Red spruce climate change workshop: *Where to from here?*

University of Vermont
September 10-12, 2021

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Workshop Goals

(1) Bring the community together to present and discuss information on red spruce climate adaptation, including relevant perspectives on ecology and natural history, physiology, genetic diversity, local adaptation, seed zones, and applied restoration and silviculture.

(2) Improve understanding of threats to red spruce climate adaptation and other threats under anthropogenic change.

(3) Identify priorities for addressing research and knowledge gaps, integration of research and applied restoration, and best practices for designing restoration plantings and assisted gene flow and migration.

Schedule

For meal schedule, see p. 14

FRIDAY, September 10

UVM Davis Center – Livak Ballroom (4th floor)

Welcome, introductions, workshop overview (8:30-9:00 a.m.)

Note: Each panelist will speak for 15 minutes. At the end, there will be a 15-minute discussion among the panelists with questions from the other participants. For panelist affiliations, see the list of workshop participants on p. 5. For presentation abstracts, see p. 6.

Panel 1: Spruce Ecology and Natural History (9:00 -10:00 a.m.) – Moderator: Brittany Verrico

- Charlie Cogbill: *The natural history and biogeography of red spruce*
- Elizabeth Byers: *Natural communities of the red spruce ecosystem, with examples from the central Appalachians*
- Ali Kosiba: *Disentangling the relationship between red spruce growth and climate*

Panel 2: Spruce Physiology (10:30-11:30 a.m.) – Moderator: Anoob Prakash

- Paul Schaberg: *Winter and shoulder seasons: periods of potential promise and peril for red spruce*
- John Butnor: *Impacts of climate transfer distance on red spruce physiology*
- John E. Major: *Physiology of red spruce: controlling for genetic and environmental factors*

Panel 3: Genetics and Local Adaptation (1:00-2:15 p.m.) – Moderator: Thibaut Capblancq

- Carrie Pike: *The genetics behind adaptation for restoration efforts*
- Anoob Prakash: *Demographic history of red spruce and genotypic variation present in climate-adaptive traits after range expansion and fragmentation*
- Brittany Verrico: *The importance of spatial scale in restoration efforts for red spruce*
- Sean Hoban: *Sampling seeds for* ex-situ *conservation of genetic diversity*

Panel 4: Modeling and Prediction-Building (2:15-3:15 p.m.) – Moderator: Steve Keller

- Thibaut Capblancq: *Using genetic information to optimize reforestation efforts of red spruce*
- Susanne Lachmuth: *Genomic offset as a tool to inform potential assisted migration in red spruce*
- Jane Foster: *Recent range-wide expansion of montane red spruce suggests where favorable restoration conditions may persist for decades*

Panel 5: Restoration and Adaptive Silviculture (3:45-5:00 p.m.) – Moderator: Sonia DeYoung

- Dave Saville: The Central Appalachian Spruce Restoration Initiative (CASRI): *A collaborative approach to forest restoration*
- Katy Barlow: *Science, practice and conservation partnerships for forest climate adaptation*
- Christine Kelly: *The Southern Appalachian Spruce Restoration Initiative's (SASRI) approach to restoring forests degraded in the past with an eye to future climate conditions*
- Pete Clark: *Assisted migration and red spruce restoration plantings as part of adaptive silviculture for climate change*

SATURDAY, September 11

UVM Davis Center, 4th floor

Livak Ballroom, Williams Family Room (403), Spruce Room (405), Boulder Society Centennial Room (411), Chittenden Bank Room (413), Handy Family Room (415)

Breakout groups within disciplines (8:30-10:00 a.m.)
We will divide into discussion groups based on our areas of expertise, with the goal of identifying priorities for addressing research and knowledge gaps pertaining to maladaptation of red spruce under future climates, and/or other threats under anthropogenic change.

Below are some example questions to prime your discussion. Pick a couple that your group wants to focus on, or propose a new version of your own!

- What are the most important or impactful findings or principles from this discipline that can help inform restoration practices in red spruce under current and future climates?
- How do these findings or principles inform discussions on a) seed sourcing, b) provenancing strategies, c) assisted gene flow/migration?
- What questions or issues remain unresolved or unaddressed within your discipline as it relates to spruce restoration?
- How vulnerable is red spruce to climate change? (This may differ for different parts of the range.)
- What are the key features of its biology, distribution, or history of anthropogenic disturbance that contribute most to this vulnerability?
- How certain are we about the perceived vulnerability, and what contributes to this uncertainty?
- Are there important gaps in data or knowledge that could help address uncertainties? How should these be addressed?

TLDR (Too Long; Didn't Read):
What do we need to know? What do we know already? Where are the gaps? How should we address them?

