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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)

August 1, 2023-July 31, 2024

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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, land use history, 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 seeks to create 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.

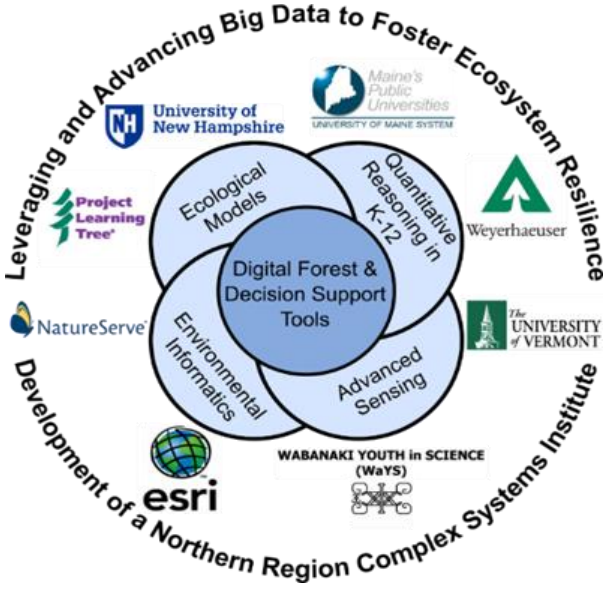

Figure 1. INSPIRES Digital Forest Research and Workforce Development Framework

The INSPIRES project aims to harness the region's complex landscape and digital information diversity through the creation of a Digital Forest resource (Figure 1), 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 2).

Our efforts address the following overarching science questions:

1. How are spatio-temporal variation and uncertainty in forest extent, composition, health, and productivity

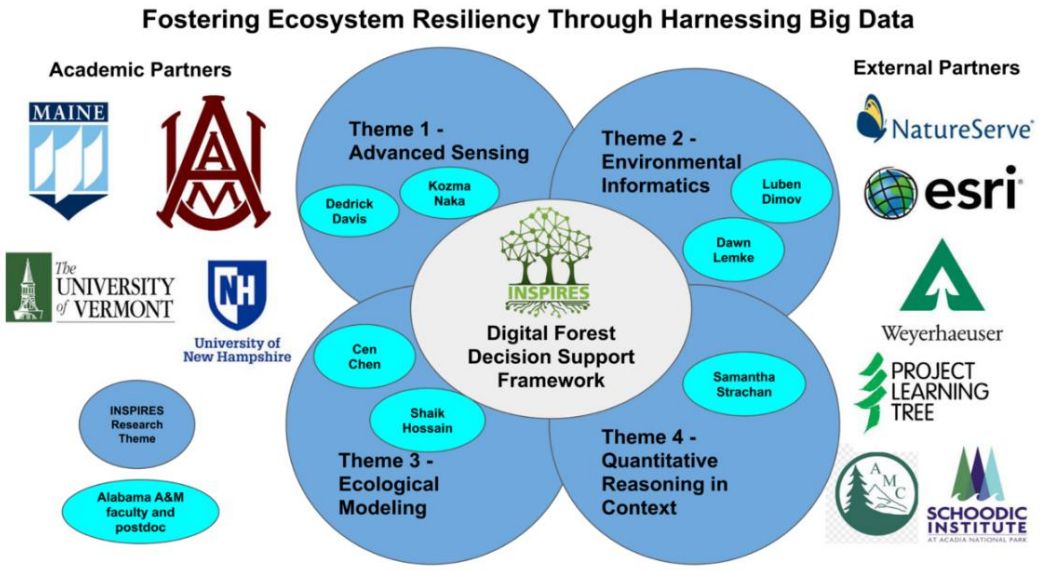

Figure 2. Thematic integration into the Digital Forest Decision Support Framework.

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 (Figure 2) 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 5 Goals

Year 5 was a no-cost extension necessary for the team to fully address some of the delays created by the pandemic and to complete some of the activities initiated to build interjurisdictional research collaboration (details of Years 1 to 4 are available at https://crsf.umaine.edu/inspires/).

The primary goals for Year 5 were to compile environmental data generated by the network of wireless sensors across the four jurisdictions, develop a network installation with a project partner, solidify the recently formed collaboration with AAMU, finalize cataloging of the various datasets and model code generated by the multi-year effort, continue to explore strategies for the future sustainability of the collaborative efforts, and finalize project outcomes, particularly synthesis publications. Project leadership continued to review and prioritize future opportunities for collaboration, while strategizing on how to effectively communicate the key outcomes and future opportunities to project partners. In addition, the project external evaluator met with project leadership, several early career faculty and students to understand project outcomes and lessons learned, which are outlined in the external evaluation report in Appendix 4. Overall, the no-cost extension allowed the project team to finalize key project outcomes and effectively complete project closeout before focusing time and attention on other efforts.

"Despite the onset of this project coinciding with a global pandemic and all the endless challenges that created, I believe INSPIRES accomplished what it set out to do and more. I am very proud of the dedicated team that made this possible and all the impressive outcomes generated. The partnership with Alabama A&M University has been highly beneficial and led to a number of recent collaborations. Maine, New Hampshire, and Vermont continue to build effective collaborations as neighboring jurisdictions, which is critical for the long-term sustainability of efforts like INSPIRES."

Dr. Aaron Weiskittel, INSPIRES PI

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"[The project was] quite successful in building research capacity – [the team] created new, highly sensored research sites across the [partnering] New England jurisdictions, ecosystems science tied to the network, and several great collaborations on publications and new research areas (e.g., cold-air pooling)."

Dr. Tony D'Amato, INSPIRES Co-PI

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"The key goal for AAMU was to build relationships and capacity for ongoing projects and integration with relevant research interests (e.g., extension of research on northern forests to AAMU's ForestGeo plot) – this was accomplished."

Dr. Dawn Lemke, INSPIRES Co-PI

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"INSPIRES gave me a great opportunity in terms of interactions with other people across disciplines and universities. I got more than I thought I needed from the project in this respect. The project helped me access forestry experts. I learned how to present information at a higher level and to communicate my work to non-domain experts."

INSPIRES, Graduate Student

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 (Colby-Sawyer 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 5

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 added a diversified perspective and specific scientific expertise and talent to the multi-institution, multi-state endeavor. In Year 5, the collaboration with AAMU has continued to grow through a successful NSF proposal that grew from INSPIRES, ongoing research collaboration opportunities, student and faculty exchange experiences, and future proposals. 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) again traveled there in June 2024 to provide ground and airborne spectroscopy demonstrations, while also conducting an extensive field campaign and helping mentor both undergraduate and graduate students. The addition of AAMU enhanced new collaborations and tangible outcomes, including an ongoing UNH-AAMU project focusing on the ecological impacts of drought that was funded by NSF's Organismal Response to Climate Change program (IOS-2222439). As part of that project, members of co-PI Ollinger's lab visited AAMU in July of 2024 to collect field measurements related to drought sensitivity at the Paint Rock Forest. INSPIRES PI Weiskittel and Co-PI Ollinger remain in regular contact with AAMU PI Dawn Lemke to continue sustaining and expanding the synergies INSPIRES created.

Prior to the no cost extension, the INSPIRES team included 132 individuals, with the majority being faculty from the four states (4; ME = 21, NH = 11, VT = 7, AL = 4), bolstered by undergraduate students (27), graduate students (30), post-doctorate researchers (4), and professional staff (16). Year 5 included active involvement by 62 individuals from all four states (faculty: ME = 14, NH = 7, VT = 6, AL = 4, Other = 2), 19 of whom are early career. Final year efforts were also supported by 5 undergraduate students, 9 graduate students, 14 technical and support staff, and 1 post-doctorate researcher. In this final project year, the team remained diverse (49% female), reinforcing the strong linkages across jurisdictions that developed throughout the project. The project's structure remained centered around the four core research themes: (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.

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	Natural Resources & Environmental Sciences	Alabama A&M University	AL

During Year 5, INSPIRES team members remained highly engaged and actively sought ways to enhance interjurisdictional research collaboration, particularly with AAMU, with whom we've developed strong ties that will last well beyond the INSPIRES project itself. 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. A key focus in Year 5 was supporting a synthesis workshop and regular meetings that have led to the submission of a manuscript on forest canopy and snow depth interactions and several collaborative proposals to both regional and national funding programs.

The CLT (Table 1) continued regular communications to discuss concerns and plan sustainability efforts. Individual research themes periodically interacted over Year 5 to discuss key research priorities and outcomes. Coordinated meetings of INSPIRES graduate students occurred at the start of Year 5 and individuals were made aware of specific professional development opportunities to help strengthen cohort connections and provide professional networking opportunities. Unlike prior project years during the pandemic, the project team was able to travel more in Year 5, which helped with the completion of various field-based efforts; increased participation at regional, national, and international conferences; and better facilitated greater exchanges across the jurisdictions involved, especially with AAMU team members. The Implementation Group (TIG; external evaluator on the project) interviewed INSPIRES CLT members, early-career faculty, and students as part of the evaluation process to assess key outcomes and potential lessons learned for future efforts, and formally compiled and summarized the results (see Evaluation [Appendix 4] of this report). TIG also completed a final project report that outlined the numerous outcomes and achievements accomplished by the effort.

Overall, the INSPIRES team made full use of the project's last year and has largely accomplished what it had originally proposed despite the challenges of the pandemic. Because of the continued emphasis and support of collaborative team science, 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, with a

shift towards new opportunities and long-term sustainability. One key focus was maintaining and potentially expanding research infrastructure, particularly regional snow monitoring. This led to the creation of the Northeast Snow Survey Feasibility Study (NESS; https://sites.usnh.edu/ness/), an ongoing effort to assess the community needs for designing a coordinated network of automated snow and weather measurement stations in the East, akin to the SNOTEL network in the western US. NESS has conducted detailed surveys and focus groups across the region to evaluate priorities and build a regionwide partnership network.

Key Achievements

- **New inter-jurisdictional synthesis research** on complex interactions between forest canopy cover and snow cover dynamics by a multi-disciplinary network of team members from INSPIRES and beyond. This effort resulted in a manuscript submission and is actively led by USFS Scientist (former UVM post-doc) Melissa Pastore and AMC project partner, Sarah Nelson, in collaboration with INSPIRES co-authors including Elizabeth Burakowski, Alix Contosta, Tony D'Amato, Dave Lutz, Grace Smith, and Aaron Weiskittel.
- The **Northeast Snow Survey Feasibility Study** was initiated under the leadership of UNH faculty members Elizabeth Burakowski and Alix Contosta. AMC project partner Sarah Nelson coordinated the initial regionwide surveys and hosted virtual and in-person interest holder workshops.
- INSPIRES PI Weiskittel developed and was **awarded an NSF EPSCoR RII e-RISE project** (OIA- 2416915) that advances the AI innovations initiated on this Track-2 award.
- Solidified a strategic partnership with the Alabama Agricultural & Mechanical University (AAMU), an Historically Black College and University (HBCU), through several new projects that will continue into the coming years. AAMU's long-term research field site at Paint Rock has become a key area of collaboration and was the focus of INSPIRES field campaigns in June and July 2024. **Student and faculty exchanges between UMaine, UNH, and AAMU** occurred throughout Year 5.
- **Wireless dendrometers continued to be refined and integrated** into an online database for near-time access and visualization.
- **Wireless dendrometers deployed at site selected by INSPIRES project partner**, AMC, for long-term monitoring of climate change and potential forest health issues.
- UMaine PhD student **Kingsley Wiafe-Kwakye successfully presented and defended his dissertation** on the creation of ontologies for semantic representations of forest types, tree species, and environmental conditions.
- UNH MS student **Emily Landry successfully completed her thesis on long-term changes in climate** spatial patterns over the northeast region between 1950 and 2020.
- Stakeholder outreach continued, with four more science/practice interactive forest climate change webinars that typically draw 60-80 participants and are archived on YouTube for future use. Well-attended (20-25 participants) **field tours showcased adaptation and implementation efforts and forest health concerns at four locations**. Topics included adaptation strategies to address changing hydrological conditions, invasive species, and alternative forest management.
- Stakeholder engagement was supported by **robust multi-media communications efforts, including two websites, INSPIRES-related videos on the YouTube channel, active social media** accounts, e-newsletters and team profiles. Year 5 included active involvement of **62 individuals, with the majority being faculty from the four states** (ME = 14, NH = 7, VT = 6, AL = 4; Other = 2), 19 of whom are early

career. The research was also supported by 5 undergraduate students, 9 graduate students, 14 technical and support staff, and 1 post-doctorate researcher.

- Research outputs continued with 26 (15 published, 11 under review or in press) peer-reviewed articles, 2 conference proceedings, 7 data/model/technology products, 10 presentations, 2 reports, and 4 dissertations.
- In Year 5, 20 research proposals (15 multi-institutional, 7 by early-career faculty) requesting **$29,775,245 were submitted with 14 awarded ($22,500,036) and 5 pending ($6,896,297)**.
- Several additional **datasets were published on the Environmental Data Initiative repository**.
- INSPIRES Theme 3 project members **completed and published the PnET-CN-Succession model**, the first simulation model of its kind to combined landscape disturbance dynamics and forest succession with coupled cycles of carbon, nitrogen and water.
- Involved **project faculty remain primarily early-career** (55%).
- Throughout the project, the **INSPIRES team remained diverse** (>50% female), and increased involvement of underrepresented minority students, particularly at AAMU.
- INSPIRES Theme 4 hosted a **teacher training workshop on forest ecology in Vermont**.

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 our understanding of ecosystem function and how forests respond to environmental change. As highlighted in the project's outcomes (Appendix 1), the INSPIRES effort has resulted in several important outcomes with high intellectual merit. In Year 5, this has included 14 proposals funded (5 multi-institutional), 17 peer-reviewed publications (2 inter-jurisdictional, 4 student-led, 5 early-career-led, 19 female-led), and 11 presentations (2 inter-jurisdictional, 4 student-led, 2 early-career-led, 7 female-led). The funded proposals include awards from NSF, USDA, NASA, and the Northeastern States Research Cooperative. Cumulatively, INSPIRES has generated a total of 137 publications (70 multi-institutional, 57 early-career led, 53 student-led, and 52 female-led), 137 presentations (26 multi-institutional, 65 early-career led, 30 student-led, and 54 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 3). Overall, the strong intellectual merit outcomes highlight the level and strength of current collaborations within INSPIRES. After completion of the project's timeline, 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 4). 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 were prioritized in Year 5 of the project.

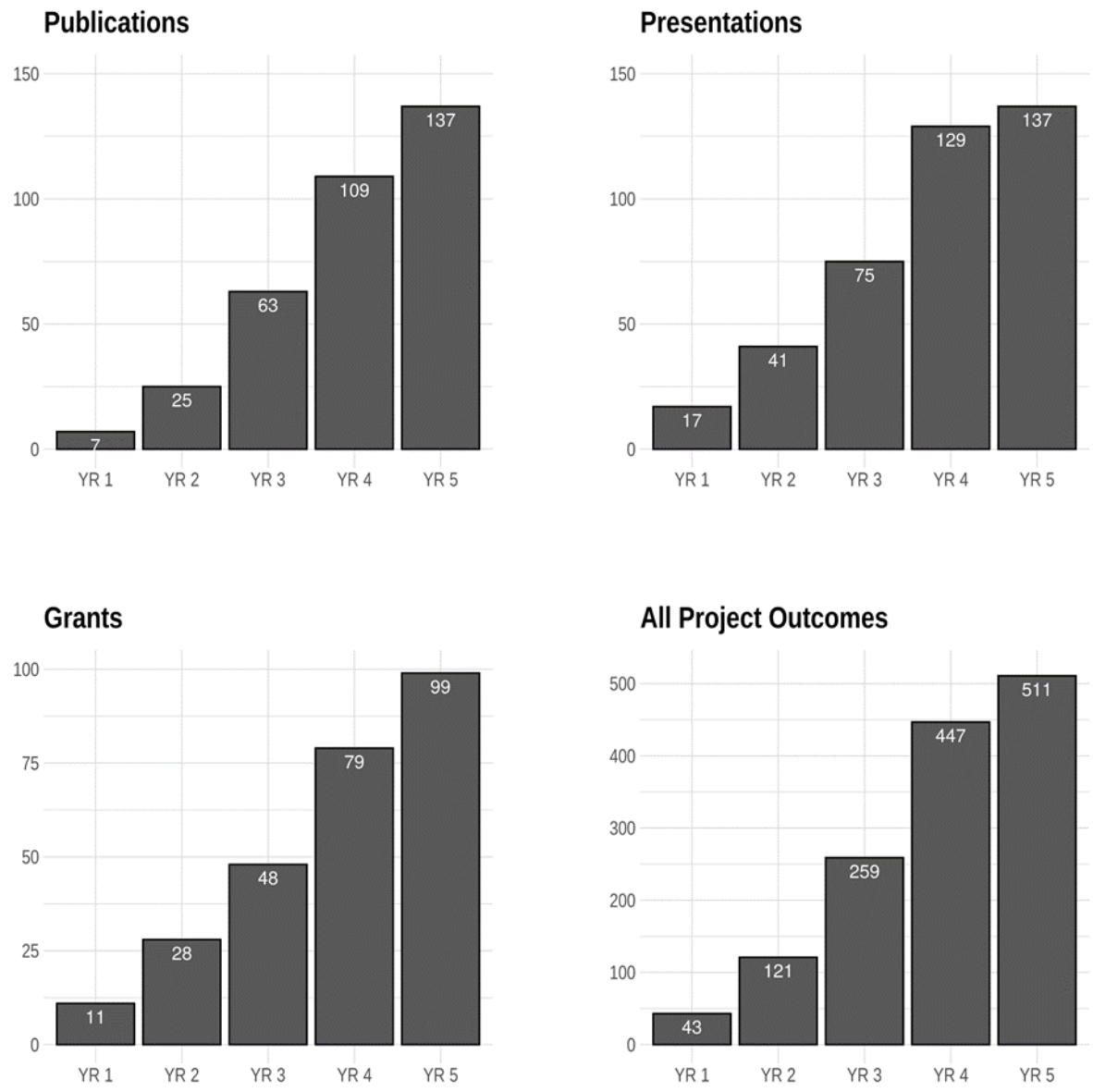


Figure 3. Cumulative publications, presentations, grants, and total project outcomes through August 2024.

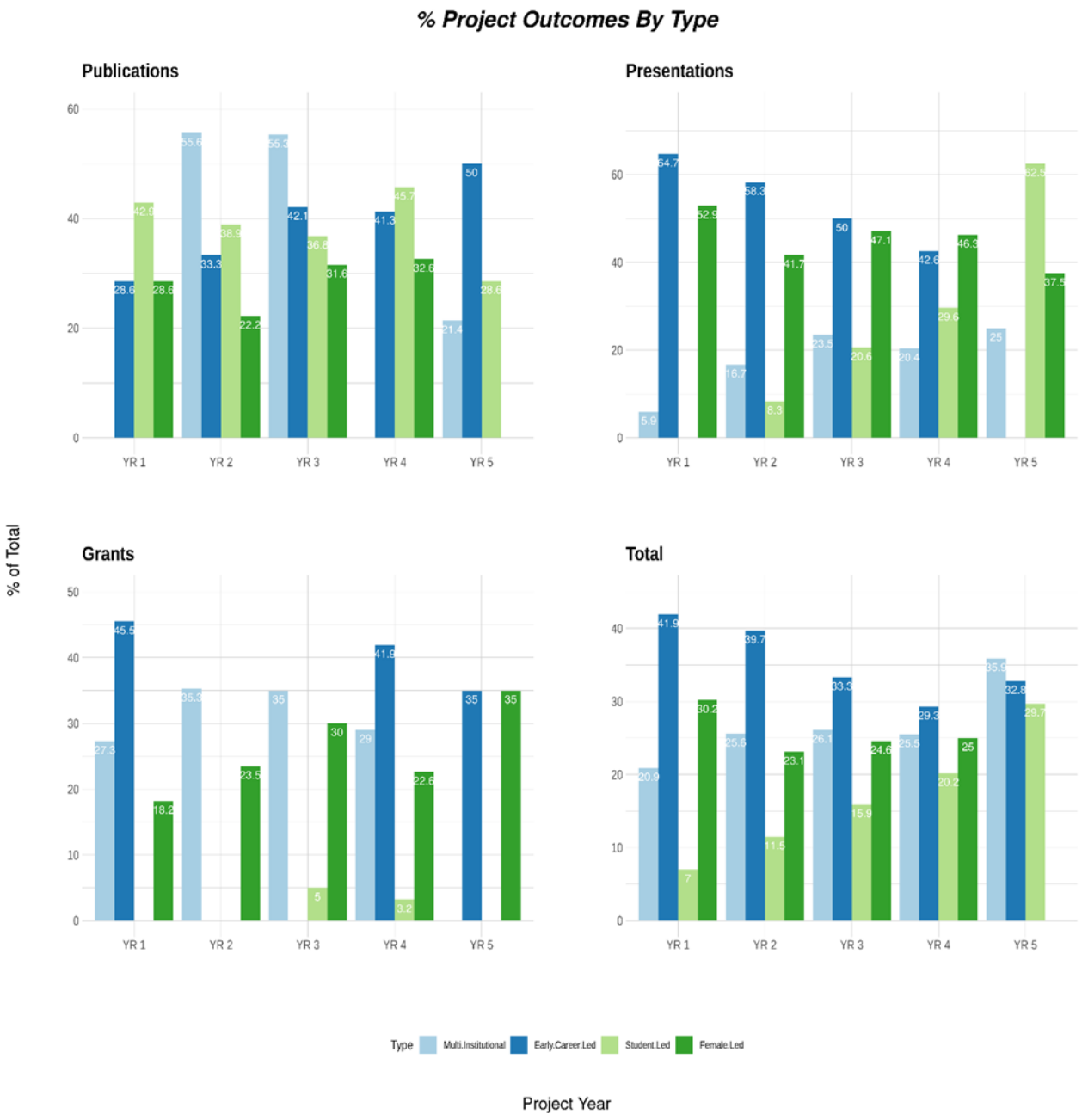


Figure 4. Percentage of publications, presentation, grants, and total project outcomes that are multi-institutional, early-career led, student-led, and female-led through August 2024.

Broader Impacts

Effective project outreach and stakeholder engagement remained a high priority for INSPIRES in Year 5. This included virtual and in-person outreach events that featured INSPIRES participants and highlighted ongoing research. A public website for educators is available to help support collaboration between teachers and Theme 4 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 fourth year and were enhanced by field tours that provide opportunities for scientists, conservationists, land managers, and operations foresters to learn and discuss climate change impacts on forest types found in Maine. The well-attended interactive webinars (40-50 participants per webinar) highlighted some ongoing research efforts from INSPIRES, and were recorded for future viewing on the Science and Practice YouTube playlist, along with video highlights from each field tour. Similarly, workshops and field tours for over 150 foresters and other stakeholders have occurred at the Corinth, Second College Grant (Figure 5), and Nulhegan Basin (Figure 6) 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 and Twitter) accounts, in conjunction with the Team Slack channel and INSPIRES website, continue to showcase the project's research successes (Appendix 3. Communications and Resources).

Figure 5. June 2024 site visit and partner field tour at the INSPIRES sensor site at Dartmouth's Second College Grant in northern New Hampshire.

Figure 6. Foresters and wildlife biologists touring INSPIRES field site at the Silvio Conte National Wildlife Refuge (Nulhegan Basin Division) as part of Forest Stewards Guild field tour led by INSPIRES Co-PI D'Amato in October 2024.

Project Problems and Mitigation Efforts

Throughout Year 5, INSPIRES maintained active and strong participation within and across the institutions involved, and largely accomplished what it originally proposed. A large portion of the project, particularly at the onset, occurred during the COVID-19 pandemic when various restrictions were imposed on nearly all aspects of life. Even after the pandemic, there were significant challenges adjusting to back to "normal" life, which created additional challenges for project participants. Although a variety of mitigation efforts were implemented (e.g., shifting efforts from extensive field data collection to computer-based activities such as modeling, shared resources for handling the pandemic, regular meetings where the pandemic was acknowledged and discussed), professional and personal challenges remained and it is difficult to assess their cumulative impact on the overall project and the team. It is clear from discussions with project leadership and the external evaluator that the pandemic added significant and complex hurdles to an already difficult task of forming and leading multi-jurisdictional, trans-disciplinary teams of researchers.

Novel Opportunities

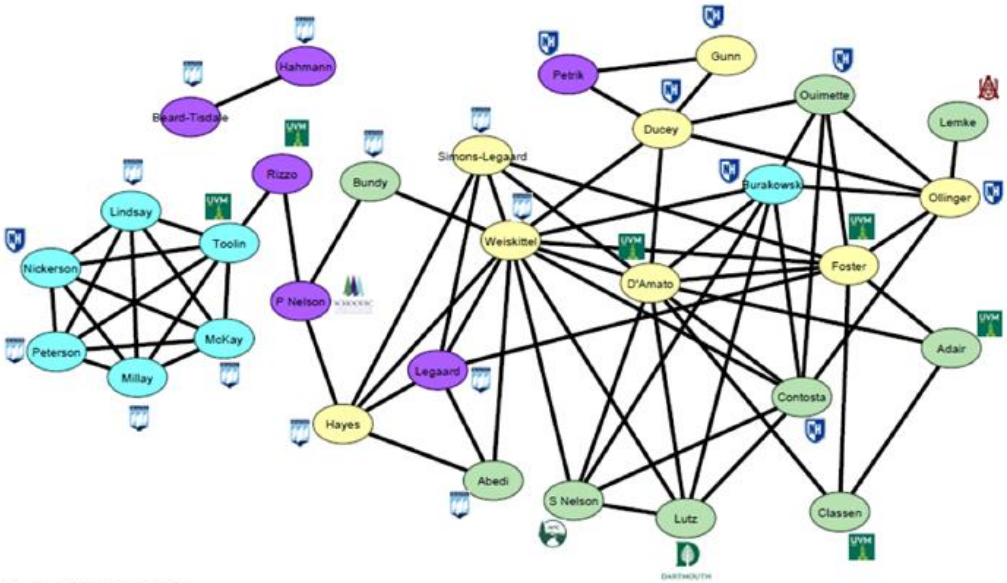
With the supplemental funding received for AAMU joining INSPIRES, several important opportunities emerged in Year 5. AAMU faculty and students continued to engage with other INSPIRES team members, with AAMU's long-term research field site at Paint Rock providing a key focal area for joint efforts. In addition, the collaboration led to a successful proposal to NSF. A prime example of the cooperative nature of INSPIRES teamwork is the deployment of wireless soil moisture sensors developed at the University of Maine by AAMU faculty and students at the Paint Rock field site. In June 2024, Theme 2 researcher Dr. Peter Nelson was able to visit and acquire additional high-resolution hyperspectral imagery for the Paint Rock field site, supplementing work from a prior visit in May 2023. This effort was followed in a summer 2024 field campaign at Paint Rock led by Dr. Nelson and several UNH INSPIRES team members, including three graduate students. This collaboration led to the recent multi-institutional submission of a USDA NIFA proposal focused on workforce development in ecological remote sensing and data science through applied forest demographics involving Dr. Nelson, several AAMU faculty, and other key partners.

Changes in Strategy

As highlighted above, the challenges created by the pandemic and limited travel and in-person meetings meant the CLT recognized that new means of virtual collaboration were required. To address this, a Collaborative Project Coordinator at the University of Maine, Dr. Emily Uhrig, was hired in Year 3 and she made several key efforts to facilitate team member participation and satisfaction. Of note, personalized one-on-one meetings with various team members were conducted, which led to follow-up meetings or identifying potential collaborative opportunities for the team. Through these meetings and reviewing project materials, a team collaborative network diagram was developed and used to assess team collaboration (Figure 7). Dr. Uhrig also coordinated monthly INSPIRES student meetings where relevant guest speakers were identified and discussed their professional journey. Finally, Dr. Uhrig initiated and facilitated regular research theme as well as the Collaborative Research Committee monthly meetings, which were helpful for identifying potential synergies between research themes and project participants. Dr. Uhrig remains an important project asset for helping to sustain ongoing collaborations created by INSPIRES.

December 2021

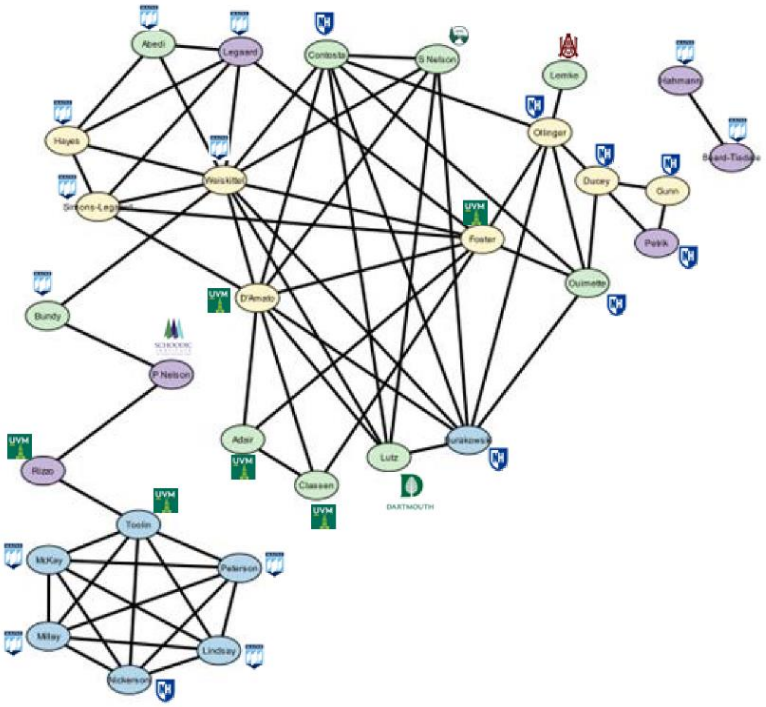
Green = Theme 1
Purple = Theme 2
Yellow = Theme 3
Blue = Theme 4



Based on publications and proposals through December 2021.

