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ABSTRACTS

Listed alphabetically by presenting author's last name.

The physiological mechanism of drought-induced tree mortality in *Pinus edulis*

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Abstract: Tree mortality due to drought, elevated temperatures, and attack by insects and pathogens has been observed in forests and woodlands around the world. This has inspired investigation into the physiological process of drought-induced mortality in trees. This research has focused on two proposed interactive mechanisms related to 1) a reduction in stored resources needed for metabolism and defense (carbon starvation), and 2) a loss of hydraulic conductivity in the xylem through increasing air embolism (hydraulic failure). No species has been better studied in this framework than two-needle piñon pine (*Pinus edulis* Englem.). Here we synthesize data on this species from experiments on seedlings, saplings, and mature trees in the field to assess the effect of ontogeny and increased temperature on the physiological response at drought-induced mortality. Percent loss of hydraulic conductivity (PLC) at death was high (≥65%) in all studies and unaffected by temperature, indicating that hydraulic failure is a consistent process in mortality across life stages in piñon pine. Experiments with both transplanted saplings and mature trees in the field have consistently found reduced non-structural carbohydrates (NSCs) at death. However, seedling NSCs were not reduced at death, suggesting a difference in mortality mechanism for earlier life stages. Lower NSCs in dying trees were mostly caused by lower starch, and seedling data showed a consistent shift in NSC storage from starch to sugar. In a sapling experiment, increased temperature did not affect NSCs relative to the ambient drought treatment. In seedlings, increased temperatures reduced NSCs whether plants were watered or died from drought, despite the lack of a drought effect. Our survey of physiological responses to lethal drought across life stages in piñon pine finds that hydraulic failure is ubiquitous, but that NSC responses during drought-induced tree mortality vary with ontogeny and temperature.

Global change increasingly imperils historical forests & large old trees worldwide: research & conservation challenges & opportunities

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Abstract: Although forest health currently appears robust in some forest regions, emerging global-scale patterns and trends of forest stress, die-off, and high-severity wildfire illustrate growing risks to historical forests in all biomes in response to hotter drought extremes and other global change stressors (e.g., land-use changes, invasive alien insects and diseases). An overview of diverse recent ecological research highlights potentials for extensive "tipping point" tree mortality responses to increased drought/heat stress – along with many countervailing compensatory and resilience-enhancing forest processes. In particular, both theoretical and empirical evidence indicates that larger (and often older) trees and forest stands are likely disproportionately vulnerable to increased growth stress and mortality under hotter drought conditions. The responses of the world's largest, oldest trees and historical forests to global

change are of particular interest, given that such ancient trees and forests are valued as: a) disproportionately large carbon sinks; b) among the most biodiverse and rare terrestrial ecosystems; c) irreplaceable archives of ecological history; and d) iconic for cultural and spiritual reasons. Despite the essential Earth-system roles of forests, amazingly large scientific information gaps and uncertainties constrain our ability to realistically project region-specific probabilities of forest turnover from mortality processes with expected climate changes this century. This presentation synthesizes recent progress on tree mortality research across diverse disciplinary approaches, highlighting both worrisome and hopeful findings – especially including key research and conservation challenges and opportunities regarding the future of the world's historical forests, with an emphasis on big ancient trees and old-growth forests.

Long-term data collection and trends of a 130-acre high desert riparian and upland preserve in southeastern Mohave County, Arizona

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Abstract: The Willow Creek Riparian Preserve (Preserve) is a privately owned 130-acre site located 30 miles east of Kingman, Arizona. The Preserve was formally established in 2007 with the purchase of 10 acres and an agreement with the eastern adjoining private landowner to add an additional 120 acres. The Preserve location was unfenced and wholly accessible by livestock, off-road vehicle use, and hunting. In October of 2008, the Preserve was fenced with volunteer efforts from the local Rotary Club and Boy Scout Troop 66. Additional financial assistance came through a large discount in the cost of fencing materials from Kingman Ace Hardware. A total of 0.5 linear mile of new wildlife friendly fencing (barbless top wire and 18 inches above-ground bottom wire) was installed along the south and west sides and connected to existing Arizona State Lands cattle allotment fencing. Baseline and ongoing studies and data collection have occurred since 2004. These have included small mammal live trapping, chiropteran surveys with the use of Anabat, migratory, breeding, and winter avian surveys, amphibian and reptile surveys, deployment of game cameras, animal track and sign identification and movement patterns, vegetation surveys, and a wetland delineation. Results and trends over a 10-year period show that livestock exclusion has demonstrated not only an increase in wildlife and plant diversity and habitat functionality, but an increase in overall abundance and wildlife use as well as additional natural habitat creation and wildlife use beyond the Preserve boundaries. Progressive natural habitat restoration within the Preserve has resulted in new and diverse suites of species based upon an increase of cover, structure, forage availability, nesting and burrowing opportunities, water availability, and other factors. Results show that small-scale conservation with minimal investments in time and money can result in positive and long-term effects for habitat restoration and associated wildlife.

Management influences forest structural development and canopy structural complexity

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Abstract: Forest canopy structural complexity is an increasingly studied component of forested ecosystems and there is evidence that structural complexity promotes increased light use efficiency and net primary productivity. However, little is known about how common forms of silviculture influence canopy structural complexity. In order to quantify the effects of single tree selection on forest canopy structure and light capture, we surveyed three long term (~60 year) silvicultural experiments in the north central United States. Each site had three treatments (low, moderate, and high basal area retention) and a control. Structural measurements were taken using portable canopy LiDAR (PCL), a user-mounted laser that fires pulses directly into the canopy and returns the height at which each was occluded. The *forestr* package in R was used to convert LiDAR point clouds into metrics of canopy structural complexity, which were then compared among treatments and controls. The fraction of above canopy photosynthetically active radiation transmitted (fPAR) was measured concurrently to assess how canopy structure and complexity influenced light capture. We illustrate that canopy structure (assessed as rugosity, or the variance of the vertical and horizontal arrangement of canopy elements) became simplified under all levels of single tree selection studied. Treatment means were 13.9, 16.8, 17.1, and 24.7 for the low, moderate, and high retention levels and the control, respectively (F value=9.16; P<0.001). While previous studies have found positive correlations between fPAR and canopy structure, fPAR was similar across all treatments in this study. These results suggest that traditional single tree selection leads to less complex crown structure, but fail to demonstrate a clear relationship between structure and canopy light interception in

this system. Results further imply that structural simplification of north-central US forest canopies could be occurring on a broad scale with direct implications for biodiversity and carbon sequestration.

Change in pinon-juniper woodland cover since Euro-American settlement: expansion versus contraction associated with soil properties

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Abstract: Woodland and forest ecosystems across western North America have experienced increased density and expansion since the early 1900s, including in the widely distributed piñon-juniper vegetation type of the U.S. Southwest. Fire suppression and grazing are often cited as the main drivers of these historic changes and have led to extensive tree-reduction treatments across region. However, much of the scientific literature on piñon-juniper expansion dates back only to the early 1900s, which is in most cases a half a century after Euro-American settlement. This study uses General Land Office surveys to establish piñon-juniper woodland extent in the late 19th century at the incipient stages of Euro-American settlement in southeastern Colorado and compares this data with 2017 aerial imagery of woodland cover. We found substantial amounts of woodland contraction as well as expansion: approximately 61% of historically dense woodland is now savanna or open (treeless) whereas approximately 57% of historically open areas are now savannas or woodlands, although analyses at finer spatial scales suggest considerably more contraction relative to expansion. The highest rates of expansion occurred on shallow, rocky soil types with low soil available water capacity (AWC). These low soil AWC areas support little herbaceous vegetation and thus had less grazing pressure and were unlikely to carry frequent surface fires historically, suggesting that fire suppression and grazing were not the primary drivers of expansion. Meanwhile, the significant contractions in woodland extent occurred on deeper, upland soils with higher soil AWC, which were likely where early settlement and tree cutting was prevalent. Our results provide mixed support for the often widespread assumption of woodland expansion since Euro-American settlement and suggest that the expansion that has occurred is unlikely a result of past grazing or fire suppression.

Forest density impacts resilience by altering drought-driven soil moisture deficits and forest growth declines

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Abstract: Managing forest density is widely recognized as a strategy to mitigate the negative effects of increasingly severe droughts due to climate change. However, most evaluations of these effects focus on forest response to periods of known drought, or to measures of climate alone, instead of considering the impact of water that is readily accessible to these communities within the soil profile. We simulated site-specific, multi-layer, soil moisture using a proven ecosystem water balance model, taking into account density specific effects on hydrological processes (i.e. interception, transpiration). These simulations were paired with dendrochronological data from a long-term (multi-decadal), ponderosa pine (*Pinus ponderosa*), forest management experiment near Flagstaff, AZ, with replicated levels of basal area density to evaluate the how forest density altered relationship between the quantity and timing of soil moisture and stand-level growth response. Our results demonstrate that stand-level growth is highly responsive to the combination of hot temperatures and low soil moisture, and we present a new metric of hot-drought stress that may be useful for anticipating forest response to drought under warming conditions. Growth in higher density stands displayed was more responsive to fluctuating conditions, while lower density treatments maintained more stable growth rates in the face of varying temperature and soil moisture. We found that growth in the current year is not only influenced by the current climate, but is also affected by conditions from a period of up to two years prior. These results provide insight into how interactions between temperature and soil moisture influence forest growth across a range of stand density treatments, and illustrate new details about how reducing plant density in water-limited forested ecosystems can mitigate drought stress and maintain growth both during and after drought events.

Chronic ungulate herbivory slows forest recovery following synchronous outbreaks of spruce and western balsam bark beetle

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Abstract: Understanding when individual disturbances and disturbance interactions compromise recovery mechanisms to alter vegetation trajectories to non-forested states is key to projecting future ecological changes. From 2005 to present, severe outbreaks (> 90% mortality) of spruce beetles (*Dendroctonus rufipennis*) affected Engelmann spruce (*Picea engelmannii*) in the San Juan Mountains, CO. The central mechanisms promoting recovery of stands affected by spruce beetle is the survival of non-host species [e.g., subalpine fir (*Abies lasiocarpa*) and aspen (*Populus tremuloides*)] and height growth release of juveniles to supplement the next forest canopy. Here we examine the effect of severe ungulate herbivory on juveniles and the concurrent mortality of subalpine fir by subalpine fir decline – a complex of western balsam bark beetle (*Dryocoetes confuses*) infestation and other biotic agents (e.g. *Armillaria* spp.) – on the feasibility for a return to a forest vegetation type (i.e. resilience). We collected field data on pre- and post-beetle outbreak stand structure and composition and ungulate herbivory on juvenile trees at 105 sites affected by varying severities of spruce beetle outbreak and subalpine fir decline. Stands with greater pre-outbreak structural and compositional complexity were less severely affected by spruce beetle or the combined effects of spruce beetle and subalpine fir decline as evidenced by high abundances of non-host trees in the main canopy and juvenile trees post-outbreak. Such stands support a high capacity to return to a forest vegetation type (86%). Stands composed exclusively of large-diameter spruce (i.e. low structural and compositional complexity) are most vulnerable to conversion to a woodland state. Shifts in relative composition of the main canopy to non-host species occurred in all multi-species stands. Ungulate herbivory on > 50 % of juveniles will severely slow recovery and preferentially limit the expected rapid height growth release of some species, creating uncertainty about the composition of the next forest canopy.

Response of the deciduous forest of southeast Canada to the severe drought of 2012

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Abstract: Prolonged drought is a climatic phenomenon that affects trees. The temperate hardwood forest in the Ottawa-Gatineau region (Canada) experienced extreme drought during the summer of 2012, with temperatures of 1.8°C above the long-term average and a 50% reduction in precipitation. Our study documented the impact of this phenomenon during the subsequent two years. In 2013, twelve temporary study plots with a range in density of canopy cover were installed along the Eardley escarpment of Gatineau Park. Tree mortality was considerably higher in 2013 (11.74%, SE=2.75%) compared to 2014 (3.88%, SE=1.27%) and the annual mortality average of 2%. White oak (*Quercus alba* L.) had a mortality rate twice that of red oak (*Quercus rubra* var. *borealis* Michx F.) and three times higher than that of sugar maple (*Acer saccharum* Marsh.) Mortality increased with the opening of the canopy ($P<0.0001$). Trees classified as dying in 2013 were assessed again in 2014; we found that 77.0% (SE=8.16%) of them survived. In 2013, sugar maple exhibited a greater rate of stump sprouting than both oak species, even in the case of dying individuals ($P<0.01$). We observed that there was a species transition towards white ash (*Fraxinus pennsylvanica* Marsh.) in 75% of the sample plots, to the detriment of white oak on xeric sites and of sugar maple on mesic sites. In light of these results, this unique site, which is of importance for biodiversity in southern Québec, shows major signs of degradation that may not be reversible under more frequent extreme events.

Bark beetle mortality patterns and random forest classification across a latitudinal gradient of sentinel sites in the Sierra Nevada, California

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Abstract: California experienced a severe drought from 2012 to 2016 that included historic dryness and warmth resulting in a massive wave of tree mortality across the state. As of 2018, over 147 million trees have died across 9.7 million acres since 2010. The response of native bark beetle populations to drought stressed trees in the Sierra Nevada, particularly the southern Sierra, precipitated the worst

insect-mediated mortality event recorded in the state. To examine mortality patterns and causes, we established eight sentinel monitoring sites in mixed conifer forests on five ownership categories along a latitudinal gradient in the Sierra Nevada in 2017. In 283 plots we measured overstory and understory trees, shrub cover, and surface fuels. Here we present patterns of overstory mortality and residual overstory structure and composition. For bark beetles, we analyzed our entire plot network by species: fir engraver (*Scolytus ventralis*), mountain pine beetle (*Dendroctonus ponderosae*), and western pine beetle (*Dendroctonus brevicomis*) using random forests as an exploratory tool to inform logit regression models. Across our sentinel sites there was a clear trend of lower tree mortality in the north (Plumas National Forest: 2.5% of basal area (BA)) versus the central (Yosemite National Park (NP): 44.8% BA) and southern Sierra Nevada (Sequoia-Kings Canyon NP: 33.8% BA). The contribution of bark beetles to recent tree mortality ranged between 2.7% to 33.7% and the fir engraver was the most damaging beetle across our site network. Random forest by bark beetle species indicated that plot level factors including density, stocking, slope, elevation, and aspect were the most important variables for classifying bark beetle mortality. In terms of climatic drivers, spring and summer precipitation were the most important variables for fir engraver, while spring and summer minimum vapor pressure deficits were the most important variables for western pine beetle mortality.

