University of Illinois. Through empirical study during his master's, Raj decided to focus on teaching rather than research.

"I like to interact with people and be more creative in my work, so teaching seems to have those things apart from the logical and critical aspects," Raj explained.

"There's room for creativity in the way you present your lesson plan; there's room for more human interaction."

https://umaine.edu/epscor/2022/08/22/inspires-graduate-student-spotlight-anupam-raj/ 1/2

5/17/23, 5:08 AM INSPIRES Graduate Student Spotlight: Anupam Raj - Maine EPSCoR - University of Maine

Raj has served as a teaching assistant in both UMaine's Mathematics and Physics departments. As a research assistant at the RiSE Center, Raj contributes to the RiSE Center's mission on improving research and research-based practice of STEM education by attending weekly meetings, doing literature reviews, and assisting with teacher interviews by transcribing, analyzing, and participating in discussions about questionnaires and programs through the NSF EPSCoR RII Track-2 INSPIRES project.

Raj was drawn to the impact factors of INSPIRES, which include educating the community about the project's research and incorporating Quantitative Reasoning in Context (QRC), forestry topics, Big Data, and Traditional Ecological Knowledge (TEK) that will directly support lesson development for classrooms of STEM teachers across Maine, New Hampshire, and Vermont.

Beyond technological innovations, Raj believes it is paramount for the community to understand what the researchers are doing and to keep that communication line open, especially regarding novel approaches. INSPIRES and RiSE aim to provide a rare opportunity through their teacher training program—especially in a science-based research project—for teachers to act as researchers: develop and test their own hypothesis as well as collect data from across the Northern Forest Region alongside INSPIRES project members of different disciplines.

"I think as a science teacher I'm always going to help my students to see the power of data and data analysis, and how mathematical thinking can help you to see beyond antidotal evidence and be able to analyze situations in a better way. It's like a sixth sense on how I see it, you have five senses to collect natural sensory data and then you make your decisions, but then there's a sixth sense called mathematical sense," Raj stated.

The RiSE Center focuses on what the teachers are currently doing in the classroom and what they want to change about their practice using a tailored approach throughout all their projects and programs.

Together, INSPIRES researchers, RiSE staff, and UM faculty as well as graduate students like Raj, communicate the collective importance of scientific research and STEM education by bringing in outside people, ideas, resources, and locations. This community component introduces vitality to STEM curricula.

After Raj graduates in August 2022, he will teach at Excel High School, a high-need title 1 school in the Boston Public School district. Age and location have a particular importance to Raj's teaching plans.

"When I was in high school, I was the most motivated version of myself, so I feel like that's a time when you're transitioning from being a child who doesn't know what to do to being an adult. Your value system is being shaped at that time, influencing what you choose. The kind of dreams you form will stay with you for the rest of your life. It is a crucial time to give people more information, more guidance in some way to make better choices," Raj concluded.

National Science Foundation

INSPIRES

Team Profiles

Kenneth Bundy

Machine Learning Software Engineer
University of Maine
Research Interests: Machine learning, programming

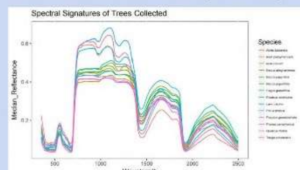
KENNETH BUNDY is developing methodologies for incorporating remote sensing and geospatial data into spatial forest models at UMaine's Center for Research on Sustainable Forests. Ken is also a research consultant in Dr. Ali Abedi's (Associate Vice President for Research and Director of the Center for Undergraduate Research) WiSe-NET Lab.

Because of Bundy's background in machine learning and programming, he was invited to join the INSPIRES project and apply his skills to the application of wireless forest monitoring sensors.

"There's two ways of making some type of model for the world. You can either use statistics, which tells you what the model should be based on the data exactly or machine learning which says I'm going to make a bad model and come up with a way to make it better, and I'm just going to keep improving it until it's good," Bundy explained.

Bundy has extensive experience applying data collection and machine learning. On a NASA SEED infrastructure grant—a research project that was focused on air leak identification—Bundy's aim was to identify the materiality of the leak. Through data collection and machine learning (e.g., building classifiers like neural networks), Bundy was able to identify the type of the material by the sound the leak produced, allowing for faster leak detection by checking only the specific location (e.g., rubber tubes) instead of the entire space station or space shuttle.

For INSPIRES, Bundy is developing a machine learning system that will control a wireless sensor network. Bundy's aim is to optimize the sensors for power usage and efficiency by fine-tuning when the sensor nodes transmit their data as well as the routing pattern (i.e., how data moves through the network as a whole and how long it takes to get the data to reach its destination).



The ecological spectroscopy process involves scanning study sites with spectroradiometers, referencing the data through ground measurements, and analyzing and modeling the data to generate high resolution forest maps for forest health and species models.

With new areas of machine learning to explore, Bundy's work ensures that the wireless sensors scattered throughout the forest are measuring parameters such as soil moisture, pH, and carbon in a way that allows them to effectively communicate with one another and efficiently send information to a base station that allows remote online access to the data.

"Machine learning methods developed in this project not only process data but also provide us with new data on the quality of wireless communication channels. This helps researchers to design a network that can last a long time in the forest without the need for daily change of batteries," Abedi said.

Bundy also works with Peter Nelson, Forest Ecology Director at Schoodic Institute, on an INSPIRES cross-theme collaboration that focuses on identifying tree species from aerial (drone-based) spectroscopy (i.e., images taken by an imaging spectrometer or hyperspectral camera) by using machine learning.

This species identification project addresses two analytical challenges: Big Data (large, complex, fast-growing data that cannot be efficiently stored or processed by traditional methods) and forest tree separation (as individual pixels from an image) by using instruments and a hyperspectral processing code developed over the years by Nelson.

Bundy then uses machine learning techniques to create maps of tree species from these hyperspectral images. Further, Bundy and Nelson are working on hyperspectral processing code through LecoSpectR imaging processing software (i.e., a code pipeline) that will allow researchers to make maps of certain species, especially those that expand Maine's economic capacity such as forest tree species separation and forest health.