December 2022

Green = Theme 1
Purple = Theme 2
Yellow = Theme 3
Blue = Theme 4



Based on publications and proposals through December 2022.

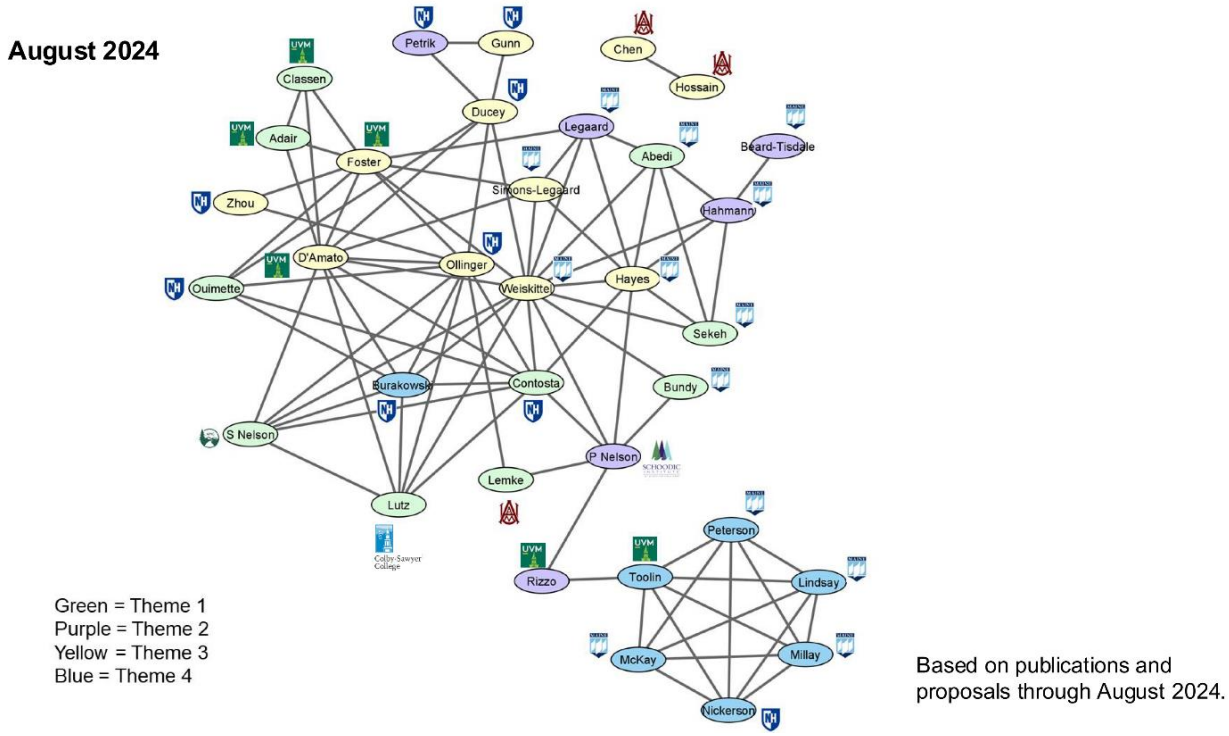


Figure 7. INSPIRES collaboration network based on project outcomes reported in Years 3 (top), 4 (middle), and 5 (bottom) by institutional partner and research theme showcasing the evolution of the team over time.

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 collaborated 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 was 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 aimed 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 was organized across four integrated themes (Table 2) that were essential to an innovative and flexible framework for harnessing Big Data across multiple spatio-temporal scales. Early career faculty led each theme, supported by senior mentors. Each theme included researchers and/or students from all four jurisdictions, and personnel cross-over to ensure sustainability and convergent

approaches to problem solving. INSPIRES faculty and students worked across the four research-integrated themes to develop a novel and flexible Digital Forest framework for effectively harnessing Big Data that enhanced our fundamental understanding of Northern Forest ecosystems across multiple spatio-temporal scales and under alternative scenarios of future environmental and management changes.

The CLT was responsible for achieving the project's objectives and providing guidance to team members. It was composed of the PI and co-PIs, representing the lead institutions. For full transparency, CLT meetings were regularly scheduled, open to all team members, and meeting notes made available through the shared OneDrive folder.

Table 2. 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 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	Research Approach	Research Goals
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

The collaborations and partnerships provided by INSPIRES project involvement positions the entire team to leverage current research participation and to sustain it well into the future.

The INSPIRES project has resulted in many key accomplishments: (1) strengthened and expanded collaboration across three New England EPSCoR jurisdictions, which has facilitated additional Track 2 awards and an NSF E-RISE (Maine-FOREST) award in these states; (2) initiation and growth of partnerships with Minority Serving Institutions, including the incorporation of AAMU as a project partner, resulting in new collaboration opportunities and research directions for the project that will be sustained through additional grants; (3) creation and support of a regional network of environmental sensors that continue to showcase the need for a more comprehensive long-term climate plan, and which led to the formation of the Northeast Snow Survey Feasibility Study (NESS); (4) support for AI-informed, Big Data-driven tools and technologies that more effectively integrate remote sensing data at a large-scale, and led to Maine's first statewide forest-type cover and aboveground carbon maps to be released in fall of 2024; and (5) supporting and mentoring students, post-docs, and early career-faculty that has led to successful opportunities including permanent positions, widened stakeholder interactions, and new grant support.

Key INSPIRES successes include the development and deployment of environmental sensors at strategic locations throughout the region (Theme 1), provision of 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), initiation and construction of a general digital framework for a multi-model comparison to understand model strengths and weaknesses (Theme 3), and enabling quantitative reasoning in context (QRC) engagement of both high school science teachers and students to better integrate project elements into hands-on curricular activities (Theme 4).

Throughout the project, INSPIRES team members directly engaged with 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. Key project stakeholders included federal partners, NGOs, and private forest landowners. As detailed in the following pages, the project made considerable progress despite three years of restrictions and challenges created by the global pandemic.

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 (Figure 8). 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, effort to deploy the developed sensors at a variety of locations, including sites in Alabama, were continued. Additional sensors were developed to measure soil CO_2 and tree radial growth. **In Year 5, the Northeast Snow Survey Feasibility Study** was initiated under the leadership of UNH faculty members Elizabeth Burakowski and Alix Contosta. AMC project partner Sarah Nelson coordinated the initial regionwide surveys and hosted virtual and in-person stakeholder workshops. In addition, a synthesis publication on the interaction between forest canopies and snow depth was drafted for publication led by former University of Vermont INSPIRES post-doc, Melissa Pastore, in conjunction with multi-jurisdictional INSPIRES faculty members Elizabeth Burakowski, Alix Contosta, Tony D'Amato, Dave Lutz, and Aaron Weiskittel.

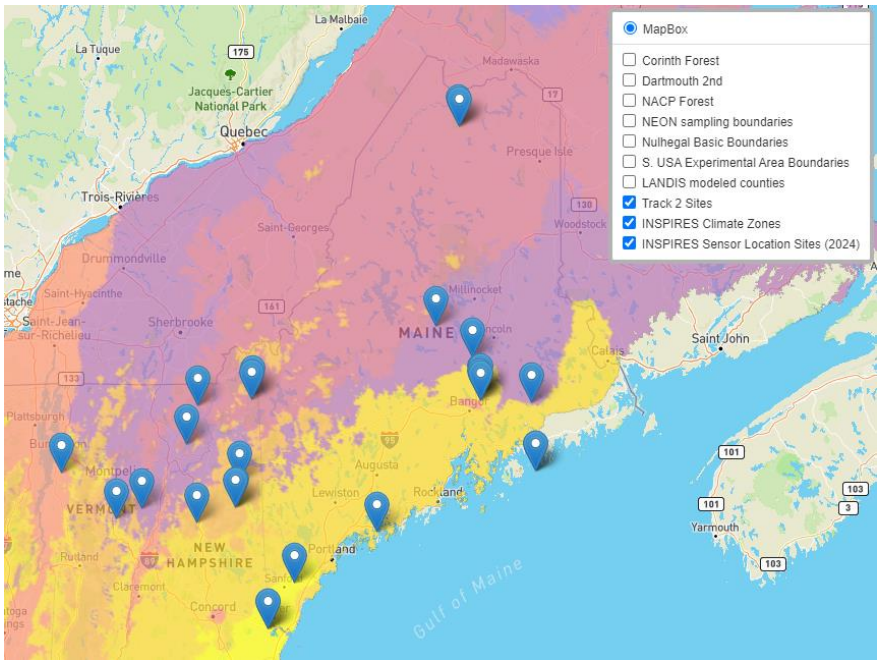


Figure 8. Map of current INSPIRES sensor network across the three New England jurisdictions with the identified regional climate zones of Roy et al. (2024). The data and geographic layers are available via InLeaf (https://inleaf.inspires.acg.maine.edu/user/leo/INSPIRES_2024_Report/).

Figure 9. The deployment of wireless dendrometer and environmental sensors at INSPIRES partner, Appalachian Mountain Club's Pinkham Notch Visitor Center in New Hampshire, was successfully deployed in the fall of 2023. Photos provided by Dr. Jordon Tourville.

Highlights

- Established three new environmental monitoring sensor sites using technology developed by Theme 1 researchers (Figure 9).
- Data acquisition continued at numerous sensor sites throughout the region including partnerships with high schools such as Old Town Maine (Figure 10).
- The IWiN system-designed modules developed under the leadership of Dr. Ali Abedi at PhD Student, Mersedeh Najishababahang, in Year 5 (Figure 11).
- UMaine's Wireless Sensor Networks Laboratory (WiSe-Net Lab) benefitted from refinements by INSPIRES researchers.
- 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.
- Synthesis publication on the interaction between forest canopies and snow depth was submitted for publication at a top-tier ecological journal (Ecological Applications) using data from several INSPIRES sensors sites and led by former University of Vermont INSPIRES post-doc, Melissa Pastore, and includes several multi-jurisdictional INSPIRES faculty members (Figure 12, Figure 13).

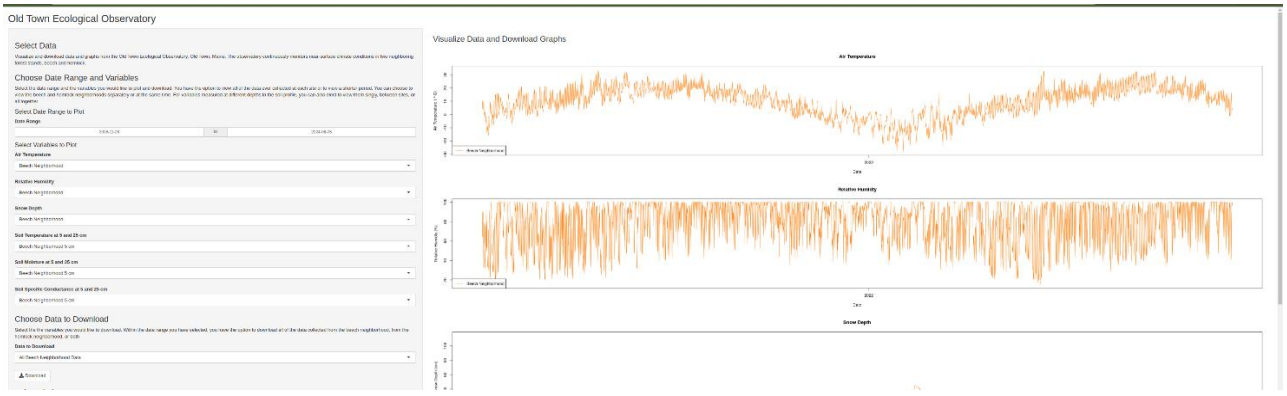


Figure 10. Online interface developed by INSPIRES UNH team members Alix Contosta and Apryl Perry to provide visualization and data access to sensor data for the Old Town research site in Maine. The interface is available at: https://ot-vernal-windows.shinyapps.io/OT_Shiny_App/.

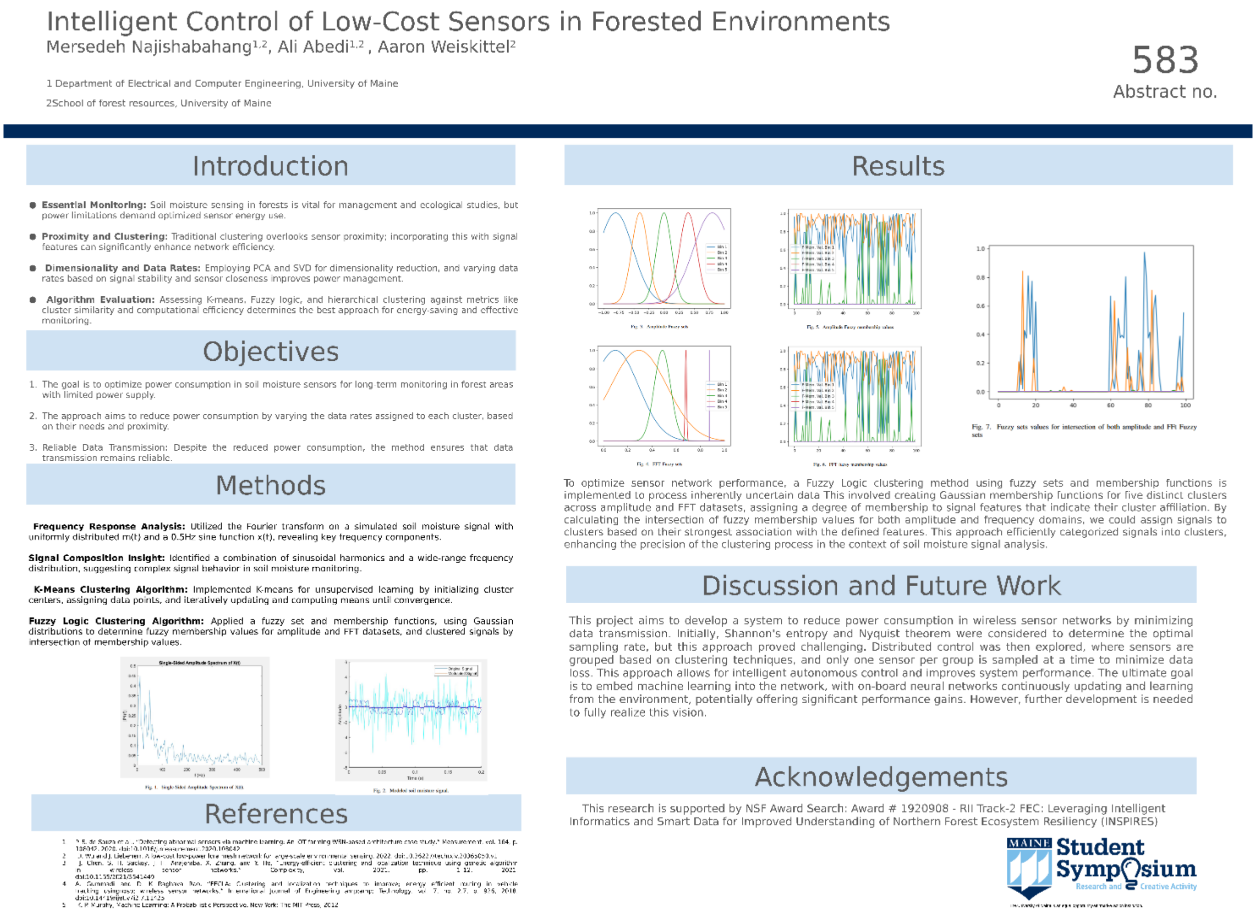


Figure 11. Student poster presented by INSPIRES PhD Student, Mersedeh Najishabahang, at the University of Maine Student Research Symposium in April 2024 on her research on low-cost sensors.

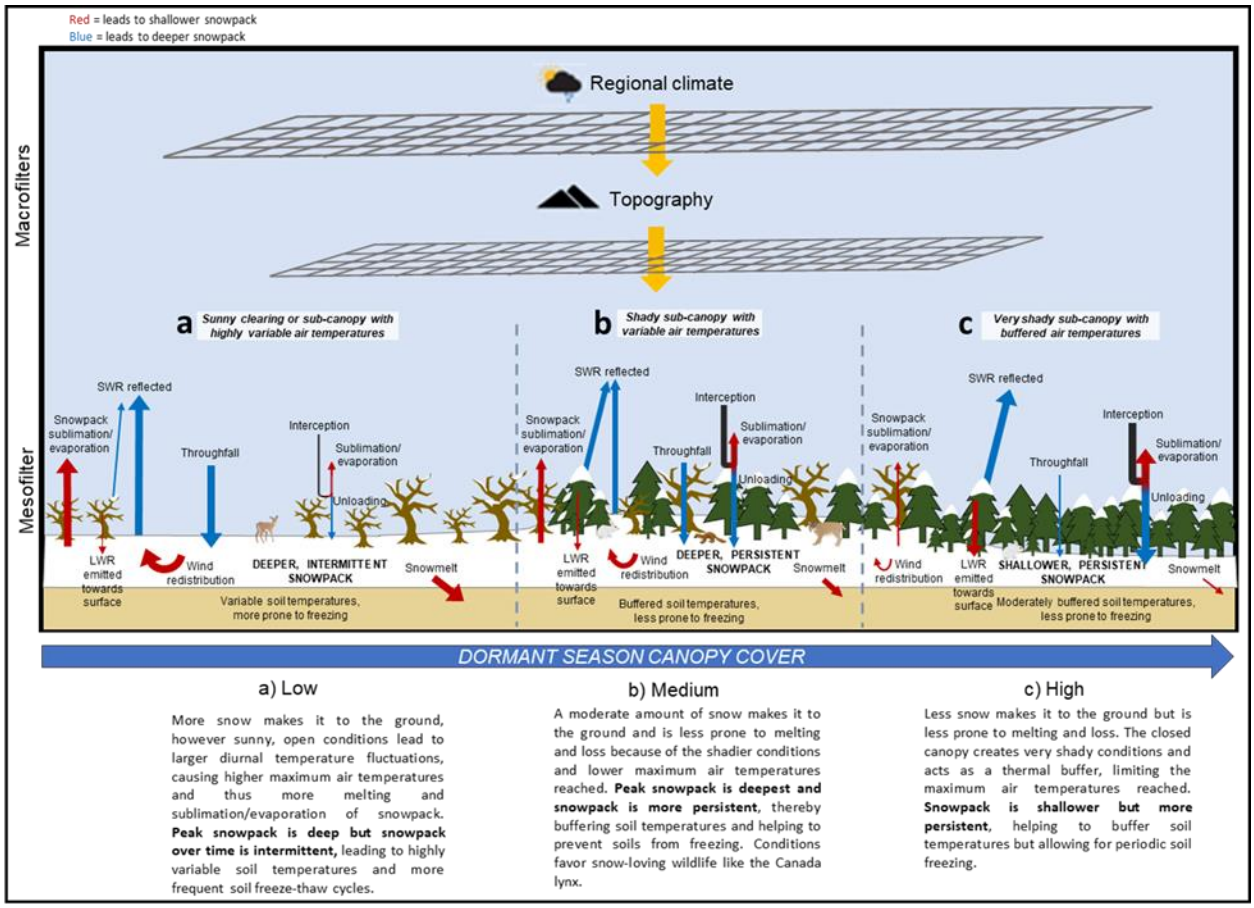


Figure 12. Conceptual diagram of the mechanisms driving differences in snowpack along a continuous gradient of dormant season canopy complexity cover (DSCC) from the synthesis publication led by former INSPIRES post-doc, Melissa Pastore. The macrofilters such as regional climate and topographical characteristics (e.g., elevation, slope, and aspect) determines base conditions, which are then modified by the interrelated vegetation mesofilter characteristics that determine canopy complexity cover (e.g., forest type/species composition, stem and tree canopy 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 of the fluxes. SWR = shortwave radiation; LWR = longwave radiation. Differences in snowpack depth among forest types over time are shown in Fig. 2. Snowshoe hare and marten icons by Erica Johnson.

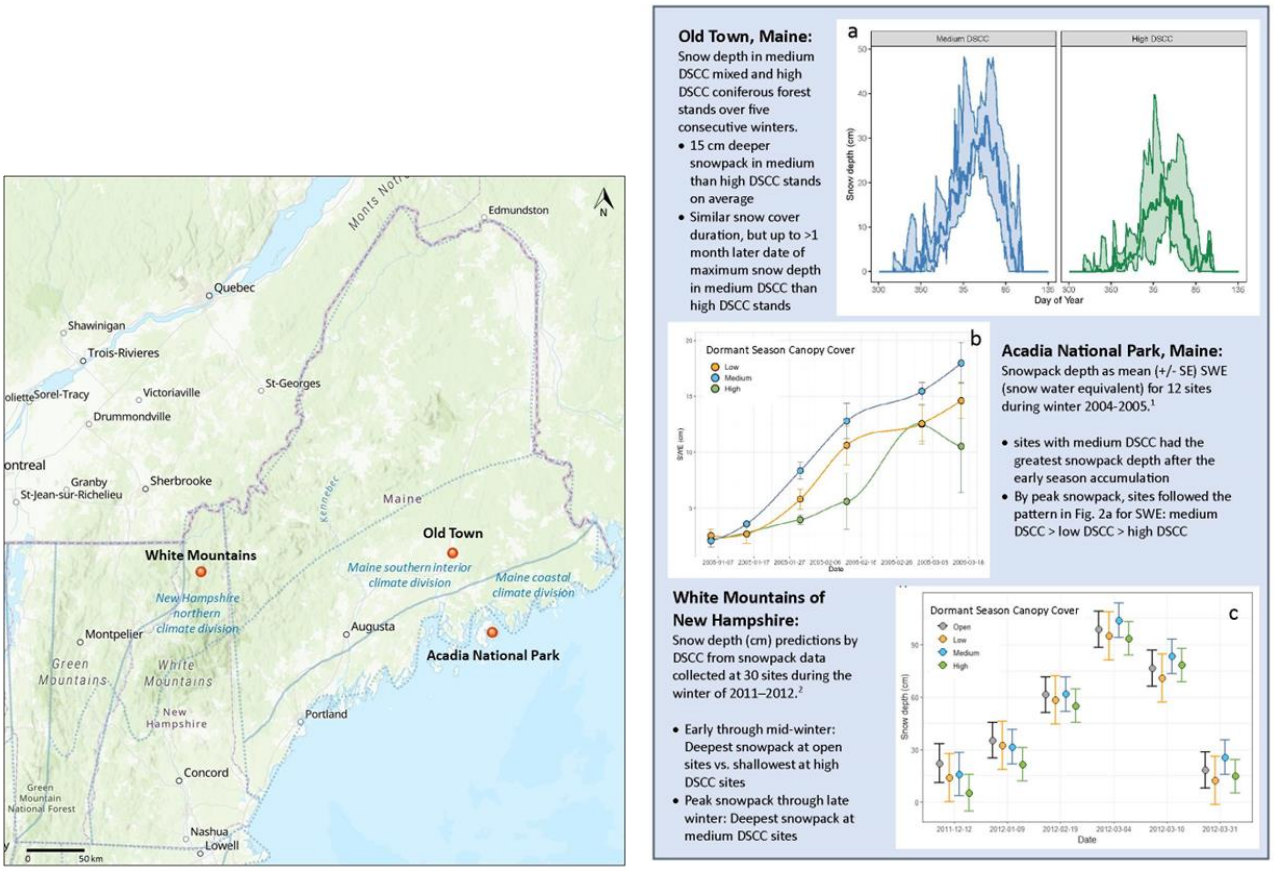


Figure 13. Location of the three study sites using INSPIRES sensor data (top) and the snowpack depth or snow water equivalent (SWE) over time in forests spanning the dormant season canopy cover (DSCC) gradient at (a) Old Town, Maine, (b) Acadia National Park, Maine, and (c) White Mountains, New Hampshire (bottom). These case studies were analyzed and presented in the synthesis publication led by former INSPIRES post-doc, Melissa Pastore. Preliminary data supports hypotheses tied to the influence of forest canopy complexity on snowpack depth and duration.

Team Members

- 9 faculty (5 early career), 7 research technicians or staff, and 2 graduate students; 5 VT, 4 ME, 4 NH, 5 AL

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	US Forest Service	NH	US Forest Service	Y	Research Staff
Apryl Perry	Earth Systems Research Center	NH	UNH	N	Research Technician

Name	Affiliation	Jurisdiction	Institution	Early Career	Role
Carol Adair	Rubenstein School of Environment and Natural Resources	VT	UVM	Y	Faculty
Dave Lutz	Environmental Studies	NH	Colby-Sawyer	Y	Faculty
Dawn Lemke	Department of Natural Resources & Environmental Sciences	AL	AAMU	N	Faculty
Dedrick Davis	Department of Natural Resources & Environmental Sciences	AL	AAMU	N	Faculty
Grace Smith	Rubenstein School of Environment and Natural Resources	VT	UVM	N	Grad Student
Helen Czech	Department of Natural Resources & Environmental Sciences	AL	AAMU	N	Research Technician
Kenneth Bundy	Department of Mathematics	ME	UMO	N	Research Technician
Patience Knight	Department of Natural Resources & Environmental Sciences	AL	AAMU	N	Research Technician
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	US Forest Service	VT	US Forest Service	Y	Research Scientist
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

Research Milestones Progress

Objective	Projects	Project responsible parties	Year 5 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,

Objective	Projects	Project responsible parties	Year 5 Milestones	Milestone Progress
				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 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

Objective	Projects	Project responsible parties	Year 5 Milestones	Milestone Progress
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, English	• 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

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 20m 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. In addition, further refinement of remote sensing and machine learning cloud computing capabilities was completed, enabling large-scale state- or even region-wide mapping. In Year 5, the Digital Forestry online beta version was presented and successfully defended by INSPIRES PhD student, Kingsley Wiafe-Kwakye. Cloud-based algorithms and processing were used to develop statewide forest type and carbon maps for Maine. Ultimately, the goal of developing a smart data and data-informed framework that leverages semantic knowledge to extract and characterize high-level places/events was completed, 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.

Highlights

- Additional 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 release candidate version of the Digital Forest Web Interface was demonstrated for better understanding tree species and environmental interaction (Figure 14, Figure 15, Figure 16).
- Kingsley Wiafe-Kwakye successfully defended his PhD dissertation (Figure 17).
- Peter Nelson completed a multi-day field acquisition in June 2024 to acquire additional hyperspectral imagery for Paint Rock field site in Alabama (Figure 18).
- Preferences for Environments Ontology (PrefEnvO) was published online by INSPIRES PhD student, Kingsley Wiafe-Kwakye, https://theskailab.github.io/PrefEnvO/prefenvo.html (Figure 19).
- Delineation of alternative climate zones used to better understand regional patterns (Figure 20) in forest type, land cover, biomass, and species diversity (Figure 21).

- Forest biomass derived from remote sensing map comparison analysis (Figure 22) conducted by INSPIRES faculty member Kasey Legaard to better understand influence of alternative machine learning algorithms on derived products.
- Completed final maps for abundant tree species in Maine, and preliminary map of regionally important forest types.

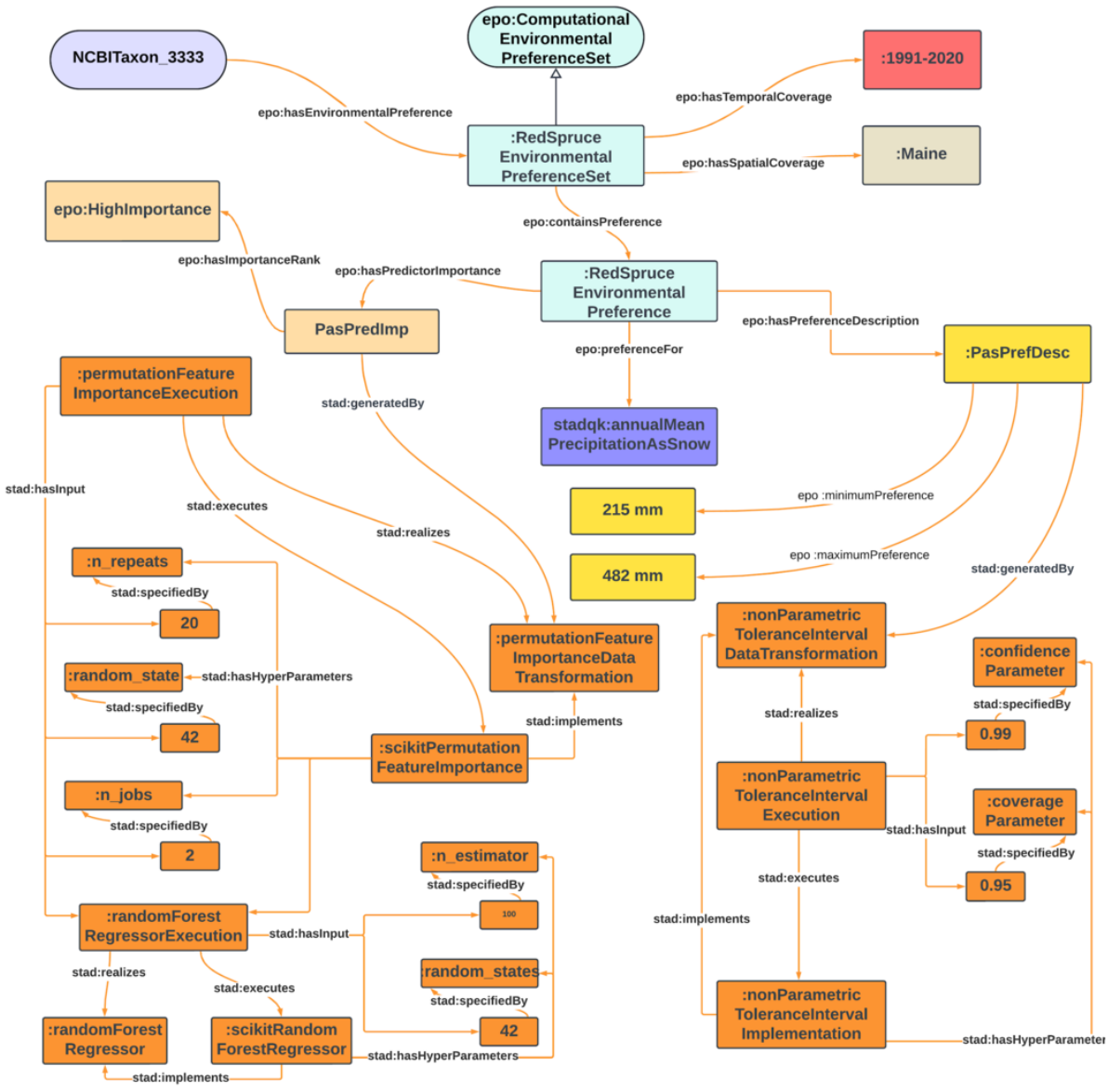


Figure 14. An example of an instantiation of the Computational Environmental Preference Set class, which shows how PrefEnvO, https://theskailab.github.io/PrefEnvO/prefenvo.html, can represent environmental preferences derived from computational methods.

```
PREFIX ex: <http://stad.spatialai.org/example/>
PREFIX stad: <http://stad.spatialai.org/core/v1/>
PREFIX time: <http://www.w3.org/2006/time#>
PREFIX qudt: <http://qudt.org/schema/qudt/>

SELECT ?quantValue ?unit ?tempResValue ?tempResUnit ?spaResValue ?
spaResUnit
WHERE {ex:NH_MeanTemp2013 qudt:quantityValue
            [qudt:numericValue ?quantValue],
            [qudt:unit ?unit];
            stad:hasBaseDataDescription ?Basedatadesc.
    ?Basedatadesc stad:hastemporalResolution
            [time:numericDuration ?tempResValue],
            [time:unitType ?tempResUnit];
    stad:hasSpatialResolution ?spatialresolution.
    ?spatialresolution stad:spatialResolutionValue
            [qudt:numericValue ?spaResValue],
            [qudt:unit ?spaResUnit].
}
```

Figure 15. Example SPARQL code presented in Kingsley Wiafe-Kwakye's dissertation for answering Which aggregate data has the same temporal coverage but different aggregation periods.