Sharing from disciplinary breakout groups (10:30 a.m.-12:00 p.m., Livak Ballroom)
Our goal here is to share summaries of the discussions from each disciplinary breakout group. The value is for the larger community to hear from each field about where there is strong consensus regarding the future of spruce under climate change, where there are still major gaps in knowledge, and possible solutions to address any identified uncertainties.

Demonstration of seed sourcing app by Susanne Lachmuth (12:30-1:00 p.m., during lunch hour)

Interdisciplinary breakout groups (1:00-2:30 p.m.)
We will reassemble into interdisciplinary groups, bringing with us the key points and summaries from the previous breakout group session. Here, we'll aim to think interdisciplinarily, working across fields to brainstorm and find some fertile new ground, with the goal of identifying priorities, obstacles, and solutions for integrating research and applied restoration for red spruce adaptation under climate/anthropogenic change.

Below are some example questions to prime your discussion. Pick a couple that your group wants to focus on, or propose a new version of your own!

- How shall we choose seeds for either current and ongoing restoration efforts, or *ex situ* conservation?
- Are we ready to implement assisted gene flow/migration in red spruce? Why or why not?
- How do we work together at these larger interdisciplinary and geographic scales?

(We'll also have a short survey about the seed sourcing app in beta version during this session.)

Sharing from interdisciplinary breakout groups (3:00-4:30 p.m., Livak Ballroom)
Our goal here is to share summaries of the discussions from each interdisciplinary breakout group. Where did your group's discussion take you? Where is the path forward obvious? Where is it less clear what the next steps should be?

Wrap-up and closing remarks (4:30-5:00 p.m., Livak Ballroom)

SUNDAY, September 12

Underhill State Park

Optional outing to Mount Mansfield (8:30 a.m.-1:00 p.m.)

We will visit a spruce-fir forest and do some needed walking after all that talking! The summit can be reached via a ~6-mile round-trip hike of moderate to high exertion from the west side of the mountain (Underhill State Park). Alternatively, a toll road allows access up to nearly 4,000 ft. from the east side (near Stowe ski area) and affords a ~1-mile hike to the summit. We can also visit one or two of the common garden sites used in Brittany Verrico's PhD research. We will coordinate options and carpools before ending the day on Saturday. Except for those who choose to stay and keep hiking, we will return to Burlington by 2:00 p.m. Boxed lunches will be provided.

Participants

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**virtual participant*

Abstracts (*In order of presentation*)

Charlie Cogbill: *The natural history and biogeography of red spruce*

Picea rubens (red spruce) is a conifer endemic to eastern North America and the economic mainstay of northeastern forestry for three centuries. It presents many enigmas to the paleoecologist, vegetation ecologist, plant physiologist, and environmentalist. A common misperception is that it is an extension (or remnant) of the boreal "spruce-fir" forest. Red spruce is the temperate pair with the closely related boreal *Picea mariana* (black spruce). South of the glacial boundary, red spruce stands are scattered in isolated, poorly drained valleys or in an elevational zone of spruce-fir forest, the "sky islands" of the southern Appalachian mountains. These southern red spruce forests, however, are apparently genetically, post-glacially and biogeographically distinct and not the source of northern red spruce forests. Paleoecological evidence argues for a glacial refugia of northern populations at or off the east coast. Red spruce was rare throughout the Holocene and suddenly expanded about 2,000 years ago. Expanding in the mountains and spreading westward, red spruce range shows a decided preference for damp and foggy temperate environments. Red spruce is affected by wind rather than fire disturbance and has limited cold tolerance. Spruce was more abundant in the Northeast at Euro-American settlement, but it has been depleted by land clearance, logging, and environmental change. The primary habitat of red spruce was not on high mountains, but in the zone at or below the deciduous/coniferous ecotone and on flats or wet shorelines. Its range has been considerably reduced because spruce was logged out from the mixed spruce-hardwood forest. The Westveld paradox proposes that spruce will not easily regenerate in this "purified" forest. Change in the coniferous/deciduous boundary and the "recovery" of spruce after spruce decline of the 1960-70s complicate the interpretation of spruce abundance and range. The future and management of spruce must be cognizant of the young, very dynamic history of the species and its subtle relation to its environment.

Elizabeth Byers: *Natural communities of the red spruce ecosystem, with examples from the central Appalachians*

Red spruce *(Picea rubens)* forests range continuously from eastern Canada to New York and Connecticut, with discontinuous patches extending southward along the Appalachian Mountains to North Carolina. Red spruce is a foundational tree species with dominance in 20 natural forest types and 12 natural wetland types. The most common associated plants range-wide are balsam fir *(Abies balsamea)*, eastern hemlock *(Tsuga canadensis)*, yellow birch *(Betula alleghaniensis)*, red maple *(Acer rubrum)*, great rhododendron *(Rhododendron maximum)*, and peat moss *(Sphagnum* spp.). Dozens of globally rare plant and animal species are associated with the red spruce ecosystem, particularly within its wetland vegetation.