Bundy on applying his work with machine learning to wireless forest monitoring sensors:

"I've developed the sensor system which works together with a wireless scheduling machine learning system using a transmission scheduling algorithm and routing piece. A lot of this work involves solving types of graph traversal problems—there is always a new algorithm you can try and compare."

INSPIRES interviews and profiles by Stefania Irene Marthakis.
University of Maine Center for Research on Sustainable Forests
crsf.umaine.edu/inspires

THE UNIVERSITY OF MAINE | ALABAMA A&M UNIVERSITY | University of New Hampshire | The University of Vermont

Smart Data for Resilient Forests

INSPIRES: Leveraging Intelligent Informatics and Smart Data for Improved Understanding of Northern Forest Ecosystem Resilience is an NSF-supported project that leverages unique expertise from the University of Maine, University of New Hampshire, and University of Vermont to construct a digital framework to better assess, understand, and forecast this complex forest at a resolution relevant to scientists, land managers, and policymakers.

•INSPIRES is supported by the National Science Foundation under Grant No. 1920908•

Appendix 4. Data Sharing

Data Sharing Subcommittee

- Alix Contosta, Theme 1, UNH
- Ami Gaspar, ACG, UMaine
- Daniel Hayes, Theme 3, UMaine
- Franziska Peterson, Theme 4, UMaine
- Ken Bundy, Theme 1, UMaine
- Leo Edmiston-Cyr (lead), CRSF, UMaine
- Mary Martin, NSF EDI, UNH
- Peter Nelson, Theme 2, Schoodic Institute

Organization, naming, and metadata sections by Leo Edmiston-Cyr, CRSF UMaine, with invaluable review and feedback from Mary Martin, Ami Gaspar, and the whole data sharing subcommittee.

Overview

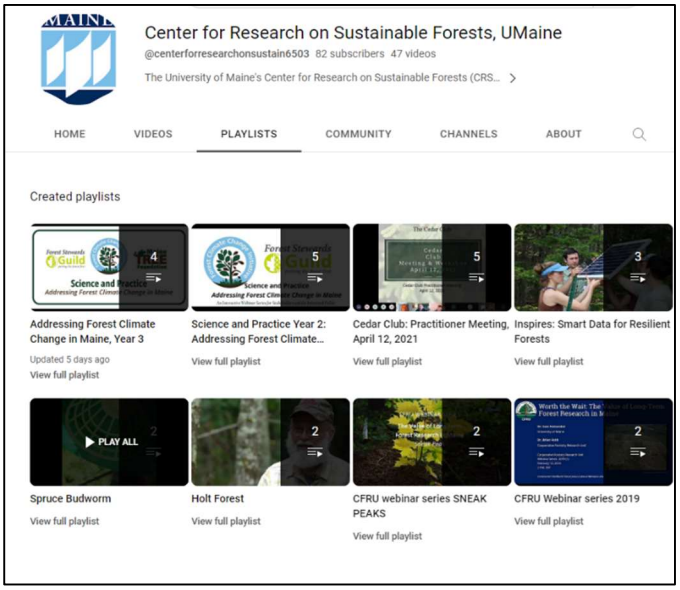
The data sharing plan provides guidance on where data is stored, naming conventions, and how metadata is recorded to ensure sufficient quality to meet NSF and publishing requirements. This is a pipeline from raw data to data and documents that are ready for publishing. Each theme has provided its own section of this plan, which includes a declaration of the data and document products they will share along with an estimated timeline.

Platform

All INSPIRES members will be added to the newly created OneDrive shared folder inside a dedicated “Shared Library. This is separate from the links that have previously been shared. All of the original documents have been consolidated into this new shared structure alongside the new organizational elements for each theme. Using this new, shared library will help keep the clutter down in our personal OneDrives as our IT departments roll them out and we use them more. This does not prevent anyone from using other platforms and systems to meet the needs of their work. This merely defines a stable platform which is well defined and accessible to all.

Appendix 5. Communications and Resources

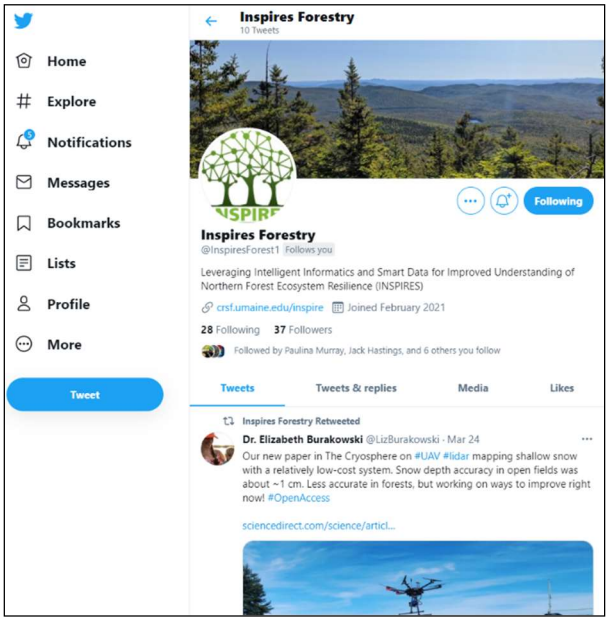
The INSPIRES team uses a number of communications outlets to share project news and information.