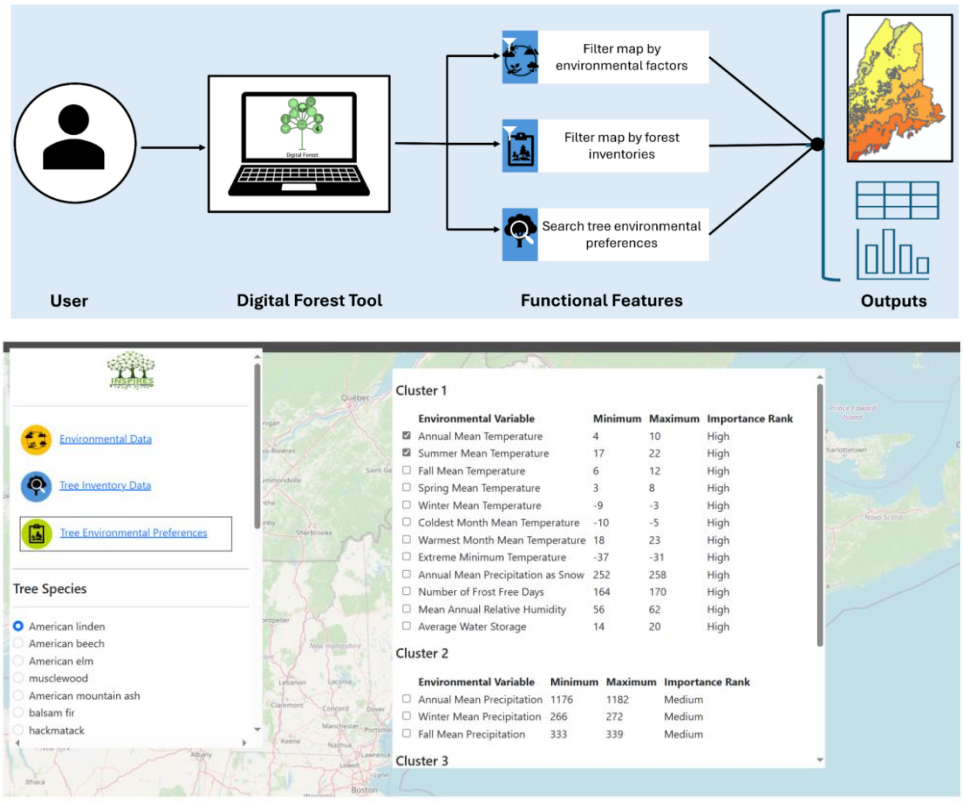


Figure 16. Online beta version of the Digital Forest Tool for visualizing and analyzing complex tree species and environmental interactions was presented and successfully defended by INSPIRES PhD student, Kingsley Wiafe-Kwakye, in July 2024.

Figure 17. INSPIRES University of Maine PhD student, Kingsley Wiafe-Kwakye, successfully presented and defended his dissertation in July 2024. Kingsley was co-advised by INSPIRES faculty, Drs. Kate Beard-Tisdale and Torsten Hahmann, in the Department of Spatial Information Sciences and Engineering.

Figure 18. Dr. Peter Nelson of INSPIRES Theme 2 working AAMU undergraduates to conduct a hyperspectral imaging acquisition at Paint Rock field site in Alabama during his June 2024 visit.

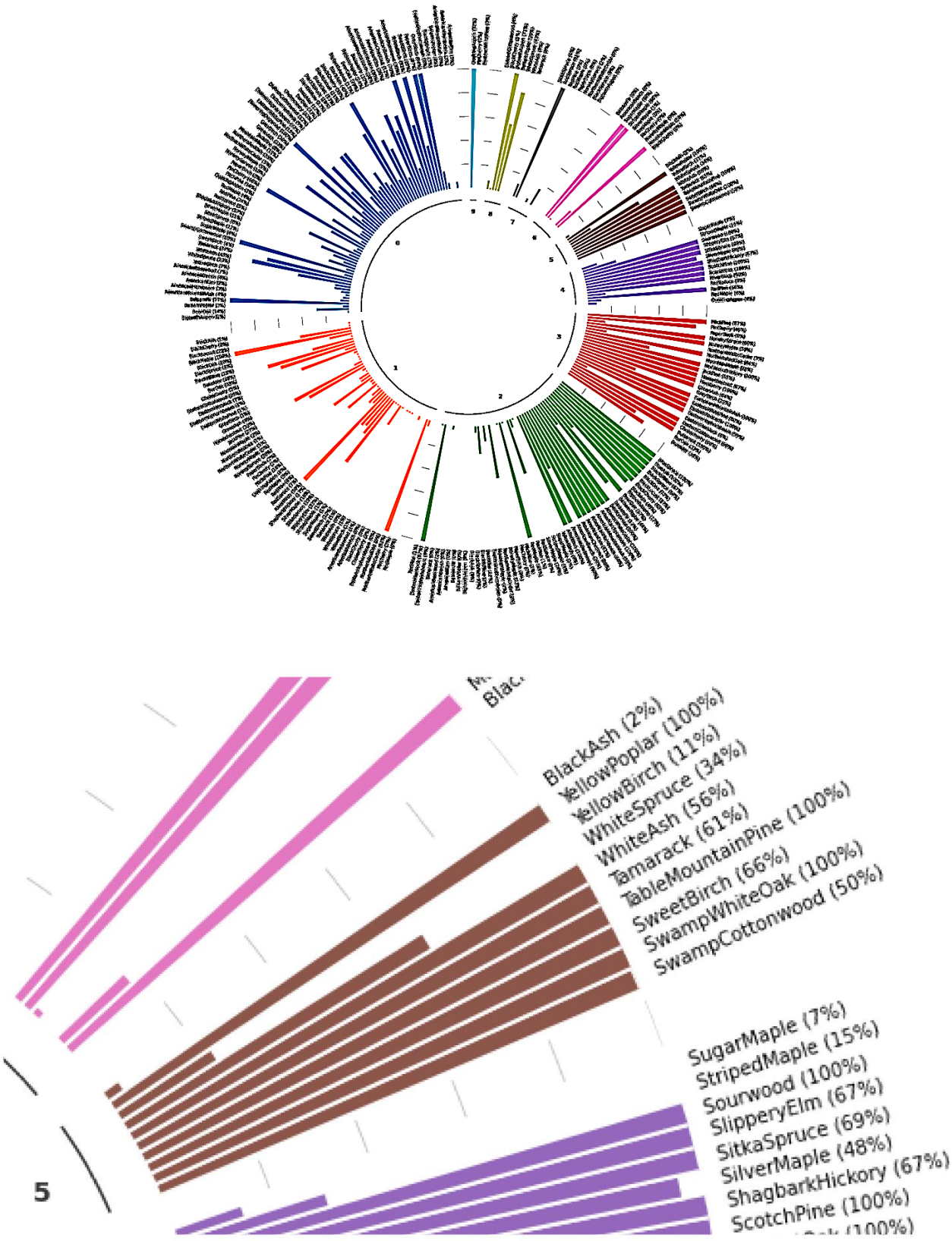


Figure 19. Overall knowledge graph (top) and a zoomed in example (bottom) on tree species classification based on environmental preferences developed by INSPIRES PhD student, Kingsley Wiafe-Kwakye, using output from the Digital Forest and environmental ontologies.

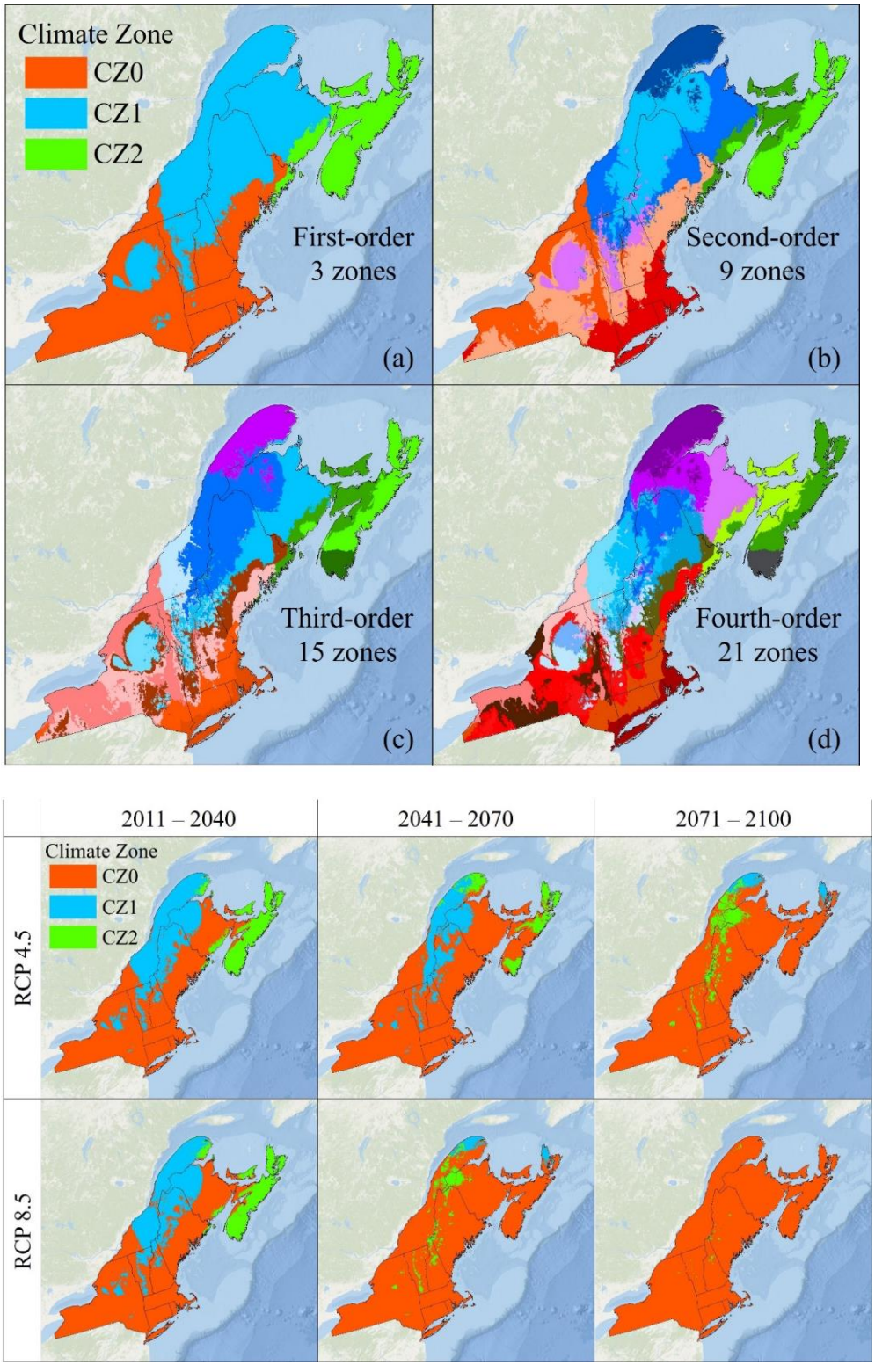


Figure 20. *Above:* Delineation of alternative regional climate zones based on alternative implementation of the ML clustering algorithm. *Below:* Shifts and changes in the primary regional climate zones over time due to climate change for different RCP paths presented in Roy et al. (2024).

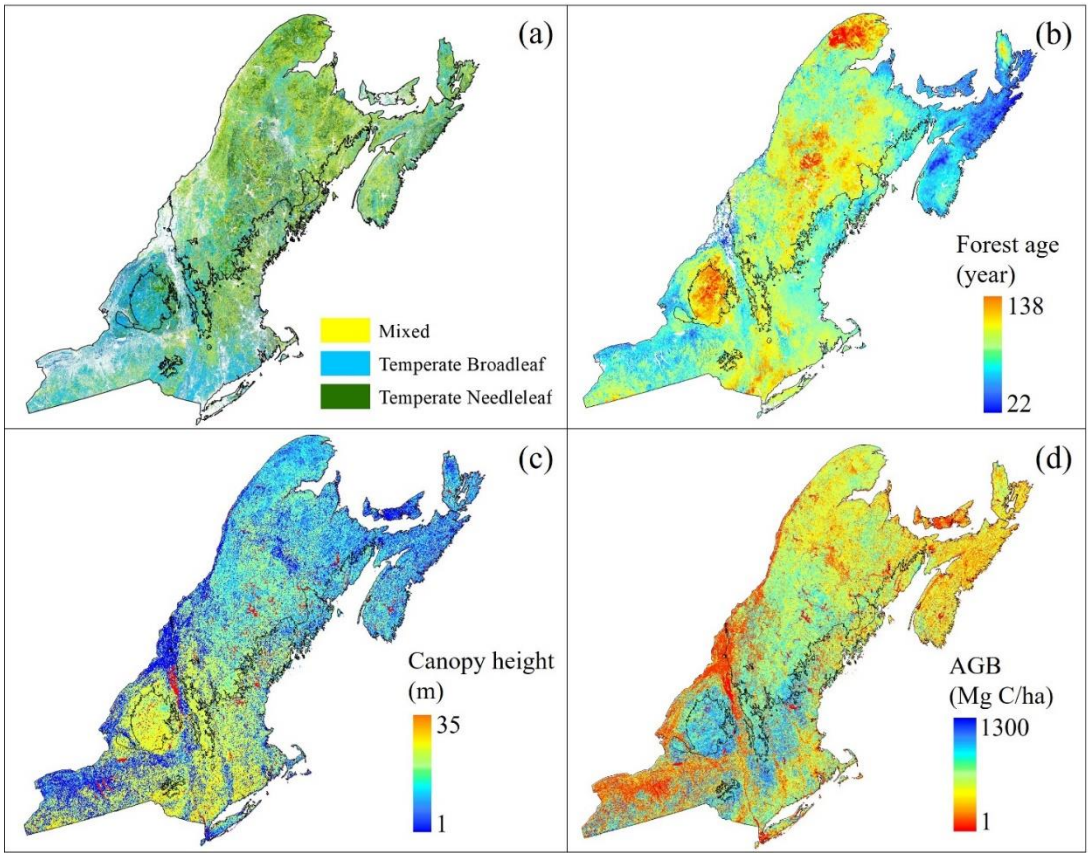


Figure 21. Relationship between the dlineated climate zones of Roy et al. (2024) and their relationship to critical regional forest attributes such as type (a), age (b), canopy height (c), and total aboveground biomass (d; AGB).

Team Members

- 10 Faculty (7 Early-Career), 2 Professional Staff, and 2 Graduate Students; 9 ME, 3 NH, and 1 VT

Name	Affiliation	Jurisdiction	Institution	Early Career	Role
Darren Ranco	Department of Anthropology	ME	UMO	N	Faculty
Donna Rizzo	Department of Civil & Environmental Engineering	VT	UVM	N	Faculty
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

Name	Affiliation	Jurisdiction	Institution	Early Career	Role
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
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
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
Torsten Hahmann	School of Computing and Information Science	ME	UMO	Y	Faculty

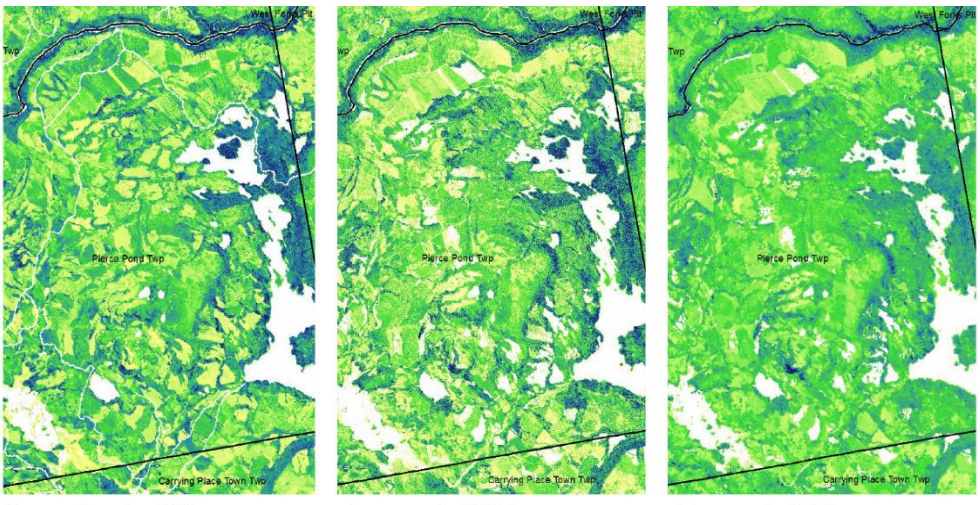


Figure 22. Comparison of three forest biomass maps by INSPIRES faculty member Kasey Legaard for northern Maine derived from different remote sensing and machine learning algorithms.

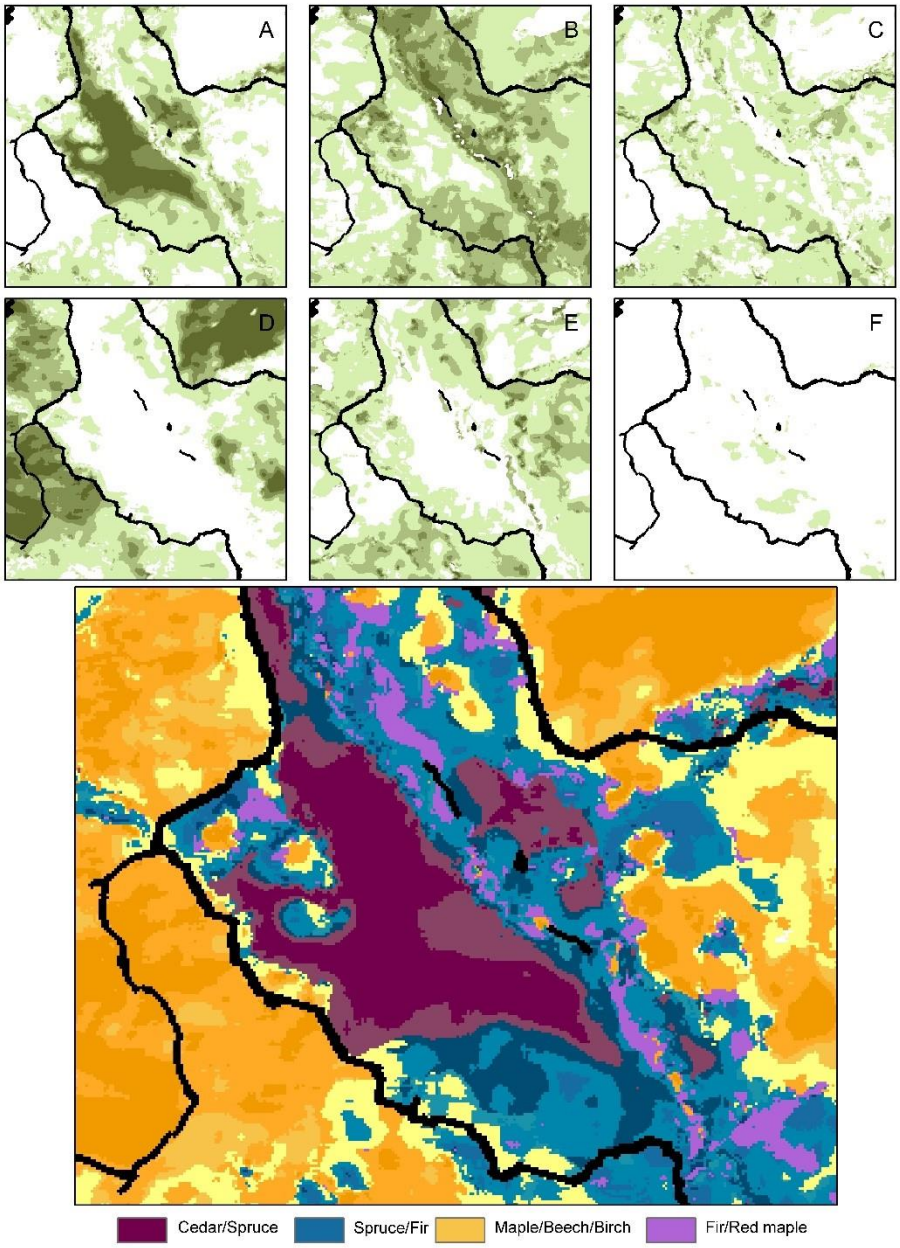


Figure 23. Example area of forest type map developed from a subset of individual species occurrence/abundance maps, including A) Northern white cedar, B) balsam fir, C) red spruce, D) sugar maple, E) red maple, and F) black spruce. Occurrence and relative abundance for each species was modeled and mapped using a combination of Sentinel-2 imagery and plot data from the USFS Forest Inventory and Analysis (FIA) program.

Research Milestone Progress

Objective	Project	Project responsible parties	Year 5 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) Developed a knowledge graph of tree species classification based on an environmental ontology (Hahmann & Beard)
	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 algorithms for analyzing spatio-temporal datasets	Legaard, Roy, Yasaei	Compare existing and newly developed ML algorithms on similar spatiotemporal datasets	Developed Forest Ecology Ontology and tested their use with clustering 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)

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

TEAL accomplishments in Year 5 are highlighted by continued student-led efforts with active involvement of several UNH faculty and staff including Co-PI Ollinger. Major field campaigns were conducted this past year, primarily to support the collaboration between UNH and AAMU and research of graduate students, Jack Hastings and Sam Vandewater. The second campaign focused on sampling tree cores and measuring structural, chemical, and physiological traits for tree species at the Thompson Farm Earth Systems Observatory in Durham, NH and the Paint Rock forest near Huntsville Alabama (Figure 25). These data are being used to understand how differences in turgor loss point and related leaf traits influence sensitivity to drought across sites and species.

MS student Emily Landry completed her MS thesis that examined how climate patterns are changing across the Northeast US. This involved analysis of how NOAA climate normal (min and max temp, precipitation) have changed in recent decades, and its implications for forest productivity across the region. 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 25. UNH graduate student Sam Vandewater collects tree cores at the Paint Rock forest in Alabama as part of the collaborative effort between UNH and AAMU.

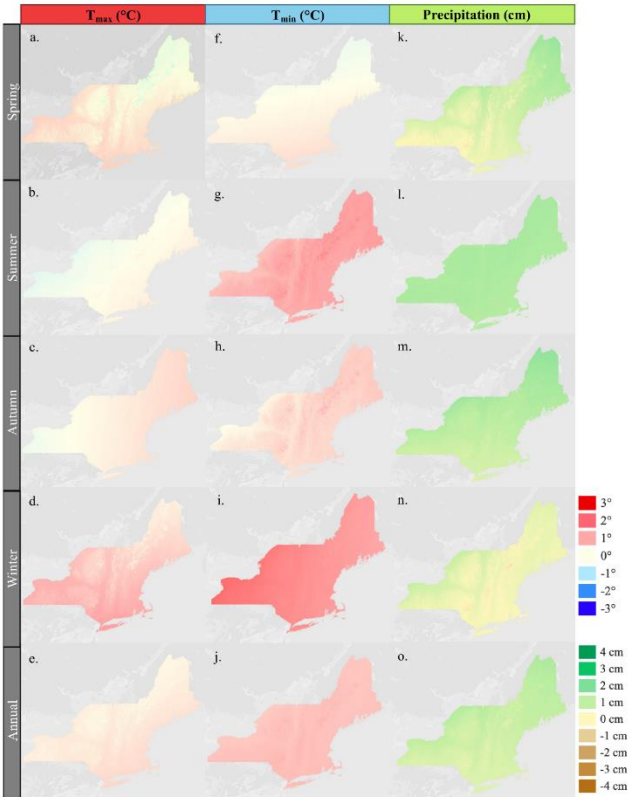


Figure 24. Change in prediction maps for maximum temperature (a- e), minimum temperature (f-j), and precipitation (k-o), averaged by spring (Mar, Apr, and May), summer (Jun, Jul, and Aug), autumn (Sep, Oct, and Nov), and winter (Dec, Jan, and Feb) presented in University of New Hampshire INSPIRES MS student, Emily Landry. The full MS thesis is available online: https://scholars.unh.edu/thesis/1766/.

Theme 2 Project: INdendro System

Two pilot field installations comprising a total of ten inDendro sensors connected to two independent base stations (for data receipt and relay) have been placed at sites on the University of Maine campus and in New Hampshire at Pinkham Notch.

The INdendro sensor network consists of three major components:

1. A band-type dendrometer which is designed to operate on a single battery for a year which communicates its measurements wirelessly.
2. A base station and combined receiver and antenna unit.
3. A real time data viewer under development will be built into the existing InLeaf data sharing system (https://inleaf.inspires.acg.maine.edu; InLeaf is an early BETA release), supported by UMS's Advanced Computing Group. A RESTful, real-time data aggregation API and database for the viewer were completed in July 2024.

It is worth noting that this system is not limited to dendrometer measurements. It can easily have sensor nodes with different suites of instruments and sensors all received and relayed by the same base station and kept separate. Every dendrometer or other instrument has its own unique device ID. In 2024-25, two undergraduates will continue work on the dendrometers under the direction and support of INSPIRES team members Ali Abedi (Co-PI) and Leo Edmiston-Cyr (INdendro technical staff).

Dendrometer Design

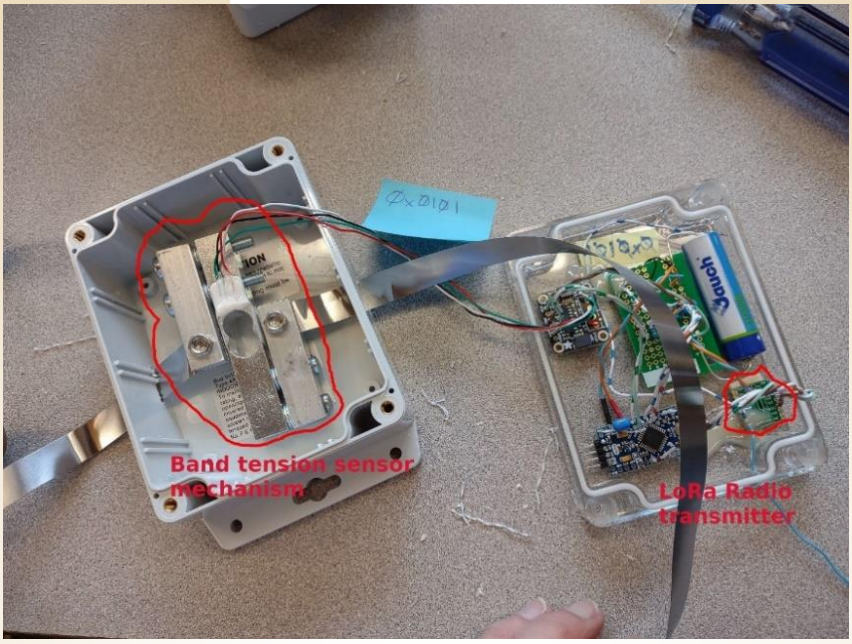
Band tension is measured and transmitted wirelessly as changes in diameter every half hour. The dendrometer measures the tension using a modified load cell and instrument amplifier. A temperature measurement is taken at every sample for raw data and tension corrections due to expansion and contraction of the metal band. The measurements are transmitted with a low-power, long-range 433MHz LoRa transceiver, able to transmit small amounts of data over surprisingly long distances. ***Under common forest canopy and understory conditions, the signal can be successfully received at distances of 200m-300m without any specialized antenna*** or high-power components that would preclude operation on a battery for a full year. The ability to pass through vegetation is a huge bonus for a forest sensor.

Each dendrometer has

- An aluminum support wire. This supports the dendrometer on the tree at the correct height. It also eases sizing, alignment, and installation of the band.
- A stainless-steel band that emerges from slots in the sides, with holes punched along the band in the correct location depending on tree diameter.
- Two springs – one for the support wire and one for the band tension.