Co-construction of ecosystem services management in tribal lands: Elicit expert opinion approach

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Abstract: The Mescalero Apache Tribal Lands (MATL) provide a diverse range of ecosystem services, many of which are of fundamental importance for the Mescalero Apache Tribe's well-being. Managing forests on MATL, especially under climate change, would involve prioritizing certain ecosystem services which may lead to a decrease in other services. This study identifies those ecosystem services that have (1) high utility - services that the Tribe uses, or could use, and are obtained directly or indirectly from the MATL; (2) irreplaceable - services that cannot be provided by any other natural resource; and (3) high level of threat - services in risk of declining or being lost directly or indirectly by climate change, thus critical for management. We used an iterative survey of experts' opinions, including scientists and practitioners, regarding the MATL and their main ecosystem types. The analysis of responses showed that (1) dry mixed conifer forests are perceived as the ecosystem providing more services and under a higher level of threat of declining due to climate change, (2) water is perceived as the most important ecosystem service, and (3) ecosystem services identified as management priority are water, teepee poles, firewood, timber, moderation of extreme events, game animals, cultural importance and sense of place. Management recommendations to mitigate and adapt to climate change effects include reintroduction of fire in the landscape, assisted migration, create age/size mosaics across the landscape and incorporation of green energy. Incorporating human perspectives into natural resource management is a critical component to maintain and adapt social-ecological systems to climate change, especially with tribal stakeholders that are deeply connected to natural resources. This study demonstrates how knowledge systems are complementary and diverse perspectives related to values and threats of ecosystems can be incorporated to co-construct ecosystem management decisions. A similar approach can be applied in other forested ecosystems managed for multiple values.

Contribution of abiotic and biotic predictors to distribution models for invasive species in western U.S. forests across spatial resolutions

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Abstract: A central question in macroecology and biogeography concerns the scale at which abiotic and biotic determinants of species' distributions act. Long-standing theory underlying the construction of species distribution models (SDMs) predicts that abiotic constraints determine species' distributions at the landscape to global scales, while interactions with co-occurring species are predicted to act primarily upon the local distribution. Tests of this theory have yielded equivocal results, and examinations of its applicability to invasive plant species' distributions are particularly rare. In this study, we examined the contributions of abiotic and biotic predictors to models for the regional distribution of six common invasive plants in western U.S. forests across five spatial resolutions. We used generalized linear mixed models and variance partitioning of logistic regressions to determine whether the contribution of biotic predictors to the deviance explained by models decreases with decreasing spatial resolution, the contribution of abiotic predictors increases, and the redundancy in the deviance explained by each predictor class also increases. Models constructed

using solely abiotic predictors did not differ significantly from those containing both abiotic and biotic predictors at any of the resolutions we examined, providing support for the practice of constructing regional-scale SDMs using solely abiotic predictors. Contrary to predictions, the relative contributions of abiotic and biotic data to models did not change with decreasing resolution, and the redundancy in the deviance explained by these predictors also remained similar across spatial resolutions. We interpret this as an indication that biotic predictors are correlated with invasive species distributions even at the low resolutions typical of SDMs. Thus, while the precision and accuracy of models built with solely abiotic predictors may not differ significantly from those built with both abiotic and biotic predictors, the latter are likely to yield more accurate models across scales.

Life or death decisions: Using forest inventory data to improve post-fire mortality modeling and management

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Abstract: Forest managers need more accurate models to predict tree mortality following fire to successfully adapt to the emerging trend of larger, more frequent fires as well as more intense droughts. Mortality models predict mortality as probability of death, which requires modelers to define when a tree is dead. This is a crucial decision point within the socio-ecological context of fire management. For example, management actions to mitigate risk based on an under-prediction of mortality of larger trees may not achieve the desired outcome of protecting habitat and cultural values provided by larger trees. Conversely, under-prediction of mortality might contribute to less early successional habitat than managers had intended to create through management activities. We used data from 438 FIA fire-affected plots in CA, OR, and WA that were re-measured 1-2 years post-fire to assess effects of fire on tree crowns (%). These plots span 105 fires from 2003 and 2015, with over 11,442 fire-affected trees. We used pre-fire dbh and crown scorch to assess the accuracy of logistic regression to predict first-order fire mortality. The most abundant conifer (Douglas-fir) had observed mortality of 38%. The most abundant hardwood tree (canyon live oak) had mortality of 62%, based on aboveground mortality. At the mortality-probability cutoff of 0.7, the prediction accuracy was 70% but climbed to 88% at 0.9. For the 1,804 Douglas-fir trees, a 0.7 cutoff resulting in 83% accuracy while 0.9 was 92%. For the 1,711 canyon live oak trees, the effect of increasing the cutoff was more dramatic, with a 0.7 cutoff had 48% accuracy while it increased to 88% at a 0.9 cutoff. I will discuss these results and the logic behind selecting an appropriate cutoff in the context of research into improving mortality modelling and silvicultural models to better manage forests in light of changing climate.

Increasing resiliency in ponderosa pine forests of the southern Rockies: Using elements from the past to guide future forests

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Abstract: Ponderosa pine (*Pinus ponderosa*) forests are a dominant ecosystem across the western United States. Historically, this ecosystem experienced frequent fires that created and maintained a mosaic of diverse forest structures across the landscape. However, a century of fire exclusion and harvesting has increased the tree density and canopy cover of these forests, and increased the prevalence of shade-tolerant, fire-prone species. This change in forest structure has resulted in undesirable outcomes during contemporary wildfires, such as large-scale tree mortality, vegetation type conversion, loss of human life and infrastructure, and impacts to municipal water sources. Concern for community safety, impacts to watershed health, and the loss of ecosystem function and resilience has stimulated forest management activities that attempt to increase the adaptive capacity and resilience of these ecosystems to future wildfires, insect outbreaks, and climate change. Initial treatments focused on reducing tree density without considering the ecological processes and outcomes of historical disturbance regimes. However, there is increased recognition for the importance of incorporating natural disturbance and subsequent stand development into silvicultural prescriptions to increase resiliency. Current research is focused on quantifying the historical forest density, composition, and structural heterogeneity of ponderosa pine-dominated forests to inform the principles of ecological forestry for this forest type. Land managers are implementing restoration treatments that utilize this information to increase the resiliency of these forests to current and future disturbances. In this presentation, we provide the results from historical dendrochronological reconstructions and how they are being implemented into treatments across the landscape.

Colorado Adaptive Silviculture for Climate Change: San Juan National Forest

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Abstract: Forest managers need robust examples of integrating climate change adaptation into silvicultural planning and on-the-ground actions. To address this need, an installment of the Adaptive Silviculture for Climate Change study was established in a dry mixed conifer forest on the San Juan National Forest to evaluate various management options designed to enable forests to respond to a changing climate. Climate in this area is expected to get warmer with longer growing seasons, fire seasons, and cycles of drought conditions. Furthermore, much of the dry mixed conifer forest structure is outside its historical range of variability due to fire exclusion, grazing, and harvesting. These activities have resulted in dense forests that contain an excessive amount of white fir compared to historical densities when fire helped regulate forest structure. Three adaptation treatments were developed to demonstrate a gradient of accommodating change: resistance, resilience, and transition. The resistance treatment focused on reducing forest density while maintaining similar proportions of the current forest species composition. The resilience treatment focused on density reduction with the priority removal of white fir and the creation of tree groups of drought tolerant ponderosa pine and Douglas-fir with tree-free openings. The transition treatment focused on the complete removal of white fir, creation of openings up to one acre, and maintenance of ponderosa pine. This replicated study will contribute to the broad understanding of adaptive management strategies designed to address the uncertainty of climate change while testing site-specific effects on forest resiliency to increased wildfire potential, drought, disease, insects, and other disturbance factors relevant to the San Juan National Forest and other dry mixed conifer forests in the region.

Seed source, climate, and disturbance history constrain regional patterns of ponderosa pine seedling density in California, Oregon, and Washington

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Abstract: The vulnerability of dryland forest ecosystems to regeneration failure, and thus long-term forest declines, may increase under climate change in western North America. However, landscape- to regional-scale responses are likely to be mediated by disturbance dynamics and resulting landscape vegetation patterns. Ponderosa pine (*Pinus ponderosa*) forests are particularly interesting as they are increasingly exposed to climate and disturbance stressors and because they are high priorities for ecological restoration. In this research, we assess the role of climate, disturbance, and vegetation pattern in determining ponderosa pine seedling density across its distribution in California, Oregon, and Washington. We incorporate USDA Forest Service Forest Inventory and Analysis plot data from the ponderosa pine forest type (n=3186) with satellite-based disturbance and vegetation maps to quantify regional patterns of seedling density as a function of climatic water deficit, past disturbance (time since disturbance, disturbance magnitude; 1985-2017), and forest conditions (tree density, abundance of ponderosa pine adults). Our results indicated that proportional abundance of ponderosa pine (% basal area) was the strongest predictor of ponderosa pine seedling density and exhibited a positive relationship, implying that local availability of seed was a major determinant of recruitment success. Seedling density decreased with disturbance magnitude and increased with time since disturbance after 20 years, indicating that high severity disturbances dampen or delay seedling recruitment dynamics. The greatest ponderosa pine seedling densities were observed at intermediate climatic water deficits characteristic of the core ponderosa pine distribution in the region. These results imply that seedling densities are most constrained by seed source availability, with climate and disturbance defining landscape-level gradients in tree recruitment. Geographic patterns of dryland forest vulnerability to climate-induced decline likely depend on the distribution of undisturbed forest and low-severity disturbance patches.

Species mixture effects on above-ground productivity of young tree communities under high and low soil moisture conditions

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Abstract: The International Diversity Experimental Network with Trees (IDENT) consists of a network of seven multidisciplinary field research trials, established to examine diversity effects on productivity and ecosystem functioning of mixtures, using high density plantations. The IDENT trial at Sault Ste. Marie, ON, established in 2013, examines how soil moisture availability influences species growth in mixtures and monocultures. Six native North American tree species (*Acer saccharum (As), Betula papyrifera (Bp), Larix larcinia (Ll), Picea glauca (Pg), Pinus strobus (Ps), Quercus rubra (Qr)*) were planted as monocultures, and 2 (n=9), 4 (n=6), and 6 species mixtures in 49 tree plots. All combinations were treated with irrigation or drainage. The high soil moisture plots were irrigated weekly with the equivalent of 2.54 cm of rainfall from June 1 to August 31 from 2014-2018. The low soil moisture plots were not irrigated and contained a rainfall exclusion apparatus that removed ~25% of ambient precipitation from May-October. The irrigation and exclusion treatments created differences in annual soil moisture availability, dependent on ambient weather conditions; therefore, we can compare drier years (2018) against more moist years (2017). Irrigation had a positive effect on total height and aboveground biomass of most species in both years. Species richness and type of mixture had significant effects on height and biomass production. Shade intolerant *Bp* and *Ll* biomass increased in more diverse mixtures. In more shade tolerant *As, Pg*, and *Ps,* growth was reduced in mixtures compared to monocultures. Mid tolerant *Qr* was largely unresponsive to mixture or richness. These differences were exacerbated in drier years, where *Bp* and *Ll* showed higher height and biomass in irrigated and more diverse mixtures, contrary to the other species. Mixture effects can favor or reduce species growth depending on species composition, and mixture effects change with water availability.

Estimating forest restoration treatment effects on forest structure: multitemporal UAV SfM model and multispectral image analysis

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Abstract: The ponderosa pine (Pinus ponderosa) forests across Arizona have undergone significant changes in their structure and composition since European-American settlement in the 1860's. At present, Southwestern ponderosa pine forests are dense with homogenous tree stands rendering the forest more susceptible to catastrophic wildfire and insect outbreaks. In an effort to mediate the present and future impacts of overcrowded forests, the Four Forests Restoration Initiative (4FRI) was formed in 2010 to plan, implement, and monitor restoration projects across a 2.4 million acres of federally managed forests. Restoration treatments are now well underway and there is a need to rapidly monitor and assess the changes to better inform adaptive management decisions. This study aimed to provide an accurate, cost-effective, and timely solution for forest restoration treatment monitoring by using multi-temporal high resolution multispectral images and structure from motion (SfM)-derived point cloud data from a fixed-wing unmanned aerial vehicle (UAV). Images were acquired before and after a forest thinning treatment. We estimated changes in stand-level canopy cover, tree density, forest patch and interspace characteristics, and quantified individual tree locations and characteristics. Results from a 73.6 ha restoration treatment study area indicate 70% reduction in the number of trees, and a 27% reduction in percent canopy cover. We discuss considerations related to data acquisition, SfM algorithm parameterization, and the effectiveness in deriving specific forest structure metrics for restoration planning, which can substantially affect the processing workflow and subsequent data products.