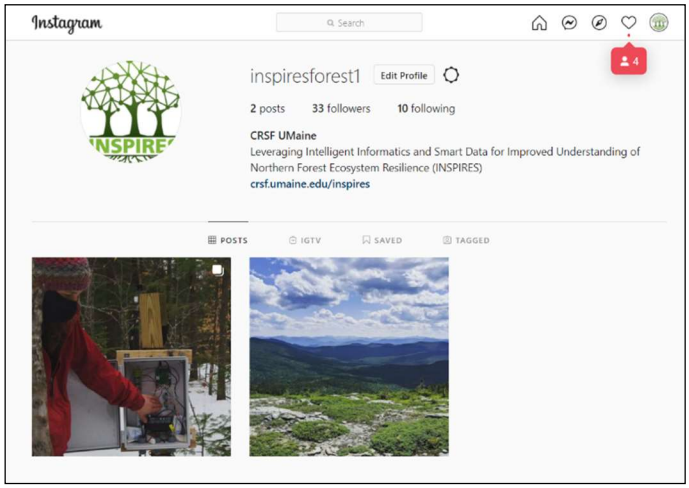
INSPIRES videos shared on CRSF YouTube channel

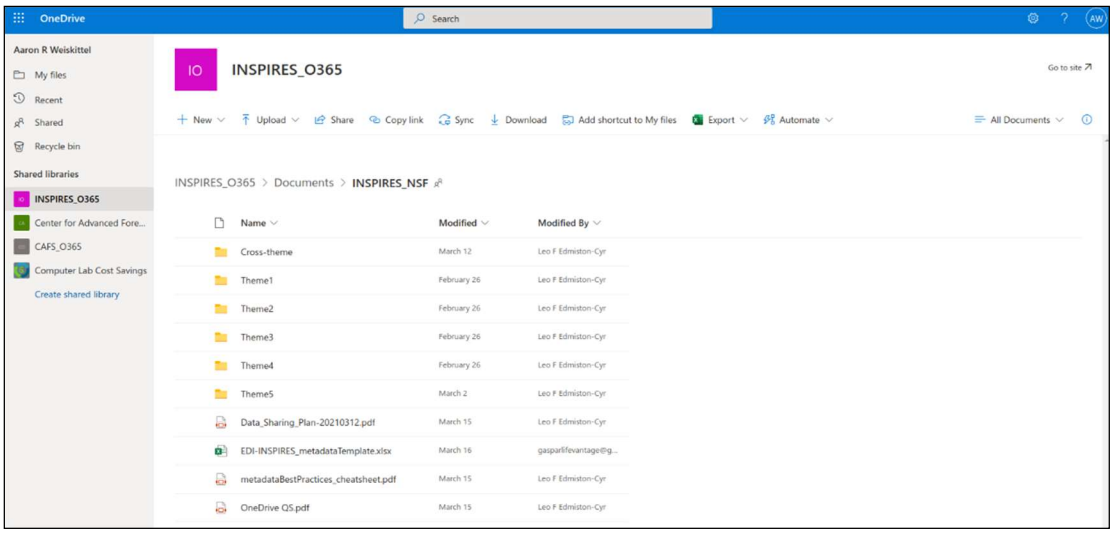
The INSPIRES website provides access to team profiles, annual reports, leadership team, faculty and researchers, research briefs, and team resources.

crsf.umaine.edu/inspires

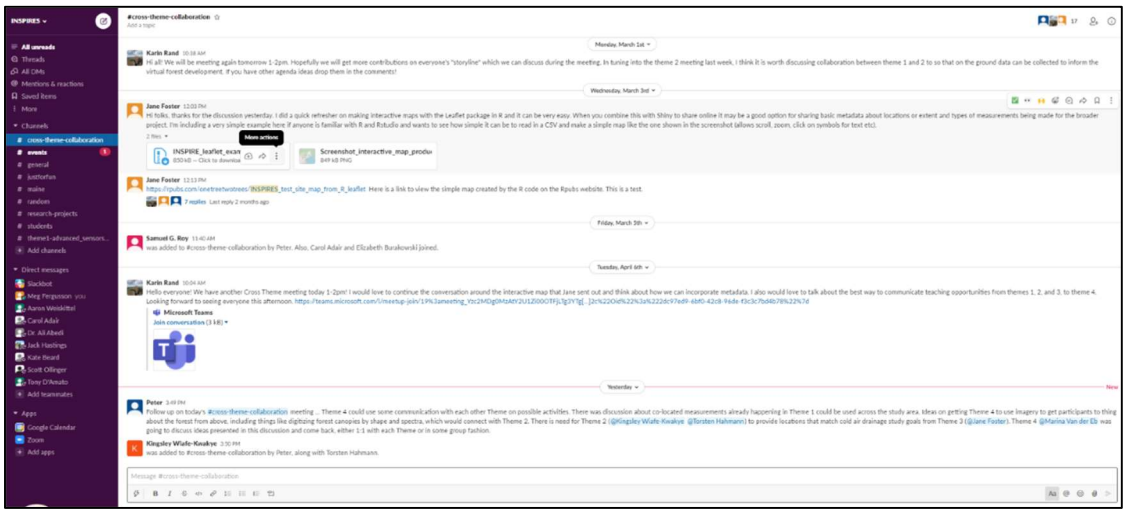


INSPIRES Twitter and Intagram accounts





Sharepoint folder in OneDrive accessible and shareable by all INSPIRES team members.



INSPIRES Slack Channel

University of Maine

ME-NH-VT EPSCoR RII Track-2 Focused EPSCoR Collaboration (INSPIRES)

Summative Assessment Report from the External Review Panel
February 2023

Dr. Jennifer Allen
Associate Professor, Department of Public Administration
Portland State University

Dr. Ragan Callaway
Regents Professor, Division of Biological Sciences
University of Montana

Dr. Christian Messier
Full Professor, Department of Biological Sciences at the University of Quebec in Montreal (UQAM) and in Outaouais (UQO)

Dr. Heather E. McInnis
Vice President, Strategic Assessment
The Implementation Group (T.I.G.)

T.I.G.
The Implementation Group

800 Maine Avenue, Southwest, Suite 800
Washington, DC 20024

Table of Contents

I. Introduction

The University of Maine (UME) leads a research collaboration with the University of New Hampshire (UNH), the University of Vermont (UVM), and Alabama Agricultural and Mechanical University (AAMU) funded by Track-2 and supplemental awards from the National Science Foundation's Established Program to Stimulate Competitive Research (EPSCoR). The four-year (2019-2023) EPSCoR RII Track-2 project, titled ***Integrating and Leveraging Multi-Dimensional Data Streams for Improved Understanding of Ecosystem Services from Complex Northern Forests (INSPIRES)***, leverages expertise, resources, and partnerships in each jurisdiction to construct a digital framework that will facilitate analysis of ecosystem health and resilience in response to environmental change.[1]

This report details the outcomes of an external, summative assessment of the project conducted by The Implementation Group (TIG) in January 2023, the mid-point of the final year of the award period.