The dendrometers are programmed to send data approximately every thirty minutes. The timestamp for each received measurement is applied by the base station. The receiver has a precision timekeeping mechanism.

Pilot Study Base Station

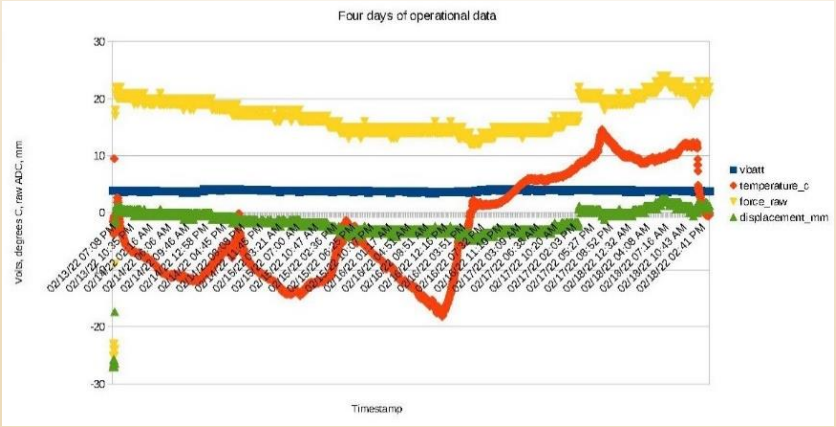


The pilot study base station has been placed on the roof of Nutting Hall on the University of Maine campus. The receiver unit is composed of a 433MHz LoRa transceiver that receives the data packets containing measurements from the dendrometers within range.

As part of the base station located on the roof of UMaine's Nutting Hall, the vertically polarized, omnidirectional, half-wave dipole antenna is enclosed in a weather proof PVC enclosure. A Raspberry Pi Zero W is used to communicate with the receiver unit and relay the wireless messages received via WiFi for real time access.

Close up of an existing install in Nutting preserve in Orono showing the spring attachment. *Note:* Before installing the band to measure the DBH; the dendrometer itself does not know how much band is wrapped around the tree – only how much its tension changes. The dendrometers send tension changes which are translated into DBH changes.

Four dendrometers that were shipped to the second pilot installation site in New Hampshire at Pinkham Notch.



Data calibration and linearity testing of the first prototype dendrometer showing temperature independence of the sensor mechanism and associated electronics.

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.
- 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

- 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 and continues to engage with numerous INSPIRES faculty across the region.

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 provides 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. A focus of Theme 3 in Year 5 was to finalize the integration of a nitrogen cycling module into the PnET-CN-Succession model, conduct validation and sensitivity analyses and prepare a manuscript for publication. All these goals were met in Year 5. A manuscript is in its final stages of preparation and is expected to be resubmitted to the journal Ecological Modeling in August 2024. 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. Another synthesis manuscript involving numerous INSPIRES faculty (Hayes, Simon-Legaard, and Weiskittel) on forest carbon models has been drafted and will be submitted to the Journal of Forestry.

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.

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.

Highlights

- Completion of new LANDIS-II extension that integrates the PnET-CN model and the LANDIS-II PnET-Succession model. This new model, called PnET-CN-Succession, allows users to model the effects of nutrient availability and tree species competition for nitrogen on forest succession.
- Preparation of a manuscript describing PnET-CN-Succession that is expected to be submitted to *Ecological Modeling* in August 2024.
- 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.
- Preparation of a manuscript quantifying the climatology of cold-air pooling for 25 watersheds across the INSPIRES project area using MODIS satellite land surface temperature and below-canopy air temperature from 6 microclimate watersheds instrumented by Theme 1 to be submitted to *Agricultural and Forest Meteorology* in September 2024.
- Completion of a new study using the Forest Vegetation Simulator (FVS) to evaluate the effects of alternative forest management strategies and salvage, in response to eastern spruce budworm, on future forest carbon. Published in *Frontiers in Forests and Global Change*.
- Completion of new study using LANDIS-II to model interactions between timber harvesting and climate change across northern Maine. In review at *Ecological Applications*.
- 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 (USFS collaborator).
- 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 26).
- MIC working group also completed preliminary comparison of model projections of live, aboveground biomass in Maine, including LANDIS-II and different variants of FVS (Figure 27).
- 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 and FVS (Figure 28).
- Cross-theme (Themes 2 and 3) working group completed prototype workflow of inverse parameterization of key LANDIS-II parameters based on USFS FIA inventory plots to improve local parameterization and representation of outcome uncertainty (Figure 29).
- 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.

- 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.
- Acadian Variant of FVS was benchmarked against regional FIA data (Figure 31, Figure 30).

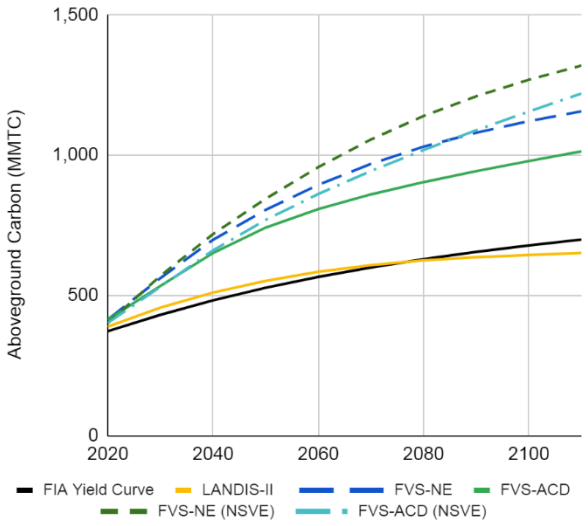


Figure 27. Intra-model comparison of aboveground carbon projections for Maine, assuming no future harvest. Models included LANDIS-II with Biomass Succession extension, four variants of the Forest Vegetation Simulator (FVS), and simple growth prediction based on USFS Forest Inventory and Analysis (FIA) plot data.

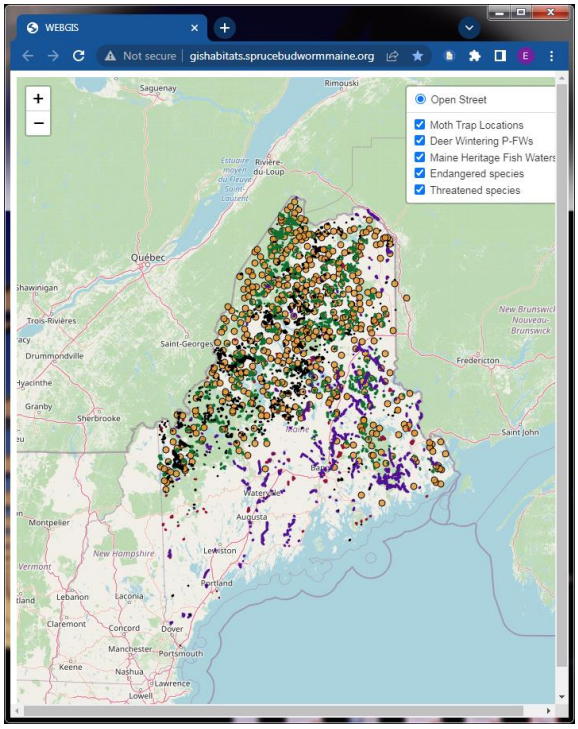


Figure 26. INleaf tool developed for outreach to members of the Spruce Budworm Task Force to help identify sensitive natural communities and habitats where application of salvage or insecticide should be limited or avoided.

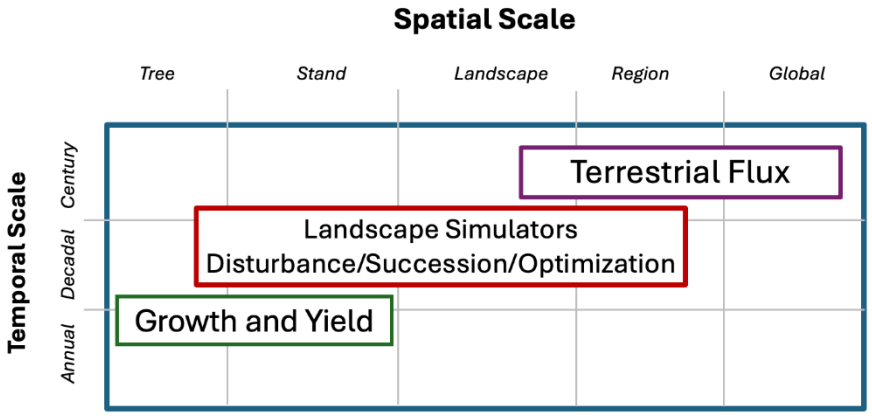


Figure 28. Spatiotemporal scales of model development, parameterization, and intended application by general type (Growth and yield, landscape simulation/disturbance/succession, and terrestrial C flux) explored by Theme 3 and presented in the forthcoming forest carbon synthesis publication developed by several INSPIRES faculty.

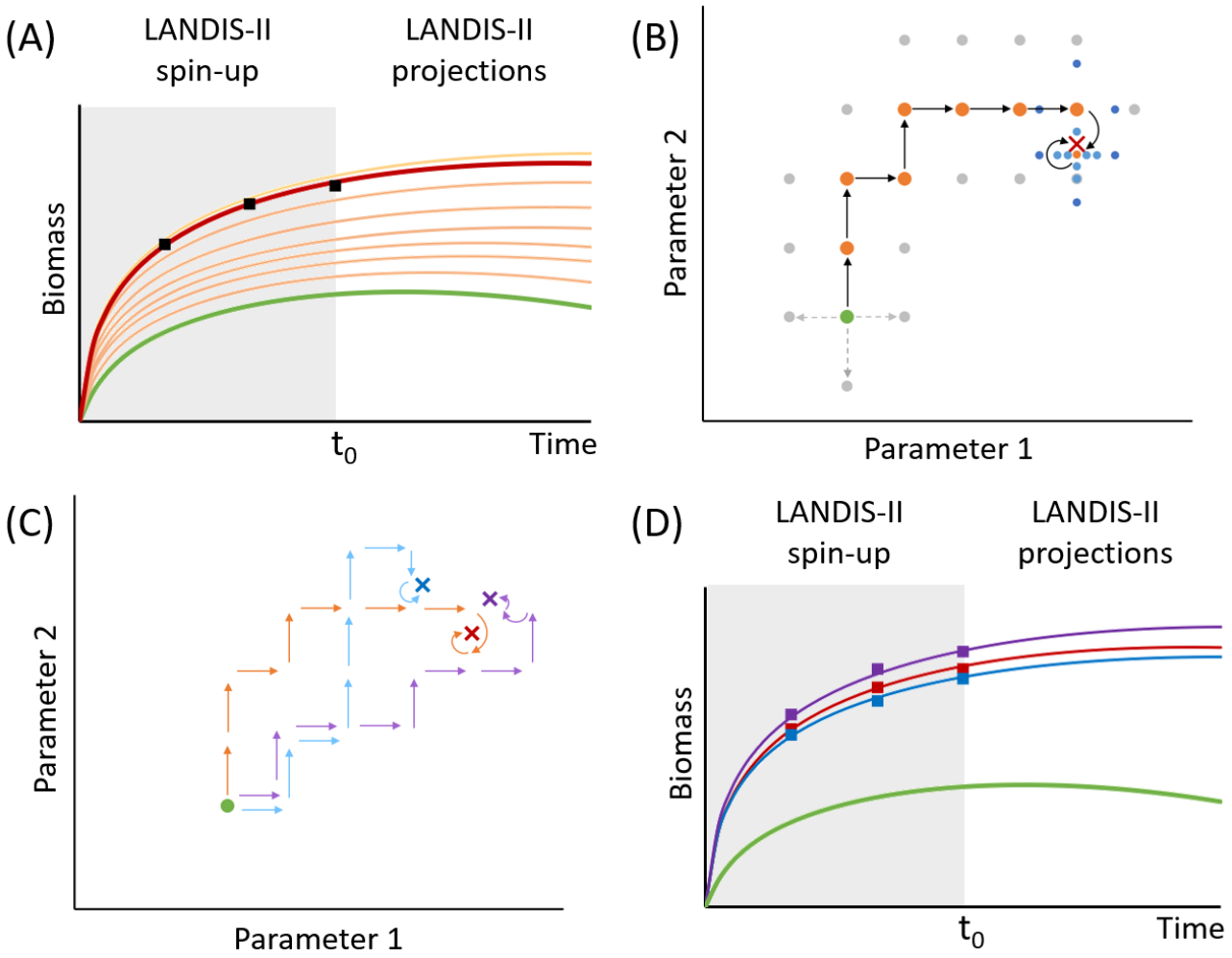


Figure 29. Schematic demonstrating inverse parameterization of the LANDIS-II biomass growth model using a pattern search algorithm informed by FIA plot data. Curves represent modeled biomass growth for a single species/age cohort based on a specific parameter combination. Model spin-up grows cohorts to match initial plot conditions at time 0, with subsequent time steps representing projected growth. (A) In our proposed approach, predictions made using an initial set of model parameters (green curve) are iteratively improved (orange curves) until they closely match (red curve) FIA observations (black squares). (B) Iterative improvements from the initial parameter set (green dot, corresponding to green curve in A) are obtained by using a pattern search algorithm to systematically test alternative parameter combinations (grey dots), only selecting those that improve predictive accuracy (orange dots). Step size used to select parameter combinations is reduced (blue dots) nearer to target, and eventually the algorithm converges on a final parameter combination (red cross, corresponding to red curve in A). (C) Measurement uncertainty is incorporated by applying the pattern search to multiple equally probable realizations of target biomass values (blue and purple crosses), constructed by, for example, bootstrap sampling of FIA measurements. (D) Resulting equally probable parameter combinations collectively express parameter uncertainty and provide a mechanism for estimating uncertainty in LANDIS-II projections (D; red, blue and purple curves). Note that this inverse parameterization process is simultaneously applied to many thousands of species/age cohorts measured on FIA plots throughout the study region.

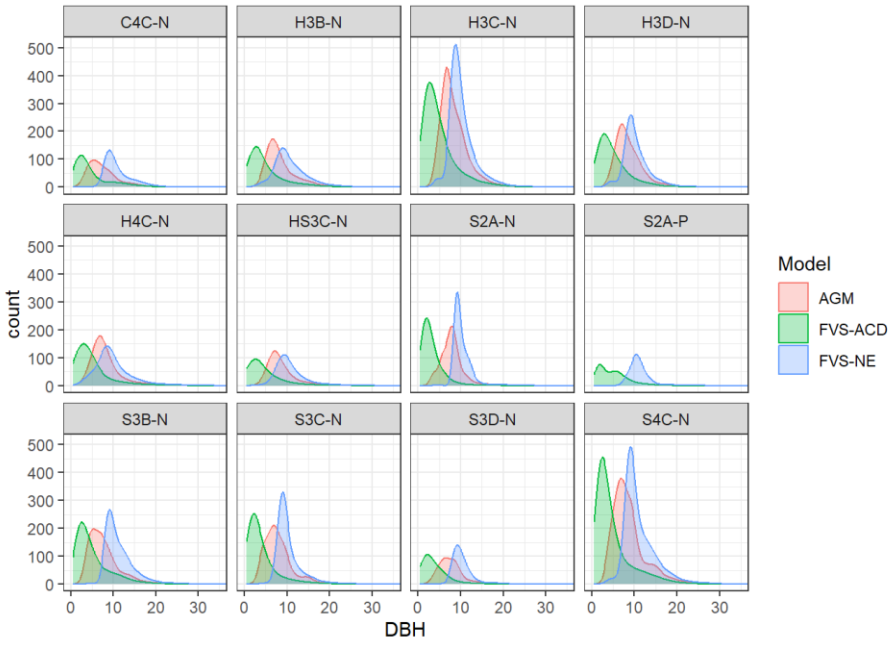


Figure 31. Comparison of alternative versions of the Acadian Variant of the Forest Vegetation Simulator (FVS-ACD) for predicting stand-level diameter distributions after 50 years of projection across various strata in Maine.

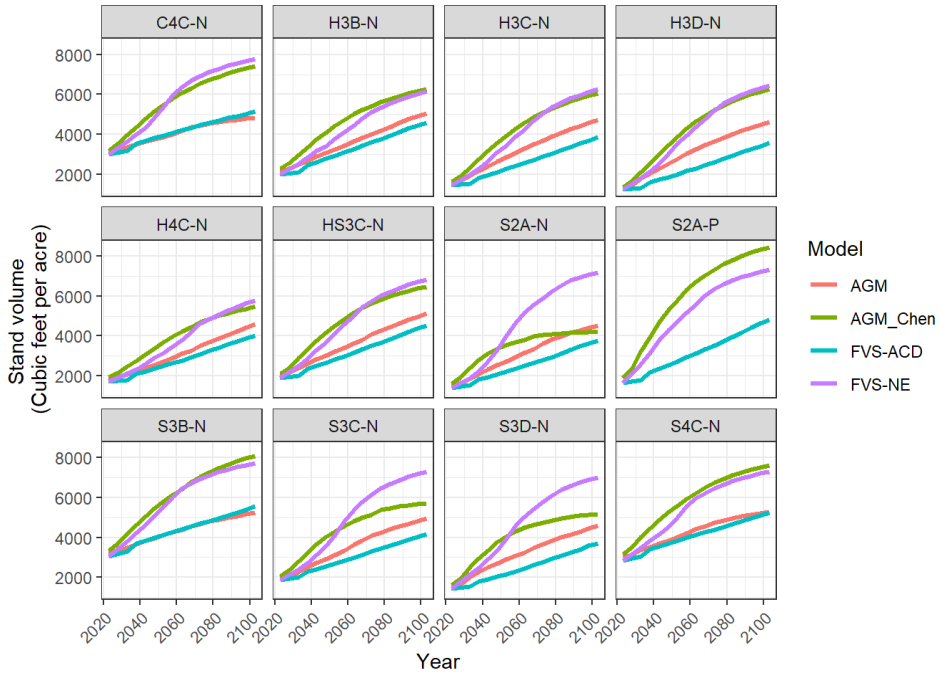


Figure 30. Comparison of alternative versions of the Acadian Variant of the Forest Vegetation Simulator (FVS-ACD) for predicting total gross volume across various strata in Maine.

Team Members

- 11 faculty (9 early-career), 1 post-doc, 2 Research Staff; 4 ME, 3 VT, 5 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
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

Name	Affiliation	Jurisdiction	Institution	Early Career	Role
Scott Ollinger	Earth Systems Research Center	NH	UNH	N	Faculty
Xinyuan Wei	School of Forest Resources	ME	UMO	Y	Faculty
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

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.

Theme 4 hosted a 3-day summer institute at the University of Vermont, June 21-23, 2023. The first day involved working group time to finalize lesson drafts and compile them on the Google Site to make them easy to share. We also took time to reflect on classroom experiences by creating posters and posters and participated in a data literacy graphing and storytelling activity involving quantitative reasoning. The next day we visited Shelburne Farms to learn about the region's forest research history from local researchers. We divided the group into several forest research stations to learn about some sampling and data collection techniques that were new to the group. The final day was reserved for reflection on the multi-year collaboration and considering the next steps for this team, including sketching ideas for a future grant proposal and opportunities for sharing teacher work through conferences and professional learning workshops, multi-year collaboration and considering next steps for this team including sketching ideas for a future grant proposal and opportunities for sharing teacher work through conferences and professional learning workshops.

Participants:

A total of 19 individuals participated in the workshop, including 5 Maine teachers and 6 Vermont teachers. INSPIRES team included 6 researchers from the University of Maine and 2 researchers from the University of Vermont.

Maine		**Vermont**	
Teachers	**Researchers**	**Teachers**	**Researchers**
Elizabeth Trenckmann	Sara Lindsay	Peter Goff	Regina Toolin
Amy Sidell	Christina Siddons	Bryn McDonald	Tony D'Amato
Ruth Poland	Marina Van der Eb	Erin Wysolmerski	
Dylan Harry	Franziska Peterson	David Cutler	
Laurie Spooner	Kelsey Davis	Meagan Denardo	
	Gabrielle Holt	David McNally	

Teacher Feedback

"Great to reconnect and hear what folks have done in their classrooms with visuals. The website is going to be super helpful in accessing the curriculum."

"It was great to be able to wrap up the lessons and see how it might look on the website (which looks awesome!!!)"

"Thank you for letting me be part of this program. I really enjoyed it and got so much out of it. I would love the opportunity to work with this group again or collaborate in another RiSE center-led group on implementing QRC/data work in the science classroom."

"Thanks SO much for the thoughtful framing and support and logistics work that you did for this program."

Highlights

- In August 2023, a third professional learning workshop led by the Theme 4 team members Sara Lindsay, Marina Van der Eb, Regina Toolin, and Susan McKay was held in Vermont. The workshop involved scientists from other INSPIRES themes including Alix Contosta (UNH). 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 32).
- A strong network of teachers across the region formed and remain interested in continuing to interact after the project ends with the INSPIRES Northern Forest Data website available for accessing and using INSPIRES data in the classroom (Figure 33).
- Over 14 INSPIRES project participants outside of Theme 4 have engaged with the teachers. INSPIRES scientists helped high school teachers and students measure and predict forest carbon using established protocols (Figure 34, Figure 35).
- Regina Toolin is leading a third year of the UVM graduate course with all VT teachers enrolled. The course 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.
- Small working groups met asynchronously during fall focused on learning experiences.
- Ongoing teacher interviews assessing learning experience development, QRC and how it may have changed during this project, and reflections on being part of the research practice partnership. Chrissy Siddons working on how to make future collaborations and partnerships between teachers and scientists successful.
- Feedback sessions were organized and conducted on: (1) content and flow of the different learning objectives and (2) details for publication dissemination.
- A NEERO proposal was developed and accepted to help sustain future efforts of this research theme.
- Forest data website is being curated to translate theme data to make them teacher and student friendly. Teachers are now piloting and using lessons learned over the past 3 years in their classrooms to improve them (Figure 36).

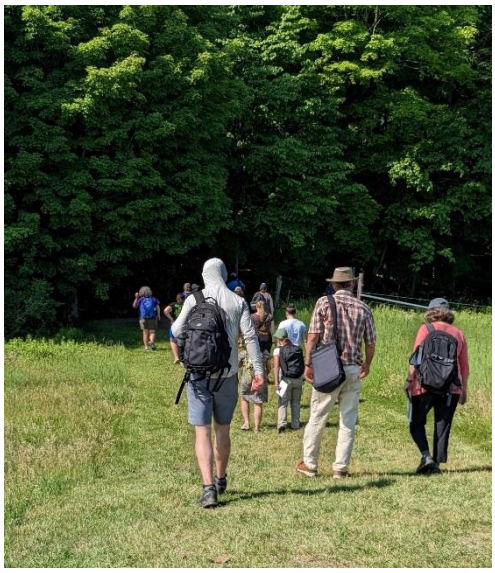
Figure 32. Teacher training on forest ecology for Maine and Vermont teachers in August 2023 organized and led by Co-PIs D'Amato and Senior Personnel Regina Toolin at Shelburne Farms in Vermont VT.

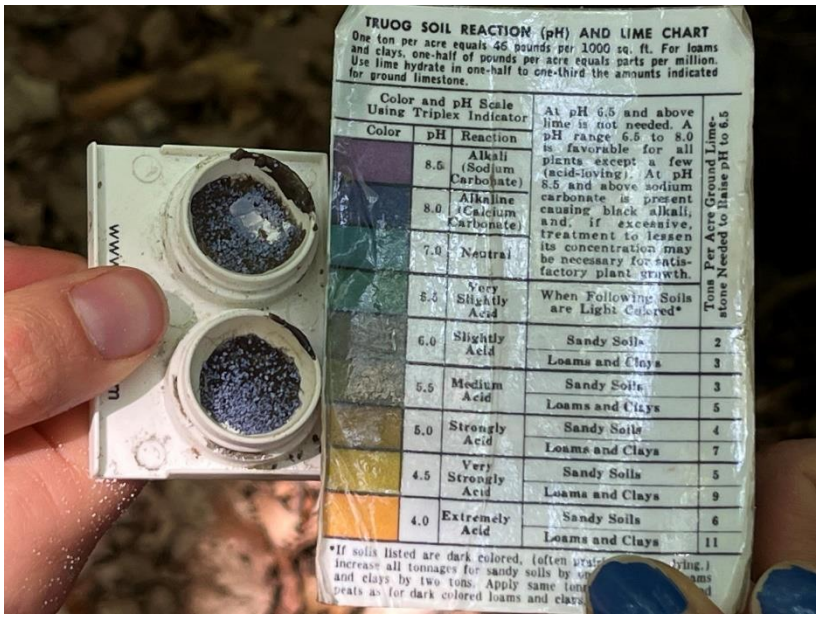
- "Integrating computer science into middle school science instruction: Assessing barriers and opportunities across diverse school districts," a multijurisdictional manuscript, was submitted to the *Journal of Science Education and Technology*.
- Awareness building of Traditional Ecological Knowledge via connections to Wabanaki Youth in Science (WaYS) Coordinator tish carr.

INSPIRES Northern Forest Data web portal

sites.google.com/maine.edu/inspires-northern-forest-data/home

Figure 33. INSPIRES Northern Forest Data web portal available to high school science teachers and science for accessing and using data generated by the INSPIRES project.





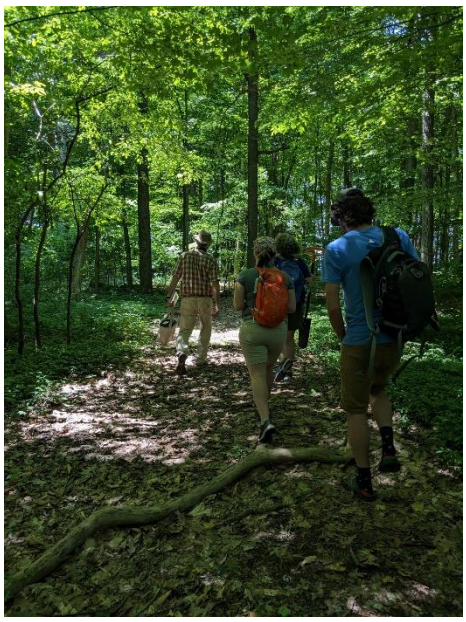


Figure 34. Teacher tour photos courtesy Marina van der Erb.

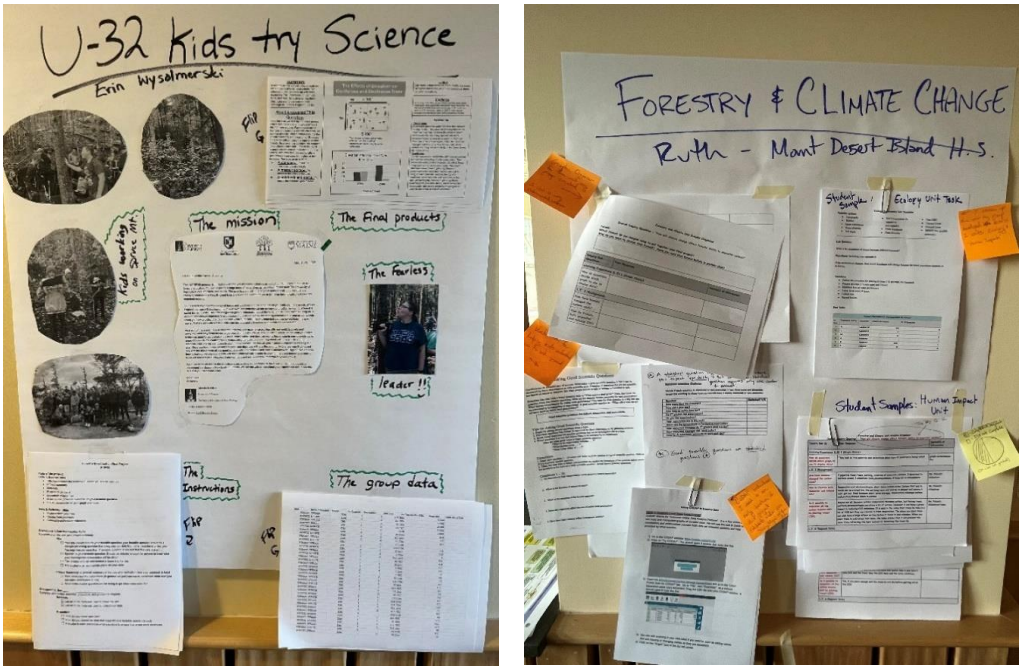


Figure 35. Posters teachers created sharing work that was done in their classroom resulting from their involvement with INSPIRES.

- A multi-jurisdictional presentation entitled, "Engaging Teachers, Education Researchers, and Scientists in Authentic Investigations with Forestry Data" was presented at American Association of Physics Teachers in January 2024.
- A workshop on Using Forestry Techniques to Improve Students' Quantitative Reasoning was developed and presented by Betsy Trenckmann, Hermon (ME) High School, and Laurie Spooner, Van Buren (ME; MSAD 24) at RiSE Center Annual Conference.
- A multi-jurisdictional manuscript entitled, "Education Researchers as Negotiators: Leveraging Expertise across Teachers and Scientists to Implement Authentic Data Investigations in Grade 7-12

Figure 36. Example high school science curriculum developed by INSPIRES Theme 4 using sensor data from the project and being implemented by network of teachers in the region. Additional lesson

	Scientists	Teachers	QRC Leadership Team
Role 1	Co-developer of curriculum	Developer of curriculum	Co-developer of curriculum
Role 2	Deliverer of content in teacher enhancement (inservice or preservice) as lecturer in a course, or workshop leader	Learner	Negotiator, Workshop leader; Learner and participant
Role 3	Visitor to the classroom, or accessible to answer queries and seek resources for students, teachers, or parents.	Host / facilitator, or active resource-seeker	Negotiator
Role 4	Scientist – student(– teacher) partnerships	Observer / supporter between scientists & students as needed	Negotiator
Role 5	Teacher mentor, or provides a teacher with the opportunity to work on a research project.	Mentee / active participant in research	Research participant
Role 6	Learner	Expert	Learner

Figure 37. Example high school science curriculum developed by INSPIRES Theme 4 using sensor data from the project and being implemented by network of teachers in the region. Additional lesson plans are available online (https://sites.google.com/maine.edu/inspires-northern-forest-data/lessons).