Variable retention harvest promotes early carbon sequestration in boreal forest biomass

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Abstract: Implementation of effective carbon management strategies for the boreal forest will require a sound and accurate understanding of carbon sequestration. Most present management scenarios aiming to preserve or enhance carbon storage are based on model estimates derived from forest types or management areas that are not always in line with local conditions. To explore the impact of such variation, we empirically quantified carbon storage in four common mixedwood forest types defined by overstory canopy (Deciduous dominated, Deciduous dominated with spruce understory, mixedwood, and Coniferous dominated) in northwestern Alberta, Canada. Furthermore, we assessed how carbon storage was affected by five retention harvesting intensities (2%, 10%, 20%, 50%, 75% green-tree retention) in comparison to unharvested stands, based on data collected at 2, 5, 10 and 15 years post-harvest. We found that mature boreal mixedwood forests stored between 230 and 300 tons of carbon per hectare (70% of it

belowground), and that storage increased with proportion of conifer trees in the stands. Interestingly, with as little as 10-20% retention of the original tree basal area in harvested deciduous dominated sites, they continued to function as carbon sinks early post-harvest. In contrast, conifer stands immediately became carbon sources, reflecting residual tree death. Despite major carbon loss from dead root and log decomposition, combined growth of regeneration and residual trees allowed deciduous dominated stands to maintain positive carbon accumulation. However, carbon loss due to mortality and decomposition of residual trees for both mixedwood and coniferous dominated stands was four- to six-fold larger than carbon sequestration in regenerating trees. Through application of a variable retention system at the landscape level with retention level adjusted to accommodate the influences of canopy composition, forest managers may encourage net positive carbon sequestration throughout an entire forestry cycle.

Comparing below-ground vs. above-ground metrics of stand condition and regeneration potential in aspen (*Populus tremuloides*)

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Abstract: Aspen (*Populus tremuloides*) regeneration in the Intermountain West is often accomplished through coppicing, and stand condition at the time of harvest is often used to predict regeneration success. Stand condition is typically assessed using above-ground metrics. Since aspen regenerates via its surviving root system, below-ground metrics would be informative, but are not generally used due to a larger labor investment and a lack of knowledge about how root conditions relate to regeneration potential and above-ground condition. We propose that below-ground metrics, alone or in conjunction with above-ground metrics, have the potential to improve prediction of regeneration potential in aspen stands. In 24 aspen-dominated sites across Utah, we collected data on both above- and below-ground stand condition. For below-ground condition, we collected aspen root biomass and size class data from six sample trenches per site. As a surrogate for vegetative regeneration potential, a subset of roots from each trench were placed in vermiculite and allowed to sucker for five weeks in greenhouse conditions, and root-suckers per surface area of root was measured. Prior to suckering, we sampled the roots for non-structural carbohydrates (NSC) to assess how NSC concentration and the size of NSC pools related to stand condition. We discuss our findings and the potential of this below-ground approach to improve regeneration predictions and land management decisions.

Effects of elevation and heat load on the landscape-scale distribution of male and female trees in aspen (*Populus tremuloides*)

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Abstract: Dioecious plants can exhibit sex-specific physiological traits that manifest as distinct landscape scale distributions, putatively due to the energetic burden associated with seed production in females. In aspen (*Populus tremuloides*), when distribution is patchy and clones are large, a strong distributional sex bias may limit successful fertilization opportunities and seed production. Variation in distribution by sex has only been described for aspen in limited, local-scale studies, with the ratio skewing higher towards males at higher elevations. Aspen sex ratios have not been assessed at a large spatial scale. We hypothesize that if seed production and physiological constraints limit female success in harsher habitats, the overall sex ratio of aspen genets on the landscape will be male-biased both at higher elevations and at sites with a greater heat load index. We sampled leaves from approximately fifty individual trees from each of thirty-three, 30 x 30 km sites across the Intermountain West. Tree sampling was intentionally distributed across elevational and moisture gradients within sites. Sex was determined using a genetic marker. Elevation and heat load index for sampling locations were determined by transforming and extracting values from USGS 10 m DEMs. A Bayesian analysis of a Bernoulli generalized linear model (GLM) was used to assess the association between aspen sex ratios and elevation, heat load index, and their interaction. Results at the study-wide scale indicate an increase in the male-to-female ratio of aspen as elevation and heat load increase separately, but no interaction between them. Site-level associations between sex ratios and elevation and/or heat load were highly variable and may have more to do with local variation than an overarching trend on the landscape.

Georgia Adaptive Silviculture for Climate Change: The Jones Center at Ichauway

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Abstract: Longleaf pines have persisted through millennia of climatic change in the southeastern USA, but recent rapid anthropogenic change presents an unprecedented challenge. Climate changes stemming from elevated atmospheric carbon dioxide levels are likely to include more droughts and intensified wind storms. Using the principles of the Adaptive Silviculture for Climate Change Network, we developed three prescriptions for southern mixed pine-hardwood forest. The *resistance* prescription enhanced fuel bed connectivity through removing hardwoods and off-site pines; the *resilience* prescription involved a small decrease in longleaf density while retaining response diversity (capping longleaf basal area at 11.5 m^2 ha^{-1}, removing mesic hardwoods, and limiting drought-tolerant hardwood basal area to 2.3 m^{-2} ha^{-1}); and the *transition* prescription planted drought-tolerant seedlings and forestalled drought stress by capping longleaf pine basal area at 6.7 m^{-2} ha^{-1}, and removing mesic hardwoods and limiting drought-tolerant oaks to 1 m^{-2} ha^{-1}. The prescriptions were intended to be simple and easily applied, and harvest treatments were implemented early in 2018. Mean basal area before treatment was 13.7 m^2 ha^{-1}. The treatments successfully reduced longleaf basal area close to target levels. Lack of a market for hardwoods necessitated girdling large oaks rather than outright removal. Oak basal area was successfully reduced in resilience (1.9 m^{-2} ha^{-1} residual) and transition treatments (1.1 m^{-2} ha^{-1} residual), but these values did not differ significantly. On October 10, 2018, hurricane-force winds struck the site; the strong force of the winds was a result of climate-change-related intensification. Treatments potentially affected damage from severe winds in two ways: decreased damage by reducing hardwoods, which tend to be more vulnerable than softwoods to wind damage, or increased windthrow from opening up the canopy. Analysis of damage patterns provides an early test of the principles of the Adaptive Silviculture for Climate Change program.

Gaga for gaps: comparing restoration approaches in Sierran mixed-conifer and southeastern longleaf forests

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Abstract: Although widely separated geographically, Sierran mixed-conifer and southeastern longleaf pine ecosystems share similar attributes. These forest types were both historically structured by recurring, low-intensity fire and were characterized by open canopies, moderate stocking levels, and sparse midstories. Despite their similarities, differences in climate, productivity, and fire regimes distinguish these ecosystems. Today, both forest types are increasingly a focus of restoration efforts. We explore historic, climatic, and fire-related factors that influence similarities and contrasts in restoration approaches. Fire exclusion is a common factor in the degradation of mature examples of both forest types, although the results of fire exclusion differ and lead to differences in management interventions and restoration pathways. Restoration of both forest types can also begin from starting conditions that require afforestation or reforestation, but cultural practices differ. Once management interventions have begun to shift forest structure towards desired conditions, reestablishment of a fire regime is desirable for continued maintenance of forest structure and function for both forest types. However, differences in climate, productivity, decomposition, and fuel distribution and loading require different approaches to fire management. The results of these comparisons are used to explore how elements of Sierran and southeastern approaches to management and restoration of long-needle pine ecosystems might contribute to each other.

Abies religiosa seedling limitations for passive restoration practice at the Monarch Butterfly Biosphere Reserve

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Abstract: In order to recover a degraded ecosystem, two strategies of ecological restoration can be applied: active restoration which eliminates disturbance agents and implements strategies to accelerate site recovery, while passive restoration eliminates disturbance agents allowing natural regeneration to happen and is claimed lately to be a more natural and low cost strategy. Before choosing passive restoration, a field evaluation of natural regeneration potential is needed. We evaluated in 2015 some biotic and abiotic factors that influence sacred fir (*Abies religiosa*) seedling density in the Monarch Butterfly Biosphere Reserve (MBBR) along an altitudinal

gradient (3050-3550 m asl). There was a higher density of seedlings at intermediate elevation sites (3050 to 3300 m asl) within canopy openings, but recruitment to other categories was low. In a second follow up survey we characterized *Abies religiosa* seedling survival through time in order to identify the environmental variables that caused the large seedling mortality above mentioned (local land owners and forest technicians claim moss layer as the main cause of seedling mortality). We labeled 661 seedlings and measured mortality each month and also soil moisture and moss thickness and moisture. Seedling survival was 51.8% at the end of the dry season (June 2016). The highest monthly mortality (14.3%) was registered in April, the month with lowest moss and soil moisture. We found no negative effects of the moss layer in seedling survival; actually, it prevents soil moisture from decreasing more quickly in April and May. Nowadays we are comparing the effectiveness of both restoration strategies (active vs. passive restoration) applied in 2016 in a 10 ha illegally logged site at the MBBR. After three years, planted seedlings showed 75% of survival while establishment of natural sacred fir seedlings has occurred in the surrounding forest but not at the logged site.

Scaling the issue of changing disturbance regimes: Implications of novel landscape conditions for black stain root disease

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Abstract: Changes to disturbance regimes resulting from shifts in forest management practices are creating novel landscape conditions in the Pacific Northwest (PNW). We analyzed the implications for black stain root disease (BSRD) of Douglas-fir, a native fungal disease. BSRD spreads via root contact and insect vectors and causes rapid decline and mortality in young Douglas-fir (below age 30-35). Management practices including thinning, harvest, soil compaction, and roadside disturbance are associated with increased BSRD incidence. Decreases in rotation lengths are altering Douglas-fir age class distributions, and the increased prominence of younger stands and harvest frequency create potential concern about BSRD. Spatiotemporal patterns of host, vector, and pathogen abundance, landscape connectivity, and source-sink dynamics potentially impact disease spread. Therefore, the probability of BSRD infection for each stand may be influenced by drivers at multiple scales, both within and beyond stand boundaries. To evaluate whether forest management and the resulting stand and landscape conditions act as drivers of BSRD increase, we used a multi-scale, spatially explicit process model. Factors affecting probability of infection, including variability and uncertainty, were determined and quantified from literature, verified by expert opinion, and used to develop and parameterize the model. By simulating and comparing BSRD spread in different landscape scenarios, we analyzed the influence of management practices, stand age class distributions, and landscape spatial configurations on the probability of BSRD infection, severity, and spatial distribution at the tree, stand, and landscape scale. We also evaluated the potential for non-linear responses and shifts in the spatial scale of disease-system drivers as well as the relative benefits of land-sparing versus land sharing for BSRD spread. Results will be presented, including hypotheses generated regarding uncertainties and knowledge gaps in the BSRD system and priorities for future research.

Importance of using continuous burn severity assessments in unveiling postfire distribution patterns

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Abstract: Wildfires generate large amounts of dead trees, which are considered as losses of revenue for regional economies. Postfire salvage logging is often used to minimize timber losses and this is depicted by the rising trend of this practice worldwide. On the other hand, it is known that postfire salvage logging should be implemented while considering various constraints, concerning both the profitability of operations and compliance with the standards of the forest ecosystem management. This management strategy aims at conserving the biodiversity associated with burned forests and its implementation requires knowledge on the impact that fire has on the forest in a spatially explicit manner. Working in recently burned stands of the Canadian boreal forest, we modelled postfire spatial distribution of woodboring insects affecting profitability of salvage logging, but also the diversity of fire-associated species and tree seedling density. Using continuous assessments of burn severity, such as the delta normalized burn ratio (dNBR), coupled with pre-fire ecoforest maps, we unveiled postfire distribution patterns not known before. Indeed, we identified quadratic relationships between burn severity and woodborer density, the diversity of fire-associated species, and tree seedling density. This approach will allow implementing improved salvaged logging plans, which better respect postfire forest ecosystem management.

Identifying robust 21st century projections of dryland forest regeneration

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In recent years, substantial attention has focused on quantifying, evaluating, and understanding tree die-off events in the US Southwest. However, forest managers do not have a commensurate understanding of forest recovery dynamics following disturbances and under current drought conditions. Furthermore, climate projections for western North America indicate rising temperatures and geographically-variable shifts in precipitation throughout the 21st century. Rising temperatures may enhance drought frequency and severity in dry forests, and potentially elevate the probability of drought-driven tree regeneration failures. As a result, understanding conditions that support regeneration and anticipating long-term future trajectories of those conditions is of growing importance. Here, we synthesize results from recent studies identifying key drought metrics, notably soil moisture and temperature, that determine the potential for tree seedlings to avoid drought-induced mortality and become established. We utilize ecosystem water balance modeling to quantify potential long-term changes in those conditions, and assess variation among climate models and emissions scenarios to assess the robustness of expected trends. The results identify broad differences among dry forest regions in historical trends and future trajectories of regeneration-related drought, highlighting some areas with clear projections for increasing ecological drought stress and other areas with less severe change. These results also indicate consistent differences in the uncertainty of projected change among drought metrics, with the largest and most consistent increases expected in drought conditions most directly influenced by temperature. Considering future patterns in these ecological drought metrics provides insight into the long-term sustainability of dry forests and offers a new perspective for mitigating uncertainty in management under climate change projections.

The heat is on, woodlands are toast, and what the heck is next?

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Abstract: Studies over the past 15 years have revealed that forests in general and semiarid woodlands in particular are highly vulnerable to experiencing drought-induced tree die-off events that are exacerbated by the increased temperature. In particular, knowledge about conditions associated with mortality of the piñon pine (*Pinus edulis*) is particularly robust, based on a plethora of observational, experimental, and modeling studies. Here we summarize recent insights on 1) tree mortality vulnerability under hotter drought and during heat waves, 2) the potential for tree mortality even where soil moisture may not be minimal if temperature is sufficient, and 3) consequences of widespread tree die-offs, including the potential for refugia, different type of transitions following die-off, and the potential for loss of trees in one location to impact a disparate one. Collectively, these results highlight the high likelihood of major mortality events and ecosystem transformations for southwestern woodlands and other forests—especially pine forests—in coming decades.