Background

The three primary goals of the INSPIRES project are to:

1. conduct novel interdisciplinary, stakeholder-engaged research by linking ecology, computer science, engineering and data science that makes significant contributions to understanding the region's forests and influence practices related to making decisions about their management;
2. connect researchers across ME-NH-VT to build collective research capacity, particularly across distinct disciplinary boundaries and in key forested regions previously under served by past investigations and research investments; and
3. develop early career researchers with expertise in ecosystem science, data informatics, engineering, and ecological modeling including graduate students, post-docs and faculty.

Project goals, activities, and participation are organized by four interdisciplinary themes: *Sensors and Advanced Computing* (Theme 1), *Environmental Informatics and Analytics* (Theme 2), *Integrated Ecological Modeling* (Theme 3), and *Quantitative Reasoning in Context* (Theme 4). An additional project, *Transitional Forest Response to Unique Stressors*, was developed in collaboration with new team members from AAMU in 2021 under a $600,000, 2-year supplemental award from NSF EPSCoR. Under this project, researchers are collaborating to extend sensor design and deployment (Themes 1 and 2) to AAMU's long-term research field site (Paint Rock), a post-doctoral teaching fellow from UME has been placed at AAMU, and Alabama high school teachers are being included in Theme 4 activities.

The INSPIRES project is led by a Centralized Leadership Team (CLT), comprising Co-Investigators Aaron Weiskittel (PI UME), Anthony D'Amato (UVM), Scott Ollinger (UNH), and Dawn Lemke (AAMU). Cross-cutting activities are guided by a Collaborative Research Committee (CRC), a Mentoring, Engagement, and Education

[1] *INSPIRES Year 3 Annual Report*. https://crsf.umaine.edu/wp-content/uploads/sites/214/2022/08/INSPIRES-Yr3-Annual-Report-1.pdf

Committee (MEE), a Data Sharing Subcommittee, and a Project Collaborative Coordinator (Emily Uhrig). Administrative and outreach support is leveraged from UME's Center for Research on Sustainable Forests (CRSF) (i.e., Communications and Outreach specialist, Meg Fergusson) and the UME EPSCoR office (Stephania Markakis). The project has included more than 80 participants, including 45 faculty (19 UME, 12 UNH, 8 UVM, 4 AAMU), 58% of whom are female, and 55% of whom are considered early career.

Review Focus

At the request of the project leadership, TIG led a summative assessment of the project to evaluate project outcomes, provide guidance on priorities for the final six months of the award period, and make recommendations for sustaining the capacity built and impact generated from the collaboration, including suggesting what aspects of the project to sustain through future grants and initiatives (e.g., UME's planned NSF EPSCoR RII Track-1 project in preparation for submission to the NSF in August 2023).

Review Process

On January 9-11, 2023, TIG convened three independent scientific and programmatic experts in a series of virtual meetings with INSPIRES Co-Is, participating researchers and trainees, and project coordination and administrative support staff. Dr. Jennifer Allen (Portland State University), Dr. Ragan Callaway (University of Montana), and Dr. Christian Messier (University of Quebec in Montreal and in Outaouais) provided this assessment; each of these panelists also participated in the previous assessment of the program conducted in January 2021. Dr. Heather McInnis, an evaluation expert with experience assessing large-scale, multi-institutional and multi-disciplinary STEM initiatives, led the assessment and coordinated the development of this report.

The assessment process involved (i) a review of program information provided through the project's ongoing annual reporting process, (ii) a 2.5-day-long virtual site visit (January 9-11, 2023) comprising meetings between the TIG review panel, project participants, and key stakeholders associated with the project and partner institutions, and (iii) evaluation of the INSPIRES progress toward Year 4 objectives. Before the site visit, TIG collaborated with INSPIRES leadership to outline a *Charge to the Panel* and a *Site Visit Agenda* (*see Appendix A: Charge to the TIG Panel and 2023 External Review Meeting Agenda*). Background materials were provided to TIG two weeks prior to the site visit, including the Year 3 Annual Report, and CLT Responses to the 2021 TIG review recommendations. During the site visit meetings, TIG panelists were presented with summaries of the project's status, outcomes, and planned work and panelists engaged with team members in brief Q&A sessions. The TIG review analyzed information available, interpreted it in the broader context of the NSF's EPSCoR goals and institutional resources, and assessed progress made toward specific goals of the ME-NH-VT EPSCoR Track-2 project. Panelists discussed their preliminary assessment with the project leadership during an oral debriefing session held at the end of the site visit.

Report Organization

The following report sections summarize the TIG review panel's observations of overall program achievements, and findings related to 1) project leadership and

implementation, 2) collaboration, 3) research accomplishments and scientific advances, and 4) sustainability. The report highlights project successes, suggests priorities for the final year award year, and recommends strategies to transition out of the award and sustain capacity and impact.

II. Overall Program Achievements

Strengths
The INSPIRES Track-2 project is extremely strong and demonstrates a high-level of productivity in terms of the achievement of NSF-determined products, technical objectives, the pursuit and acquisition of follow-on funding, and the development of a collaborative spirit across the institutions and themes. The team from AAMU has been successfully integrated into the project, despite only having finalized the subaward and received funding in January 2022.

The PI and CLT has done an excellent job of minimizing the administrative burden on those engaged directly in the on-the-ground work. Early Career researchers have been productive and successful, with several of them advancing into new careers in INSPIRES-related fields and positions within the partnering jurisdictions. Importantly, the CLT has wisely given a great deal of intellectual freedom to Early Career researchers and graduate students for problem solving and developing novel and sustainable ideas for expanding the research accomplishments of INSPIRES. Accordingly, research results are strong across Themes 1-3, and there have been significant broader impacts to the community through the efforts under Theme 4 to engage teachers and other community partners. There was strong participation in the TIG review panel's virtual site visit and review discussions from a suite of stakeholders, including staff from several non-profits as well as teachers engaged in Theme 4. The TIG review panel was also impressed with project's strong communications team and the efforts and strategies focused on effectively informing the broader public about INSPIRES work.