Red spruce vegetation types occur in nearly every topographic position, from summits and slopes to plateaus, river valleys, and depressions. Soils range from excessively well-drained, as on scree slopes, to very poorly drained swamps. Soils are typically acidic, nutrient-poor, high in organic matter, and are often sandy or stony and may occur over shallow bedrock. Common environmental characteristics include cold temperatures, often with cold air drainage or cold air accumulation in frost pockets and moist climates or microclimates with high rainfall and frequent fog.

Natural disturbances are infrequent and related to high winds and associated windthrow, ice storms, debris avalanches, rockslides, and rare lightning fires associated with decadal droughts. Recent anthropogenic stresses have included decline from air pollution and secondary pathogens, logging, clearing for land development, mining, fires, excessive deer herbivory, and climate change. More than half of the 32 described red spruce vegetation types are currently vulnerable to extinction or elimination due to their fairly restricted range, climate change, and other threats. On the positive side, the red spruce ecosystem has several key characteristics that impart resilience, including large tracts of relatively well-connected landscapes under public ownership, high current levels of biodiversity, and cooperation among conservation partners.

Ali Kosiba: *Disentangling the relationship between red spruce growth and climate*

Following decades of growth declines and increased mortality linked to acid rain, red spruce in the Northeast have been experiencing a period of increased growth. In a study of 52 red spruce plots (658 trees) across five states (MA, ME, NH, NY, VT), we found that more than 75% of red spruce trees and 90% of the plots exhibited increased growth since 2001. To understand this change, we assessed the relationship between red spruce radial growth and factors that may influence growth: tree age and diameter, stand dynamics, plot characteristics, temperature, precipitation, and acid deposition. We found that there was variability in response to climate and acid deposition by plot elevation and location, but plot and tree factors did not adequately explain growth patterns. Higher temperatures outside the traditional growing season (i.e., fall, winter, and spring) were related to higher growth, but there were both legacy effects from past conditions and complex relationships with moisture availability, suggesting a sensitivity to drought. Nitrogen deposition was associated with lower growth, but the strength of this relationship has lessened over time as air pollution has declined. Overall, we predict favorable conditions for red spruce in the near term as acid deposition continues to decline and non-traditional growing season (fall through spring) temperatures moderate; however, this is contingent on overall temperature and precipitation remaining adequate for growth.

Paul Schaberg: *Winter and shoulder seasons: periods of potential promise and peril for red spruce*

The northern border of red spruce's range is consistent with cold as a limitation to its competitive success. This has been verified by laboratory measurements of cold tolerance and assessments of foliar winter injury in the field. Indeed, red spruce's foliage is significantly less cold tolerant than that of other regional conifers such as eastern white pine, eastern hemlock and red pine. This limited foliar cold tolerance was not a significant limitation to red spruce's historic success, as evidenced by its predominance in regional pre-settlement forests. However, this marginal cold tolerance was a limitation during the era of high acid deposition because acid inputs leach calcium from forests and reduce red spruce cold tolerance, making needles vulnerable to injury and loss at ambient winter temperatures. But why would red spruce take this seemingly risky posture of having such limited cold tolerance? Likely because marginally cold tolerant foliage is better poised to gain carbon via photosynthesis. The various changes in foliar sugars, lipids and proteins that increase cold tolerance also reduce the photosynthetic potential of needles. The trade-off between cold tolerance and photosynthetic function has been verified for red spruce through controlled laboratory studies and evaluations of physiological changes during thaws in the field. Red spruce has been shown to drop more than 10˚C in cold tolerance in just a few days of winter thaw while simultaneously experiencing significant increases in photosynthetic capacity. Indeed, winter photosynthesis increases foliar sugars for red spruce when co-occurring angiosperms are leafless and other conifers are less physiologically active. The balance between potential freezing damage versus photosynthetic gain favored injury and decline during the peak of pollutant inputs to the atmosphere. However, studies of the relationship of red spruce radial growth to pollutant and climatic factors have shown that, with reductions in pollution loading and increases in temperature in the fall, winter, and spring, red spruce growth has increased across wide portions of its range. At least for now, red spruce appears to be realizing the promise of the trade-off between foliar protection and function during the cold season.