Restoring fire to conserve SGCN wildlife in an urban pine barrens preserve

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Abstract: Pitch pine-scrub oak barrens (PPSOB) are rare, fire-dependent ecological communities in the northeastern United States that support large assemblages of rare species. The 3,300 acre Albany Pine Bush Preserve in eastern NY contains one of the best remaining examples of an inland PPSOB and provides habitat for 76 of NY's 366 wildlife Species of Greatest Conservation Need (SGCN), including the federally endangered Karner blue (*Plebejus melissa samuelis*). Working with state and federal partners, the

Albany Pine Bush Preserve Commission has employed a variety of strategies to restore fire's fundamental role in this landscape. More than 1,204 acres of fire-suppressed PPSOB have been treated with prescribed fire. Initially (1991-2002) managers relied exclusively on dormant season fire, but those fires had limited success in restoring PPSOB and were counter-productive in areas invaded with native and invasive hardwoods. High flame lengths and rates-of-spread also presented significant challenges at the edge of the state capital city. However, chemical and mechanical treatments followed by growing-season prescribed burns consistently produced manageable fire and smoke behavior while meeting management goals. These treatments have improved ecosystem viability and facilitated an increased distribution and abundance of fire-dependent SGCN wildlife, including the recovery of the local Karner blue metapopulation and the return of eastern whip-poor-will. This presentation will examine solutions to the many logistical challenges associated with successfully using fire in a fragmented urban landscape. Growing and dormant season fire will be used to maintain "restored" barrens, while degraded and invaded areas require continued use of mechanical, chemical, and planting treatments to reach management objectives.

Water relations of a threatened white pine: field assessments in a common garden

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Abstract: Rapid climate change and non-native invasive pests and pathogens will challenge the adaptive capability and persistence of many native North American tree species. Southwestern white pine (*Pinus strobiformis*; SWWP), a five-needle conifer native from southern Mexico to Colorado, faces dual threats from the invasive pathogen white pine blister rust (caused by the fungus *Cronartium ribicola*), and significant predicted range contractions related to warming and drying of the southwest. We measured predawn and midday water potentials and collected foliage in 44 SWWP families, representing 10 populations, across two watering treatments (drought and non-drought) and three common gardens planted on an elevational gradient. Our questions were: 1) Are there differences in water use strategy among populations or planting environments? 2) Does this species alter water use strategy when stressed with moisture and temperature limitations? 3) Are population differences reflective of population source environment? We addressed these questions through the quantification of the isohydric-anisohydric continuum, which provides insight into how populations differ in stomatal regulation across a thermal gradient. We calculated hydroscape area, a relatively new depiction of this continuum, to understand how site temperature and water stress interact to influence stomatal regulation of leaf water potential. Additionally, we present results from corresponding carbon isotope analyses to identify those populations that alter integrated water-use efficiency between stressed and non-stressed conditions. We will present our findings in the context of species sustainability and management strategies.

Efforts to incorporate sustainability of traditionally used medicinal plants into forest management of the upper Skeena River basin of northwestern British Columbia

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Abstract: Through literature reviews and consultation with First Nations elders, it is estimated that more than 100 plant species were historically used for food, medicine, technological, and spiritual purposes by the Indigenous peoples of northwestern British Columbia. Of these, an estimated 63 species were used specifically for medicinal purposes by First Nations in the upper Skeena River basin, of which 14 species may be actively gathered and used today. Devil's club (*Oplopanax horridus*) is widely used for a wide variety of ailments and as a tonic. Soapberry (*Shepherdia canadensis*) is used to treat intestinal disorders and to assist women during childbirth. It is also used as a prestigious feast food, served to Chiefs, when whipped into a frothy confection known as "soapberry ice cream." Blueberries (*Vaccinium* spp.), although primarily a food, also have medicinal value due to their high vitamin content and anti-oxidant properties, which contribute to overall general health. A workshop on medicinal plants attended by First Nations, academics, consultants and Provincial government representatives was held in 2017 as part of the Skeena Environmental Stewardship Initiative. Participants said that the maintenance of healthy populations of traditionally used medicinal plants should be considered an essential component of forest management. Knowledge of medicinal plants is an important aspect of First Nations culture, to be transferred from one generation to the next, and to maintain a close relationship to the land. Where important gathering places of medicinal plants are known, user surveys and population-level monitoring should be carried to determine whether plants are being overharvested and whether plant recovery and restoration options are possible. Due to the large area of forest in the region, however, predictive habitat

models and mapping is also needed in order to effectively inventory and monitor this resource, and to avoid inadvertent damage by industrial forestry operations.

Why have recent mega-fires in British Columbia left some established plantations unburned?

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Abstract: In 2017 British Columbia experienced the greatest annual area burned in a hundred years (1.22 million hectares), which was then surpassed by another record year in 2018 (1.35 million hectares burned). With hundreds of ignition events and individual wildfires growing over the course of several weeks, these fires resulted in many final fire perimeters encompassing more than 10,000 ha, with one complex of merged fires reaching 545,151 ha. Fires in the province's central interior consumed a wide range of wild and managed forest stands, dominated by different combinations and ages of lodgepole pine, hybrid white spruce, subalpine fir, Douglas-fir, and trembling aspen. As post-fire surveys were conducted, however, it was frequently observed that well established, fully stocked plantations, apparently 20 to 40 years of age, were skipped by fires. These patterns were investigated using Landsat TM imagery to calculate differenced normalized burn ratios (dNBR) to map unburned, lightly, moderately, and severely burned areas. Overlaid on pre-burn forest cover maps, contingency table analysis confirms that planted second-growth stands of various species and ages have survived fires at a rate more than could be expected by chance. A program of ground inspections, plot-based sampling and UAV-assisted measurements is exploring the underlying mechanisms responsible for this phenomenon. It is hypothesized that plantations remained unburned where surface fuels are lacking or are in an advanced state of decay, limiting critical surface fire intensity required to initiate crown fire. High levels of crown closure and shading may also result in cooler moister surface conditions and lower in-stand wind speeds. Understanding the patterns and mechanisms of fire behavior in young managed stands will inform wildfire vulnerability assessments, silvicultural practices, and fire management strategies, tactics, and operations. More research is needed on fuel dynamics during stand development in the natural and managed forests of western North America.

Impacts of disturbance on the vegetation of a pine-oak forest in southern Mexico

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Abstract: Vegetation is an indicator to evaluate the impacts of different activities on natural ecosystems, to implement mitigation and conservation measures for their sustainable use. In this study, the floristic composition was analyzed, vegetation structure and successional changes as well according to the chronosequence of different types of impact in a pine-oak forest in Oaxaca, Mexico. 28 permanent plots of 400 m^2 were established, where a census of plant species was conducted in dry and rainy seasons, height and diameter at breast height ≥ 10 cm of trees and shrubs were registered. An alpha analysis and beta diversity, vertical and horizontal structure was made, according to a completely randomized design (DCA). In the conserved area (C1), during the dry season a total of 53 species were registered; the species that presented the maximum crown area was *Pinus pseudostrobus* var. *apulcensis* with a value of 22.84 %. This area shows floristic similarity (Bray-Curtis) with the agricultural resting area for twenty years (C7), where in the rainy season there were 89 species (P= 0.0154), mostly herbaceous species of the family Asteraceae. In the impacted area with forest fire a year ago (C3), there was dominance of *Crotalaria* sp. With a population density of 4556 individuals in the dry season and 5039 in the rainy season. The highest value index of importance (IVI) (86.55 %), was calculated for *Pinus lawsonii* Roezl, with 8750 trees/ha^{-1}, this species also obtained the highest IVI (79.94 %) for the area impacted by forest fire one year ago (C3) and in the area with agricultural rest of eight years (35.85%). In the grazing area (C2) and C1 stands out the presence of epiphytic species (P= 0.0078), which contribute 46.67 and 60.87% to the dissimilarity, followed by the herbaceous with 6.25 and 60%.

Measuring and understanding effects of fire severity on landscapes

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Abstract: The development of Landsat satellite indices that use near- and mid-infrared bands to quantify burn severity has catalyzed a proliferation of research on the spatial patterns of burn severity within burned landscapes and bioclimatic drivers of burn severity. There has been a coincident proliferation in analytical approaches, but thus far, there have been few systematic tests of the effects of different approaches on the ecological dynamics observed. We provide an overview of the many different analytical choices that researchers make when conducting a spatial analysis of burn severity. In some cases, best practices are clear, particularly if the ecological questions being asked are clearly defined. In many cases, though, there is uncertainty as to which methods provide the optimal approach. Some of the key analytical choices include (1) extent of the analysis area, which can range in scale from sub-continents to individual pixels within a fire, (2) the minimum fire size mapped, (3) where to place classification thresholds if data are being classified, (4) whether to average pixel reflectance values using a smoothing filter, and (5) the choice of spatial pattern metrics. Variability in any of the above choices can substantially influence ecological inferences. Likewise, in analyses, the bioclimatic drivers of burn severity methods for addressing spatial autocorrelation can impact statistical results and inferences. We provide worked examples showing how analytical choices regarding several of these analytical decision-points above can influence both quantitative results and qualitative interpretations of burned forest landscapes.

Evaluating predictive accuracy of fire-induced tree mortality in the First Order Fire Effects Model (FOFEM)

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Abstract: Predictive models of tree mortality and survival are vital for management planning and understanding fire effects in forest communities and landscapes. Post-fire tree mortality has been traditionally modeled as an empirical function of tree defenses (e.g., bark thickness) and fire injury (e.g., crown scorch). We are finalizing a tree mortality dataset built from 40 contributed datasets from across the USA, which will include observations of >150 species and >170,000 trees. We are using this dataset to formally evaluate the accuracy of fire-induced tree mortality models from the First Order Fire Effects Model (FOFEM) software system. Here, we present FOFEM model accuracy for 11 species: *Chamaecyparis lawsoniana, Cornus nuttallii, Juniperus occidentalis, J. osteosperma, Oxydendrum arboreum, Pinus attenuata, P. virginiana, Quercus coccinea, Q. garryana, Q. prinus,* and *Sequoiadendron giganteum.* For each species-model combination we created receiver operating characteristic (ROC) curves, which evaluate sensitivity (i.e., correctly classified dead trees), and specificity (i.e., correctly classified live trees). We identified probability thresholds for which the model performed best using the package pROC in R. Land managers who use FOFEM may be interested in optimizing predictions of either mortality or survival, so we also identified the best threshold with ≥80% sensitivity, and the best threshold with ≥80% specificity and calculated model performance statistics. Models for *C. nuttallii, J. occidentalis, and S. giganteum* performed excellently (AUCs>0.93). Models for *C. lawsoniana* and the two *Pinus* species performed poorly (0.633≤AUCs≤0.67), primarily reflecting low sensitivity. Models for *Quercus* species and *O. arboretum* were no better than a random classification (AUCs<0.6). By adjusting thresholds, the specificity of models for *J. occidentalis, O. arboretum, and P. virginiana* could be improved without reducing overall accuracy below 65%. Once our dataset is finalized, we will evaluate FOFEM models for all available species (>50 species) and explore whether performance varies for clades of species and among geographic regions.

The missing fire: quantifying human exclusion of wildfire in Pacific Northwest forests, USA

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Abstract: Western U.S. wildfire area burned has increased dramatically over the last half-century. How contemporary extent and severity of wildfires compare to the pre-settlement patterns to which ecosystems are adapted is debated. We compared large wildfires

in Pacific Northwest forests from 1984 to 2015 to modeled historic fire regimes. Despite late twentieth-century increases in area burned, we show that Pacific Northwest forests have experienced an order of magnitude less fire over 32 yr than expected under historic fire regimes. Within fires that have burned, severity distributions are disconnected from historical references. From 1984 to 2015, 1.6 M ha burned; this is 13.3–18.9 M ha less than expected. Deficits were greatest in dry forest ecosystems adapted to frequent, low-severity fire, where 7.2–10.3 M ha of low-severity fire was missing, compared to a 0.2–1.1 M ha deficit of high-severity fire. When these dry forests do burn, we observed that 36% burned with high-severity compared to 6–9% historically. We found smaller fire deficits, 0.3–0.6 M ha, within forest ecosystems adapted to infrequent, high-severity fire. However, we also acknowledge inherent limitations in evaluating contemporary fire regimes in ecosystems which historically burned infrequently and for which fires were highly episodic. The magnitude of contemporary fire deficits and disconnect in burn severity compared to historic fire regimes have important implications for climate change adaptation. Within forests characterized by low- and mixed-severity historic fire regimes, simply increasing wildfire extent while maintaining current trends in burn severity threatens ecosystem resilience and will potentially drive undesirable ecosystem transformations. Restoring natural fire regimes requires management that facilitates much more low- and moderate-severity fire.

Flux Puppy – an open-source software application and portable system design for low-cost manual measurements of CO_2 and H_2O fluxes

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Abstract: Manual chamber-based measurements of CO_2 (and H_2O) fluxes are important for understanding ecosystem carbon metabolism. Small opaque chambers can be used to measure leaf, stem, and soil respiration. Larger transparent chambers can be used to measure net ecosystem exchange of CO_2, and small jars often serve this purpose for laboratory incubations of soil and plant material. We developed an Android application (app), called Flux Puppy, to facilitate chamber-based flux measurements in the field and laboratory. The app is designed to run on an inexpensive handheld Android device, such as a tablet or phone, and it has a graphical user interface that communicates with a LI-COR LI-820 (CO_2) or LI-840 (CO_2/H_2O) infrared gas analyzer. The app logs concentrations of CO_2 and H_2O, cell temperature and pressure at 1 Hz, displays the output graphically, and calculates the linear regression slope, R-squared, and standard error of the CO_2 time series. A metadata screen allows users to enter operator, site, and plot information, as well as take a photograph using the Android device's built-in camera, and log measurement location using the device GPS. Additionally, there is a notes field, which can be revised after the measurements are taken. Data files (the 1 s raw data, photograph, and metadata including statistics calculated from the raw data) are then transmitted off the device through file sharing options (Gmail, Outlook, Google Drive, Dropbox, etc.). Because Flux Puppy code is open-source (available on GitHub) and the flux measurement system we describe is relatively inexpensive and straightforward to assemble, it should be of interest to forest ecologists, and more broadly the carbon cycling community.