Challenges
The partnerships and collaborations that have been developed through INSPIRES are even more impressive in the context of the challenges posed by the COVID pandemic. While the pandemic was at some level a shared experience, its impacts were greater for those team members either at a vulnerable moment in their careers (e.g., early in their academic careers) or experiencing difficult personal circumstances. Navigating the isolation and disruptions to work and home environments has placed additional and continuing stress on many participants, including tensions related to work-life balance, maintaining productivity, and the challenges of developing and maintaining relationships with colleagues in the absence of in-person interactions. Again, the collaborative spirit that was evident to the TIG review panel through interactions with numerous team member during the virtual site visit as well as assessment of the work produced through the project is particularly remarkable given these pressures.

The TIG review panel noted that while teams collaborating under each of the four research themes have made significant progress toward their research and engagement goals, they have not yet had time to explore many of the potential

linkages between the themes. While the activities under each theme offer very important contributions, the overall impacts of this work could be elevated if the infrastructure, data, and research findings are integrated across the overall INSPIRES project. This is discussed in more detail in *Section V* of this report, *Research Accomplishments and Scientific Advances*, below.

The TIG review panel also noted that in some cases the graduate students and others who presented to the panel struggled to articulate the connections between their research and the broader objectives of INSPIRES. This may, in part, reflect the focus on theme-specific goals to-date.

Recommendations:

Considering these strengths and challenges, the panel offers the following suggestions for what to prioritize during the project's wrap-up phase and what successes to showcase and sustain through grants and ongoing or future initiatives. To be clear, these recommendations are not expectations to be executed for a successful completion of INSPIRES, instead they are meant to be ideas that might expand and sustain the achievements of the participants.

- ***Prioritize further exploration of the practical and conceptual linkages between the themes through publications or other mechanisms to provide a forum to share work across themes and explore connections.*** For example, a graduate student forum may be a way to explore existing and potential linkages among themes that can be developed into future graduate projects, papers or proposals that would extend even beyond the end of this award. Perhaps the deployment and use of sensors (Theme 1) could be expanded, or at least maintained by K-12 teachers connected to Theme 4. Might sensors be deployed to field sites in Alabama, if they have not been already?

- ***Highlight and elevate the completed and ongoing research that is filling key knowledge gaps in a particular field. Spotlight the impact and significance of research efforts (e.g., cold air pooling) and findings in reports and communications so that the project is more fully recognized locally and internationally. Continue to tout the novel technology of inexpensive and easy-to-use sensors and their role in collecting important data in remote area****. Such sensors will become more and more important in the future as we want to monitor changes occurring in remote areas and the advances in Theme 1 should be highlighted. Also highlight the potential roles of citizen scientists in the deployment and monitoring of these sensors.*

- ***Explore opportunities to help graduate students and early career researchers to better articulate the significance, novelty, and value of their work.*** This engagement can provide an opportunity to help students and early career researchers to better articulate the reason, purpose, and impact of their research. Such effort will help them get the best opportunities for further studies or work. In addition, it can feed into broader communication efforts and contribute to Annual and Final Reports to the NSF and to the planned application to NSF EPSCoR for a no-cost extension.

- ***Continue coordination and communication activities, like writing sessions, that foster connections and collaboration among graduate students and other researchers.*** These sessions may play an important role in the completion of peer-reviewed student papers and theses.

- ***Pursue a 12-month no-cost extension.*** The panel strongly encourages the INSPIRES leadership to apply to the NSF for a 12 month no-cost extension (NCE) to provide time to build on the strong foundation of collaboration that has been laid to-date. The panel recommends that a focus on integrating science (e.g., sensors and analytics) across themes be a substantial component of the NCE.

The TIG panelists hope the strong collaborative spirit that has been fostered and partnerships that have been developed across jurisdictions continues successfully.

III. Project Leadership and Implementation

Administrative Leadership

Strengths
The INSPIRES' leadership has done an excellent job of building a collaborative spirit among the participants. A number of productive, cross-jurisdictional partnerships and collaborations have been developed across the participating universities, despite COVID-related challenges. INSPIRES' leadership has also empowered independent conceptual development by team members, including graduate students, as evidenced by the research presentations and the intellectual energy demonstrated by the researchers and trainees the panel interacted with. The PI and CLT has clearly prioritized and invested in the success of the project.

While the PI has shouldered significant administrative burdens himself in support of strong program performance, he has been aided in this by leveraging existing administrative support from UMaine's Center for Research on Sustainable Forests (Meg Fergusson; PI is Director of the Center), UMaine's EPSCoR program office (Stephania Marthakis) and UNH's EPSCoR program office (Michelle Gregoire). The part-time support provided by Project Collaborative Coordinator Emily Uhrig has been extremely valuable as well.

As noted previously, the TIG review panel was impressed with the strong communications team and the thoughtful approach being taken to make information about INSPIRES work accessible to the public. The importance of investing in communications is not always recognized and can contribute significantly to overall project impact. In addition to the organization of the communications team, the panel found that the network of focused committees assigned to lead and communicate aspects of the project (Mentoring, Education, and Engagement, Collaborative Research, Data Sharing, Inter-jurisdictional Advisory Board) is an excellent approach to keeping key components of INSPIRES on track without the need for top-down control.