John Butnor: *Impacts of climate transfer distance on red spruce physiology*

Picea spp. populations around the world are adapted to local climates where they evolved, and functional traits (physiology, phenology, growth) may be affected when they are transferred to new locations. This is especially relevant to the Southern and Central Appalachians, where red spruce restoration efforts are actively being pursued and informed decisions about seed sources are needed. Across its range, red spruce exists in places with a mean annual temperature (MAT) of roughly 2-12°C but buffered from extended periods of high temperatures. A common garden experiment was designed to examine red spruce physiological adaptations and responsiveness to climate. Seeds were collected from both a broad geographic scale (latitude range 39-46° N) and a fine geographic scale (elevation range 425-1129 m) from a single mountain in Vermont (Mount Mansfield). Seedlings were planted at two elevations (425 m & 700 m) that differed by 2.3° C MAT. At the end of their second field season in September 2020, a variety of physiological measures were collected: ACi curves (photosynthetic capacity), temperature response curves (photosynthesis), leaf mass per area (LMA), chlorophyll content, fiber analysis (lignin, cellulose, hemicellulose), leaf N content, and growth. Climate transfer distance (CTD) was calculated as the difference between garden location MAT and seed source MAT (30 year average) and ranged from -2 to 6° C. A key finding was that trees moved to warmer climates (+ CTD) had greater LMA and higher rates of photosynthesis and photosynthetic capacity. However, there was a limit to the positive effects of warming, which peaked at +2-3° C before declining depending on seed source. The large level of differentiation by CTD exhibited at the fine geographic scale indicates that physiological adaptation can occur over very short distances, in this case a single mountain in Vermont.

John E. Major: *Physiology of red spruce: controlling for genetic and environmental factors*

For the restoration of red spruce *(Picea rubens)*, we need to understand its natural ecophysiological responses to various environmental factors in order to identify its environmental niche and thus its competitive advantage. It helps immensely to clearly identify/control the genetic factors, plant them across common garden plots, and control or measure environmental factors to evaluate their physiological responses. To help better understand red spruce, we will present some physiological and morphological results from comparative genetic factors, including geographic provenances, red spruce and black spruce *(P. mariana)* species comparisons, and comparisons to their hybrids. Environmental change responses include elevated CO_2, soil moisture stress, low temperature tolerance, and light levels.

Carrie Pike: *The genetics behind adaptation for restoration efforts*

Trees and plants are sessile organisms that are forced to adapt to conditions where they are planted. Environmental factors such as length of growing season, depth of cold in winter months, and drought during the active growing season impact survival of plants and trees. The ability to adjust to these conditions is dependent on many factors with both genetic and non-genetic origins. Genetic diversity is a vital component for species to survive a multitude of conditions where they are planted and is facilitated by the movement of genes across a landscape through seed and pollen. Gene flow can be rapidly measured through studies of population genetics that compare the prevalence of specific, albeit neutral, genes (or alleles) within and among populations. Gene flow is typically high in trees because of their stature and tendency for wind pollination and/or seed dispersal. Common garden studies, provenance trials or progeny tests, are useful for characterizing phenotypes of known lineages as well as the interaction of phenotype with environment. Taken together, a collective body of information on population genetics and phenotypic variation can lead restorationists to seed sources that are most likely to thrive in sites that are artificially regenerated.

Anoob Prakash: *Demographic history of red spruce and genotypic variation present in climate-adaptive traits after range expansion and fragmentation*

Climate change is predicted to shift the range limits of many species due to warming temperatures. However, the rapid pace of climate change will challenge the natural dispersal capacity of long-lived, sessile forest tree species such as red spruce. The history of red spruce does not inspire confidence in its adaptation to novel environments. Historical evidence indicates a temporal population decline that has been going on for thousands of years. Its survival is further threatened by its fragmented distribution, especially in its southern range. The genetic subdivision of the 65 populations in our study into three distinct genetic clusters makes the *in situ* response needed for survival more complicated. Thus, to understand the adaptive response of red spruce across its range, we looked at the level of plasticity, genetic variation, and correlations present in the climate-responsive traits.

More than 5,000 offspring were sampled from three genetically distinct regions (termed Core, Margin, and Edge) and grown in three common gardens replicated along a latitudinal gradient in Vermont, Maryland, and North Carolina. Genetic variation in phenology and growth showed differentiation among regions, suggesting some potential to respond to selection. Phenology traits were highly plastic, but this plasticity was generally neutral or maladaptive in its effect on growth, revealing a potential liability under warmer climates. These results suggest future climate adaptation will depend on the regional availability of genetic variation in red spruce, and they provide a resource for the design and management of assisted gene flow.