Using a dynamic global vegetation model and stakeholder input to assess the climate change vulnerability of vegetation and tribally-important ecosystem services in the Pacific Northwest

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Abstract: Native Americans that rely on tribally important ecosystem services such as traditional foods, hunting, timber production, non-timber forest resources, and cultural resources, may be highly vulnerable to the impacts of climate change. Many tribal members are also culturally tied to the historical landscape and recognize many places that are sacred yet are outside tribal reservation boundaries. However, there are no known region-wide assessments that have examined the potential impact of climate change on tribally-important ecosystem goods and services. In response, we demonstrate a generalizable approach for assessing climate change effects on vegetation and ecosystem services. Our approach uses five basic steps:1) identify tribally-important ecosystem services, 2) relate those ecosystem services with biologically-relevant vegetation projections from a dynamic general vegetation model (DGVM), 3) identify meaningful timeframes and appropriate future climate scenarios, 4) assess future changes for vegetation types and

ecosystem services, and 5) highlight how uncertainty can be leveraged to emphasize resilience building and adaptation planning. Applying this approach, we consulted with stakeholders and identified 78 tribally important ecosystem services and linked them with appropriate simulated potential vegetation types. We then show how changes in some vegetation types could impact economically and culturally important ecosystem services throughout the Pacific Northwest. Surprisingly, some first foods and medicinal plants may increase due to increased areas of suitable habitat whereas arid-land species and grazing quality are projected to decline. We further highlight details for two key resources–huckleberries and bitterbrush–to demonstrate the potential for greater level of detail as part of the assessment process and show how this information can be applied to help inform resource management and adaptation planning.

Leveraging existing data to assess climate change vulnerability of wildlife in south and central Oregon

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Abstract: Conservation and natural resource practitioners are responsible for managing species facing increasing threats such as climate change. Although climate vulnerability assessments have been completed for some high-profile species, their approaches differ considerably and the vast majority of species have not been assessed. We demonstrate a generalizable methodology for assessing vulnerability to climate change by using publicly available data and applying it to 53 bird and mammal species in central Oregon. In addition to assessing the relative vulnerability of individual species to climate change, we also identify key drivers that contribute to their vulnerability across two taxonomic groups–birds and mammals. We estimate that approximately 20% of the species analyzed are highly vulnerable to climate change. In addition, we found that of the species we analyzed, mammals were more vulnerable than birds. However, we also conclude that approximately one quarter of species in the study had low confidence in the estimated level of vulnerability, highlighting the need for additional research on the natural history of species and determining how sensitive they are to climate change. Thus, our approach demonstrates both the utility and the limitations of leveraging existing data to assess climate change vulnerability in the face of an uncertain future.

Accounting for the risk of decline and mortality when assessing the financial maturity of sugar maple trees

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Abstract: In selection silviculture, a key parameter used to select trees for harvest is the maximum diameter, which is often set to be the size at which a tree no longer achieves a minimum rate of value growth (RVG). In northern hardwood forests, such as those in Ontario, it is assumed that trees do not reach financial maturity until they reach the maximum diameter of 60 cm. However, few studies have quantified how tree value and RVG vary with size, quality, or vigor. Furthermore, most studies overestimate the RVG of larger trees, because they exclude the risk that a tree will decline in quality or vigor, as well as the risk that the tree will die altogether. To estimate the maximum diameter of hardwood trees, we quantified the RVG of sugar maple (*Acer saccharum*) trees in three steps. First, we conducted product recovery and time-motion studies to quantify the value (net of processing costs) of trees as a function of tree size, quality, and vigor. Second, we fit multi-state transition models to long-term inventory data to quantify growth, decline, and mortality as a function of size, where decline includes the transitions from high to low quality and high to low vigor. Third, we combined the multi-state transition models with the value models (step 1) to quantify the RVG of both large- and medium-sized trees (>48 cm and 36-48 cm, respectively). Our results show that large-sized trees depreciated in value, even when deemed to be vigorous, because the risk of decline and mortality increase with size. While vigorous, medium-sized trees appreciated in value, non-vigorous ones did not. We conclude that the maximum diameter should be lower than 48 cm if harvesting at financial maturity is the goal, and that separate maxima should be used for high- and low-vigor trees.

Physiological response of *Picea chihuahuana* Martinez to CO_2 increase during the last century

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Abstract: Understanding how *Picea chihuahuana* responded to extreme climatic events in the past is crucial for advancing our ability to predict how recent atmospheric changes of CO_2 will impact this forest ecosystem in the future. *Picea chihuahuana* is a long-lived, climate sensitive species thriving in specific habitats along the Sierra Madre Occidental. Currently the species is considered in danger of extinction and is included under protection of Mexican norm NOM- 059- SEMARNAT-2010. Here, a dual isotope ($\delta^{13}C$ and $\delta^{18}O$) approach was combined with standard dendrochronological methods to examine how *Picea chihuahuana* trees have physiologically responded to extreme climatic events over the past 150 years in Chihuahua, Mexico. We found that trees recorded extreme dry events in 1850,1865, 1880, 1893, 1920, 1940, 1953, 1965, 1982, 2000, 2005, and wet events in 1870, 1885, 1910, 1929, 1951, 1966, 1975, 1987, 1995, and 2010. Tree ring $\delta^{13}C$ and $\delta^{18}O$ recorded shifts in precipitation patterns, as well as physiological adjustments following dry and wet events. A positive relationship between $\delta^{13}C$ and $\delta^{18}O$ was observed over time, with the highest $\delta^{13}C$ discrimination and the lowest $\delta^{18}O$ recorded in tree rings during wet periods. Rising atmospheric CO_2 levels caused increases in water use efficiency (iWUE), but no more growth due to the fertilization effect by the increase of atmospheric CO_2. Tree growth decline and divergent isotopic signals indicated critically low stomatal conductance during dry periods. Therefore, if currently observed precipitation patterns continue in this region, it will likely cause a widespread increase in forest dieback for this species.

Differing effects of mortality agents on snag persistence in southwestern ponderosa pine forest

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Abstract:
We compared two key mortality agents, high-intensity crown fires and an outbreak of bark beetle, in southwestern ponderosa pine (*Pinus ponderosa* Laws). Our objectives were to conduct a longevity analysis to predict the persistence of standing dead trees (snags) from large mortality events and determine characteristics of snags that remained standing. We documented ponderosa pine snag dynamics in northern Arizona with repeat sampling of 14 variables in 18 one-ha permanent plots across two national forests. Specifically, we followed two high-intensity wildfires that occurred in 1996 and 2000 and 4 bark beetle outbreaks from 2002-2005. After field sampling >2500 snags for 1 to 13 years post-mortality, we estimated a 7.6 (± 0.1) year period for a snag to remain standing. Mortality agent was the strongest predictor of how long a snag stood, with the hazard of falling for beetle-killed snags 2.5 greater than for fire-killed snags. Beetle-killed snags with intact tops, higher degree lean, and smaller diameter were most likely to fall. Inversely, the snags more likely to stand longer were fire-killed, with broken tops, straighter (low degree lean), and larger diameter. Our long-term study provided a useful model to forest managers seeking to select longer-standing snags for wildlife immediately following a high-intensity fire or beetle outbreak. Given the likelihood of drought and the elevated densities of ponderosa pine in the Southwest, these mortality agents likely will recur. When combined with increased drought-related tree stress due to climate change and the similarity of southwestern snag dynamics to the western United States, snag demography reported in our research indicates future conditions across a broader geographic region.

Ponderosa pine regeneration following high-severity wildfires is driven by overstory, topo-climatic, and ground layer conditions

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Abstract: Ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) dominated forests of the western USA are increasingly burning with a high-severity component that is unprecedented in the available historical record. The ability of ponderosa pine to regenerate in high-severity patches of such fires is unclear, as seeds must disperse from surviving trees. Topo-climatic and ground layer conditions may further constrain regeneration. We utilized pre-existing and new data from 11 recent wildfires, distributed across a three-state region in the interior western USA, to examine broad-scale patterns of post-fire ponderosa pine regeneration in high-severity patches. Our approach centered on using piecewise structural equation modeling (SEM) to identify how regeneration density was directly and indirectly influenced by (1) overstory conditions (distance from surviving forest), (2) topo-climatic conditions (normal annual climatic water deficit and post-fire annual climatic water deficit), and (3) ground layer conditions (cover of graminoids and forbs, shrubs, litter and duff, and coarse wood). Our preliminary results indicate that ponderosa pine did regenerate post-fire in high-severity areas, but densities were generally low. Regeneration densities were directly and negatively influenced by increasing distance from surviving forest and normal annual climatic water deficit, and directly and positively influenced by increasing litter and duff cover and coarse wood cover. Regeneration densities were also driven by indirect effects, because distance from surviving forest negatively influenced litter and duff cover and positively influenced coarse wood cover. These results suggest that ponderosa pine establishment within high-severity patches of interior western ponderosa pine dominated forests may be limited, particularly in sites farther from surviving forest, with more xeric environments, and with lower abundances of litter and duff and coarse wood.

Cone production of longleaf pine forests under climate fluctuation

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Abstract: Longleaf pine (*Pinus palustris* Mill.) forests are ecologically important and also endangered ecosystems in the southeastern United States. One major character of longleaf pine is the sporadic seed production, which presents a continuing challenge to their recovery. We characterized relationships between cone production and climate fluctuation by relating approximately 60 years of cone production data for longleaf pine forests at different sites with local climate variables. We found no general correlations between annual or monthly temperature or precipitation and cone production. However, there were high correlations between the entropy (information disorder) of cone production and entropy of annual mean air temperature or annual total precipitation at all sites. On a decade scale, there was a significantly positive correlation between the coefficient of variance (CV) of cone production and CV of average annual air temperature, but the CV of annual precipitation was negatively correlated with the CV of cone production at the Escambia, AL and Blackwater, FL sites. There was no general trend of increasing CV in cone production through time. Phase coupling of cone production was weak and not significant, which indicated that longleaf pine was different from masting species. These results provided new understanding of cone production in longleaf pine forest under climate fluctuation. The implications for its management will be discussed from a perspective of spatial and temporal complexity, including both internal biological processes and external environmental processes.

Integrating the work of wildfires into landscape restoration: Post-fire landscape evaluations

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Abstract: Wildfires are currently the most significant change agent of western US forests. Landscape scale restoration and climate adaptation thus require integrating the "work" of wildfires with mechanical, prescribed fire, and other treatments. Yet, how wildfires shape landscape-level patterns of composition and structure relative to historical and future (climate change adapted) ranges of variation (HRV-FRV) is not well understood. Consequently, it is challenging to prioritize post-fire management actions in the burned and unburned portions of planning areas in an integrated landscape framework. We quantified how four recent fires in eastern Washington, USA, moved landscapes towards and away from landscape-level HRV-FRV envelopes. Fires reduced over-abundant,

fire-intolerant, and dense forest patch types, often to within HRV-FRV ranges. Moderate and low severity fire shifted dense patches to more open, fire resistant structural conditions, but these patch types were still under-represented and overly fragmented after fires. High severity fire greatly reduced large tree, dense forest patch types and fragmented them into smaller patches. Small to mid-sized high severity patches added to overly fragmented landscape patterns, while large patches of high severity fire reduced fragmentation but increased homogeneity. Large, high severity patches greatly increased the amount and patch sizes of herbland and shrubland, shifting them from being below HRV-FRV ranges to above both ranges. The future developmental trajectories of these patches will determine whether these landscapes move towards or away from the desired patchwork of forest, herbland, and shrubland. Our results show that wildfires are a blunt restoration tool. They can be restorative in many respects, but can also move landscapes backwards in terms of resilience to future disturbance. Post-fire landscape evaluations can identify where management actions can augment the beneficial work of wildfire, and where they may be needed to shift future vegetation patterns towards conditions that are better adapted to future climates.

Invasive insects, fire management, and the persistence of mixed composition forests in the mid-Atlantic region, USA

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Abstract: Over the last decade, damage from outbreaks of gypsy moth (*Lymantria dispar* L.) in oak-dominated stands and southern pine beetle (*Dendroctonus frontalis* Zimmermann) in pine-dominated stands have far exceeded the area impacted by wildland fires or wind damage in forests on the mid-Atlantic Coastal Plain. How do these infestations affect forest structure and composition, and what is their long-term impact on forest carbon dynamics and hydrologic cycling? We used comparative forest census data in insect-impacted and control stands, and eddy covariance measurements made pre- and post-disturbance in oak-, mixed, and pine-dominated stands to understand the ecological consequences of invasive insects on forest structure, carbon dynamics, and hydrologic cycling in the Pinelands National Reserve in New Jersey. In oak-dominated stands, multi-year defoliation by gypsy moth resulted in >40% mortality of oak trees, leading to the release of pine saplings and seedlings in the understory and an increase in understory shrub biomass and productivity, while tree mortality was minimal in mixed and pine-dominated stands. In pine-dominated stands, southern pine beetle infestations resulted in >90% mortality of pine trees within afflicted stands, while having relatively little effect on oaks in upland stands and other hardwoods in lowland stands, and more rarely impacted pines in mixed or oak-dominated stands. Because insect-driven disturbances are both resetting and accelerating successional sequences in monogeneric stands, but having little effect in mixed composition stands, long-term dynamics may be favoring the formation of mixed stands at the landscape scale. Long-term changes in species composition may have little impact on forest carbon sequestration and evapotranspiration; although seasonal patterns differed, with highest daily carbon sequestration rates occurring in the oak stand and lowest in the pine stand, integrated annual rates of carbon sequestration and evapotranspiration were more similar among oak-, mixed, and pine-dominated stands.