Challenges
Reporting requirements and the overall demands related to administrative coordination for these projects are burdensome. The relatively limited amount of funding provided under a Track-2 award has placed pressures on administrators and researchers, as both juggle other commitments. As noted above, it has been necessary to leverage other sources of administrative support for this multi-university, multi-state initiative. Given that the funding was distributed equally across the three institutions, it was fortunate that the PI was able to leverage administrative infrastructure of the Maine and New Hampshire EPSCoR offices and existing resources to help with this work. The INSPIRES project management strategies were effective in the context of the Track-2 goals, reporting requirements, and relatively large size of the team. Importantly, the panelists were made aware that the strategies were recognized as best practices by the NSF EPSCoR (PI Weiskittel was asked to present on these to new Track-2 cohorts and at the recent national EPSCoR meeting in November 2022. The project management strategies and outcomes can inform planning to ensure similar critical support for future large-scale collaborative research projects, including UME's EPSCoR RII Track-1 proposal currently in development.

The panel noted that the interactions with researchers from UNH New Hampshire seems to have diminished over the years (though there has been added engagement from Dartmouth). However, this perception may be due, in part, to different intensities of thematic requirements across the project award years. In addition, the panel learned that COVID impacts on researchers more junior in their careers and graduate student recruitment challenges delayed ramp up and spend down at UNH. These circumstances should be considered in the NCE request.

Recommendations:
Because INSPIRES is near the end of the award period, the TIG review panel has few recommendations for administrative or management changes. Furthermore, the panelists' perspective on these issues, despite the challenges, are positive. The panel's thoughts about the challenges that have been faced by the INSPIRES leadership and the ways these challenges have been met are intended to be helpful to future EPSCoR teams in these jurisdictions, or to the NSF.

- ***Highlight the outcomes of project management and communication strategies in the final reports to the NSF.*** The level of administrative work that is required to successfully manage an EPSCoR project, particularly with a team this large, imposes a significant institutional burden on participating institutions. The panel recommends that the Annual and Final Reports to the NSF articulate in some detail the unique approaches the CLT adopted to facilitate and coordinate interjurisdictional and interinstitutional collaborations, convey and collect information from team members and partners, disseminate information to external partners and the public, and report on progress. In addition to informing NSF's ongoing efforts to improve and adapt its programs and each jurisdiction's efforts to establish new large-scale capacity-building research programs, the strategies offer models that may be useful to the project's early career researchers and advanced graduate students as they navigate ongoing collaborative research

challenges

- ***Pursue opportunities for sustainability such as new funding with AAMU that will keep the new cross-institutional and cross-jurisdictional relationships going****. It may be helpful to consider if there are activities underway with AAMU that would knit well into the focus of the Track 1 proposal currently under development.*

Early Career Researcher Support and Development

Strengths
There are many early career researchers involved in the INSPIRES project, and a number of them have developed relationships with each other during this project. Several of the researchers supported by "soft money" have successfully secured permanent positions with federal agencies and other organizations and in several cases, they are moving into positions that will allow them to continue to collaborate on these projects. The panel saw all this progress with early career researchers as very positive and a great outcome from this Track 2.

Challenges
A number of challenges face early career researchers, some of which are reflective of broader issues in academia. For example, the interdisciplinary work that is highly encouraged under this and other NSF efforts is often not valued or recognized in hiring processes for tenure line positions, which can create a dilemma for young faculty. Furthermore, it normally takes more time and effort to produce scientific papers in this type of interdisciplinary work, which is a further constraint on their career. The disconnect between recognition of the importance of interdisciplinary and policy-relevant science among funders and the lack of recognition of this same work can be demoralizing for early career researchers and for research faculty interested in pursuing more stable tenure line positions.

In addition, INSPIRES involves many "soft money" faculty; the precariousness of their jobs places additional strain on these participants. As noted previously, several soft-money research scientists have left or will be leaving their university posts to take more stable positions at other institutions and agencies. While it is clear that INSPIRES has provided relevant and effective resources to support research productivity, these team members may have very different professional development interests and skills training needs than tenure-track faculty, postdocs, or advanced graduate students pursuing academic careers.

Recommendations:

- ***The INSPIRES leadership and senior faculty should engage with early career faculty as the project winds down to advise and mentor them towards their career goals after INSPIRE ends and to explore how their engagement in the INSPIRES work might be emphasized or leveraged for their future success.*** In the context of the NCE, consider what support could be focused on participating and productive research faculty who are funded on "soft money", as their INSPIRES outcomes might be underpinning a pivotal transition in their careers.

IV. Research Accomplishments and Scientific Advances

Novelty and Innovation

INSPIRES has developed novel low-cost sensors, hyperspectral uses and analyses, and uses for artificial intelligence (AI) for interpreting data. Many high-quality papers have been published on these topics. One striking example of innovative science presented to the panel was a peer-reviewed publication on topographically based cold air pooling and how this pooling might buffer some effects of global warming. An exciting knock-on extension of this first paper is the ongoing and future integration of the sensors and AI analysis of cold air pooling.

Thematic Outcomes and Convergent Research

Strengths
INSPIRES has made excellent progress in establishing information networks, sensor networks, and the use of AI in these contexts (Themes 1 and 2). INSPIRES leadership and researchers and education, outreach, and diversity-focused team members have made good connections with teachers, the National Park service, and community organizations (Theme 4). Within-theme projects have produced interesting and important new knowledge and have outstanding rates of scientific publications.

Challenges
INSPIRES has been very productive in terms of papers and advances in each of the research Themes, but less so in developing cross-theme papers. The panel did not see strong connections between Themes 1 and 2 and Theme 3. In addition, Theme 3 seems less developed than the other Themes. A strong potential exists in developing linkages between these Themes and this should be a focus of the work in the next 12 months. The panel also noticed that while students appeared to be skilled and productive in their own work, they seemed to have more limited knowledge or understanding of how their work is related to the overall objective of the project.

There is clearly a strong partnership with many potential users of the research tools and data sets being developed by each theme, but the panel did not see many examples of how these were used by the partners to change their practices or inform policy changes. The panel recognizes that it takes significant time to develop relationships and build trust with tribes and others who would be central to the further integration of Traditional Ecological knowledge (TEK) into the project's activities. Likewise, it takes time to develop productive relationships with industry. Given the Co-I's deep experience with forestry industries, it would be helpful both to understand how INSPIRES' findings are being used by industry partners as well as where other opportunities may lie to further expand industry connections.