Brittany Verrico: *The importance of spatial scale in restoration efforts for red spruce*

Several studies have assessed phenotypic and genetic variation using a range-wide collection of red spruce distributed across a broad latitudinal gradient, but the relevance of genetic structure and adaptive trait variation at fine spatial scales (e.g., elevation) has been understudied. To investigate fine-scale genetic population structure, we used genomic data from 815 individuals spanning the elevation gradients on two different peaks in the Green Mountains of Vermont. We found weak but detectable genetic divergence between mountains but little to no divergence across the two elevational gradients, suggesting pollen and seed dispersals are expansive enough to prevent fine-scale structured genetic neighborhoods. To characterize the link between the spatial scale of environmental variation and the extent of local adaptation and phenotypic variation in red spruce, we initiated a common garden study (i.e. provenance trial). Replicated common gardens were established at multiple sites along an elevation gradient in Vermont, and within each garden we planted seedlings originating from 63 maternal trees sampled from a similar climate gradient but at contrasting spatial scales: fine (< 1 km) and broad (~1600 km). We found weak evidence of local adaptation in early-life performance traits among both spatial scales, but strong phenological (i.e. timing of bud set and flush) adaptation in broad scale families. While our results indicate that red spruce does show genetically based responses to climate, seedling performance is more severely impacted by cold temperatures and freezing damage than by warm temperatures. Together, these findings highlight an important relationship between spatial scale, genetic diversity, and local adaptation which can help inform red spruce restoration efforts.

Sean Hoban: *Sampling seeds for* ex-situ *conservation of genetic diversity*

The world's botanic gardens and seed banks, and other *ex situ* collections, provide an important conservation resource. They are used for safeguards, restoration, scientific study, and public outreach. However, it is not known how many individuals should be preserved *ex situ* of each species to conserve genetic diversity and adaptive potential, or how best to sample on the landscape. At the Morton Arboretum, with many collaborators, my team has investigated this question with empirical datasets and with simulations from numerous long-lived plant taxa in six genera (oaks, cycads, magnolias, hibiscus, palms, and ash), focusing on rare species but also including a case study in a common tree species *(Fraxinus excelsior)*. Our investigations have helped develop recommendations for on-the-ground sampling decisions such as how to spatially sample, when to stop sampling, and how to allocate effort among populations. These decisions matter for best use of conservation resources. We have shown that current collections of many rare taxa are not optimal—with improved collection strategies, collections could remain the same size and capture up to twice as much genetic diversity. There are also opportunities for duplication of collections to protect against disasters. In summary, many current plant collections are not (yet!) reaching targets, but new guidance can be achieved with data and models. Empirical data on local adaptation also need to be incorporated into this work to improve it in the future. I hope these results spark discussion and resolution on critical next steps for the plant conservation community.

Thibaut Capblancq: *Using genetic information to optimize reforestation efforts of red spruce*

Red spruce is a coniferous tree with a highly fragmented range in eastern North American montane forests. It serves as a foundational species for many locally rare and threatened taxa and has therefore been the focus of large-scale reforestation efforts aimed at restoring these montane ecosystems, yet genetic input guiding these efforts has been lacking. To tackle this issue, we took advantage of a common garden experiment and a whole-exome sequence dataset to investigate the impact of different population genetic parameters on early-life seedling fitness in red spruce. The level of inbreeding, genetic diversity, and genetic load were assessed for 340 mother trees sampled from 65 localities across the species range and compared to different fitness traits of 5,100 of their seedlings grown in a controlled environment. We identified an overall positive influence of genetic diversity and negative impact of genetic load and population-level inbreeding on early-life fitness. Those associations were most apparent for the highly fragmented populations in the central and southern Appalachians, where lower genetic diversity and higher inbreeding were associated with lower germination rate, shorter height, and reduced early-life fitness of the seedlings. These results provide unprecedented information that can be used by field managers aiming to restore red spruce forests and to maximize the success of future plantations.

Susanne Lachmuth: *Genomic offset as a tool to inform potential assisted migration in red spruce*

Human-induced climate change is disrupting species' local adaptation to climate at an unprecedented rate and will almost certainly exceed the ability of red spruce populations to rapidly adapt to new conditions *in situ* or to track favorable climate by dispersing to new locations. Climate-aware management may thus require substituting *in situ* conservation with assisted migration. The concept of genomic offset is a promising tool for using genomic information to assess climate change impacts and for climate-aware, predictive seed-provenancing in the context of assisted migration.