Germination, phenology, and plant allocation patterns of northeastern tree seedlings in response to future precipitation scenarios

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Abstract: Seedling germination, growth, and establishment is a sensitive period and a critical bottleneck in the regeneration of forest trees, yet little is known about how this process will be impacted by a shifting climate. Despite projected future shifts in species ranges, the germination and regeneration response of locally adapted (current) tree species compared to those predicted to be better adapted to future conditions is poorly understood. Understanding forest regeneration response under novel future climate scenarios is important as it may lead to compositional or functional shifts in forests with implications on forest health, productivity, and biodiversity. To examine the regeneration of forest trees under shifting climate, we test the response of fourteen currently- and "future-adapted" species grown from seed and bare-root seedlings under precipitation manipulation located in forest harvest gaps. Tree species were selected across a suite of functional traits from species currently common in northeastern US forests as well as from species projected to be better adapted to future climates. Two seedbed treatments (scarified and undisturbed) and four precipitation scenarios (projected shifts in rainfall frequency and magnitude) were used to examine species response in establishment, phenology, allocation, and water use efficiency. Results indicate a strong germination response to seedbed treatment with a mean increase of

128% (±58) in scarified treatments. Seedlings grown from seed and bare-root seedlings responded most positively to rainfall frequency while rainfall magnitude had less effect. Precipitation treatment most positively influenced growth and establishment of larger seeded species such as *Pinus strobus*, *Fagus grandifolia*, and *Castenea dentata*, but had no effect on *Quercus rubra*. The implications of this research may refine future species distribution models as well as provide tangible information for managers of northern forests seeking to maintain ecosystem function during a time of uncertain future global conditions.

The role of community wildfire planning in changing forests: Assessment of community wildfire protection plans in Arizona and the west

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Abstract: Many forests across North America are experiencing increasingly uncharacteristic wildfires that are impacting social and ecological systems. These impacts are further exacerbated by continued human development into forested and fire-prone landscapes. The intermingling of social and ecological systems in North American forests creates complex landscapes in which meeting objectives to increase ecological resilience in a changing climate must include consideration of the role that communities play. Indeed, communities-at-risk from wildfire are often a key element in determining how broader restoration and resilience objectives are accomplished. It is important to understand the role that communities-at-risk from wildfire play in accomplishing broader landscape objectives while planning for their own safety and adaptation to wildfire. One mechanism with which communities-at-risk from wildfire have addressed planning and adaptation to wildfire are Community Wildfire Protection Plans (CWPPs), which were created as part of the Healthy Forest Restoration Act in 2003. CWPPs are required to include measures to reduce hazardous fuels, reduce structural ignitability, and increase collaboration and outreach. Communities across the West have used a wide range of approaches for developing CWPPs with varying outcomes. This presentation will provide results from a study that assessed CWPPs in Arizona and throughout the western United States. In addition to providing an overview of what CWPPs are and how they relate to broader forest restoration and resilience planning, I will provide results from an assessment of CWPP effectiveness in Arizona, results from a survey of CWPP strategies in other western states, and lessons learned and recommendations for effective community wildfire planning and CWPP development, implementation, and maintenance in Arizona and throughout the West. I will end with recommendations on how community wildfire planning can reflect and operationalize broader forest restoration and resilience objectives on the ground and allow communities to better adapt to living with more fire.

Using art to communicate about fire science and management in a changing climate: Evaluation results from an art exhibit in Arizona

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Abstract: Climate change presents a great deal of complexity and uncertainty for land managers, scientists, and the public. There is an increasing need for adaptive management practices that incorporate the best available science and are supported by the public in order to foster resilience in social and ecological systems impacted by changing fire regimes. But effectively using the best available science in management, as well as communicating about science and management actions to the public is an ongoing challenge. One mechanism for enhancing understanding and support for complex topics is art; however, little is known about the outcomes of communicating science through art. This presentation will provide an overview of the "Fires of Change," a collaborative science and art project resulting in science-based art exhibits that communicated the science behind fire, climate, and management in the Southwest. "Fires of Change" was led by the Southwest Fire Science Consortium (SWFSC) and the Landscape Conservation Initiative, two boundary organizations that work to connect scientists, decision makers, and stakeholders through the production and dissemination of actionable science. The overarching hypothesis of "Fires of Change" was that partnering artists with scientists and land managers would provide a mechanism for conveying understanding of the complex nature of land management to the general public. To assess whether "Fires of Change" was an effective method of knowledge transfer resulting in support for management actions, we administered formal surveys to public attendees of the exhibits. We also administered post-exhibit surveys of the artists, scientists, managers, and governing board of SWFSC to assess the outcomes of the collaborative process. We found that Fires of

Change effectively communicated complex ecological and scientific ideas to the general public and created more support for management actions to address climate change.

Severe drought restructures plant community diversity, composition, and phylogenetics in a semi-arid woodland

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Abstract: The southwestern US is an ideal location to assess ecosystem consequences of global climate change, as severe droughts and large-scale tree dieback events have occurred in the recent past. While dominant tree mortality has been well documented, an assessment of the effects of drought on whole plant communities is lacking. In this study, we investigate the ecological and phylogenetic changes to plant communities tracking both elevational and mortality gradients in a northern Arizona cinder field spanning nearly a decade since severe drought in 2002. By combining traditional community ecology measures with community phylogenetics, we may better understand the response of plant communities to extreme climate events. We found three major patterns: 1) Species richness and diversity significantly increased through time, and in high mortality plots, with a shift in the dominant plant functional group from woody shrubs and grasses to herbaceous species; 2) Plant communities did not track elevation or mortality gradients, but continue to become compositionally different from each other through time; and 3) In general, the evolutionary relationships of co-occurring species shifted from distantly related (phylogenetically overdispersed) to closely-related (phylogenetically clustered) after the drought event. We conclude that plant communities are not tracking climate change as a cohesive unit, but are exhibiting individualistic species responses to drought. In addition, communities are becoming narrower with respect to the breadth of their phylogenetic relationships. These findings have important implications for the future functionality of native landscapes, as severe drought becomes an increasing phenomenon in the Southwest. Although we found increases in species diversity, the post-drought assemblages were more closely related than before drought, suggesting a shrinking of plant functions and ecosystem services available within the community.

Dendroclimatic analysis of sugar maple: Challenges of modeling climatic response in late successional tree species

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Abstract: Sugar maple is a long-lived, shade-tolerant, late successional tree, which grows in closed-canopy eastern deciduous forests. It is a less than ideal species for dendroclimatic analysis because climate is only one of many factors, which influence tree-ring width. However, to predict potential climate change impacts on forests, dendroclimatologists must examine all tree species, including those that do not strongly record climate signals. This study focused on the southern portion of sugar maple's geographic range and used newly developed tree-ring chronologies and existing chronologies to examine the dendroclimatic response in sugar maple across 13 study sites. Tree-ring master chronologies from each site were correlated with temperature, precipitation, and Palmer Drought Severity Index to identify geographic patterns in dendroclimatic response across the study area. To identify temporal changes in dendroclimatic response, running correlations were calculated to for the lifespan of the trees at each study site. At all study sites, sugar maple growth was significantly correlated with several to many climatic factors. However, there were no generalized spatial or temporal patterns in dendroclimatic response. Each site had a set of unique months and climatic variables correlated to radial growth. These results make predictions about sugar maple's response to potential climate change nearly impossible. Dendroclimatic response of sugar maple does not appear to be related to elevation, latitude, longitude, soil type, or topographic position; therefore, without physically sampling and analyzing tree rings from a specific site, it is impossible to predict dendroclimatic response. The strong competitive ability of sugar maple appears to make the species capable of growing under a wide diversity of climatic conditions and thus, a particularly challenging species to connect growth to climate.

Comparison of the resistance of even-aged and uneven-aged stands to environmental stresses in temperate forests

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Abstract: With global change, forest trees will be exposed to more and more stress in the coming decades. However, little is known about how forest management will interact with these stressors and how they will impact the ability of trees to resist disturbances. Resistance is the capacity of an ecosystem to absorb the effect of a disturbance and to remain largely intact; therefore, in our case, tree mortality can be presumed to be a lack of resistance. The objective of this study was thus to compare stress-related tree mortality in the most common silvicultural systems used in northern hardwoods: even-aged and uneven-aged silviculture (hereafter EAS and UAS). Our hypothesis is that the forest management system (EAS vs UAS) influences the probability of tree mortality, because trees undergoing EAS and UAS experience very different neighborhood competition throughout their lifespan. Using a novel terrestrial mobile LiDAR technique, we mapped all dead and living trees (>10 cm DBH), within 40 sugar maple dominated stands, comprising: 16 even-aged, 16 uneven-aged and 8 old-growth stands. We first determined the relative role of forest management on individual tree mortality compared to other factors such as size, species and neighbor competition. We then evaluated the overall impact on the stand. We observed that competition-related mortality was similar between EAS and UAS stands. Nevertheless, for large trees, stress-related mortality was greater in the UAS stands than in the EAS stands. This is due to the fact that trees in UAS stands can go through several periods of growth suppression, increasing their vulnerability to different types of stress compared to trees in EAS stands, which experience a more stable neighborhood competition during their lifecycle. Our study shows that silviculture - past and present - will have profound effects on the resistance of forests to global changes.

An approach for the spatio-temporal analysis of tree physiology from dendrochronological and remotely-sensed information

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Abstract: Rising atmospheric CO_2 concentration in tandem with warmer conditions are expected to accelerate tree growth by enhancing photosynthetic activity in montane forest ecosystems. However, tree responses are not expected to be universal and how site conditions (i.e. altitude and aspect) will influence forests ecosystems remains unclear. Therefore, we investigated trees' physiological adjustments to ongoing climate change and its relationship with a satellite-derived photosynthetic activity variable (NDVI) across two elevations (3500 and 3900 m asl) and two aspects (NW and SW) in a high-elevation forest dominated by Mexican Mountain Pine (*Pinus hartwegii*). Annually resolved tree-ring stable isotope signatures ($\delta^{13}C$, $\delta^{18}O$), and isotope-derived physiological variables ($\Delta^{13}C$, C_i, and iWUE), for the period 2000 to 2016, were analyzed by linear mixed-effects models and then correlated with NDVI 16-day composite time series (250-meter spatial resolution) according to a pixel-wise Kendall's tau correlation. Results showed that carbon isotope composition ($\delta^{13}C$) has decreased regardless of spatial position, while oxygen isotope composition ($\delta^{18}O$) showed an altitude and time effect. The changes in leaf intercellular CO_2 concentration (C_i) were more concordant to iWUE at the 3500-NW site. Although carbon isotope discrimination ($\Delta^{13}C$) was not related to altitude or aspect, we observed a notable concomitant reduction with the most severe drought in 2011, as reported by Mexican Drought Monitor. Previous winter NDVI values were negatively related with both isotopes ($r = -0.48$) as well as with the end of the dormant period (May) for $\delta^{13}C$. This suggests that high greenness or photosynthetic activity during May is coupled with both lower $\delta^{13}C$ (more negative) and higher carbon discrimination, explained by the stomata mechanisms. Thus, remotely-sensed variables coupled with tree physiology indices have a high potential to integrate with dendroecology and evaluate tree responses to fluctuations in environmental conditions.

Linking remote sensing and dendrochronology to quantify climate-induced shifts in high-elevation forests over space and time

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Abstract: It is well known that tree growth is strongly affected by climate at high elevations, but it is still unclear how climate variability influences the distribution of montane forest ecosystems, particularly tree line species. To advance knowledge in this field, we combined temporal (tree ring measurements) and spatial data (remotely sensed variables), to quantify how forests responded to climatic variability across altitudinal gradients in Central Mexico. Normalized difference vegetation index (NDVI), tree-ring chronologies, and site-level climatic data were used in a vegetation trend analysis of greenness and browning and to reconstruct canopy vigor for the last century. Although a common ring width chronology was developed, we found significant site-dependent forest growth response, where young trees (<100 years) exhibited heterogeneous growth trends, without an altitudinal pattern. However, mature trees (100–200 years) showed a common growth decline during the middle twentieth century, regardless of their altitude. Annual maximum NDVI anomalies did not show a general greening effect at high elevations. The forest showed both greening and browning zones denoting spatial variability in tree vigor. Furthermore, temperature from the previous year had a positive effect on both NDVI and ring width index but negative at beginning of the growing season. The significant relationship between winter-spring NDVI (December to March) and ring width index ($r=0.64$, $P<0.05$), was useful to reconstruct the canopy vigor for the last 151 years. Thus, the greening effect derived from NDVI should be carefully interpreted as a direct forest growth increase. These results highlight the potential of integrating remotely sensed and dendrochronological methods to improve predictions of forest ecosystem responses.

Mortality in California forests: vital rate estimates and their local to climatic contributions

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Trees are dying all the time, but many forest ecosystems, including those throughout the North American West, lack serviceable estimates of mortality patterns and rates. Still, recent warm droughts, bark beetle irruptions, and legacies of ecosystem degradation have contributed to massive and recurring mortality events across the West. Anticipating and mitigating future mortality requires a clear characterization of key players. This motivates our study of the environmental conditions and forest characteristics that influence mortality in California forests. In this work, we use a comprehensive ground-based inventory (USFS Forest Inventory and Analysis Program data) to quantify contemporary patterns and drivers of mortality across California forests, 2001-2015. Our goals are to 1) estimate mortality rates in detail, and 2) quantify the contributions of the tree, stand, and forest characteristics that influence elevated mortality. We particularly emphasize communities severely impacted by the 2012-2015 drought, an event unparalleled in hundreds of years. We are further investigating how the contributions of structure, canopy position, and species vary with drought severity and between ecoregions. We found that annual mortality rates for all trees more than doubled, from 0.54±0.09% of basal area lost per year in 2001-2003 to 1.23±0.10% in 2012-2015. In 2012-2015, mean annual mortality for trees exclusive of fire effects was 0.71±0.04% BA/year. Species with highest mean annual mortality 2008-2015, and largest increases through time, were red fir (*Abies magnifica*), sugar pine (*Pinus lambertiana*) and white fir (*A. concolor*). Mortality patterns were dependent on canopy position, diameter, and crown condition. Local precipitation and maximum temperature anomalies also shaped mortality patterns. Measures of tree mortality derived from widespread plot-based inventory provide an essential estimate of forest vital rates, patterns rarely captured in other approaches. FIA-based quantification can therefore serve as a valuable reference in assessing long-term trends and discerning the trajectories of our forest ecosystems.