Classrooms" led by INSPIRES professional staff member, Kelsey Davis, highlighted various strategies (Figure 37) for engaging scientists and teachers for classroom QRC activities (Figure 36). Key findings include:

i. QRC Leadership Team (Theme 4) negotiation practices, including aligning language between project stakeholders and aligning the needs and assets of stakeholder groups (e.g., forest scientists and classroom teachers);
ii. Creating equitable participation spaces for education researchers, scientists, and teachers to feel empowered to contribute to collaborative work; and
iii. Positioning teachers as experts and scientists as learners.

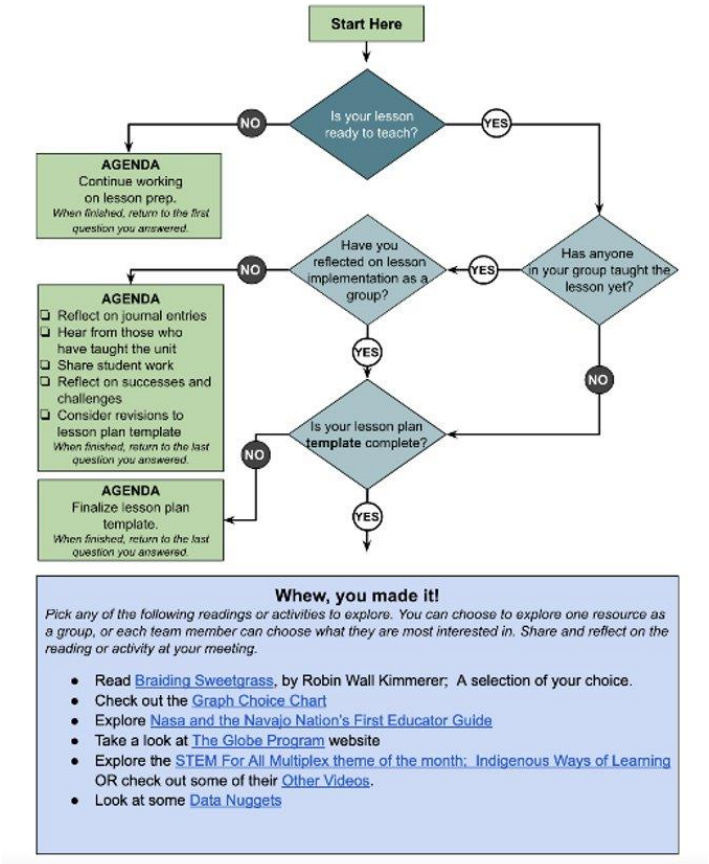


Figure 38. Example curriculum materials developed and piloted by regional high school teachers. Additional lesson plans are available online at: https://sites.google.com/maine.edu/inspires-northern-forest-data/lessons.

Team Members

- 5 Faculty (2 Early-Career), and 4 Professional Staff; 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	Professional Staff
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	Peterson, Toolin, Millay, Lindsay, McKay, Shulman,	Curricular materials and lessons learned are disseminated across the education networks of ME, NH, and VT	Curriculum materials developed and used in the classroom across the region Regular network meetings with teachers to discuss science and

Objective	Project responsible parties	Year 4 Milestones	Milestone Progress
curricular material	Nickerson	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	potential curriculum content Student surveys and classroom assessment of developed curriculum materials are being administered and analyzed for effectiveness
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

PROJECT OUTCOMES

Inter-jurisdictional and multi-institutional research collaborations were a key focus of the NSF EPSCoR RII Track-2 program. The INSPIRES project promoted these collaborations by enabling its participants to work across four integrated research themes that spanned the region. Responses from both the external evaluator and project participant recognized this as a unique strength of the INSPIRES effort as the majority of participants noted new collaborations because of the project (see Evaluation section). Project participants were actively encouraged to work on or across more than one theme or research project, which resulted in several important project outcomes. 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 participation in collaborative research networks. In Year 5, almost half (48%) of the papers published, and almost 25% of the grants awarded were produced by collaborations among researchers from partnering jurisdictions. This is highlighted by a synthesis publication that involved 8 team members from the partnering jurisdictions (i.e., AMC, UMO, UNH, and UVM) describing initial results from a novel line of research on snow refugia in temperate forest canopies (Figure X). Over 44% of the papers published, 39% of the presentations made, and 42% of the grants awarded were led by early career faculty in Year 5.

> *The INSPIRES project was able to achieve all of its objectives and even more during a very difficult time (COVID shutdown). I was particularly impressed by the ability of the leader to bring a very disparate group of people to actually work together to produce really nice interdisciplinary works. This is a very difficult thing to do and INSPIRES was able to do it to produce novel and very useful new knowledge.*
> *Christian Messier,*
> *External Evaluator,*
> *Professor of Forest Ecology,*
> *University of Quebec*

In Year 5, research products included 21 peer-reviewed articles, 8 presentations, 6 data/model/technology products, and 20 proposals (14 funded) (Appendix 1). The Year 5 publications were in top-tier ecological and remote sensing journals, including *American Geophysical Union Earth's Future* (IF=8.7), *Environmental Science & Technology* (IF = 11.6), *Journal of Ecology* (IF = 5.3), *Environmental Research Letters* (IF = 5.8), and *Ecological Indicators* (IF = 7.0). Several of the publications were interjurisdictional (6) that included INSPIRES trainees (3), early-career (12), or women (13) as co-authors. In fact, women-led 39% of the papers published in Year 5, which is consistent with the overall project average of 38%. Overall, INSPIRES has resulted in 137 peer-reviewed publications with the majority (70) being interjurisdictional with either early-career (57), female (52), and/or student involvement (53). Over the course of the project, INSPIRES published 43 unique journals with an average impact factor of 6.7 with a range of 54.3 (minimum = 0.13 and maximum = 54.5). The total number of presentations for the project is relatively low (137), reflecting the lack of regional or national conferences due to the pandemic. However, the Year 5 presentations were primarily by INSPIRES trainees (63%).

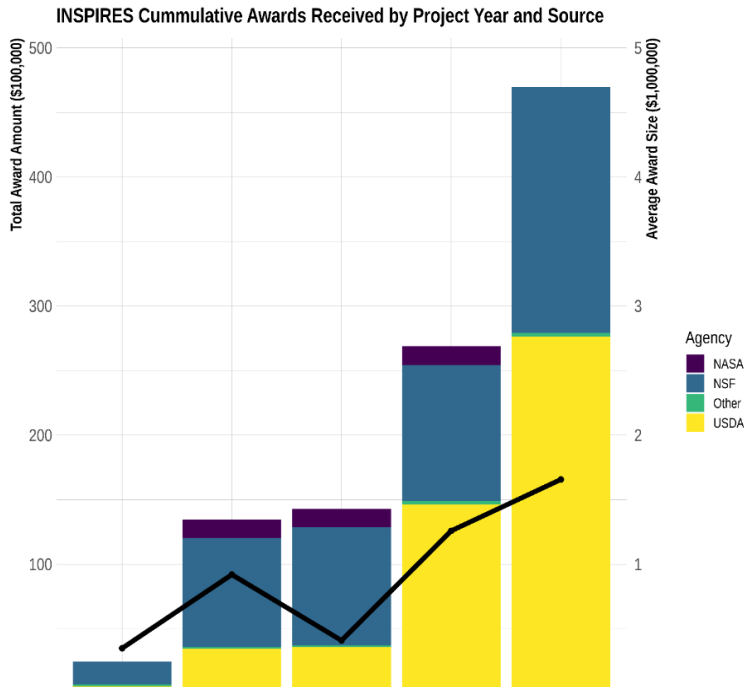


Figure 39. Cumulative awards received by project year and funding source with average annual award size.

The number and size of proposals awarded in Year 5 was much higher than prior years as the focus has continued to shift to larger competitive grants. INSPIRES researchers submitted 20 proposals with $29,775,245 in requested funding. Based on these submissions, 14 projects were awarded ($22,500,036), and five are still pending ($6,896,297). Several Year 5 proposals were led primarily by early-career (7) and women faculty (7) were submitted to various sources including ding NASA, NSF, USDA, and other federal agencies. Fifteen of the awarded proposals were inter-jurisdictional and totaled $28,796,333 in funding. Details on the specific research proposals and Year 5 awards are provided in Table 3.

Table 3. Year 5 Proposals and Funding Status

PI/CO-PIs	Proposal Title	Funding Program	Amount Requested	Status	Amount Awarded
NASA					
Hayes (UMO)/Weiskittel (UMO)	Phase 2 prototype development of a scalable MRV framework that integrates inventory, remote sensing, and landscape modeling to support stakeholder decision-making for carbon in managed forests	Carbon Monitoring Systems	$964,806	Awarded	$964,806
Wei* (UMO)/Hayes (UM)	Promoting habitat diversity in response to climate-driven transformations in managed forest landscapes	Early Career Research Program	$279,539	Pending	$279,539

PI/CO-PIs	Proposal Title	Funding Program	Amount Requested	Status	Amount Awarded
NSF					
Hahmann (UMO)*	Proto-OKN Theme 1: Safe Agricultural Products and Water Graph (SAWGraph): An OKN to Monitor and Trace PFAS and Other Contaminants in the Nation's Food and Water Systems	Innovation and Technology Ecosystems (ITE)	$1,499,735	Awarded	$1,499,735
Weiskittel (UMO)	Enhancing Maine Forest Economy, Sustainability, and Technology (Maine-FOREST) Ecosystem to Accelerate Innovation	EPSCoR E-RISE RII	$7,000,000	Awarded	$7,000,000
USDA					
Adair (UVM)	Relating dynamic soil properties in forested ecosystems to ecological site state and transition models	NRCS	$399,570	Awarded	$399,570
Asbjornsen (UNH)/ Contosta* (UNH)	Promoting Climate-Smart and Sustainable Agriculture in New England through Regionally Adapted Agroforestry Systems	NIFA	$10,000,000	Awarded	$10,000,000
D'Amato (UVM)	Developing forest adaptation strategies to support diverse values and ecosystem services	McIntire-Stennis ARS	$514,751	Awarded	$514,751
Hossain* (AAMU)	Patterns in natural regeneration of shortleaf pine (*Pinus echinata* Mill.) across the southeastern United States facing climate change.	NIFA	$260,590	Awarded	$260,590
Adair * (UVM)	The impacts of cold-air pooling on Northeastern Temperate Forest structure and function	Forest Ecosystem Monitoring Cooperative	$49,852	Awarded	$49,852

PI/CO-PIs	Proposal Title	Funding Program	Amount Requested	Status	Amount Awarded
Burakowski* (UNH)	Feasibility Study to expand Mountain Weather Monitoring System to New England	Natural Resources Conservation Service	$995,114	Awarded	$995,114
Foster (UVM)	Testing the resilience of Mature and Old-Growth Forest carbon capture to canopy disturbance at NEON sites	U.S. Forest Service (Southern Research Station)	$120,000	Awarded	$120,000
Ollinger (UNH)	The impact of climate-smart silviculture on carbon fluxes and wood growth in northeastern U.S. forests.	Northeastern States Research Cooperative (NSRC)	$298,237	Awarded	$298,237
Ollinger (UNH)	Improving Multiscale Tree Species Dynamics in a Forest Landscape Model	Northern Research Station (U.S. Forest Service)	$70,000	Awarded	$70,000
Weiskittel (UMO)	Improved Digital Soil Maps, Ecological Classification, and Assessed Productivity of Maine's Forest	Natural Resources Conservation Service	$300,000	Awarded	$300,000
Granato De Souza (AAMU)/Lemke (AAMU)/Nelson (UMO) [*,+]	Workforce Development in Ecological Remote Sensing and Data Science Through Applied Forest Demographics	NIFA	$600,000	Pending	$600,000
Wei* (UMO)/Hayes (UMO)	Bridging data and decision-making with a comprehensive digital solution for forest carbon analysis	NRCS	$378,912	Declined	$378,912
Other					
Contosta*,[+] (UNH)	Future Forests Meet Future Winter	Schmidt Sciences Foundation	$5,500,000	Pending	$5,500,000

PI/CO-PIs	Proposal Title	Funding Program	Amount Requested	Status	Amount Awarded
Hastings (UNH)	Enhancing Climate Change Research at the Thompson Farm Earth System Observatory through Continuous Monitoring of Canopy Temperature	University of New Hampshire	$27,381	Awarded	$27,381
Total					
Awarded (14)					$22,500,036
Pending (5)					$6,896,297
Declined (1)					$378,912

*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 was a significant challenge created by the ongoing global pandemic. To address this challenge, 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. A particular focus of Year 2 of INSPIRES, given the pandemic, focused on continuing to build cross-theme, inter-jurisdictional collaboration. As a result of these efforts, several 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 led to the integrative and synthetic publications. 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, which was fostered AAMU PI Dawn Lemke spending several weeks in the region to meet with project participants and external stakeholders to better understand potential collaborative opportunities. This resulted in highly successful faculty/student exchanges in Year 4, which included AAMU undergraduate students and faculty traveling to Maine to learn about wireless sensor development and UNH hosting a summer AAMU undergraduate in New Hampshire. Also, several field campaigns were conducted at Paint Rock in Alabama by Maine- and New Hampshire-based INSPIRES researchers. In Year 5, Peter Nelson from Maine again traveled to Alabama to continue shared work on hyperspectral data processing and analysis at Paint Rock, where high-resolution imagery was flown. Analysis of this data that involve AAMU faculty and students, and is now become part of the open-source package available on GitHub and a critical addition to a newly created tree spectral library (https://github.com/nelsopet/Tree_Spectral_Library). These collaborations will continue beyond the INSPIRES project as evidenced by the NSF Integrative Organismal Systems grant (IOS-2222439) recently awarded to AAMU and UNH.

As recognized above, inter-jurisdictional collaborations were constrained during the project's first 3 years. However, the INSPIRES team endeavored to build and sustain collaborations virtually during those years, and when restrictions lifted and safer conditions allowed, they resumed a variety of in-person partnerships, meetings, and fieldwork. Inter-jurisdictional collaborations initiated with the addition of AAMU in Year 3 continued to grow in Year 5, with several faculty and student exchanges occurring. In the last two years of INSPIRES, specific emphasis was placed on collaborative proposals and publications with a list of ideas formulated in Year 4 and presented in our last project annual report. As highlighted above, several large grants have recently been received from various federal funding agencies. Numerous collaborative synthesis publications have been published or are currently underway, including a manuscript (in revision at a top ecology journal) describing initial results from a novel line of research on snow refugia in temperate forest canopies that involves 8 team members from the partnering jurisdictions (i.e., AMC, UMO, UNH, USFS, and UVM; Figure 40). Also, in Year 5, researchers reported 9 interjurisdictional collaborations developed through the project among 38 project participants and collaborators from external institutions (e.g., The Nature Conservancy) or federal agencies (e.g., USDA, US Forest Service). New collaborations ranged from provision of technical support for research in AAMU's Paint Rock Forest site, to development of research on snow refugia in collaboration with The Nature Conservancy and the US Forest Service, to development of a model to predict combined forest ecosystem and landscape succession.

Collaborative Project Coordinator Dr. Emily Uhrig supported several key inter-jurisdictional collaborative opportunities for project participants throughout the project's final year. As noted in the final evaluation report, several researchers commented that the scale of the research projects and regional network of researchers of INSPIRES allowed for interjurisdictional collaborative interactions that were productive and sustainable. For example, UNH and AMC are collaboratively maintaining new sensor transects at the Barlett, NH site Barlett, even after the project. The partnership with AAMU via a supplemental award secured in Year 2 of the project extended the geographic reach of the research initiatives and training opportunities. A key sustaining inter-jurisdictional outcome of INSPIRES is the developed low-cost climate sensors, as they are some of the few non-national weather service sensors that can measure snow. In an exit interview, one researcher explained that some of the INSPIRES work, as well as the PI's advocacy for national appropriations for national snow measures (i.e., $1 million in USDA NRCS funding through appropriations), has been critical in helping the community to better understand how few snow measurements are available. This should further support a key significant outcome of the project for developing a regional sensor network and a new line of collaborative research on snow refugia, which has already resulted in a collaborative publication and proposals in submission and revision looking at snowpack in forests.

Figure 40. INSPIRES researchers engage with stakeholders from Appalachian Mountain Club on a field tour to the sensor site on AMC Woodlands.

Workforce Development

One of the most successful aspects of the INSPIRES project was the number of trainees involved (undergraduates, graduates, and postdocs; Figure 41). Many of the INSPIRES team early career faculty or research scientists are now in permanent science positions (Jane Foster, Research Ecologist, USFS SRS; Melissa Pastore, Research Ecologist, USFS NRS; Andy Ouimette, Ecologist, USFS NRS; Paulina Murray, Holt Research Fellow, Maine TREE), faculty roles (Dave Lutz, Assistant Professor, Colby-Sawyer College) or grad school (Karin Rand, Research Lab Specialist, University of Michigan Biological Station; Colby Bosley-Smith, UM PhD student studying coast spruce dynamics).

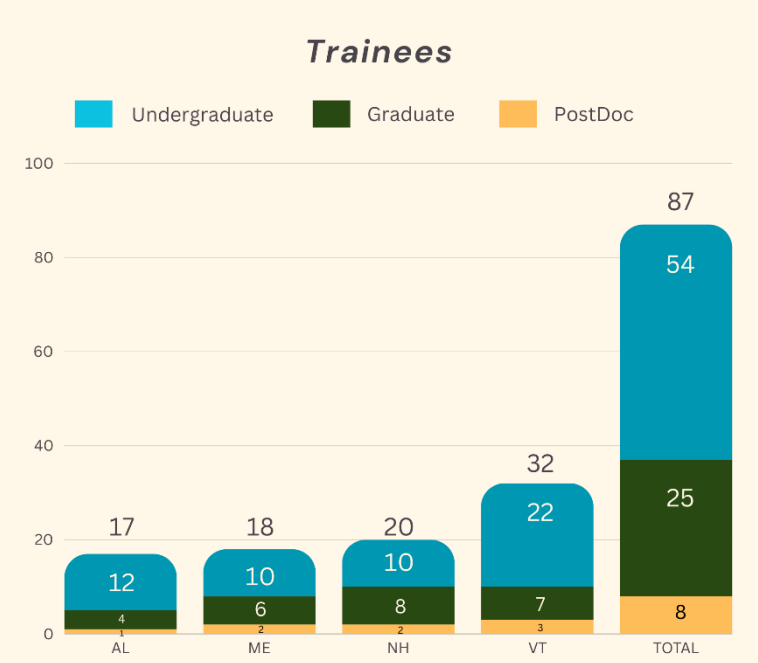


Figure 41. Number of Trainees involved in INSPIRES-related research.

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 collaborative research networks. search 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 collaborative research network 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 several new project participants onboarding, which has helped broaden and diversify participation. In Year 4, INSPIRES enhanced research capacity across the institutions involved by significantly leveraging the investment being made by NSF. In its final year, INSPIRES researchers were active with proposal development and submission. For example, 20 proposals with $29,775,245 in requested funding were submitted in Year 5. Based on these submissions, 14 projects were awarded, and five are still pending ($6,896,297). These efforts have resulted in $22,500,036 in available new funding, including 3 inter-jurisdictional projects that will help sustain INSPIRES collaborations. In total, INSPIRES researchers submitted grant requests totaling $116.7 million and secured nearly $50 million

in funding over the project's five years, which represents a ratio of 8.2 for funding generated to the amount of funding awarded by the NSF EPSCoR RII Track-2 grant. Most awards were secured from federal agencies, including $25.6 million (53% of the total funding secured) from the USDA, $18.9 million (39% of the total) from the NSF and $1.4 million (3% of the total) from NASA. As evidenced by these numbers, INSPIRES researchers have been 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.

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), and a Collaborative Project Coordinator (Emily Uhrig). During Year 5, the University of Maine continued to lead communications and outreach efforts and provide direct support to several graduate students on the projects. Kingsley Wiafe-Kwakye defened his PhD in July, while Mersedeh Naji continued her PhD program with projects focused on wireless sensor technology. INSPIRES PI Weiskittel was awarded a $7 million NSF RII E-RISE grant, which builds on numerous key outcomes from INSPIRES. In particular, INSPIRES research continues to be prominently featured in the Climate Change Science and Practice webinar/field tour series. Throughout the series, research and outcomes from INSPIRES work was showcased, particularly long-term monitoring work for climate adaptation and healthy forests. The collaboration with AMC to maintain and expand their environmental sensor networks will continue after the completion of INSPIRES. Going forward, colleagues at AMC and UMaine-Farmington will assist with maintenance/download work with sensors in expectation of using the data to support their own regional lakes or phenology research and monitoring. Many of the UMaine INSPIRES team are building off the momentum and prior investment from NSF in INSPIRES via the USDA Sustainable Agricultural Systems grant, *Promoting Economic Resilience and Sustainability of the Eastern U.S. Forests (PERSEUS)*, a collaboration with Purdue University and University of Georgia. PERSEUS aims to use an integrated transdisciplinary approach to provide scientifically sound

information, outreach, and educational opportunities that will lay the foundation for a long-term paradigm shift in forestry toward data-driven, AI-supported forest management systems that increase both the provision of ecosystem services and operational efficiency. The project encompasses the northern hardwood forest in the northeast, the central hardwood region, and the southern pine and mixed hardwood. Finally, the newly announced E-RISE award from NSF included many INSPIRES team researchers, including Ali Abedi, Dan Hayes, and Salimeh Yasaei Sekeh, which should effectively build upon outcomes from INSPIRES.

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 5, UNH team members focused on finalizing research infrastructure efforts and strengthening their collaboration with AAMU, and developing plans for project continuity beyond the completion of INSPIRES. Over the past year, led by early career faculty, Elizabeth Burakowski and 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 remote sensing techniques and 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.

Co-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 made possible by adding 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, temperature tolerance, and 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.

A key sustaining effort of INSPIRES at UNH is creating and funding the Northeast Snow Survey Feasibility Study (NESS; https://sites.usnh.edu/ness/) through direct collaboration with the US Department of Agriculture, Natural Resources Conservation Service. Through this effort, UNH and numerous external

collaborators will assess the community needs for designing a coordinated network of automated snow and weather measurement stations in the East, like the SNOTEL network in the western US. The ultimate goal of the NESS project is to comprehensively monitor snowpack, weather, and hydrological variables across elevational gradients and mountain ranges in the region so that we can better understand the impacts of climate change on mountain snowfall and runoff, mountain ecology, flood, and avalanche danger, backcountry recreation, and tourism. Since its inception, NESS has conducted a regional survey of partner needs and priorities, held several regional stakeholder events, and drafted numerous technical reports and recommendations for future consideration. The focus on developing a regional environmental monitoring network as a critical priority for INSPIRES and NESS has the potential to realize this vision fully.

Vermont

The team based out of the University of Vermont represents a team of 7 faculty, 2 graduate students and 1 research technician. These participants span 3 academic units within the University of Vermont. Dave Lutz, from Colby-Sawyer College, also remained 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 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 Nulhegan, Corinth, and Second College Grant INSPIRES sites in June and October 2023 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. Considerable effort in Year 5 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. The sensor transects will continue data collection long after INSPIRES concludes. 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 being revised, 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. 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

Figure 42. AAMU students with partners from Oak Ridge at the Paint Rock site.

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 continued to expand in Year 5. This third year of collaboration has developed several long-lasting collaborations. 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. 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 5. Dr. Lemke has continued to build new and strategic partnerships (Figure 42) 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 three collaborative proposals with INSPIRES faculty. Graduate students have been involved with INSPIRES graduate meetings, 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. A team of undergraduate student technicians completed fieldwork at Paint Rock this summer. This included hosting visiting students from UNH on a joint NSF project and a second acquisition of hyperspectral imagery by Maine's Dr. Peter Nelson (Figure 43). These collaborations are planned to continue after the completion of INSPIRES.

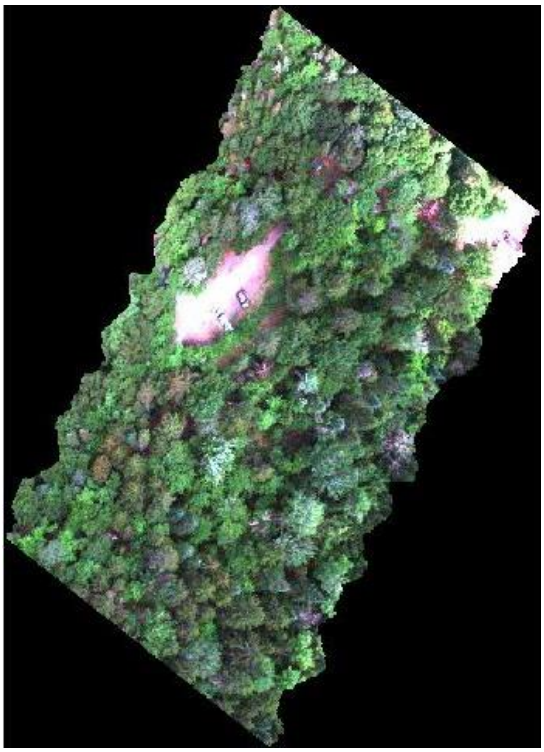


Figure 43. Tile of high-resolution digital imagery at the Paint Rock long-term field site in northern Alabama. Collected by INSPIRES team member Peter Nelson and used to support collaboration with AAMU.

Overall Project Integration

Project integration remained a high priority in the final year of the project. The success of these project integration efforts, bolstered each year by specific initiatives such as cross-theme meeting, increased involvement and interactions between students, collaborative publications, stakeholder engagement, and strong involvement of project participants across all research themes as well as jurisdictions, are a clear successful outcome of the INSPIRES project that will ensure future sustainability of this effort. The overall project integration outcomes of the INSPIRES project were marked by significant achievements in fostering cross-disciplinary and multi-jurisdictional collaboration. The project successfully brought together diverse teams from multiple institutions to address complex forest ecosystem challenges. This integration was particularly evident in the project's ability to merge expertise from different fields, such as data science, ecology, engineering, and environmental informatics, into cohesive research efforts.

One of the standout outcomes was the development of novel, low-cost sensors and the application of artificial intelligence to interpret environmental data, which were made possible through the collaboration of multiple research themes within INSPIRES. The integration of these themes not only advanced scientific knowledge but also created practical tools for monitoring and managing forest ecosystems. Additionally, the project's emphasis on cross-disciplinary work led to significant research outputs, including numerous peer-reviewed publications that highlighted the innovative approaches developed through these collaborations. Moreover, the project's integration extended beyond academia, involving partnerships with non-profit organizations, educators, and industry stakeholders. This broader integration ensured that the research conducted had real-world applications and could influence policy and management practices. The INSPIRES project also achieved integration in its educational initiatives, linking research activities with workforce development and K-12 education, thereby creating a pipeline of future scientists and informed citizens. Overall, the project's success in integrating various disciplines, institutions, and stakeholders not only enhanced its research outcomes but also established a strong foundation for sustained collaborative efforts in the future. The evaluation highlighted these integration outcomes as a key strength of the INSPIRES project, demonstrating its ability to bring together diverse elements to address complex environmental challenges in a holistic and impactful manner.

BROADENING PARTICIPATION

Team Demographics

An overall summary of current team member composition across the four jurisdictions is provided in Table 4, while a detailed list of all personnel is provided in Appendix 2. 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 5). Including AAMU in the project helped to diversify the team where 54% of their participants are an underrepresented minority. Since the project started, 3, 6, and 8 post-doc, undergraduate, and graduate trainees have graduated.

Table 4. Summary of INSPIRES Team Personnel by Role and Justification

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 5. 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/	86% F;	100% F;	100% F;	100% F;	92% F;

Role	Jurisdiction				Total
	Maine	**New Hampshire**	**Vermont**	**Alabama**	
Support)	0% URM	0% URM	0% URM	33% URM	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 key goal for INSPIRES was to encourage 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 enhanced research and analytical skills for team members. There have been multiple opportunities for early career faculty, particularly helping to lead or co-lead within the specific research themes. Currently, there are 16 early-career faculty in INSPIRES with a nearly equal representation in gender. The four research themes were all led or co-led by early-career faculty with direct support from senior faculty members, which helped build leadership and organizational skills. Support for undergraduate and graduate students, equipment, and travel support were provided to early-career faculty members. This has also had direct benefits for the early-career faculty members. For example, early-career faculty members and their students presented at several national conferences, which highlighted the outcomes of their research and expanded their professional networks.

At each institution, the Core Leadership Team made a strong effort to conduct regular check-ins with team members, particularly early-career faculty, to ensure they had 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. Early-career faculty on this project at each institution successfully leveraged their INSPIRES work through additional seed grants and opportunities, ensuring the necessary resources to build and sustain their productivity. For example, of the 25 faculty researchers who were classified as “early career” by the NSF (i.e., Assistant Professor or equivalent at the time of the proposal submission), several were promoted as faculty or entered into permanent positions with non-academic organizations during the award

period. David Lutz (Colby-Sawyer) moved from a lecturer to a tenure-track position. Carol Adair (UVM) grew into her position and made a case for full professor. Andy Ouimette (UNH), a soft-money funded researcher landed a permanent government position. Two postdocs secured permanent forest service positions: one developed a unique line of inquiry through INSPIRES that allowed them to become competitive and offer a unique skills set aligned with government research priorities.

Collaborations and team science approaches benefited early career researchers, albeit unevenly and in different ways. As reported in 2023, COVID-related disruptions and the focus and priorities of researchers with research appointments, versus tenure-track appointments, impacted the extent to which researchers accessed and benefited from project resources. Overall, INSPIRES positively impacted the professional development of early career researchers during a difficult period for most project participants.