Genomic offset quantifies the disruption of existing genotype-environment associations under environmental change based on models of genomic turnover along environmental gradients. Here, we present the application of such a modeling approach in red spruce. We first evaluated the power of genomic offsets to predict red spruce growth in three common gardens. Following validation, we used the offsets to estimate the climate change risk that red spruce will face across its range under mid- and late-21st century climate. In addition, we applied genomic offsets to identify seed sources that have the best genomic adaptations to the future climate in a given planting area or, conversely, the most suitable future planting area for existing seed material.

We introduce a first version of an interactive web app that uses genomic offsets to identify seed sources adapted to future climate. During the workshop, we will survey and discuss participants' opinions on the implementation of additional app features, as well as the functionality and applicability of the app in restoration practice. Decisions about assisted migration are complex and require careful consideration of risks and benefits, taking into account the interests and ethical principles of various stakeholders. We hope that our research and tools such as the web app can provide useful information for evaluating and maximizing the expected success of potential translocations.

Jane Foster: Recent range-wide expansion of montane red spruce suggests where favorable restoration conditions may persist for decades

Montane forests of the eastern U.S. are dominated by red spruce *(Picea rubens)* and fir *(Abies)* species and surrounded by mixedwood transition zones. Restoration of red spruce in these mountain zones is subject to considerable uncertainty under climate change. Simple models predict retreat of montane forests, but diverse observations report that spruce and fir are recovering along ecotones, suggesting overlooked opportunities for successful restoration of red spruce. Here, we tested whether spruce-fir mixedwoods have changed in composition and extent across montane regions throughout the eastern U.S. We used multilevel models to test what might drive change in these systems, including stand dynamics, disturbance, and changing patterns in climate and atmospheric deposition. We analyzed a time series of Landsat data from 1984 to 2012 to map trends in montane spruce-fir composition and used Forest Inventory and Analysis (FIA) data to infer demographic change in red spruce and associated fir species.

We found that the conifer component in montane mixedwoods increased more than it decreased over 28 years. This pattern dominated montane ecotones of the Northeast but differed by geographic subregions. Spruce-fir increases declined with distance from a source population and increased with time since disturbance. Differences in the legacy of sulfate deposition significantly affected spruce-fir recovery in five of seven subregions and interacted significantly with minimum temperatures in four: Maine, Vermont, the Adirondacks, and the Central Appalachians. FIA data showed red spruce abundance increasing through growth and ingrowth from the sapling layer more than it declined, due to overstory mortality in every region except the Catskills, NY. This recent expansion of red spruce highlights areas for potential recovery and restoration from West Virginia to Maine, but leaves open the question of how sensitive red spruce will be to future changes at its southern extreme.

Dave Saville: *The Central Appalachian Spruce Restoration Initiative (CASRI): A collaborative approach to forest restoration*

CASRI is a 20+ year partnership of diverse interests with the common goal of restoring historic red spruce–northern hardwood ecosystems across the high-elevation landscapes of Central Appalachia. It has no Charter, Articles of Incorporation, Board of Directors, President, Chairman, Treasurer, or Bank Account. But it does hold quarterly meetings, keep minutes, organize and sponsor annual workshops and conferences, host a website (www.restoreredspruce.com) and an active Facebook Page, produce an annual report, and maintain an email list-serve to keep members and the public informed. It has an Action Plan and a Strategic Communication Plan. Work is guided by a detailed Restoration Approach, which defines restoration and sets out goals and objectives by which we annually evaluate our progress.

But CASRI is more than a collection of Agencies, Organizations, and Institutions. It is a collaboration of people. We are partners, allies, coworkers, teammates, and helpers. We are encouragers, problem solvers, enablers, supporters, and cheerleaders. We are a diverse collection of professionals from even more diverse backgrounds who recognize the importance of this ecosystem for its ecological, aesthetic, recreational, economic, and cultural values, and who share a passion for, and receive personal job satisfaction from, working towards CASRI's goals. Whether those goals are wildlife, clean water, soil carbon sequestration, climate change resilience, or merely a love of the magic of spruce forests, CASRI provides a means and an outlet for science-driven problem solving and cooperative goal achieving. And while we may not have a rigid collaborative structure or *modus operandi*, we do have a working framework established to help us all achieve our individual and organizational objectives, as well as our overall goals.

Katy Barlow: *Science, practice and conservation partnerships for forest climate adaptation*

The Nature Conservancy's Central Appalachians Program partnered with the University of Vermont's Ecological Genomics research group and public lands management agencies to implement climate-adapted restoration of red spruce forests across three states. Red spruce forests in the central Appalachians are fragmented from past land use and threatened by future warmer and drier climates. Restoration will enhance red spruce adaptive capacity by planting genetically diverse stock and increasing landscape connectivity. Restoration seed source locations were determined by identifying optimal combinations of three or four potential seed source populations within the region proximate to the restoration site that resulted in the highest ratio of genetic diversity to genetic load, using genomic data spanning populations across the Appalachians. This information guided our local conservation partner to produce over 100,000 red spruce from five sources, which were planted along with thousands of native hardwoods in the spring of 2021. Long term, communicative partnerships of scientists, management practitioners, and conservationists are what enable science-informed conservation at scale. Communications to advance climate adaptation strategies target a regional restoration collaborative, the Central Appalachians Spruce Restoration Initiative (CASRI), with a field workshop, and a national audience of public land-management partners with two films and an infographic.