Assessing drought tolerance in New Zealand kauri (*Agathis australis)* via throughfall exclusion (TFE) in a native, mature forest

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Abstract: Large trees can be particularly vulnerable to drought stress, potentially leading to both reduced growth and higher mortality rates. This can significantly impact broader forest communities because large trees are disproportionately important contributors to water and carbon budgets across spatial scales. Drought-manipulative experiments on large, mature individuals in natural forests are scarce. A first-for-New Zealand throughfall exclusion (TFE) experiment is underway to evaluate the physiological effects of drought on kauri (*Agathis australis*). Kauri, an endemic conifer, comprise some of the largest and oldest living trees on earth. Possessing deep cultural significance to Māori, kauri survival is uncertain as their conservation status was recently listed as threatened. The country traditionally enjoys a maritime climate with high annual precipitation. However, like many parts of the western US, it is now experiencing more frequent and severe drought events and it remains unclear how resilient these forest giants, along with their associated communities, are over prolonged dry periods. The experiment is underway in the Waitākere range of west Auckland. We have designed and installed custom tarps and gutters to catch and divert rainfall of a 4.5 m^2 dry-down zone around individual boles. Sapflow, soil moisture, and stem diameter fluctuations are continuously monitored, coupled with meteorological data. Periodic canopy measurements such as leaf-level gas exchange and leaf water potential are also being conducted throughout the duration of the experiment. Our method is suitable for forest giants such as redwoods and isolated trees or in savanna ecosystems where trees are widely dispersed.

Montana Adaptive Silviculture for Climate Change: Coram Experimental Forest/Flathead National Forest

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Abstract: Western larch (*Larix occidentalis* Nutt.) forests are iconic in the U.S. interior northwest, and here we document the preemptive steps that scientists and managers are taking to steward these forests into the future. Changing climate is forecast to have acute and chronic impacts on growth and disturbance in western larch forests. A group of scientists and managers in the northern Rocky Mountains have teamed up with the Adaptive Silviculture for Climate Change Network in an experiment to proactively manage forests for climate adaptation – especially for warmer, drier climate and associated drought and fire. The collaborative group developed a gradient of adaptation treatments (i.e., *resistance*, *resilience*, and *transition*) focused on climate change at Coram Experimental Forest and the Flathead National Forest, Montana. Treatments are scheduled for 2019 and monitoring will follow to fuel future research and to help guide regional managers that seek to learn from our treatments. This collaborative process has bolstered the region's research-to-management interface by formalizing a modified Common Stand Exam protocol for measurement that fulfills research needs while providing the National Forest System with reportable monitoring data in a repeatable manner. Additionally, treatments were designed within the National Forest System's silvicultural prescription framework and using agency-standard tree improvement seed sources, which sets an important precedent for future implementation on public lands. We describe the unique treatments developed for this forest type, then conclude with predictions of future forest dynamics and emphasize the necessity for long-term monitoring of silvicultural experiments.

Aggregated retention influences understory functional identity and diversity in similar, but not identical ways to intact forest

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Abstract: Increasingly, guidelines designed to conserve biodiversity encourage the retention of mature forest patches in stands historically managed with clearcutting systems. We assessed the effectiveness of this practice by comparing the influence of unharvested patches ("aggregates") with the influence of intact forest on the understory woody community of aspen-dominated forest in northern Minnesota, USA 12 years after harvest. This involved sampling the woody understory along transects spanning the transition from mature, unharvested forest (within both intact forest stands and 0.1 ha retention aggregates) to harvested, regenerating forest. We then quantified the magnitude and depth of edge effects on taxonomic diversity, functional diversity, and functional identity (based on seven plant traits). Aggregates and intact forest influenced many measures of diversity in the understory of unharvested and adjacent, regenerating forest in similar ways, including community-weighted means for functional traits such as shade tolerance and drought tolerance in the sapling layer (stems >1 m height with diameter <10 cm). However, trends in several traits observed in the seedling layer (e.g. shade tolerance, seed mass, specific gravity) suggest the influence of intact forest extended further into adjacent, regenerating forest than that of aggregates. Trends in these and other traits also indicate aggregates may be more susceptible to edge effects compared to intact forest. Our results support other findings that suggest larger aggregates may provide greater ecological benefits. At the same time, aggregates of the size assessed here (0.1 ha) still maintained many functional attributes associated with interior forest and influenced adjacent regeneration, affirming the continued implementation of retention forestry practices to achieve ecological objectives.

Integrating modeling, informatics, and experiments to guide macrosystems ecology research

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Abstract: Macrosystems biology focuses on integrating data and analysis across large scales in space and time to address emergent system properties and develop management and conservation solutions to continental to global scale ecological problems. Integrating modeling, informatics, and experiments provides a powerful synergistic approach to address the challenges and realize the opportunities of macrosystems research. Bioinformatics work to develop, curate, archive, and analyze genomic and epigenomic data, modeling of the influences of population processes on genomic patterns within populations, and controlled and replicated experiments to test hypothesized relationships are all critical to advancing our field. The greatest challenges and opportunities lie in the intersections among these three branches of research. Bioinformatics should inform design of experiments, and results of genetic experiments should guide what genomic and epigenomic data are collected for a given research effort. Modeling should guide pattern-process relationships across scale, and experiments should guide the parameterization and calibration of models. Bioinformatics should provide modelers with genomic and epigenomic data appropriate for model development, calibration, optimization, and validation, while models should inform bioinformaticians as to which genomic and epigenomic data is most relevant for a particular question. The three-way intersection of bioinformatics, modeling, and experimentation provides the strongest potential synergy to advance evolutionary and population genetics.

Moving forward: mainstreaming ecological silviculture through linkages to past and future objectives and approaches

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Abstract: Silvicultural systems based on natural development models have been promoted by forest scientists for over seven decades, yet adoption by practitioners remains limited to specific ownerships or regions. A significant barrier to greater implementation of these systems has been a reluctance to shift from more timber-focused models that place a central focus on maximizing crop-tree growth and development, often at the expense of ecological complexity and biodiversity. The rise of third party certification over the past several decades has served as an important catalyst for greater integration of ecological silvicultural principles into landscapes managed for wood products; however, the degree to which natural models are followed varies widely across ownership types and regions depending on local standards and level of experience with ecological silvicultural systems. This presentation will argue that a fundamental limitation to greater application of these approaches has been a lack of localized, ecological silvicultural systems that build from an understanding of natural development models, yet acknowledge the outcomes of historic silvicultural approaches. Merging these two knowledge bases provides an opportunity to apply ecological silvicultural strategies promoting structural retention

and continuity while also ensuring desired compositional conditions are being maintained for long-term wood production goals. This talk will conclude that the recent emergence of objectives associated with forest adaptation provide an opportunity for mainstreaming ecological silviculture due to the ability of these systems to generate forest conditions that contain multiple pathways for recovery and adaptation in response to changing climate and disturbance regimes.

Operational evaluations of adaptive silviculture strategies for northern hardwood-dominated ecosystems: The New England Adaptive Silviculture for Climate Change project

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Abstract: The structure and functioning of northern hardwood-dominated ecosystems in northeastern North America are threatened by the impacts of changing environmental conditions and disturbance regimes, including more frequent extreme precipitation events and an increasing prevalence of non-native insects and diseases. Silvicultural systems for these forests have long been based on uneven-aged approaches that rely primarily on natural regeneration; however, these systems may need to adapt to changing and uncertain future conditions. The installation of the Adaptive Silviculture for Climate Change project on Dartmouth's Second College Grant in New Hampshire provides a unique opportunity to operationally evaluate adaptation strategies for sustaining northern hardwood ecosystems in the context of emerging stressors. Experimental treatments build from traditional and ecological approaches to northern hardwood silviculture to generate a range of structural and compositional conditions that can both resist projected changes in climate while conferring future adaptive capacity. Resistance strategies being tested at this site involve traditional silvicultural approaches, namely single-tree selection, whereas variable density thinning and continuous cover irregular shelterwoods are being evaluated as resilience and transition treatments to increase ecosystem complexity and the number of pathways for recovery following future disturbance and climate change impacts. Deliberate retention and creation of deadwood legacies is also a common element in these treatments as a biodiversity conservation measure and a potential strategy to minimize runoff from future extreme precipitation events. Although not a common practice in northern hardwood systems, transition treatments include planting to increase future-adapted species in these forests, including northern red oak, black birch, bitternut hickory, and American chestnut. This presentation will summarize initial structural and compositional responses to these treatments, including the survival of future-adapted tree seedlings, as well as the response of biodiversity components, including small mammal communities, and litter decomposition to these treatments to highlight broader ecosystem impacts of forest adaptation strategies.

Mixedwoods: Why and how should we manage for hardwood – softwood mixtures?

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Abstract: Mixtures of hardwoods and softwoods (mixedwoods) often confer benefits such as market flexibility, wildlife habitat diversity, and resistance and resilience to forcing agents such as insect pests, diseases, and climate change. Recent work in the central and northeastern regions of North America on the ecology and management of mixedwoods, focusing on *Pinus*–*Quercus*, *Tsuga*–hardwood, *Picea*–hardwood, and *Abies*–hardwood forests, investigated outcomes of species mixtures relative to pure hardwood or softwood stands. This work has documented a number of benefits of mixedwoods, such as greater belowground carbon storage in *Picea rubens*–hardwood stands than in pure hardwood stands, and increased compatibility and adaptability to anticipated future climate in *Pinus echinata*–*Quercus* stands relative to pure stands of either component. Though increases in aboveground carbon storage were not observed in northern mixedwoods, findings did not reveal climate-related disadvantages of these species mixtures. This suggests that mixtures desired for other reasons (e.g., greater resistance to defoliation by *Choristoneura fumiferana* in *Abies balsamea*–hardwood stands, or by *Lymantria dispar dispar* in *Pinus*–*Quercus* stands) need not be shifted to hardwood or softwood dominance due to climate-related concerns. However, because mixedwoods commonly result from disturbances that create

regeneration niches for new species in softwood- or hardwood-dominated stands, they can be transitional in nature. As a consequence, such mixtures cannot be sustained without deliberate efforts to regenerate and recruit species with differing silvical properties and functional traits. Silvicultural recommendations vary by mixedwood forest type, but include maintaining conifer seed sources or planting, manipulating regeneration substrate, controlling microclimate for regeneration, and reducing competition with mechanical or chemical treatment of the submerchantable classes. With judicious application of these treatments, stand compositions can be achieved to maximize not only desired production objectives, but ecological outcomes.

Overstory, sapling, and seedling responses to restorative prescribed fires in upland oak-hickory forests, Arkansas

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Abstract: Prescribed fires were implemented in 2006-2007 to evaluate impacts on overstory health conditions and oak regeneration potentials in degraded upland oak-hickory stands within the Ozark-St. Francis National Forest, AR. This long-term study not only tracked changes in density, composition, and size of oak and non-oak species (e.g., red maple, blackgum, blackcherry) but also evaluated individual stem responses to fire across different size classes (overstory, sapling, and seedling). Prior to prescribed fires, overstory crown conditions of red oak species were worse than those for white oak and non-oak species as a result of severe drought and a red oak borer outbreak. Red oaks with a dbh >10 inches only survived to post-12 years if they had a healthy (dieback <25%) crown initially. The majority of red oaks of this size with an initial crown dieback >50% were dead 12 years post-fire, creating canopy gaps. Overstory red oaks with a dbh <10 inches had a greater survival rate and likelihood of recovering than red oaks with a larger dbh regardless of crown health. Nearly all red oaks with dieback >75% were dead two years following prescribed fires. The effects of the single growing season fire appeared to be less severe on red oaks than the dormant season fire, despite initial crown condition. The majority of white and post oak were not negatively impacted by either the dormant or growing season burns and maintained a healthy crown up to 12 years following prescribed fires. Smaller non-oak overstory trees with a dbh <10 inches were more sensitive to dormant and growing season burns than oaks. Oak and non-oak saplings and seedlings experienced similar topkill rates following the prescribed fires, however, a greater proportion of oaks re-sprouted. These findings will assist forest managers in predicting mortality in overstory trees based on pre-burn crown health status.

Anticipating the effects of climate change and wildfire on low elevation forests in the western US

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Abstract: Climate change is increasing fire activity in the western United States, which has the potential to accelerate climate-induced shifts in vegetation communities. Wildfire can catalyze vegetation change by killing adult trees that could otherwise persist in climate conditions no longer suitable for seedling establishment and survival. Recently documented declines in post-fire conifer recruitment in the western US may be an example of this phenomenon. However, the role of annual climate variation and its interaction with long-term climate trends in driving these changes is poorly resolved. Here we examine the relationship between annual climate and post-fire tree regeneration of two dominant, low-elevation conifers (ponderosa pine and Douglas-fir) using annually resolved establishment dates from 2820 destructively sampled trees from 32 wildfires across four regions in the western US. We show that regeneration had a non-linear response to annual climate conditions, with distinct thresholds for recruitment based on vapor pressure deficit, soil moisture, and maximum surface temperature. At dry sites across our study region, seasonal to annual climate conditions over the past 20 years have crossed these thresholds, such that conditions have become increasingly unsuitable for regeneration. High fire severity and low seed availability further reduced the probability of post-fire regeneration. Together, our results demonstrate that climate

change combined with high severity fire is leading to increasingly fewer opportunities for seedlings to establish after wildfires and may lead to ecosystem transitions in low-elevation ponderosa pine and Douglas-fir forests across the western US.