Recommendations:

- ***Use the next 12 months to complete and publish findings from the***

work being done under Theme 3, as well as further develop the connections between Themes 1 and 2 and Theme 3. The main research goal of Theme 3 is "integrating sensor data, remote sensing imagery, and semantically enriched information from Themes 1 and 2 to better enhance as well as complete an inverse parameterization of regional ecological models for projecting forest ecosystem integrity and its uncertainty under an array of alternative futures that include variation in climate, land use, regulatory policies, and natural disturbance scenarios." A great achievement of Theme 3 would be to do the inverse parameterization of Landis-II. It seems that they have everything in place to achieve this and some resources, if possible, should be put toward this objective.

- ***Work closely with partners to identify where and how they might incorporate findings from the research to improve their practices.*** What kinds of policy changes have been or would be informed by the research in the different Themes? In what ways are practitioners or utilizing the findings from the research to change their practices? The importance of the cold-air micro-habitats in the region for biodiversity protection should be emphasized and management strategies could be put in place with the partners to insure their protection.

- ***Identify what aspects of the project activities and findings might inform and support ongoing relationship-building with regional Tribes and advance the integration of traditional ecological knowledge in research and forestry management practices.*** Highlight these aspects in final reports and new funding proposals, and through engagements with partners, stakeholders. The panel sees good potential for collaboration with Tribes through the findings on the cold-air micro-habitats.

- ***Leverage connections with industrial partners to disseminate novel information coming out of the Track-2.*** As the Co-Is already have very good connections with industry partners (from other projects) there is a good opportunity to disseminate the novel information such as the cold-air pooling project coming out of this Track 2 to this sector.

V. Cross-Disciplinary and Cross-Jurisdictional Collaboration

Strengths

INSPIRES is a highly collaborative project: participants communicated eagerness to collaborate with one another, and the spirit of collaboration was evident. In particular, the project has succeeded in deploying sensors and collecting data from hard-to-reach places across the three New England jurisdictions. As a result, new regional data sets, hands-on training sites, and educational opportunities are available to and shared by researchers, partners, and educators. Team members from different institutions across the three jurisdictions and academic and non-profit partners (e.g., AMC, Schoodic Institute, etc.) have collaborated on a number of peer-reviewed papers and proposals. Educators in Maine and Vermont have convened in training sessions.

There has also been excellent collaboration within each thematic team. There appears to be unusually strong potential to develop transformative products by continuing to pursue links across themes. For example, the continuation and expansion of the cold-air microhabitat research will help to link Themes 1 and 3. Expansion of this could involve deploying and using new sensors at the Alabama research site. Additionally, Themes 1, 2, and 3 coordinated with Theme 4's development of teacher training in Quantitative Reasoning in Context (QCR) through a workshop held at the Schoodic Institute. The Year 3 Annual Report also reports a cross-theme effort to refine the software system used to process remote sensing data. Finally, a cross-theme/cross-institutional subcommittee finalized and updated a data sharing implementation plan.

The panel learned that in May, team members from all institutions met to discuss collaborative projects, among other things, to plan for when EPSCoR support ends. This meeting appears to have initiated a number of collaborative projects with strong potential for sustainability. Research faculty who are taking permanent positions expressed that they would continue to purse research and collaborate with partners and stakeholders conducting regionally focused research. In addition, AAMU's involvement offers a new field site and with it, opportunities to build and sustain cross-jurisdictional research.

Challenges
INSPIRES appears to have only recently been exploring and tackling inter-theme objectives. As a result, it was hard for the panel to see conceptual links across themes. With this said, INSPIRES personnel were clearly eager to continue working on these objectives and see them as integral to their own longer term research goals. Efforts will need to be made to make sure that the modeling work led by the UNH team that is still in development will continue to be linked to the developments made by other Themes from other jurisdictions. While it might be difficult to achieve all of the cross-cutting efforts that were planned before the end of the award period, the interest in exploring potential ongoing synergies bodes well for their ultimate completion in a post-INSPIRES timeframe. The list of concept papers mentioned in table 2 of the year-3 report provides good examples of feasible achievements during the no-cost extension period. Additionally, a critical priority will be to maintain cross-jurisdictional access to the new research sites in mixed management forests established through INSPIRES.

Recommendations:

- ***Continue efforts to develop cross-theme papers and products over the next 6 to 12 months.*** The panel recommends the team present plans in the Final Report to NSF EPSCoR for cross-cutting post-INSPIRES products that will sustain and leverage collaborative opportunities. For example, are there conceptual papers that advance aspects of INSPIRES work relevant to new large-scale, statewide, or regional research initiatives, such as UME's new EPSCoR RII Track-1 proposal in development?

- ***Extend interjurisdictional collaboration, specifically with AAMU, through the NCE.*** As noted above, this could be through the deployment and monitoring of sensors in Alabama.

VI. Sustainability

Strengths
There is an excellent foundation of solid professional relationships that hopefully will continue for many years, which is one of the most basic and important of all sustainability outcomes. The potential impact and relevance of INSPIRES research to land managers should also contribute to the longer-term impacts of the project, for example via interactions with the National Park Service. The low-cost, low-maintenance sensor network is a novel product that will provide excellent infrastructure for the region that can be utilized and sustained over the longer-term, in large part because this network is being used by INSPIRES partners. There is a great deal of interest in the educational modules and workshops being produced or co-produced by INSPIRES personnel, specifically the summer institute teacher training and the forest science research training implemented with the Schoodic Institute. The cold air pooling research appears to be set to continue for several years as the findings from this research have laid a foundation for ongoing work.

Challenges
The significant sustainability produced via the developing Maine EPSCoR Track-1 proposal would be almost exclusively in Maine, and it might be difficult to ensure ongoing engagement with UNH and UVM stemming from some of the INSPIRES themes. Perhaps continuation of the Tri-Jurisdictional Institutional Advisory Board may help continue aspects of INSPIRES beyond the timeframe of the award. Regardless, the developing Track-1 intention to integrate workforce development in emerging wood products with the forest resource science and human dimensions would be an outstanding sustainable product derived from INSPIRES. Furthermore, as stated in the Year 3 Annual Report, keeping project elements like website, communication materials, and data management running beyond the end date would be another excellent example of sustainability that will add to this already very successful Track-2 project.