Christine Kelly: *The Southern Appalachian Spruce Restoration Initiative's (SASRI) approach to restoring forests degraded in the past with an eye to future climate conditions*

The focus of the Southern Appalachian Spruce Restoration Initiative (SASRI) is on forests that, in their natural condition, would be dominated or co-dominated by red spruce or would have the species as a significant component in the overstory. SASRI endeavors to restore the system to as close to a natural condition as is feasible where this natural condition has been lost through past alteration. Degradation of these forests began with widespread logging of red spruce from the late 1880s to 1930s, wildfires in the resulting logging slash, and later impacts from acid precipitation and loss of mature Fraser fir forests to balsam woolly adelgid from the 1960s to 1980s. The regenerating forest covers a smaller extent and is skewed to hardwoods. SASRI formed in 2012 and issued a restoration plan in 2015 with goals to restore spruce to natural abundance in ecologically appropriate locations where canopy density has been reduced, to develop capacity to store seed and to grow seedlings, and to refine mapping and field criteria to support resilient restoration projects in the face of climate change. Projects are developed using a variety of resources, including logging history, maps of conifer cover, wildlife survey data, and current forest condition data, as well as SASRI guidelines for seedling propagation and silviculture prescriptions. Thus far, restoration projects have focused largely on improving habitat structure, composition, or connectivity for federally and state-listed endemic wildlife species. A combination of forestry tools is used to increase the diversity of tree species and size classes and to accelerate conifer growth rates in degraded stands. Examples include understory planting and release treatments to increase the conifer component in Carolina northern flying squirrel habitat and the creation of canopy gaps in even-aged spruce stands to diversify forest structure and composition for a variety of wildlife.

Pete Clark: *Assisted migration and red spruce restoration plantings as part of adaptive silviculture for climate change*

Tree species ranges are changing, but natural migration rates fail to track the pace of climate change, generating an interest in assisted migration. Simultaneously, forest management efforts aimed at species restoration (e.g., red spruce) or the potential replacement of threatened species (e.g., eastern hemlock, ash species) have led to greater attention to adaptation plantings. Although planting of seedlings has increasingly been viewed as a climate solution to maintain diverse, well-stocked, future-adapted forests, few empirical evaluations exist in the northeastern U.S. that test the performance of functionally diverse, mixed-species plantings in operational-scale silvicultural systems. Here we report on the three-year survival and growth response of seedlings planted for climate adaptation across northern hardwood and mixedwood forest types, with an emphasis on red spruce restoration plantings. Results show that the performance of seedling transplants was controlled by species, the strength of vegetative competition, local site adaptation and source distance, and extreme climate events, highlighting barriers for managing forests for shifts in composition. Despite forecasted declines in future habitat, red spruce seedlings had the highest rates of survival compared to all species tested, particularly those projected to be most "future-climate adapted" and to require assisted migration. The implications of this work highlight the potential inertia of red spruce recovery and restoration as well as the resilience mechanisms that maintain "ecological memory" of hardwood-dominated forests that resist efforts to introduce new or novel species.

Logistics

COVID-19 Restrictions

Masks are required indoors on UVM's campus, and visitors to campus are expected to be vaccinated. No other social distancing requirements are in place. Out-of-state visitors can take comfort in the fact that Vermont's vaccination rate is the highest in the country and that only 0.2% of vaccinated Vermonters have tested positive for COVID-19.

Meals

Breakfast will be available to guests at the DoubleTree Hotel each morning from 6:30 on. Just tell them you are a UVM red spruce workshop participant and they will bill us. Mid-morning and mid-afternoon **snacks and coffee** will be served in the main conference room each day.

<u>Thursday, September 9</u>

5:30-7 p.m: Informal outdoor gathering on the DoubleTree Hotel patio with pub food available on us and a cash bar. Open to all workshop participants. *DoubleTree Hotel, 870 Williston Rd, South Burlington*

<u>Friday, September 10</u>

12-1 p.m: Lunch vouchers will allow you to buy lunch from the Davis Center Marketplace (2nd floor)

6-9 p.m: Catered dinner with cash bar on the lakeside, covered outdoor terrace of the ECHO Leahy Center for Lake Champlain, Burlington's science museum. The first floor will be open to us—don't miss the tank of lake sturgeons! Paid parking is available in nearby lots, or the free College Street shuttle goes directly there from the edge of campus. *ECHO Center, 1 College St, Burlington*

<u>Saturday, September 11</u>

12-1 p.m: Boxed lunches provided.