Development/Recruitment of Diverse Students

In Year 5, there were 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 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 worked 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 been able interact across institutions and jurisdictions in Year 5. Additional opportunities were provided for students to present findings during all-team and theme virtual meetings. Graduate students were encouraged to give flash talks about their research at the external review panel assessment and the all-team meetings, and to 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. The pandemic, which was particularly onerous for grad students and researchers throughout the first three years of the project, had lingering effects due to limited in-person support and high isolation. The Core Leadership Team recognized these challenges and strived to work hard to resolve hardships for both mentors and mentees. Efforts in Year 5 focused on refining MEE materials and ensuring students have every opportunity to gain new professional experiences. In July 2024, students from New Hampshire traveled to Alabama and learned about ongoing field data collection efforts happening as part of INSPIRES, which provided invaluable in-person time to connect with fellow students and mentors across the jurisdictions. Overall, the students on INSPIRES were highly engaged and enthusiastic about the project, particularly the involvement of underrepresented from AAMU.

Leadership and Governance

The leadership and governance efforts by the Core Leadership Team (CLT) have been detailed in prior INSPIRES annual reports. In Year 5, the CLT continued to engage on various fronts but felt the ongoing impacts of the global pandemic have made things challenging for large efforts like INSPIRES. Also, in the past year, the CLT worked to identify key project strengths and potential opportunities for the INSPIRES project and project members. They supported interactions and collaboration among applied ecologists and data science experts; integration of education and outreach efforts into specific activities and objectives to enhance inter-

institutional collaboration; supported the development of an integrated entity to produce convergent outcomes and products (e.g., the Digital Forest Framework); and bolstered integration and collaboration with AAMU.

Overall, the leadership and governance of the INSPIRES project were marked by several key strengths, contributing to the project's overall success in achieving its ambitious goals (Table 6). The CLT effectively coordinated a complex, multi-institutional collaboration, ensuring that the project remained on track despite the considerable challenges posed by the COVID-19 pandemic. A significant achievement of the CLT was their ability to foster a strong collaborative spirit across the participating institutions. This was particularly important given the interdisciplinary nature of the project, which required seamless coordination among researchers from diverse fields such as ecology, data science, and engineering. A notable aspect of the project's governance was the CLT's commitment to empowering early career researchers. By providing these researchers with intellectual freedom and robust support, the leadership team enabled them to make significant contributions to the project while also advancing their careers. Several early career participants secured new roles within their fields as a direct result of their involvement in INSPIRES, highlighting the project's success in building regional STEM capacity. The CLT's emphasis on mentorship and professional development was highly appreciated by participants and played a crucial role in fostering a productive and motivated research environment.

Despite these successes, the CLT leadership continued to face challenges related to the administrative demands of managing such a large-scale, multi-institutional initiative. The need to leverage existing resources from each jurisdiction's EPSCoR office and other sources underscored the considerable administrative burden placed on the CLT. While the project team managed these challenges effectively, future projects of similar scale might benefit from additional dedicated administrative support to further ease this burden. Additionally, the external evaluators also noted some variability in engagement levels across the different jurisdictions involved in the project, particularly with UNH. This variation could be attributed to the different thematic focuses during the project's various phases, but it suggests that more consistent engagement strategies might be beneficial for ensuring sustained collaboration across all partner institutions.

Moving forward, it is recommended that the successful management practices employed by the INSPIRES leadership be documented and shared as best practices for similar NSF efforts. These strategies could serve as a model for other large-scale, multi-institutional projects and are currently being leveraged by PI Weiskittel's new e-RISE award. Additionally, to sustain the momentum of the successful collaborations established during INSPIRES, the leadership team should pursue further funding opportunities and explore new partnerships, particularly with institutions like AAMU. Finally, future projects should maintain consistent engagement across all jurisdictions throughout the project's lifecycle, potentially through regular thematic workshops or check-ins, to ensure that all partners remain actively involved and contribute to the project's goals. Overall, the leadership and governance of INSPIRES were highly effective, laying a strong foundation for continued success in future efforts.

Table 6. INSPIRES Benchmarks and Accomplishments

Program Area	Output/Outcome/ Impact Indicators	Project Benchmarks	Year 4 Accomplishments
Research Capacity	Interdisciplinary and convergent research collaborations; post-docs recruited; graduate students enrolled; new regional Complex Systems Research Consortium	12 post-docs and 20 graduate students, 10 research assistants, strategic plan presented to internal/external advisory boards	6 post-docs, 30 graduate students, 8 research assistants; Strategic plan updated & refined, inclusion of AAMU; Potential publications and proposals identified; Formation of Northeast Snow Survey Feasibility study
Research Productivity	Peer-reviewed publications; submitted (awarded) grants (by funding source); patents, licenses and commercialization opportunities; amount and resolution of data generated	25 publications (50% multi- institution), 50 presentations, 20 proposals submitted (50% multi-institution), 5 cross-jurisdictional grants funded, 20 data products publicly available (25% being integrated)	137 publications (70 multi-institution), 137 presentations (26 multi-institution, 30 student-led), 99 awards (40 multi-institutional), 12 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)	40 undergraduates involved, 20 undergraduate & graduate students enrolled in certificate programs, 5 training events, 35% of project participants from underrepresented groups, 1 inter-institutional graduate course	Undergraduates involved (30), 47% female trainees, and trainee participation from underrepresented backgrounds (14), collaborative project coordinator supported, monthly student meetings, implementation of a scientific technical writing online module; Faculty and student exchanges with AAMU

Program Area	Output/Outcome/ Impact Indicators	Project Benchmarks	Year 4 Accomplishments
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	20 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); 20 high school science teachers actively involved in Maine (11) and Vermont (9); Summer hands-on teacher's workshops in 2022 and 2023; Project participants presented and collaborated with K-12 educators on a regular basis; A 3-credit INSPIRES Teacher Professional Learning graduate course offered by UVM
Stakeholder Engagement	Collaborations and partnerships with local organizations, industry, and other academic institutions; benefits to participants in collaborative networks	20 involved partnerships, 10 outreach events, 10 media features, 100 event participants	10 new partnerships created; 25 outreach events across the primary jurisdictions; 20 recent media features; 250 event participants; Active social media presence; Connections to Maine tribal councils strengthened with collaboration planned

EVALUATION Year 5

Overview

The external assessment and evaluation of the INSPIRES project highlighted several notable achievements and outcomes (see Appendix 4 for the detailed report). The evaluators felt the project demonstrated a high level of productivity, successfully meeting NSF-determined objectives and securing follow-on funding. Despite the challenges posed by the COVID-19 pandemic, the evaluators noted that INSPIRES managed to cultivate a strong collaborative spirit across the participating institutions. The project was particularly lauded for its innovative research contributions, such as developing low-cost sensors, using artificial intelligence for data interpretation, and exploring cold air pooling and its implications for biodiversity in northern forest ecosystems. These efforts resulted in a significant number of peer-reviewed publications and positioned INSPIRES as a leader in advancing interdisciplinary research in ecosystem science. The project also excelled in fostering cross-disciplinary and interjurisdictional collaboration, engaging a diverse team of researchers, educators, and non-profit organizations. This collaboration was not only instrumental in driving research outcomes but also in building regional STEM capacity. A key focus of INSPIRES was on education and workforce development, where it made substantial contributions by supporting early career researchers and providing them with opportunities for professional growth. Many of these researchers secured permanent positions within their fields, further enhancing the project's long-term impact on regional scientific capacity. Additionally, the project's efforts in education extended to K-12 educators, with training programs that connected classroom learning with cutting-edge research. The assessment recognized these achievements as critical to the project's success and recommended strategies to sustain and further expand the impact of INSPIRES in the future.

For future efforts, the evaluation provided several key recommendations aimed at sustaining and enhancing the impact of the INSPIRES project. One of the primary recommendations was to deepen the integration of the project's diverse research themes, as this would elevate the overall scientific impact and foster more comprehensive and convergent research outputs. Developing cross-theme publications and creating forums for researchers to explore interdisciplinary connections were suggested as ways to achieve this integration. The evaluation also emphasized the importance of sustaining the momentum built by the project through additional funding opportunities. Specifically, expanding collaborations with institutions such as Alabama A&M University was identified as a critical step in maintaining the cross-jurisdictional partnerships that have been central to INSPIRES' success. Another key recommendation was to continue and enhance communication efforts to ensure that the significant research findings, particularly in areas like cold air pooling, are effectively disseminated and applied in practical contexts. This includes working closely with industry partners, policymakers, and other stakeholders to translate research outcomes into actionable strategies that can inform policy and management practices. Finally, the evaluation suggested that future projects should build on INSPIRES' successful education and workforce development initiatives by continuing to support early career researchers and integrating their work into broader project goals. This could involve offering additional mentorship, professional development opportunities, and platforms for early career researchers to showcase the significance and impact of their work. By implementing these recommendations, future efforts can build on the successes of INSPIRES and further contribute to the resilience and sustainability of forest ecosystems and the communities that depend on them.

PROGRESS ON SPECIFIC PROGRAM ELEMENTS

Committees & Subcommittees

INSPIRES had three internal committees and one advisory board. The committees were Mentoring, Education, and Engagement (MEE; led by Co-PI D'Amato), Collaborative Research Committee (CRC; led by Co-PI Ollinger). and Data Sharing Subcommittee (DSS; Co-led by UNH's Mary Martin and UMO's Leo Edmiston-Cyr), while the project advisory board was the Inter-jurisdictional Advisory Board (IAB). The MEE provided guidelines for effective collaboration for student mentors and mentees, which were regularly updated and revised throughout the project based on input from team members and the interviews conducted by the external evaluator. The MEE also provided students with the space to openly discuss challenges they faced, network with fellow students, and hear from the other INSPIRES team members about their research and professional development, led by INSPIRES collaborative coordinator Dr. Emily Uhrig. MEE was especially important during the highest impact years of the pandemic, which was particularly challenging for graduate students starting new programs. MEE played a vital role in keeping the students engaged and helping to support them. The CRC met regularly throughout the course of the project to discuss cross-theme and inter-jurisdictional research collaborations with the aim of project continuity. This committee led to the creation, implementation, and refinement of InLeaf (https://inleaf.inspires.acg.maine.edu/), which is an online platform for geospatial data sharing and visualization. InLeaf has been refined, updated, and expanded by INSPIRES team member Leo Edmiston-Cyr, which will remain available online after the project's completion. The CRC also identified key regional research infrastructure needs, particularly environmental sensor networks, which led to the Northeast Snow Survey Feasibility Study (NESS) described above. The DSS committee was a cross-theme/cross-institutional group that finalized and updated a concise document that would provide a foundational data sharing implementation plan in Year 3, which had active participation from across the different themes. Throughout the project, the DSS maintained the necessary cyberinfrastructure for effective data sharing and provided additional data standards as well as templates to maintain consistency across themes, which helped to support the cross- theme, multi-jurisdictional nature of the project. These data sharing templates were also used 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 was developed to further simplify the process. In Year 5, the DSS worked with several INSPIRES researchers to prepare and upload their data to the Environmental Data Initiative's online repository, which resulted in 6 new data publications. Even after project completion, the DSS plans to continue to support INSPIRES team members to provide data via InLeaf and EDI. Finally, the IAB was formed in Year 2, formally met in Year 3 (August 2021), and received email updates in Years 4 & 5. The IAB consisted 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), former Dean of Rubenstein School of Environment and Natural Resources; and Arne Bomblies, State Director of Vermont EPSCoR.

Collaborative Research Development

INSPIRES was a relatively large multi-jurisdictional, multi-disciplinary effort, with over 80 team members across six academic institutions at its peak. Over the project, INSPIRES focused on team building to organize the project effectively to produce optimum, synergistic outcomes over the long-term, particularly in the face of a global pandemic. Despite pandemic-imposed difficulties, the CLT 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. Online documents and resources to help to foster team collaboration, while the team website, shared project calendar, project jargon or acronym dictionary, summary of project resources, anonymous feedback form, social media sites, and YouTube channel highlight a multitude of team successes. The project implementation plan developed in Year 1 provided the necessary structure, governance, strategic assessment, and plans for research, communications, and evaluation, which were updated and refined over the years to guide strategic project activities. A major success in Year 2 was the development and implementation of a detailed data sharing implementation plan. In Year 3, collaborative research was enhanced by the addition of collaborative project coordinator Dr. Emily Uhrig, who helped to facilitate synergistic connections, particularly with our team members at AAMU. Year 4 continued to refine these efforts and led to strategic thinking focused project wind-down and research sustainability. Year 5 focused on project synthesis and sustainability with numerous collaborative proposals submitted and awarded, while many of the numerous outcomes from INSPIRES including the project governance, tools (e.g., InLeaf), sensors, and collaborations will live beyond the effort. Overall, INSPIRES collaborative research development was facilitated by identifying key topics that resonated across themes. Some of the most important key topics have been team collaboration platforms, knowledge to action, and K-12 education. In particular, the online tool InLeaf, which allows researchers to openly share and visualize data from INSPIRES across the involved themes and jurisdictions, and the work on the Digital Forest online platform will continue and be expanded beyond the region.

KEY PROJECT OUTCOMES

The key project outcomes of the INSPIRES project were:

1. **Innovative Research and Technological Advances**: The project developed novel low-cost sensors and applied artificial intelligence to environmental data, leading to significant advancements in monitoring and understanding forest ecosystems. These technological innovations resulted in numerous peer-reviewed publications and set new standards for data-driven environmental research.

2. **Cross-Disciplinary and Cross-Jurisdictional Collaboration**: INSPIRES successfully integrated expertise from multiple disciplines and institutions, fostering strong collaborations across the University of Maine, University of New Hampshire, University of Vermont, and Alabama A&M University. This collaboration enhanced the quality and scope of the research and built lasting partnerships that extend beyond the project's duration.

3. **Educational and Workforce Development**: The project made substantial contributions to education by supporting early career researchers, providing them with mentorship and professional development opportunities, and engaging K-12 educators in research activities. This led to the successful career placement of many early career participants and strengthened the regional STEM workforce.

4. **Real-World Application and Policy Influence**: The research findings, particularly those related to cold air pooling and biodiversity, were translated into actionable insights for land management and policymaking. The project's collaboration with industry and non-profit organizations ensured that the scientific outcomes had practical applications, influencing forest management practices and environmental policy.

5. **Sustainability and Long-Term Impact**: INSPIRES laid a strong foundation for sustained research and collaboration, with recommendations for future funding and continued partnerships. The project's outcomes are poised to have a lasting impact on forest ecosystem research and management, as well as on regional STEM capacity.

APPENDICES

Appendix 1. Products Year 5

Appendix 2. Year 5 Team Roster

Appendix 3. Communications and Resources

Appendix 4. External Evaluation Report Survey

Appendix 1. Products Year 5

Journal or Juried Conference Papers – Published (17; INSPIRES team members in **bold)**

Adam Daigneault, **Erin Simons-Legaard, Aaron Weiskittel**. 2024. Tradeoffs and synergies of optimized management for maximizing carbon sequestration across complex landscapes and diverse ecosystem services. doi.org/10.1016/j.forpol.2024.103178

Alexandra Contosta, Kyle Arndt, Helen Baulch, Nora Casson, Adrian Harpold, Toni Lyn Morelli, Alexej Siren, Pamela Templer. Threshold changes in winter temperature and precipitation drive threshold responses across nine global climate zones and associated biomes. doi.org/10.1146/annurev-ecolsys-110421-102101

Bina Thapa, P.T. Wolter, Brian Sturtevant, **Jane R. Foster,** P. A. Townsend. 2023. Linking frass and insect phenology to optimize annual forest defoliation estimation. doi.org/10.1016/j.mex.2023.102075

Dennis Heejoon Choi, Elizabeth A. LaRue, Jeff W. Atkins, **Jane R. Foster,** Jaclyn Hatala Matthes, Robert T. Fahey, Bina Thapa, Songlin Fei, Brady S. Hardiman**.** 2023. Short-term effects of moderate severity disturbances on forest canopy structure. doi.org/10.1111/1365-2745.14145

Ethan Crockett, Jeff Atkins, Qinfeng Guo, Ge Sun, Kevin Potter, **Scott Ollinger,** Carlos Silva, Hao Tang, Christopher Woodall, Justin Holgerson, Jingfeng Xiao**.** 2023. Structural and species diversity explain aboveground carbon storage in forests across the United States: Evidence from GEDI and forest inventory data. doi.org/10.1016/j.rse.2023.113703

Jianheng Zhao, Adam Daigneault, **Aaron Weiskittel, Xinyan Wei.** 2023. Climate and socioeconomic impacts on Maine's forests under alternative future pathways. doi.org/10.1016/j.ecolecon.2023.107979

Lisa N. Scott, Sean M. Smith, John S. Gunn, Marek Petrick, Mark J. Ducey, Thomas JS. Buchholz, Ethan P. Belair**.** 2023. Salvage decision-making based on carbon following an eastern spruce budworm outbreak. doi.org/10.3389/ffgc.2023.1062176

Madan Ravi Ganesh, Dawsin Blanchard, Jason J. Corso, **Salimeh Yasaei Sekeh**. 2024. Slimming Neural Networks Using Adaptive Connectivity Scores. doi.org/10.1109/tnnls.2022.3198580

Mallory L. Barnes, Quan Zhang, Soctt M. Robeson, Lily Young, **Elizabeth Burakowski,** A. Christopher Oishi, Paul C. Stoy, Gaby Katur, Kimberly A. Novick**.** 2024. A Century of Reforestation Reduced Anthropogenic Warming in the Eastern United States. doi.org/10.1029/2023ef003663

Melissa A. Pastore, Aimee Classen, Marie English, Serita Frey, Melissa A. Knorr**, Karin Rand, E. Carol Adair**. 2023. Soil microbial legacies influence freeze-thaw responses of soil. besjournals.onlinelibrary.wiley.com/doi/full/10.1111/1365-2435.14273

Melissa Pastore, Aimee Classen, Anthony D'Amato, Jane R. Foster, E. Carol Adair. 2022. Cold air pools as 'ecosystem function preserves' in the face of climate change. esajournals.onlinelibrary.wiley.com/doi/abs/10.1002/ecy.3717

Melissa Pastore, Aimee Classen, Anthony D'Amato, Marie English, Karin Rand, Jane R. Foster, E. Carol Adair. 2024. Frequent and strong cold-air pooling drives temperate forest composition. doi.org/10.1002/ece3.11126

Peter R. Nelson, Kenneth Bundy, Kevaughn Smith, Matt Macander, Catherine Chan. 2024. Predicting Plants in the Wild: Mapping Arctic and boreal Plants with UAS-based Visible and Near Infrared Reflectance Spectra. doi.org/10.1016/j.jag.2024.104156

Samuel Roy, Xinyuan Wei, Aaron Weiskittel, Daniel Hayes, Peter Nelson, Alexandra R. Contosta. 2024. Influence of climate zone shifts on forest ecosystems in northeastern United States and maritime Canada. doi.org/10.1016/j.ecolind.2024.111921

Xinyuan Wei, Daniel J. Hayes, David E. Butman, Junyu Qi, Daniel M. Ricciuto, Xiaojuan Yang. 2024. Modeling exports of dissolved organic carbon from landscapes: A review of challenges and opportunities. doi.org/10.1088/1748-9326/ad3cf8

Xinyuan Wei, Daniel J. Hayes, Denghui Li, David E Butman, Robert J.W. Brewin. 2024. Fates of Terrigenous Dissolved Organic Carbon in the Gulf of Maine. doi.org/10.1021/acs.est.3c08218

Xinyuan Wei, Jianheng Zhao, Daniel J. Hayes, Adam Daigneault, He Zhu. 2023. A life cycle and product type based estimator for quantifying the carbon stored in wood products. doi.org/10.1186/s13021-022-00220-y

Journal or Juried Conference Papers – In Press or Under Review (7)

Christina Siddons, Mitchell Bruce, Mia Callahan, **Sara Lindsay, Laura Millay, Susan McKay,** Eizabeth Muncey, Emilie Oesterlin, **Marina Van der Eb**. Integrating computer science into middle school science instruction: assessing barriers and opportunities across diverse school districts.

E. Carol Adair, Anthony D'Amato, Shawn Fraver, **Paulina Murray.** Impacts of Extreme Precipitation Events on Leaf Litter and Wood Decomposition Rates.

Elizabeth Burakowski, Alexandra Contosta, Anthony D'Amato, David Lutz, Sarah Nelson, Melissa Pastore, Grace Smith, Aaron Weiskittel, E. Carol Adair, Marie E. English. Snow refugia: Managing temperate forest canopies to maintain winter conditions.

Kaitlyn Baillargeon, John Hastings, Scott Ollinger, Adam Daigneault. Biodiversity does not drive patterns of primary productivity in temperate forests of the northeastern United States.

Kasey Legaard, Aaron Weiskittel. Declining conifer productivity will drive future forest dynamics as climate changes in northern New England.

Kelsey Davis, Susan McKay, Franziska Peterson, Christina Siddons, Regina Toolin, Marina Van der Eb, Adam Daigneault**, Xinyuan Wei.** Education Researchers as Negotiators: Leveraging Expertise across Teachers and Scientists to Implement Authentic Data Investigations in Grade 7-12 Classrooms.

Scott Ollinger, Zaixing Zhoupnetr. An R package for the PnET family of forest ecosystem models.

Journal Papers – In Preparation (2)

Jane Foster, Scott Ollinger, Zaixing Zhou. Integrating nitrogen and carbon cycling into LANDIS-II/PnET-Succession to improve forest landscape modeling: Methods and sensitivity analyses

Mersedeh Najishababahang, Mallory L. Barnes, Gaby Katul, Kimberly A. Novick, A. Christopher Oishi, Scott M. Robeson, Paul C. Stoy. A Review of Electromagnetic-Wave Propagation in Forested Areas for Wireless Sensor Network Power Optimization.

Conference Presentation/Paper/Poster (11).

Alexandra Contosta. Exploring the impacts of changing winters and shifting seasonality on forest carbon and water dynamics. 34th Annual Harvard Forest Ecology Symposium, March 19, 2024.

E. Carol Adair, Aimee Classen, Anthony D'Amato, Marie English, David King, David Lutz, **Sarah Nelson, Melissa Pastore, Karin Rand**. Climatology of cold-air pooling for montane watersheds and forests of the Northeastern US from MODIS data. Alabama Academy of Science Oral Presentation-2023.pdf

Franziska Peterson, Regina Toolin, Christina Siddons, Sara Lindsay, Susan McKay, Marina Van der Eb. 2023.Engaging Teachers, Education Researchers, and Scientists in Authentic Investigations with Forestry Data. Proceedings of the 54th annual meeting of the New England Educational Research Organization (NEERO) Conference, January 31.

Jack Hastings. Shedding (near infrared) light on our ability to remotely estimate canopy nitrogen concentration. 34th Annual Harvard Forest Ecology Symposium, March 19, 2024.

Jane Foster, Melissa Pastore, E. Carol Adair, Karin Rand, Marie English, Aimee Classen, Anthony D'Amato. Poster. Below-canopy Temperature Inversions More Common and Persistent in Temperate Forests Than Land Surface Temperatures Suggest. American Geophyscial Union, San Francisco, CA, December 11-15, 2023. agu.confex.com/agu/fm23/meetingapp.cgi/Paper/1419151

John Dionis, John Hastings, Scott Ollinger. Can Leaf-level Spectral Indices Detect Sapling Water Stress in a Greenhouse Droughting Experiment? Purdue Institute for Digital Forestry: February 24, 2024.

Kate Beard-Tisdale, Torsten Hahmann, Kingsley Wiafe-Kwakye. Growing a Digital Forest: An Ontology-Based Approach to Analyzing Spatio-Temporal Data for Forest-Environment Interactions. Proceedings for Computer Science Workshops. efaidnbmnnnibpcajpcglclefindmkaj/https://ceur-ws.org/Vol-3637/paper40.pdf

Keith Krause, **Jack Hastings, Scott Ollinger**, Jan A. van Aardt. Estimating the Number of Scattering Events that Contribute to the Hyperspectral Reflectance of a Forest Canopy. Estimating the Number of Scattering Events that Contribute to the Hyperspectral Reflectance of a Forest Canopy. American Geophysical Union, San Francisco, CA, December 11-15, 2023. agu.confex.com/agu/fm23/meetingapp.cgi/Paper/1359365

Melissa Pastore, Aimee Classen, Anthony D'Amato, Marie English, Jane R. Foster, E. Carol Adair, Karin Rand. Frequent and Strong Cold-Air Pooling Linked to Temperate Forest Composition. American Geophysical Union, San Francisco, CA, December 11-15, 2023.

Mersedeh Najishabahang , Ali Abedi. Power Optimized Near-Ground Radio Frequency Sensor Systems for Soil Sensing. 2024. The 12th Annual IEEE International Conference on Wireless for Space and Extreme Environments (WISEE 2024), December 16 to 18, Daytona Beach, FL, USA.

Shaik Hossain. Growth-drought relationships of two southern pine species in northern Alabama. Alabama A&M University Stem Day Annual Meeting 2023.

Dissertation/Thesis (3)

Emily Landry. 2023. Changing Long-Term Spatial Climate Patterns of the Northeastern U.S. MSc thesis, University of New Hampshire.

Kingsley Wiafe-Kwakye. 2024. Development of an Ontology-Based Approach to Spatio-Temporal Data Analysis for Forest-Environment Interactions. PhD thesis, University of Maine.

Paulina Murray. 2023. Exploring the biotic and abiotic drivers of leaf litter and wood decomposition in response to changing climates and associated adaptive management regimes. MSc thesis, University of Vermont.

Database/Datasets/Models/Technology Products (7)

Kate Beard-Tisdale, Torsten Hahmann, Kingsley Wiafe-Kwakye. Preferences for Environments Ontology (PrefEnvO). theskailab.github.io/PrefEnvO/prefenvo.html

Kate Beard-Tisdale, Torsten Hahmann, Kingsley Wiafe-Kwakye. Spatial and Temporal Aggregate Data (STAD) Ontology Design Pattern. theskailab.github.io/STAD/stad.html

Kaitlyn Baillargeon, Scott Ollinger. Estimates of productivity and multiple measures of biodiversity at Bartlett and Hubbard Brook Experimental Forests. doi.org/10.6073/pasta/e7ab901abda706eb5016ae9c8e08533a

Kaitlyn Baillargeon, John Hastings, Scott Ollinger, Andrew Ouimette et al.. Leaf temperature of northeastern US tree species. doi.org/10.6073/pasta/964891a1931f6b562ffa8ce538f29b7f

Alexandra Contosta, Apryl Perry, Serita Frey. New Hampshire Soil Sensor Network: Air Temperature, Soil Temperature, Soil Water Content, and Soil Electrical Conductivity, 2012-ongoing. doi.org/10.6073/pasta/9f31b023820f207979e9c07275d0a84e

Kaitlyn Baillargeon, Andrew Ouimette, John Hastings, Rebecca Sanders-DeMott, Scott Ollinger. Regional and local variation in chemical, structural, and physical leaf traits for tree species in the northeastern United States. doi.org/10.6073/pasta/067108e9983d30d9149c14fc649f75c1

John Hastings, Scott Ollinger, Andrew Ouimette. Thompson Farm Ameriflux data. ameriflux.lbl.gov/download-log/BASE/US-TFF/

UMS Advanced Computing Group (ACG) Support

ACG High Power Computing (HPC) and/or Cloud Resources Uses

Peter Nelson, Ken Bundy: Machine Learning classification of hyperspectral images. Grid search for hyperparameter tuning on ACG resources for thousands of models, set and run.

Kasey Legaard, Ken Bundy: Tree species and forest composition mapping using Machine Learning on ACG HPC and Cloud systems.

Kasey Legaard, Ken Bundy: Web mapping application that is hosted on an ACG Cloud Virtual Machine.

Salimeh Yasaei-Sekeh: ACG HPC resources were used on our work that focused on deep network compression via information-theoretic measures to trim neurons. In addition, we worked on semantic segmentation of hyperspectral images (HSIs) toward forestry science applications. We used clustering and ensemble techniques to enhance the performance of deep networks for segmentation of HSIs. We showed that our method outperforms baselines on existing benchmarks. Four papers have been published based on this work.

Leo Edmiston-Cyr: INleaf sharing database.

ACG Consulting/Programming

Kasey Legaard: ACG CyberInfrastructure Engineer Larry Whitsel helped develop Machine Learning system to scale Machine Learning methods over large areas to be run in parallel on the ACG HPC cluster.

Kasey Legaard: ACG personnel helped to develop an inverse approach to the parameterization of the LANDIS forest landscape model. Ken Bundy tested some long-running versions of this on the HPC cluster.