Recommendations:

- ***The Final Report to the NSF should explicitly describe how the project will sustain the regional research capacity built from INSPIRES.*** This might include, for example, future directions and plans for the cold-air microhabitat research, integration of the sensor and informatics themes, and building on components of Theme 4. These and others of interest to the INSPIRES team should be communicated to the NSF when applying for a NCE.

- ***The Final Report to the NSF should include a section that communicates products that may not be completed by the end of the project but that are highly likely to be completed during several years after INSPIRES ends.*** *Provide a list of publications and proposals that are definitely planned during this time, such as the inverse parameterization of Landis-II. This will provide concrete examples of how INSPIRES will drive and contribute to long-term productivity and advances in the field.*

Appendix A: Charge to the TIG Strategic Assessment Panel Year 4

Charge to TIG Strategic Assessment Panel Year 4

Three of the goals of this project are:

1. To conduct novel interdisciplinary, stakeholder-engaged research by linking ecology, computer science, engineering and data science that makes significant contributions to understanding the region's forests and influence practices related to making decisions about their management.
2. To connect researchers across ME-NH-VT to build collective research capacity, particularly across distinct disciplinary boundaries and in key forested regions previously under served by past investigations and research investments.
3. To develop early career researchers with expertise in ecosystem science, data informatics, engineering, and ecological modeling including graduate students, post-docs and faculty.

General Goals for the Panel

Provide a final assessment appropriate for this project in the following areas:

- Assess progress toward goals. What remains to be done during this last year of the project?
- Assess sustainability planning. What aspects of INSPIRES are relevant to the UMaine Track-1 proposal?
- Assess early-career researcher development
- Assess student outcomes
- Assess stakeholder engagement

Appendix B: 2023 TIG Strategic Assessment Meeting Agenda

Virtual Meeting Agenda

Mon, Jan. 9 – Wed, Jan. 11, 2023
Times are Eastern Standard

- Panelists
  - Jen Allen, Portland State University
  - Ray Callaway, University of Montana
  - Christian Messier, University of Quebec

- Materials provided in advance
  - Year 2, Year 3 Annual Reports to NSF
  - Summary of UMO Track-1 proposal concept
  - Responses to 2021 TIG panel recommendations

- **Monday, Jan. 9**
  - 11:00 – 11:30 AM: Welcome and Review of Meeting Objectives (Aaron Weiskittel [UMO]/Heather McInnis [TIG])
  - 11:30 – 12:30 PM: Project Update (Aaron Weiskittel [UMO], Tony D'Amato [UVM], and Dawn Lemke [AAMU])
  - 12:30-1:00 PM: Break
  - 1:00 – 1:30 PM: Theme 1 Update (Sensors & Advanced Computing) Karin Rand [UVM], Ali Abedi [UMO], Dedrick Davis [AAMU]
  - 1:30 – 2:00 PM: Theme 2 Update (Environmental Informatics & Analytics) Torsten Hahmann [UMO], Peter Nelson [Schoodic], Kasey Legaard [UMO])
  - 2:00 -- 2:30 PM: Supplemental project (Transitional Forest Response to Unique Stressors) [Dawn Lemke, AAMU]
  - 2:30 – 3:00 PM: Data Management [Leo Edmiston-Cyr, UMO]
  - 3:00 – 3:15 PM: Break
  - 3:15 – 3:45 PM: Theme 3 (Integrated Ecological Modelling) Erin Simons-Legaard [UMO], Jane Foster [UVM], Zaixing Zhou [UNH]
  - 3:45 – 4:15 PM: Theme 4 (Quantitative Reasoning in Context) Marina Van der Eb [UMO], Chrissy Siddons [UMO], Dawn Lemke [AAMU]
  - 4:15 – 5:00 PM: Recap and Open Discussion (All)

- **Tuesday, Jan. 10**
  - 11:00 – 11:15 PM: Agenda Review and Desired Outcomes (Aaron Weiskittel [UMO]/Heather McInnis [TIG])
  - 11:15 – 12:15 PM: Graduate Student Flash Talks (Paulina Murray [UVM], Kingsley Wiafe-Kwakye [UMO], Thayer Whitney [UMO], Nick Soucy [UMO], Jack Hastings [UNH], Emily Landry [UNH], Kindrea Gibbons [AAMU])

- 12:15 – 1:15PM: Meeting with Early Career Faculty (Salimeh Yasaei Sekeh [UMO], Erin Simons-Legaard [UMO], Jane Foster [UVM], Dave Lutz [Dartmouth], Melissa Pastore [UVM], and Cen Chen [AAMU])
- 1:15 – 1:30 PM: Break
- 1:30 – 2:00 PM: Inter-theme and -jurisdictional collaboration (Cold air pooling subteam, Melissa Pastore [UVM], Sarah Nelson [AMC], Grace Smith [UVM])
- 3:00 – 4:00 PM: Project stakeholders and partner organizations Ed Lindsay [Old Town High School], Erin Wysolmerski [U-32 High School, VT], Sarah Nelson [AMC], Peter Nelson [Schoodic]
- 4:00 – 5:00 PM: Project Communications and Outreach (Emily Uhrig [UMO], Meg Fergusson [UMO], Stefania Marthakis [UMO], Michelle Gregoire [UNH])

- **Wednesday, Jan. 11**
  - 12:30 – 2:00 PM: External Review Committee Discussion (Heather McInnis [TIG])
  - 2:00 – 3:00 PM: Debrief Meeting with Core Leadership Team (Aaron Weiskittel [UMO], Tony D'Amato [UVM], Dawn Lemke [AAMU], Heather McInnis [TIG], Michelle Gregoire [UNH])
  - 3:00 PM Adjourn