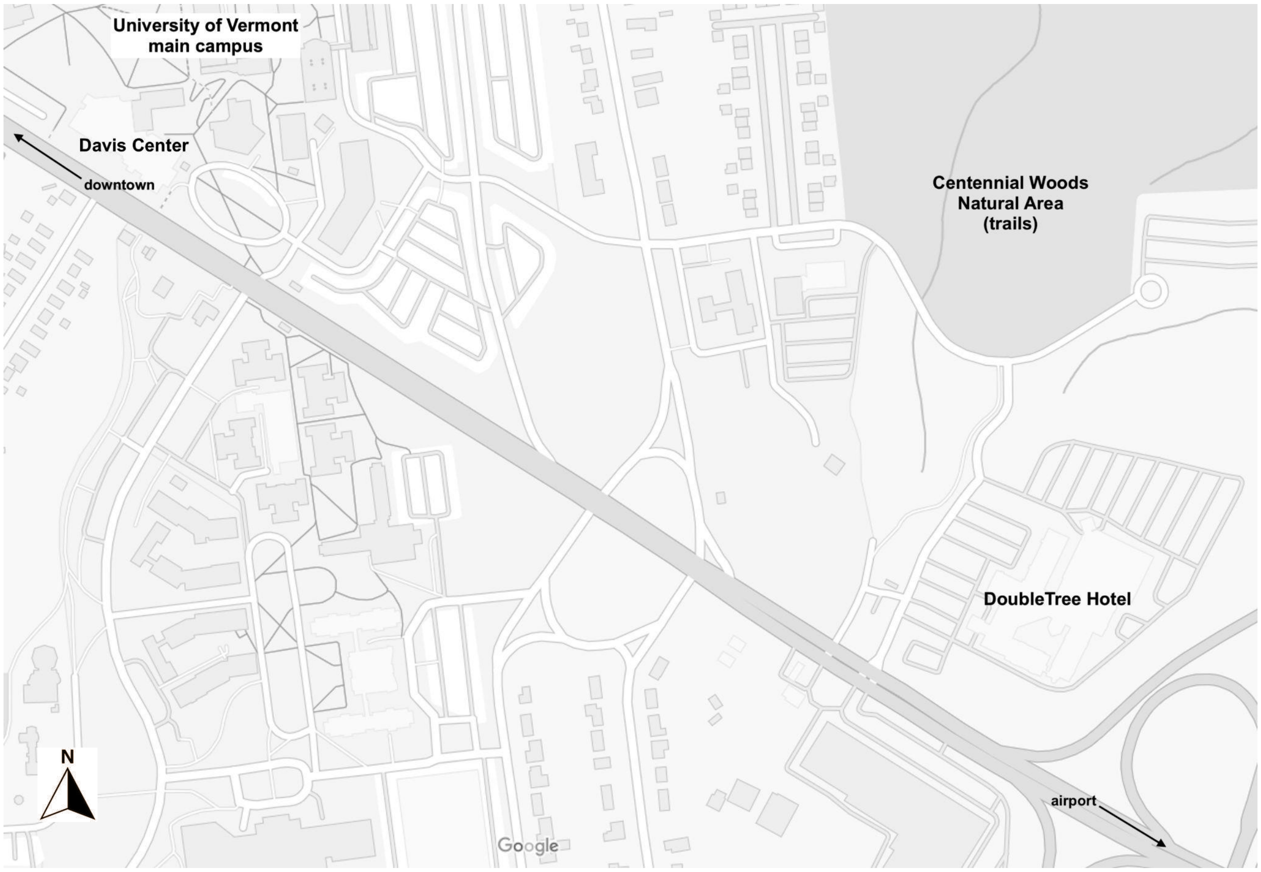
You are free to make your own arrangements for dinner, which we will reimburse if you submit your receipts.

<u>Sunday, September 12</u>

12-1 p.m: Boxed lunches provided during our field trip to Mount Mansfield.

Transportation

We can arrange airport pick-ups with advanced notice, and we'll arrange carpooling to Mount Mansfield for those taking part in Sunday's outing. Green Mountain Transit bus lines stop at the hotel and go to the airport and downtown. www.ridegmt.com



Note: The distance from the hotel to the Davis Center is about a half a mile.