ACG Outreach Specialist **Ami Gaspar** helped migrate INSPIRES researchers to Sharepoint at the beginning of the project

Appendix 2. Year 5 Team Roster

Name	Project Role Type	Institution
Aaron Weiskittel	PI	University of Maine
Aimee Classen	Faculty	University of Vermont
Alexandra Contosta	Faculty	University of New Hampshire-Main Campus
Ali Abedi	Co-PI	University of Maine
Anthony D'Amato	Co-PI	University of Vermont
Apryl Perry	Technical Support Staff	University of New Hampshire-Main Campus
Ashley Woods	Undergraduate Student	Alabama A & M University
Austen Johnson	Undergraduate Student	Alabama A & M University
Carol Adair	Faculty	University of Vermont
Cen Chen	Faculty	Alabama A & M University
Colin Warhola	Technical Support Staff	University of Maine
Daniel Hayes	Faculty	University of Maine
David Lutz	Faculty	Colby-Sawyer College
Dawn Lemke	Co-PI	Alabama A & M University
Dedrick Davis	Faculty	Alabama A & M University
Elizabeth Burakowski	Technical Support Staff	University of New Hampshire-Main Campus
Emily Uhrig	Non-technical Support Staff	University of Maine
Erin Simons-Legaard	Faculty	University of Maine
Evan Tenorio	Graduate Student	Alabama A & M University
Franziska Peterson	Faculty	University of Maine
Grace Smith	Technical Support Staff	University of Vermont
Heather McInnis	Evaluator	The Implementation Group
Holland Haverkamp	Graduate Student	University of Maine
Jane Foster	Faculty	University of Vermont
Jane Pettit	Technical Support Staff	University of Maine
John Dionis	Undergraduate Student	University of New Hampshire-Main Campus
John Hastings	Graduate Student	University of New Hampshire-Main Campus
John Hodson	Undergraduate Student	University of Maine
Kaitlyn Baillargeon	Technical Support Staff	University of New Hampshire-Main Campus
Karin Rand	Technical Support Staff	University of Michigan-Ann Arbor
Kasey Legaard	Faculty	University of Maine
Kate Beard-Tisdale	Co-PI	University of Maine
Ken Bundy	Technical Support Staff	University of Maine
Kingsley Wiafe-Kwakye	Graduate Student	University of Maine
Leo Edmiston-Cyr	Technical Support Staff	University of Maine
Leslee Noyes	Non-technical Support Staff	University of Maine

Name	Project Role Type	Institution
Luben Dimov	Faculty	University of Vermont
Marek Petrik	Faculty	University of New Hampshire-Main Campus
Marina Van der Eb	Technical Support Staff	University of Maine
Mark Ducey	Faculty	University of New Hampshire-Main Campus
Mary Martin	Faculty	University of New Hampshire-Main Campus
Meg Fergusson	Non-technical Support Staff	University of Maine
Melissa Pastore	Postdoc	University of Vermont
Mersedeh Najishabahang	Graduate Student	University of Maine
Michelle Gregoire	Non-technical Support Staff	University of Maine
Paulina Murray	Graduate Student	Maine TREE Foundation
Peter Nelson	Faculty	University of Maine
Regina Toolin	Faculty	University of Vermont & State Agricultural College
Salimeh Yasaei Sekeh	Faculty	University of Maine
Samuel Vanderwater	Graduate Student	University of New Hampshire-Main Campus
Sara Lindsay	Faculty	University of Maine
Sarah Nelson	Faculty	appalachian mountain club
Scott Ollinger	Faculty	University of New Hampshire-Main Campus
Shaik Hossain	Faculty	Alabama A & M University
Stefania Marthakis	Non-technical Support Staff	University of Maine
Susan McKay	Faculty	University of Maine
Taylor Petty	Graduate Student	Alabama A & M University
Thayer Whitney	Graduate Student	University of Maine
Torsten Hahmann	Faculty	University of Maine
Tucker Nugent	Undergraduate Student	University of New Hampshire-Main Campus
Xinyuan Wei	Faculty	University of Maine
Zaixing Zhou	Faculty	University of New Hampshire-Main Campus

Appendix 3. Communications and Resources

Outreach

Forest Climate Change & Adaptation Webinar Series, Year 4 (webinar recordings)

Burning as a Management Tool

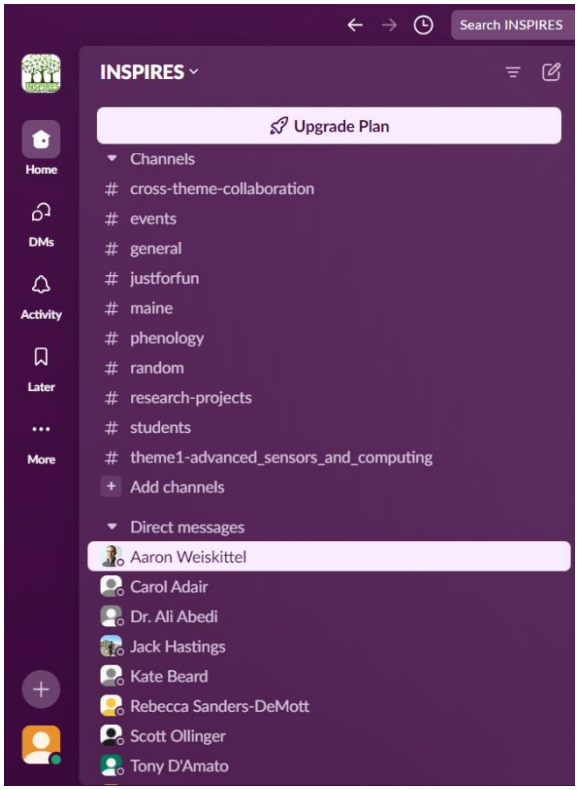
Restoration & Sustainable Forestry in the Face of Pests & Pathogens

Williamsburg Forest: Forest Adaptation & Implementation, Women in Forestry

Bear Brook Watershed: Understanding nitrogen and sulfur deposition on forested watersheds

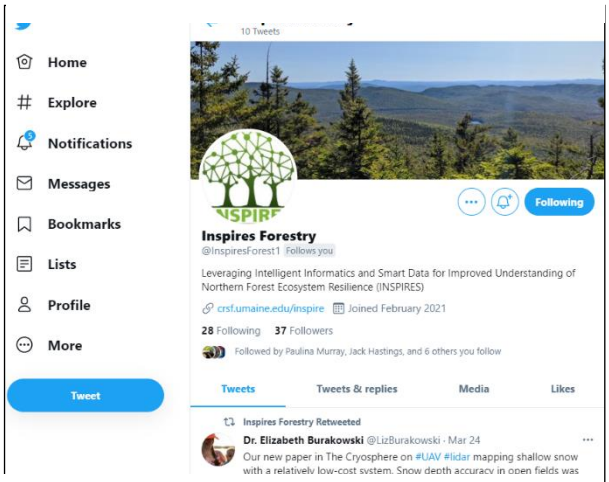
The INSPIRES team uses a variety of communications outlets to share project news and information.

INSPIRES Slack Channel

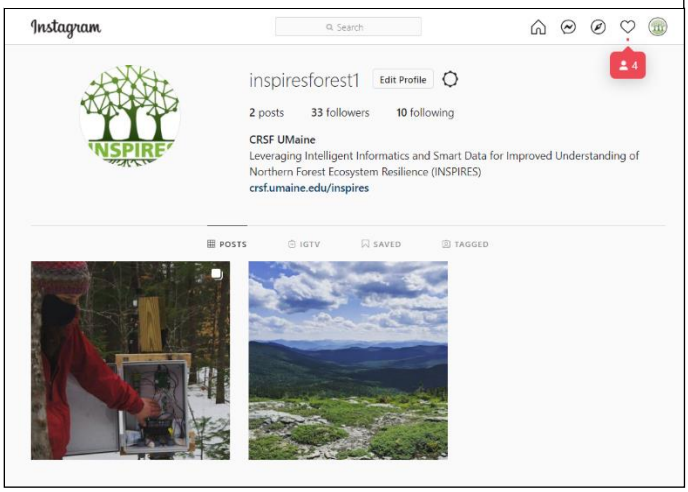


INSPIRES Twitter

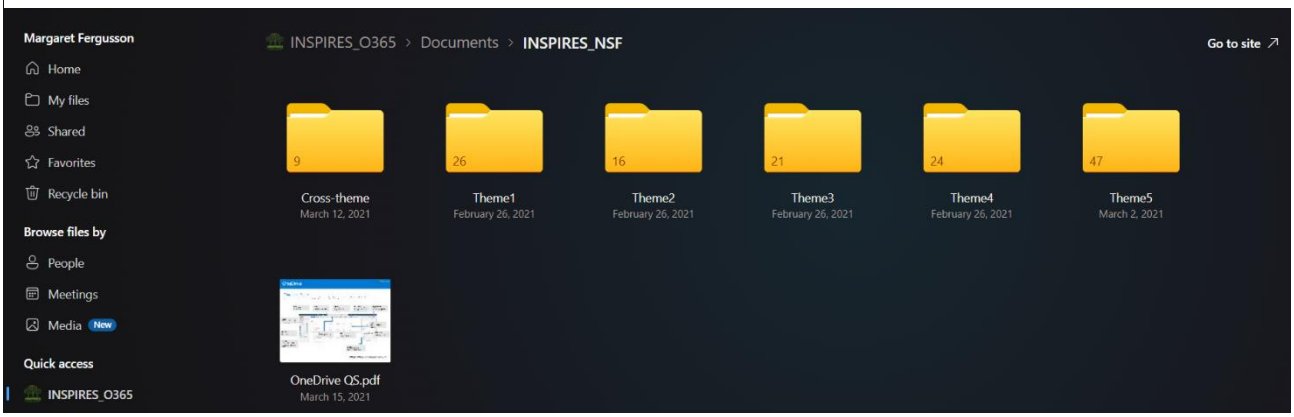
Share

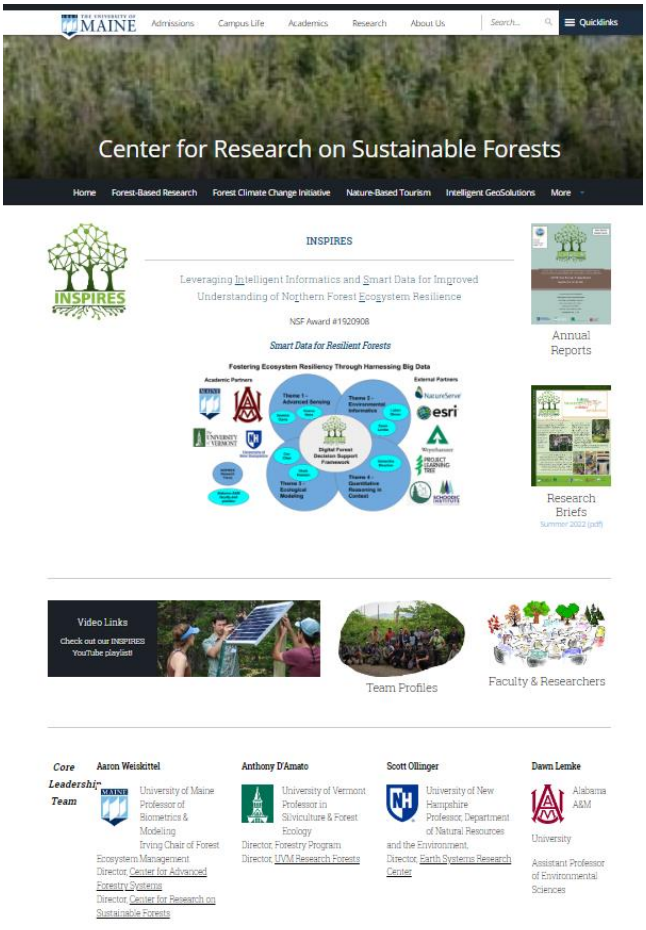


INSPIRES Instagram



Sharepoint folder provides access across themes, projects, and institutions for all INSPIRES team members.





The INSPIRES website is hosted by the INSPIRES lead site, UMaine's Center for Research on Sustainable Forests, provides easy, public access to project details and outcomes.

crsf.umaine.edu/inspires

Appendix 4. External Evaluation Report Survey

University of Maine – University of New Hampshire – University of Vermont

NSF EPSCoR RII Track-2 (INSPIRES)

External Evaluation Report

August 2024

Heather McInnis, Ph.D.

External Evaluator
The Implementation Group (TIG)

Table of Contents

Introduction

In May 2024, the *Leveraging Intelligent Informatics and Smart Data for Improved Understanding of Northern Forest Ecosystem Resiliency* (INSPIRES) project completed the final year of a Research Infrastructure Improvement Track-2 Focused EPSCoR Collaboration award from the National Science Foundation (NSF). Over five years, the project leveraged complementary expertise and resources at the University of Maine (UME), University of New Hampshire (UNH, University of Vermont (UVM), and the Alabama Agricultural and Mechanical University (AAMU), to address complex forest ecosystems issues, build regional STEM capacity and broaden participation in science, and support the development of early career faculty.

This report summarizes findings related to the team's development of research capacity, inter-jurisdictional and cross-disciplinary collaborations and partnerships, and education and workforce contributions drawn from two sources of evaluation data collected at the end of the no-cost extension period of the project (May 2023 – April 2024).

1) ***Year 5 (NCE) Outcomes Data:*** Products and outcomes from activities conducted in the fifth no-cost extension year and updated demographic information were reported by INSPIRES researchers in April 2024.
2) ***Exit Interviews with INSPIRES Co-Is, Researchers, and Post-Doctoral Scholars:*** Feedback from 2 INSPIRES Co-Investigators, 2 researchers, and 2 post-doctoral scholars was collected by the external evaluator through individual interviews, conducted virtually June 4-21, 2024.

The evaluation plan for the INSPIRES project outlined key goals to be achieved in each of the EPSCoR Track-2 Award target areas: development of research capacity, inter-jurisdictional collaborations and partnerships, and education and workforce development. Outcomes from Year 5 activities, assessed in the context of cumulative outputs generated across the award period, highlight key products, successes, and outcomes. Feedback generated from exit interviews with participants captures perceptions of the value and impact of the INSPIRES project on individual's research, professional development, and career plans.

Evaluation Data Collection and Reporting

Demographic and outcomes data were collected from INSPIRES researchers and trainees, annually for five years following guidelines and using reporting tools provided by the NSF EPSCoR program. From the start of the project through March 31, 2022, data related to research productivity were analyzed in *NSF EPSCoR RII Track-2 Data Outcomes Portal Formative Feedback Reports* and used to inform the team's annual reports to NSF EPSCoR.[1]

Supplemental data were collected from project participants each year by the external evaluator, including information about participants' backgrounds and expertise, individual roles in the project, prior and current research collaborations, research and professional development interests, and perceptions about project

[1] *NSF EPSCoR RII Track-2 Data Outcomes Portal Formative Feedback Report*, *Award Year 3* (April 16, 2022), prepared by Integrated Learning Innovations, Inc.

implementation. A timeline for all external evaluation activities is provided in ***Appendix I*** of this report. INSPIRES researchers were surveyed in Year 1[2] (January 2020), and in the first halves of Year 2 (November-December 2020) and Year 3 (December 2021) of the project. AAMU researchers who joined the project in January 2022 as part of a supplemental award were surveyed in March 2022. INSPIRES trainees were surveyed in Year 1 (September 2020), Year 2 (September 2021), and Year 3 (January 2022), and sub-sets of INSPIRES graduate student trainees participated in group interviews conducted by the external evaluator on November 10, 2021, and April 3, 2023. Informal exit interviews approximately 20 minutes in length were conducted with available Co-Is, early career researchers, and postdocs between June 4-24, 2024: interview questions are detailed in ***Appendix II*** of this report. Evaluation methods and findings from project outcomes, survey data, and the 2021 interview with graduate students were summarized in *Annual Evaluation Reports* delivered to the project leadership in April of each year of the award from 2020-2023.

External assessments of the project were conducted in January 2021 and January 2023 by external panels of disciplinary experts (i.e., External Review Panel). The 2021 formative assessment examined the team's progress toward organizing and initiating activities outlined in the team's Strategic Plan. The 2023 summative assessment examined the outcomes of project activities and potential for sustaining research momentum and capacity built through the Track-2 FEC. The External Review Panel included a professor of applied forest ecology with expertise in Northern New England and Canadian forests, a professor of natural sciences and director of an EPSCoR RII Track-1 program, and a professor of environment and natural resources with expertise in sustainability science. The assessments involved virtual site visits with INSPIRES researchers and trainees, led by the external evaluator. Details on the assessment process and findings and recommendations to guide implementation and sustained impact were summarized in the *2021 Formative Assessment Report*, provided to the leadership team in March 2021, and the *2023 Summative Assessment Report*, provided to the leadership team in February 2023.

INSPIRES Team

The INSPIRES team included researchers and trainees from diverse geographies, institutions, fields of study, and career stages.

Interjurisdictional & Multi-institutional Participation

The project enabled new and sustained engagement and collaboration opportunities across the partnering research focused universities, primarily undergraduate institutions, and non-profit organizations (Table 1). The project reported that 132 people from 4 states have participated in the project. At the end of Year 5, the project roster included 62 participants (including the external evaluator): 8 team members were affiliated with AAMU, 28 with UME, 13 with the University of New Hampshire (UNH), 8 with the University of Vermont (UVM), 1 with the Appalachian Mountain Club (AMC), 1 with Colby-Sawyer College, 1 with the University of

[2] Year One (Year 1), Year Two (Year 2), and Year Three (Year 3) are used throughout this report to describe data collection timing and surveys, based on definitions used here (in the introduction section).

Michigan Ann-Arbor, and 1 with the Maine TREE Foundation. Of the 31 faculty who participated in Year 5 activities, 16 can be classified as "early career" by the NSF (i.e., they hold a position of Assistant Professor or equivalent).

Table 44: INSPIRES Year 5 Participants by partnering jurisdiction and career stage (N=6).

INSPIRES Participant Role	AAMU	UME	UNH	UVM	Other	Total # Participants by Career Stage
Early Career Faculty	3	7	3	2	1	**16**
Senior Faculty	1	6	3	4	1	**15**
Technical Support Staff	-	5	3	1	1	**10**
Non-Technical Support Staff	-	5	-	-	-	**5**
Post-doctoral Scholars	-	-	-	1		**1**
Graduate Students	2	4	2	-	1	**9**
Undergraduate Students	2	1	2	-	-	**5**
Total # Participants by Jurisdiction	***8***	***28***	***13***	***8***	***4***	***61***

Gender and Racial/Ethnic Diversity

In Year 5, at least 43.5% of the team members self-reported their gender as female, and 30.6% as male. Year 5 demographic data were self-reported by INSPIRES participants via the NSF EDOCS portal: demographic reporting was optional. Of the 62 participants, 12 did not report gender or race and ethnicity data, 27 identified as female, 19 as male, and 1 chose not to report gender. Thirty-eight (38), or 85.7% of the participants who did report race and ethnicity data, self-identified as white, 1 as Black or African American, 3 as Asian, 4 as 'some other race', and 1 chose not to report race. One (1) participant reported Hispanic ethnicity and 4 chose not to report ethnicity. One (1) participant reported a disability and 3 chose not to report disability status. No participants reported being a Veteran and 1 chose not to report Veteran status. Four (4) participants reported that they were first-generation college students, 2 chose not to report their generational status, and 25 did not provide these data.

Cross-Disciplinary Expertise

Overall, the team included a breadth of expertise, including in data science, forestry, ecology, remote sensing, and spatial informatics, as well as in STEM education. As reported in 2023, INSPIRES faculty researchers were affiliated with at least 23 academic institutes, centers, or departments at the four partner institutions.

Biogeochemistry • Biometrics • Climate Science • Computational Groundwater Hydrology • Computer Science • Data Science • Ecology • Ecosystem & Global Change Ecology • Electrical Engineering • Forestry • Forest Biometrics, Management, Remote Sensing, Ecology, and Silviculture • Geochemistry • Machine Learning/Artificial Intelligence • Marine Sciences • STEM Education • Spatial Informatics • Physics • Wildlife / Habitat Ecology

Project Organization, Management, and Team Science Strategies

In conducting the 2023 summative assessment of the project, the External Review Panel reported that, overall, the project excelled in the development of a "collaborative spirit." Despite initial and ongoing COVID-related challenges that coincided with the award timeframe, the team's thematic organization, senior leadership strategy, and support from UME's Center for Research on Sustainable Forests and the state EPSCoR office, fostered collaborations and partnerships across the large team and reduced administrative burden on early career researchers.

Participant Feedback on Project Organization, Management, and Team Science Strategies

In exit interviews with the evaluator, held in June 2024, INSPIRES researchers and postdocs were asked to provide feedback on the extent to which the organizational structure and management strategies supported inclusion, engagement, and collaboration, as well as the extent to which team members from each jurisdiction were engaged.

The overall sentiment from the 6 participants interviewed was that the team members were collegial, and the team's leadership had provided strong support that facilitated their work together through the challenging circumstances of the COVID pandemic.

Co-I D'Amato stated:

> *"COVID allowed for personal bonding and the project provided an outlet for creative energy and brought people together in remote spaces (virtual and forests).*

One researcher stated:

- *"I enjoyed how wonderful everyone is on the project – this is a compatible team, a good group of people. I give a lot of credit to the PI for coalescing the team."*

Similarly, another researcher stated:

> *"Everyone was always welcomed to be involved cross-jurisdictionally, there was inclusiveness, it never felt territorial."*

Co-I D'Amato commented:

- *"The key was to empower early career researchers to lead the science. This led to more openness to work across different regions."*

He also reported that *"to some degree, funding allocations created some differences in terms of enabling collaborative work."* Yet some researchers *"embraced the opportunity to work across jurisdictions and project teams"* and acted as *"bridge-builder[s] across teams"*, regardless of funding sources.

Co-I Lemke echoed this observation, stating:

- *"Collaboration is hard work. A lot of engagement was due to individuals – this takes effort on both parts to establish relationships with people as individuals and not just as a resource."* Lemke noted, *"all-team meetings were good for sharing knowledge about what was going on across the project. They didn't build collaborations or strong relationships, but they did open the door to developing the ongoing collaborations with individuals through follow-on meetings and engagements."*

A postdoc's feedback supports these statements:

- *"I started off working in a close-knit network with a core group of people at [my institution], but through the broader INSPIRES network, I was able to branch out and connect with others, like Sarah Nelson from the AMC. The project acted as glue between people."*

Collectively, team members reported that the project organization and meeting strategy worked well, despite significant impacts from the COVID pandemic (e.g., forced virtual meetings and impacts to planned student exchanges). Co-I Lemke (AAMU) noted that the flip side to the COVID limitations to in-person interactions was that the virtual meeting strategies kept AAMU engaged, even at a distance. Another researcher commented that once in-person meetings started up (halfway through the award period), they offered great opportunities to informally mentor graduate students.

A challenge raised by several interviewees was managing time commitments on the project. One participant commented:

> *"This was a large group, there were a lot of meetings that took a lot of time. The meetings were necessary, and because of the type of work I do, I needed to attend many of them. Meetings were helpful, but in the future, I hope to better manage time to allow for one-on-one collaborations in addition to the team meetings."*

One researcher expressed that an orientation to the project would have been helpful in onboarding new team members as there was a bit of a learning curve for those who joined after the project start and during the Covid pandemic.

Research Productivity and Capacity Building

Over the 5 years of the project, INSPIRES researchers reported information on the following outcomes from project activities:

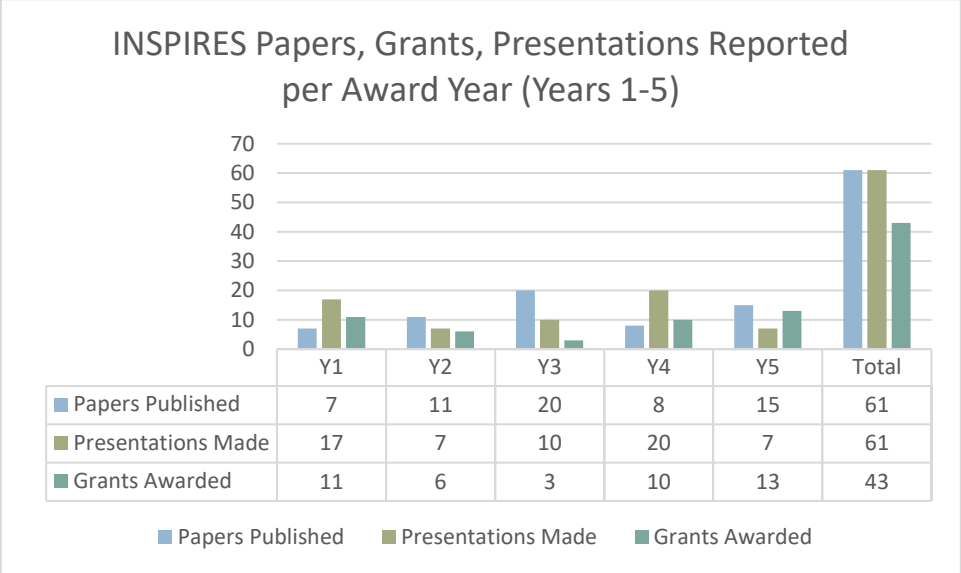
- Publications
- Presentations
- Funding Awards (proposals submitted and funded)
- Other Outcomes

Details on INSPIRES research products resulting from Year 5 (1 May 2023 to 30 April 2024) activities are described in the team's *2024 Final Report*. The following summary presents Year 5 outcomes data in the

context of the project's cumulative reported outcomes over the five-year award period (August 2019-April 2024).

Publications, Presentations, and Awards

The INSPIRES team reported producing a total of 61 published papers, 61 presentations, and 43 grants awarded totaling over $48 million in funding during the five-year award period (**Figure 1**). In Year 5, INSPIRES team members published 15 papers and 2 conference proceedings, submitted 20 funding proposals, and were awarded 13 grants totaling over $21 million. In addition, team members presented 7 conference presentations at international, national, regional, and project meetings, produced 6 datasets or databases, 1 report, and posted content. Two graduate students (1 at UME, 1 at UVM) completed their dissertation or thesis.



	Y1	Y2	Y3	Y4	Y5	Total
Papers Published	7	11	20	8	15	61
Presentations Made	17	7	10	20	7	61
Grants Awarded	11	6	3	10	13	43

Figure 1: Number of papers, grants, and presentations produced by INSPIRES participants per award year (August 2019-April 2024).

Almost half (48%) of the papers published, and almost 25% of the grants awarded were produced by collaborations among researchers from partnering jurisdictions, and (Figure 2). The fifth, no-cost extension year of the project enabled researchers to synthesize collaborative products, for example, the paper by *Roy et al. (2024)*[3] in *Ecological Indicators*, involving contributions from UNH and UMaine researchers toward developing approaches to :delineate and characterize potential shifts in regional climate zones in the northeastern U.S. and maritime Canada to better identify and understand associated changes in forest ecosystems. Over 44% of the papers published, 39% of the presentations made, and 42% of the grants awarded were led by early career faculty. Students were also active in publishing (participating in 34% of papers published) and presenting research results (involved in 33% of presentations made), and 1 grant awarded was student-led. Although the gender representation on the team was relatively balanced over the award period, women led 39% of the papers published, and only 28% of the grants awarded.

[3] http://dx.doi.org/10.1016/j.ecolind.2024.111921

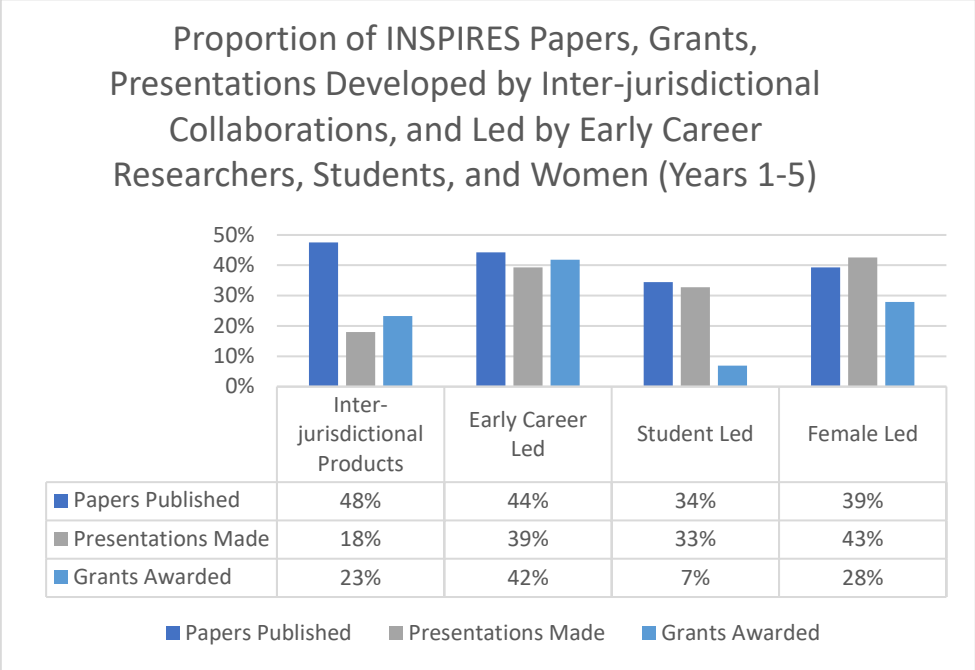


Figure 2: Proportion of INSPIRES publications, published presentations, and grants awarded developed by inter-jurisdictional collaborations, and led by early career researchers, students, and women (August 2019-April 2024).

In the 5-year award period, INSPIRES team members published 61 papers in 38 journals, including in open access and high-impact journals such as *Nature*, *Global Change Biology, Environmental Science & Technology, IEEE*, and the *Proceedings of the National Academy of Sciences*. Table 2 lists all journals in which project participants have published their research since joining INSPIRES in August 2019, and their current impact factors. In Year 5, 15 papers were published in 15 peer reviewed journals (see bold font in Table 2), and 8 team members from the partnering jurisdictions (i.e., AMC, UME, UNH, and UVM) collaborated to draft a manuscript (in preparation for submission) describing initial results from a novel line of research on snow refugia in temperate forest canopies.

Table 2: Journals where INSPIRES participants have published, with current impact factors (bold font indicates journals where researchers published in Year 5)**.**

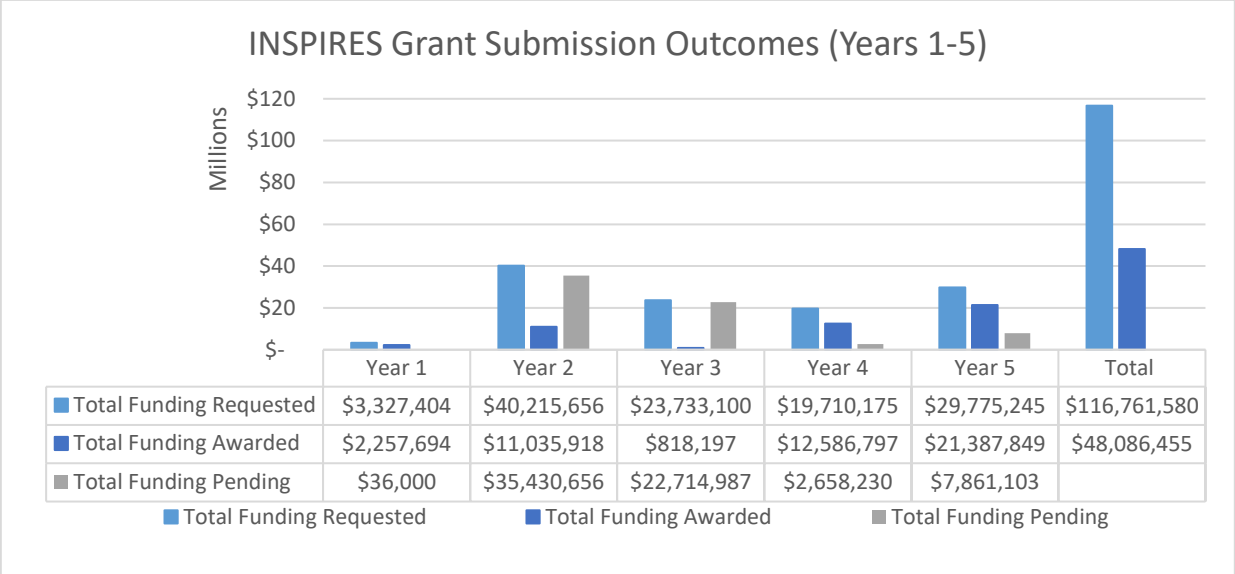
Journal or Publication Title	Impact Factor
American Biology Teacher	0.485
American Geophysical Union Earth's Future	**8.7**
Annals of Forest Science	3.3
Canadian Journal of Forest Research	1.8
Carbon Balance and Management	**4.8**
Carbon Management	4.1
Diversity and Distributions	4.6
Ecological Economics	**6.6**
Ecological Indicators	**7.0**
Ecological Modeling	2.6
Ecology	**4.4**
Ecology & Evolution	**2.3**
Ecosphere	2.7
Ecosystems	3.9
Environmental Research Letters	**5.8**
Environmental Science & Technology	**11.6**

Journal or Publication Title	Impact Factor
Forest Ecology and Management	3.7
Forest Policy and Economics	**4.0**
Frontiers in Forests and Global Change	**2.7**
Functional Ecology	4.6
Global Change Biology	10.8
IEEE Transactions on Geoscience and Remote Sensing	7.5
IEEE Transactions on Neural Networks and Learning System	10.2
IEEE Xplore	-
International Journal of Wireless Information Networks	1.4
Journal of Applied Ecology	5.0
Journal of Big Data	12.4
Journal of Ecology	**5.3**
Machine Learning with Applications	-
Mathematical and Computational Forestry & Natural-Resource Sciences	.3
MethodsX	**1.6**
Nature	54.4
Northeastern Naturalist	.13
Proceedings of the National Academy of Sciences	10.8
Remote Sensing	4.9
Remote Sensing of Environment	**11.1**
Scientific Reports	4.3
The ISME Journal	12.3
2020 25th International Conference on Pattern Recognition (ICPR)	-
Maine Policy Review	-
MIT Undergraduate Research Technology Conference	-
Proceedings of the 13th Workshop on Ontology Design and Patterns (WOP 2022)	-
Tiny Papers	-

INSPIRES researchers reported 61 presentations were given during the award period, including 13 in Year 5. Team members primarily disseminated their work through conference presentations or posters. Other presentations included seminar talks, webinars, workshops, professional society meetings, and data updates or summary presentations at INSPIRES all-team meetings. Eleven (11) presentations were produced by inter-jurisdictional collaborations, 18 were led by early career faculty, and 3 were presented by students. The project's communication team also disseminated information about INSPIRES activities through a variety of mechanisms, including direct contact, quarterly all-team meetings, monthly theme and project meetings, student-focused collaborative meetings (the collaboration coordinator arranged and moderated invited speaker presentations), an e-newsletter and EPSCoR program highlights, and team member profiles and content published to the website.

INSPIRES researchers submitted grant requests totaling $116.7 million and secured over $48 million in funding (Figure 3). Most awards were secured from federal agencies, including $25.6 million (53% of the total funding secured) from the USDA, $18.9 million (39% of the total) from the NSF and $1.4 million (3% of the total) from NASA (**Figure 4**). **Table 3** lists awards received by INSPIRES team members by project year, funding agency, and program. Notably in Year 5, PI Weiskittel (UME) secured a $7 million grant from the NSF EPSCoR's new RII E-RISE program. Dr. Contosta (UNH), an early career researcher, collaborated with researchers at UNH to secure a new $10 million USDA NIFA award. Dr. Burakowski (UNH), also an early career faculty member, secured almost $1 million in funding from the *National Resources Conservation Service (NRCS)*. And, in 2023, Co-Is Ollinger (UNH) and Lemke (AAMU) secured $1.2 million in NSF funding to support ongoing

INSPIRES-related collaborative research that will enable regional comparisons between the northern and southern forests under study.



	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Total Funding Requested	$3,327,404	$40,215,656	$23,733,100	$19,710,175	$29,775,245	$116,761,580
Total Funding Awarded	$2,257,694	$11,035,918	$818,197	$12,586,797	$21,387,849	$48,086,455
Total Funding Pending	$36,000	$35,430,656	$22,714,987	$2,658,230	$7,861,103	

Figure 3. Total grants submitted, awarded, and pending (reported pending at the end of each reporting year) by INSPIRES team members by project year (August 2019-April 2024).

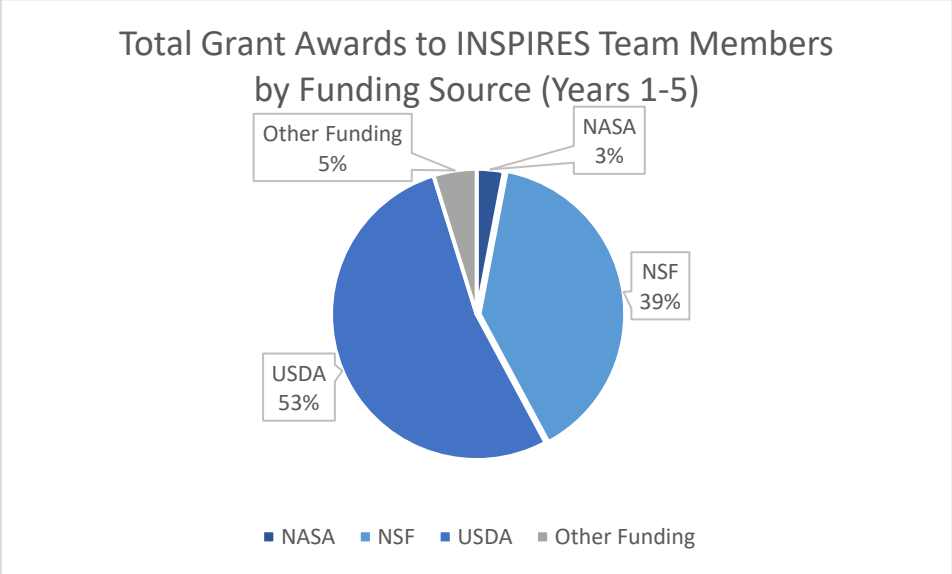


Figure 4. Total funding awarded to INSPIRES team members by funding source (August 2019-April 2024).

Table 3. Federal Funding Awards received by INSPIRES participants August 2019 – April 2024, by project year and agency. *(*= early career-led; **= student-led; + = multi-institution-led)*

PI (Affiliation)	Agency/Program	Year 1	Year 2	Year 3	Year 4	Year 5
	NASA	$ -	$1,437,777	$ -	$11,279	$ -
*Hayes (UME)**	*Carbon Monitoring System*		$940,308			

PI (Affiliation)	Agency/Program	Year 1	Year 2	Year 3	Year 4	Year 5
*Hayes (UME)**	*Global Ecosystem Dynamics Investigation (GEDI)*		$497,469			
*Hayes (UME)**	*University of Southern Maine/Maine Space Grant/NASA*				*$11,279*	
	NSF	$1,769,977	$6,695,146	$679,004	$1,302,547	$8,499,735
Contosta (UNH)+*	*Snowed Under*	$1,119,977				
*Contosta (UNH)**	*Macrosystem Biology*		$1,199,387			
*Hahmann (UME)**	*Innovation and Technology Ecosystems (ITE)*					$1,499,735
Ollinger (UVM)/Lemke (AAMU)+*	*Collaborative Research*				$1,252,547	
Ranco (UME)					$50,000	
Rizzo (UVM)	*Collaborative Research*		$2,499,000			
Rizzo (UVM)	*Future of Work at the Human-Technology Frontier*	$150,000	$2,996,759			
Weiskittel (UME)	*EPSCoR RII E-RISE*					$7,000,000
Weiskittel (UME)	*Industry-University Research Partnerships*	$500,000				
*Yasaei Sekeh (UME)**	*Career Award*			$679,004		
	USDA	$487,717	$2,872,995	$ -	$11,138,527	$11,174,911
Adair (UVM)	*NRCS*					$399,570
Asbjornsen (UNH)/ Contosta (UNH)*	*NIFA*					$10,000,000
D'Amato (UVM)	*McIntire-Stennis ARS*					$514,751
*Contosta (UNH)**	*NIFA AFRI Foundational Program*		$1,199,160			
D'Amato (UVM)	*NIFA AFRI Foundational Program*		$470,835			
D'Amato (UVM)	*NIFA AFRI CARE Program*		$300,000			
*Gunn (UNH)**	*Conservation Innovation Grants*		$120,000			
*Hahmann (UME)**	*NIFA*		$500,000			
*Hayes (UME)**	*NIFA AFRI*				$643,848	
Hossain (AAMU)	*NIFA*					$260,590
Ranco (UME)	*NIFA- New Beginnings for Tribal Students*		$283,000			
Ranco (UME)					$300,000	
Ranco (UME)+	*UVM/USDA NSRC*				$94,679	
*Simons-Legaard (UME)**	*NIFA AFRI*	$487,717				

PI (Affiliation)	Agency/Program	Year 1	Year 2	Year 3	Year 4	Year 5
Weiskittel (UME)	*NSF EPSCoR RII Track-1 Planning Grant*				$100,000	
Weiskittel (UME)	*SAS*				$10,000,000	
	Other Funding	$186,000	$30,000	$139,193	$104,444	$1,860,584
Adair (UVM)	*Forest Ecosystem Monitoring Cooperative*					$49,852
*Classen *UVM)*	*Gund Institute for the Environment Catalyst Awards*	$50,000				
Burakowski (UNH)	*Natural Resources Conservation Service*					$995,114
D'Amato (UVM)	*Northeastern States Research Cooperatve (NSRC)*			$139,193		
Foster (UVM)	*U.S. Forest Service (Southern Research Station)*					$120,000
*Hahmann (UME)**	*U.S. Forest Service*		$30,000			
*Hastings (UNH)***	*University of New Hampshire*					$27,381
*Hayes (UME)**	*Cooperative Forestry Research Unit*				$104,444	
Ollinger (UNH)	*Northeastern States Research Cooperative (NSRC)*					$298,237
Ollinger (UNH)	*U.S. Forest Service (Northern Research Station)*					$70,000
*Roy (UM)**	*Maine Water Resources Research Institute*	$36,000				
*Roy (UME)**	*DOE - U.S. China Clean Energy Research Center*	$100,000				
Weiskittel (UME)	*National Council for Air and Stream Improvement (NCASI)*				$30,000	
Weiskittel (UME)	*Natural Resources Conservation Service*					$300,000
	Total Funding by Project Year	***$2,443,694***	***$11,035,918***	***$818,197***	***$12,556,797***	***$21,535,230***

Of the grants 20 grant proposals submitted in Year 5, 6 proposals totaling $7.8 million in funding requests were pending in Year 5, including a proposal to the *Schmidt Sciences Foundation* for $5.5 million developed by INSPIRES collaborators from UNH and UVM (**Table 4**).

Table 4: Pending Grant Awards Reported by INSPIRES Participants in Year 5.

PI(Affiliation)	Agency/Program	Year 5
Contosta (UNH)+*	*Schmidt Sciences Foundation*	$5,500,000
D'Amato (UVM)	*USDA NRCS*	$494,758
*DeSouza (AAMU) / Lemke (AAMU)**	*USDA ARS*	$600,000
*Hayes (UME)**	*NASA Carbon Monitoring Systems*	$964,806

Ollinger (UNH)	*U.S. Forest Service (Northern Research Station)*	$22,000
Wei (UME)	*NASA*	$279,539
	Total Funding Pending - end of Year 5	$7,861,103

Other Research Products

The project generated research products beyond publications, grants, and presentations that will sustain research momentum and impact beyond the project. Notably, the team produced a low-cost, wireless sensor, a suite of data products (e.g., INSPIRES Wireless Network (IWIN) Design, IecospectR package, Refegen, Digital Forest Date Explorer, INdendro Dendrometer, and Inleaf), preliminary ecological modeling functions, a new graduate course at UVM (*INSPIRES Teaching Professional Learning*), 6 virtual professional learning workshops for K-12 teachers, and a 4-day summer institute for teachers at the Schoodic Education Research Center (Maine). In Year 5, team members produced 4 published datasets (including regional leaf traits and leaf temperature for tree species in the northeastern U.S., productivity and biodiversity data for Bartlett and Hubbard Brook Experimental Forests, and Thompson Farm Ameriflux data) and 2 ontology databases (*Preferences for Environments Ontology (PrefEnvO); Spatial and Temporal Aggregate Data (STAD) Ontology Design Pattern)*. Five (5) of the 6 data products included contributions from students, and 2 from early career researchers.

Collaborations and External Partnerships

In Year 5, researchers reported 9 intra and interjurisdictional collaborations developed through the project among 38 project participants and collaborators from external institutions (e.g., *The Nature Conservancy*) or federal agencies (e.g., *USDA, U.S. Forest Service*) (Table 5). New projects range from provision of technical support for research in AAMU's Paint Rock Forest site, to development of research on snow refugia in collaboration with *The Nature Conservancy* and the U.S. Forest Service, to development of a model to predict combined forest ecosystem and landscape succession.

Table 5: Collaborations Reported by INSPIRES Participants in Year 5.

Collaboration Title or Focus	Collaborating Institution / # Collaborators
Development of a combined forest ecosystem and landscape succession simulation model.	UNH (3), UVM (1), U.S. Forest Service (3)
Research on forest microclimate and soil carbon.	U.S. Forest Service (3)
Investigation of drought and cold resistance of northeastern U.S. trees to inform ecological modeling and forest management practices.	AAMU (3), UNH (4)
Research on forest carbon sequestration.	UNH (2)
NRCS investigation of forest management impacts on soil carbon.	USDA NRCS (1)
Paint Rock hyperspectral support.	AAMU (2), UME (1)
Regional phenology study.	UME (2)
Seeking cohesion, co-deployment and possible unification of two independent sensor networks --	UME (6)

soil moisture sensors and an automated band-dendrometer network.	
Snow refugia: Managing temperate forest canopies to maintain winter conditions.	The Nature Conservancy NH (1), UME (1), UMA Amherst (1), UNH (3), UVM (2), U.S. Forest Service (1)

Participant Feedback on Research and Collaboration Goals and Objectives

In exit interviews with the evaluator, held in June 2024, INSPIRES researchers and postdocs were asked to provide feedback on the extent to which research goals and objectives for the project were met, and the extent to which the project provided new opportunities for collaborative engagement across jurisdictions and disciplines.

All six participants interviewed reported that they were able to meet the majority of their research goals and overall, the project was very successful in building capacity for ongoing research among collaborators from the 4 jurisdictions.

Co-I D'Amato (UVM) reported:

- *"[The project was] quite successful in building research capacity – [the team] created new, highly sensored research sites across the [partnering] New England jurisdictions, ecosystems science tied to the network, and several great collaborations on publications and new research areas (e.g., cold-air pooling)."*

In particular, Themes 1 and 3 were reported to have had great synergy on publications and proposals as part of INSPIRES. Researchers from UNH, UVM, and the Appalachian Mountain Club (AMC) also highlighted the extended climate data monitoring capacity built through the project's deployment of low-cost instrumentation (sensors) in New England. Importantly, INSPIRES climate sensors are some of the few non-national weather service sensors that are able to measure snow. One researcher explained that some of the INSPIRES work, as well as the PI's advocacy for national appropriations for national snow measures (i.e., $1 million in USDA NRCS funding through appropriations), has been critical in helping the community to better understand how few snow measurements are available. A significant outcome of the project is the new line of collaborative research on snow refugia, which has already resulted in a collaborative publication and proposals in submission and revision looking at snowpack in forests.

Researchers also commented that **the scale of the research projects and regional network of researchers allowed for collaborative interactions that are productive and sustainable.** For example, new sensor transects at the Barlett, NH site are being collaboratively maintained by UNH and AMC. The partnership with AAMU via a supplemental award secured in Year 2 of the project extended the geographic reach of the research initiatives and training opportunities.

Co-I Lemke (AAMU) noted:

- *"The key goal for AAMU was to build relationships and capacity for ongoing projects and integration with relevant research interests* [e.g., extension of research on northern forests to AAMU's ForestGeo plot] – *this was accomplished."*

The extension of research from UNH to AAMU developed into a collaboration between Co-I's Lemke (AAMU) and Ollinger (UNH) on a new *NSF Organismal Response to Climate Change (ORCC)* grant. Additionally, a PhD student from Ollinger's lab at UNH travelled to AAMU in summer 2024, along with Dr. Peter Nelson (UMaine, Schoodic Institute), to conduct forest ecology research and provide additional field methods training in ground and airborne spectroscopy to AAMU technicians and graduate students.

A postdoc reported that the project enabled them to be highly productive and generate new lines of research, commenting:

"I was able to be very productive and strategic to come up with projects and papers quickly and then set some longer-term goals for getting outcomes out, like the cold-air pooling paper. A goal was 2 to 3 publications, but I got 4 publications plus two ongoing projects with continuing outcomes. I also have given lots of talks and conference presentations. New lines of research developed from INSPIRES also offer ongoing collaboration opportunities for graduate students and postdocs."

A graduate student reported several publications in preparation for submission in summer 2024, as well as a *"knowledge graph with a user interface in preparation to support queries of data sets."* They also stated:

- *"INSPIRES gave me a great opportunity in terms of interactions with other people across disciplines and universities. I got more than I thought I needed from the project in this respect. The project helped me access forestry experts. I learned how to present information at a higher level and to communicate my work to non-domain experts."*

Several researchers commented on the success of Theme 4, the educational component of the project. The involvement of the educational team via the teacher training component provided a unique opportunity for researchers to integrate with educators and think about how the research activities and results can be incorporated into materials implemented in the classroom. One Co-I noted, *"The driving force of Theme 4 was teachers."* And they noted that projects and collaborations have grown from the work, resulting in new publications and grants.

An early career researcher reported that one of her most memorable experiences was a teacher workshop held at the Schoodic Institute:

> *"The curriculum was fun to deploy…[and it] demystified data collection and field work. I went to two campuses to install instrumentation and felt part of bringing science to classrooms."*

When asked to describe concerns or challenges with the research outcomes, researchers reported that the planned sensor technology was underdeveloped, and there were some challenges in meeting Theme 2 objectives and connecting this work to other areas of the project. Team members reported that ongoing measurements from the extended sensor network are still being collected and have not been used yet, but one researcher noted, *"it is helpful to know data are available"* and they stated that they have 4-5 ongoing projects and *"foresee more work stemming from INSPIRES in the future."* Another researcher noted that there is some movement in Maine to leverage machine learning to new projects (e.g., soil map development).

Education and Workforce Development

Professional Development Outcomes

Overall, the project positively impacted the professional development of early career researchers. In addition to the data on research products produced by early career researchers, the project tracked participants' transitions in position and employment. Of the 25 faculty researchers who were classified as "early career" by the NSF (i.e., Assistant Professor or equivalent at the time of the proposal submission), several were promoted as faculty or entered into permanent positions with non-academic organizations during the award period. David Lutz (Colby-Sawyer) moved from a lecturer to a tenure-track position. Carol Adair (UVM) grew into her position and made a case for full professor. Andy Ouimette (UNH), a soft-money funded researcher landed a permanent government position. Two postdocs secured permanent forest service positions: one developed a unique line of inquiry through INSPIRES that allowed them to become competitive and offer a unique skills set aligned with government research priorities.

Collaborations and team science approaches benefited early career researchers, albeit unevenly and in different ways. As reported in 2023, COVID-related disruptions and the focus and priorities of researchers with research appointments, versus tenure-track appointments, impacted the extent to which researchers accessed and benefited from project resources.

Participant Feedback on Professional Development Outcomes

In exit interviews with the evaluator, held in June 2024, INSPIRES researchers and postdocs were asked to provide feedback on the extent to which the project influenced their career development or research direction.

Co-I Lemke noted she hired a postdoc for the first time in her experience and in AAMU's history. The postdoc was tasked with conducting research and teaching (adjunct position) undergraduate students 1 course per semester. Lemke stated that the postdoc "probably exposed the students to knowledge in new ways" but she did not have the experience or resources at AAMU to most effectively support the role. She acknowledged that she could have asked INSPIRES colleagues for more advice on managing the postdoc.

One researcher noted that they had not had a lot of experience with sensors prior to INSPIRES, and they may not have worked with researchers the partnering institutions if not for this project. They also noted that when the micro-climate theme (snow refugia) emerged in the literature, **being able to work with others on this helped them think about other directions to go with their research**.

Co-I Lemke reported benefits of researcher exchanges for AAMU's research technicians. Collaborations and visits from researchers from UME and UNH were leveraged into training opportunities in which new skills and research methods were transferred to AAMU technicians and graduate students in ways AAMU could not.

An early career researcher reported that she experienced disruptions to participation due to COVID and personal circumstances that resulted in having to extend a leave of absence during the pandemic, when she normally would have been preparing to submit her promotion and tenure package. **This researcher conveyed that although women at early career stages were in particularly vulnerable positions during the pandemic, working in the INSPIRES team was helpful in mitigating disruptions.** She said that she felt supported in adapting to the circumstances and that she ended up doing her own work with a different project team, noting,*"Each time I came back to the project I was welcomed to contribute however possible."*

Education and Training Outcomes

Despite significant disruptions to planned work due to COVID, the project was highly effective in providing funding and formal and informal research and skills training for postdocs, graduate students, and undergraduate students. During a group interview conducted by the external evaluator in April 2023, several graduate students stated that although COVID created challenges early in the project, particularly with field components, the project provided critical field, lab, and quantitative analytic training, and enabled the development of a regional network of supportive and productive researchers. Several students also reported feeling better prepared to enter the workforce outside of academia (e.g., non-profit conservation sector) and to continue to develop research tools with practical application. Two students from UME completed graduate degrees: 1 transitioned to a position in a related field with a state-based non-profit (*Maine TREE Foundation*).

As reported in 2023, the project influenced graduate students' career choices. During the 2023 group interview, students were asked what career goals they had coming into the project, and whether their plans had shifted as a result of the project. One student reported they had thought they wanted to be a professor and do research at a university – a "nice, stable job" – but they were now interested in opportunities with non-profit organizations (conservation). Another student reported they had intended to gain experience in wildlife conservation, and the project demonstrated opportunities in broader fields and sectors (i.e., state, government, non-profit).

Postdocs and graduate students leveraged skills gains, hands-on experiences, and research products to secure jobs in related fields. For example, in Year 4 (fall 2023), 1 postdoc was reported to have transitioned to an early career (Assistant Professor) position at Smith College, and a UNH graduate student was reported to have taken a research staff position at the university. In Year 5, a postdoc at UVM transitioned to a permanent Research Ecologist position with the U.S. Forest Service where they continue to collaborate with INSPIRES team members on topics developed from the team's research.

Participant Feedback on Education and Training Outcomes

In exit interviews with the evaluator, held in June 2024, INSPIRES researchers and postdocs were asked to provide feedback on the extent to which the project engaged students in new learning opportunities, and the extent to which the project influenced their career development.

Co-I D'Amato (UVM) stated that **the biggest component of the project impacted by COVID was the graduate student cohort.** The pandemic and logistics of shared courses were barriers to mentoring and graduate student exchanges. Despite this, the team was able to attract and support students and postdocs.

Co-I Lemke (AAMU) reported **that the project had led to a high level of engagement with technicians and students on the AAMU campus**, and *"let people see more possibilities beyond AAMU and Alabama."* Her students joined research meetings with visiting graduate students and researchers and another student was preparing to work with Co-I Ollinger (UNH) in summer 2024. Dr. Peter Nelson (UME/Schoodic Institute) is currently serving on one of her graduate student's committees. Co-I Lemke noted that she engaged with a lot of undergraduate biology students who had plans for medical careers, but through their work on the INSPIRES project, several are considering other options. For example, 1 former undergraduate student is now pursuing a graduate degree in Environmental Health.

With this said, Co-I Lemke noted that **all of the work to engage students in the project was carried out on the AAMU side, and she had managed significant institutional barriers, largely related to sub-award contracting and the travel approval and reimbursement process.** Issues with travel reimbursement at AAMU were so significant that students were unable to participate in the planned student exchange between the New England campuses and AAMU. She noted that she has yet to be reimbursed for a trip made to New England last summer (2023), and one AAMU student traveled to New England and participated in the project on a voluntary basis, without compensation or travel reimbursement, to gain experience. In the future, she concluded that it would have been more efficient if UME had disbursed the travel funds.

A graduate student noted that there were no INSPIRES courses or trainings – the project provided funding for his research assistantship. He recalled discussion at the mid-point of the project about developing science communication coursework, but he was unsure whether that had come to fruition.

A postdoc expressed that the project was instrumental in enabling her to secure a permanent job in the field that she is happy with. Through the project she was able to access to "a great team of mentors" and they were very happy with all mentoring received from all of them. She stated:

- *"It was nice to have different perspectives available. I had help to figure out projects and a strategy to identify initial projects that could be done quickly, as well as longer-term projects. I received mentoring around the job hunt and worked with her [a mentor] on the full process, including on a teaching statement, how to interview, giving research seminars over interviews."*

A graduate student from UME reported that the project has changed his career pathway. When he came on the project, his background was focused on GIS, and though he had a general interest in how to draw insights from data, his advisor steered them in the direction of learning ontologies, which he anticipates will be a big part of his ongoing work. He has successfully defended his dissertation and feels well prepared to look at academic and industry positions.

Appendix I: Timeline for External Evaluation Activities

External Evaluation Activities	2020			
	Q1	**Q2**	**Q3**	**Q4**
Baseline Survey – Faculty and Researchers	√			
Year 1 Annual Evaluation Report		√		
Baseline Survey – Graduate and Undergraduate Students				√
Annual Survey – Faculty and Researchers				√
	2021			
	Q1	**Q2**	**Q3**	**Q4**
Formative Expert Panel Assessment	√			
Year 2 Annual Evaluation Report		√		
Annual Survey – Graduate and Undergraduate Students				√
Focus Group Interview – Graduate Students				√
Annual Survey – Faculty and Researchers				√
	2022			
	Q1	**Q2**	**Q3**	**Q4**
Baseline Survey – AAMU Faculty and Researchers	√			
Year 3 Annual Evaluation Report		√		
	2023			
	Q1	**Q2**	**Q3**	**Q4**
Summative Expert Panel Assessment	√			
Group Interview – Graduate Students		√		
Year 4 Annual Evaluation Report			√	
	2024			
	Q1	**Q2**	**Q3**	
Exit Interviews with Researchers and Postdocs		√		
Year 5 Final Evaluation Report			√	

Appendix II: 2024 Exit Interview Questions for Project Participants

INSPIRES Exit Interviews: Researchers, Postdoctoral Fellows, Graduate Students June 2024

Participants
Interviewer: Dr. Heather McInnis (INSPIRES External Evaluator, The Implementation Group)
Team Members Interviewed:
Elizabeth Burakowski (Researcher, UNH): June 21, 2024
Dawn Lemke (Co-I, AAMU): June 4, 2024
Anthony D'Amato (Co-I, UVM): June 7, 2024
Sarah Nelson (Researcher, Appalachian Mountain Club): June 12, 2024
Melissa Pastore (Postdoc, UVM): June 11, 2024)
Kingsley Wiafe-Kwakye (Graduate Student, UME): June 10, 2024

Interview Focus Areas and Questions:

1. **Ask participants to briefly describe key outcomes from the INSPIRES project generally, and from their participation in the project specifically as related to 1) research goals and objectives, 2) collaboration and engagement, and 3) education and training.**
2. **Ask participants to give brief examples of the most valuable and most challenging aspects of participating in the project.**

Research Outcomes:

- To what extent were you able to meet the research goals and objectives you set for yourself on the INSPIRES project?
- To what extent did INSPIRES provide new opportunities for collaborative engagement across jurisdictions, institutions, or disciplines?
- To what extent were you and/or your team members able to leverage results to extend or build upon research, develop new collaborations and funding opportunities?
    -

Collaboration and Engagement Outcomes:

- To what extent did the project's organizational structure and/or management strategies support collaboration and engagement?
- To what extent were you and/or your team members from other jurisdictions engaged in project activities?
- Can you provide any examples of sustained collaborations that are extending beyond the award?
    -

Education and Training Outcomes:

- To what extent were students engaged in new learning opportunities through this project?
- To what extent did your participation in INSPIRES influence your career development (or that of others on the project)?
- To what extent did the project support student professional skills training and career development?
- To what extent will new curricula or training approaches be sustained past the award?

Overall Value of the Project:

- What were the most valuable aspects of participating in the project for you?
- What were the most challenging aspects of participating in the project for you?
- Can you give me an example of a lesson learned from the project that you think you will carry forward?