Variations in sugar maple (*Acer saccharum* Marsh.) shoot architecture with ontogeny reveals its contrasting ability to respond to disturbances during its life cycle

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Abstract: Tree ontogeny is related to major changes in tree structure and function at different scales, from individual organs to the whole tree. Yet, little is known about the direct effects of tree ontogeny on shoot specialization and branching patterns. Such specific architectural changes occurring with tree growth and aging are of critical importance for understanding the response of trees to disturbances and especially sylvicultural practices. The uppermost branching system of 0.1 to 23 m-tall sugar maple trees was sampled at the end of the growing season. Measurements were made at both the branching system (n=40) and annual shoot scales (n=803). An algorithm for automated shoot typology was developed to characterize branching pattern variations. Sugar maple shoots were divided into four types with contrasting sizes and levels of foliage (i.e., relative biomass allocation into leaves, LMF). These morphological differences were interpreted as functional specializations for light exploitation (high LMF) or space exploration and support (low LMF). Only annual trunk shoots exhibited trait value changes during ontogeny such as a minimum allocation to foliage in the current-year shoots for the 5 m tall trees, which is related to lower light interception capabilities but higher space exploration abilities. However, this relative loss of light interception function is compensated by ontogenetic changes at the branching system scale, which are associated with higher rates of ramifications to produce lateral shoots. This study reveals how branching system and annual shoot traits change simultaneously during tree ontogeny to fulfill different functions, particularly light exploitation and space exploration. Knowing this ontogeny driven changes in tree temperament will help in understanding tree response to disturbances.

Introducing the NH-SEED: A holistic experiment to revisit classical and test novel silvicultural systems in a changing world

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Abstract: Forest stewards aim to "ensure the continued health, integrity, and use of forests to benefit society in perpetuity" (Society of American Foresters 2000) through the application of the best available science. Currently available silvicultural recommendations represent the best available science; however, they were developed under historical social, economic, and ecological conditions. When applied under novel conditions, these silvicultural recommendations may have unpredictable or undesirable outcomes. Furthermore, we increasingly aim to manage ecosystems as complex adaptive systems for long-term sustainability, which requires us to have a holistic understanding of ecosystem processes and functions. To meet these challenges, we need to monitor the outcomes of our current management, but also explore new silvicultural systems and revisit "old and untested" ones. Therefore, we established the Northern Hardwood Silviculture Experiment (NH-SEED) to develop alternative silvicultural systems for the management of northern hardwoods in the Great Lakes region through identifying critical, process-limiting dynamics. This before-after, control-impact (BACI) experiment uses a replicated split-plot design to investigate the potential impact of light limitation, seedbed limitations, deer browse, and seed limitation on diversity of forest regeneration through the application of gradients of harvest intensity, site preparation, deer exclusion, and direct seeding. Simultaneously, we are assessing: 1) logging productivity and impacts, 2) stand composition, structure, and development, 3) financial returns, 4) understory plant community dynamics, 5) changes in wildlife assemblages and population viability of vulnerable wildlife populations, and 6) social impacts in response to the experimental treatments. Furthermore, we are leveraging the design of this experiment to advance 1) the development of remote sensing and geographic information system technologies, and 2) outreach and education opportunities. Our poster will highlight the importance of using holistic frameworks when establishing silvicultural experiments and provide a discussion of the lessons we have learned through establishing the NH-SEED experiment.

Differences in drought adaptation between southwestern provenances of ponderosa pine

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Abstract: Ponderosa pine (*Pinus ponderosa*) forests of the southwestern US are threatened by climate change. Deforestation and drought-related tree mortality have already started in southwestern ponderosa pine forests and will intensify over the next century as atmospheric temperature and drought severity increase. We are conducting greenhouse and field common garden studies to investigate genetic variation in growth, drought-adapted structural and physiological traits, and survival in ponderosa pines sampled from 21 sites across Arizona and New Mexico over elevational and environmental gradients. The objectives of the study are to 1) identify ponderosa pine populations in the southwestern US most suitable for future reforestation projects in increasingly arid conditions; and 2) investigate which traits in ponderosa pine are most strongly associated with genetic adaptation to dry and warm conditions. The greenhouse study is being conducted at the Northern Arizona University Greenhouse Facility in Flagstaff, Arizona. The experimental common gardens have been established across the thermal range of ponderosa pine in July 2018. The hot edge site is located at Blue Chute, AZ (elevation 1930 m, Mean Annual Temperature (MAT) 9.7°C), the range core (Flagstaff Arboretum site, AZ (elevation 2200 m, MAT 7.6°C)), and the cold edge (Cedar City site, UT (elevation 2700 m, MAT 4.9°C)). Approximately 1150 seedlings are being used for the greenhouse study and 1000 seedlings are planted at each of the field common garden sites in a randomized block design. We expect populations from the lower elevation, drier sites to have greater genetic adaptation to aridity as compared to core and cold edge populations, and the early mortality results at the hot site have shown the expected pattern.

Collapse, reorganization, and regime identity

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Abstract: Decades ago, ecology underwent a paradigm shift from an equilibrium-based perspective of the climax community to one that embraces the potential for multiple alternative regimes within a single system. However, the identity of an ecological regime (i.e. grassland state versus forest state) is assigned without consideration of disturbance history, leading to debate as to whether modern characterizations of alternative regime dynamics are simply an extension of equilibrium theory. Using post-fire forest-grassland dynamics, we tested for differences between the typically assigned identity (forest or grassland) of a site and its disturbance history based on fire severity (which we term transition class) 27-years after wildfire. In many current applications of alternative regime dynamics, forests that experience high severity fire will reorganize to resemble an unburned grassland following fire, while forests and grasslands that experience low severity fire will reorganize to resemble unburned forests and grasslands, respectively. In each case, we found that sites that experienced wildfire driven collapse and reorganization deviated significantly from undisturbed sites assigned to the same identity nearly 30 years after disturbance. In all instances, each transition class hosted its own unique species, structures, and community compositions. Forests predicted to transition to grassland hosted the greatest level of uniqueness. Although these sites had few to no live trees, plant and animal community composition and structure more strongly resembled forested sites than grassland sites. Our findings highlight the importance of considering the novel patterns and processes created by regime collapse and reorganization when modeling ecological systems. Continuing to develop and enhance models of ecosystem dynamics to emphasize the importance of collapse and re-organization is imperative, particularly as we demonstrate that the influence of such events persist well over management relevant time scales.

Wood structure drives secondary growth phenology of Eastern US temperate species

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Abstract: Climate models project warmer summer temperatures leading to increasing drought in temperate forests of Eastern North America (ENA). Such droughts are increasingly documented to affect tree growth, with critical impacts on carbon sequestration, forest dynamics and timber provision. Considering recently acknowledged high sensitivity of growth to the timing of drought events, an accurate species-level understanding of radial growth phenology is crucial to assess the vulnerability of temperate stands to climate change. In this study, we use well-replicated dendrometer band data from the Harvard Forest in Massachusetts (USA) to assess the growth phenology of 611 trees from 15 northern temperate species across six years. Radial growth follows a typical logistic shape, with initially low growth rates reaching a maximum in June, and then decreasing until process termination. Focusing on the period of rapid growth, we find that diffuse-porous species take 18±10 days less than other wood-structure types to put on 50% of their annual increment. This higher growth rate is associated with a delayed phenology, as diffuse-porous species attain 50% of their annual increment almost a full month (24±4 days) later than ring-porous and conifer species. When we match each species period of rapid growth with water availability during the six-year study period, we find that the later window of growth in diffuse-porous species is associated with higher water deficit of 88±19mm, compared with 15±35 mm and 30±30 mm for ring-porous and coniferous species, respectively. Considering the high climatic sensitivity of wood formation, our findings suggest that diffuse-porous species may react differently to climate because of their later summer window of growth, which coincides with higher evapotranspiration and lower water availability.

A burning question: can wildfire risk be predicted through physiological drought responses in the invasive eastern redcedar?

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Abstract: Encroachment of *Juniperus virginiana*, eastern redcedar, due to fire suppression, is one of the greatest contributors to the degradation of Oklahoma's cross timbers forest. Mature trees are unlikely to burn during wet periods. However, during extended dry periods when live foliar moisture (LFM) approaches 60% they become more easily ignited and combustible. Currently, the amount of drought that is necessary to cause reductions in LFM is unknown. To identify factors that contribute to wildfire risk we examined correlations between LFM in *J. virginiana* and leaf water potential and soil moisture. We used a dual greenhouse/field approach to link field conditions with changes in LFM and water potential. In the greenhouse, we watered eastern redcedar saplings to field capacity at the start of the experiment. We ceased watering on all redcedar saplings except for the randomly chosen controls. All saplings were measured twice a week for water potential and LFM. Simultaneously, all pots were measured gravimetrically for soil moisture. The field study was designed to relate greenhouse results to realistic field conditions. We chose three sites in Oklahoma with different levels of annual precipitation: Woodward (dry), Stillwater (middle), and Cookson (wet). We measured LFM, water potential, and soil moisture in the field through a range of seasonal variation in climate. In both the field and greenhouse experiments, we observed relationships between LFM and water potential, and soil moisture and water potential. The greenhouse experiment showed that LFM drops below the important 60% threshold at a lower water potential than we observed in the field. Future work will incorporate remote sensing through spectral reflectance, while evaluating the same relationships in plants that are recovering from prolonged drought. Overall, our results demonstrate that increased drought conditions alongside future climate shifts could frequently cause elevated wildfire risk in Oklahoma's forests.

Invasions in the Sierra Nevada: Forest management impacts on understory species

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Abstract: Forests in the Sierra Nevada are facing an unprecedented legacy of fire suppression, which is leading to more frequent catastrophic fires. In order to mitigate the adverse effects of wildfires in California, managers have adopted various treatment strategies to reduce fuel loads. However, few studies document the exotic species response to these treatments and even fewer research long-term effects. The dearth of long-term data is problematic for two reasons: first, vegetation can take many years to recover after disturbance, and second, it is difficult to conclude whether the vegetation response directly following disturbance is ephemeral or perennial. Here we sampled eleven years after treatments to overcome some of these limitations. Research was conducted at the University of California Blodgett Forest Research Station located in the north-central Sierra Nevada. Between 2001 and 2002, the following fuel reduction treatments were replicated three times: (1) prescribed fire, (2) thinning and mastication, and (3) thinning, mastication, and prescribed fire. Initial surveys from 2003 indicated that exotic species increased following all treatments, and this trend persisted eleven years later. The increase of exotic species in the understory augmented the relative abundance of annual species and exotic grasses, which have been associated with increased fire frequency in chaparral systems. Our study suggests that forest treatments increase exotic species invasion in the understory for long periods, which has consequences for biodiversity conservation and ignitability.

Long-term patterns and consequences of white pine blister rust spread in the southern Sierra

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Abstract: The invasive pathogen, white pine blister rust (Cronartium ribicola), is an insidious agent of mortality in white pines. Following its introduction to North America in 1906, white pine blister rust infected many white pines populations throughout the US and Canada. The declines of eastern and western whites were so severe that blister rust ranked as one of the worst disease epidemics in history. While blister rust spread rapidly throughout much of the US, the southern Sierra Nevada historically had lower levels of invasion. To determine whether this trend persists today, we surveyed long-term monitoring plots in Sequoia and Kings Canyon National parks between 2013-2017. Our results suggest that there have been substantial changes in incidence and severity over the past twenty years. Incidence dropped by over 50% in sugar pines, while it doubled in western white pines. We identified blister rust in whitebark pine for the first time, though no infections were confirmed in foxtail pine plots. Severity of infection also varied by species; the highest average severity was found in western white pines. Our results suggest that blister rust is becoming a much greater threat to higher elevation white pines in the southern Sierra. These findings have important implications for whitebark pine, which is currently being assessed for listing under the Endangered Species Act. In contrast, blister rust spread has slowed in low-elevation sugar pines. This surprising result can be attributed to a number of interacting factors, including fire, warmer temperatures, and a decreasing uninfected population. Sugar pine mortality rates over the past twenty years were also very high and suggest that sugar pine is currently declining in the southern Sierra. Our results highlight that the southern Sierra may continue to experience major changes in blister rust invasion, which could have negative consequences for the long-term outlook of white pines.

Red tree voles: examining the potential factors limiting occupancy and activity in young forests

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Abstract: The red tree vole (*Arborimus longicaudus*) is a highly specialized small mammal, endemic to the forests of western Oregon and northern California. Tree voles nest in tree canopies and forage on conifer needles. They are important prey for the northern spotted owl (*Strix occidentalis caurina*) and are currently a candidate for the endangered species list. Tree voles have been reported as

associated with old-growth forests (>120 years) while younger forests (<80 years) are categorized as less suitable habitat. Today, novel disturbance regimes, including frequent large-scale wildfires threaten old-growth forests throughout the tree vole's geographic range. Understanding the factors limiting tree vole occupancy and activity in younger forests is therefore important, especially when most forest management practices, including basal area removal (thinning), are implemented in forests less than 80 years old. Our study examined two potential limiting factors in younger forest: 1) structural availability for nest building; and 2) interconnected branches for movement, foraging, and escape routes. To examine structural availability in younger forests we placed cameras above artificial nest platforms in two, paired younger and old-growth forest stands. Our data suggest that occupancy rates of artificial nest platforms in younger forests were higher than those platforms in older forests. When we removed interconnected branches between nest trees and adjacent trees in younger forests, there was no effect on tree vole activity at those nest trees. Increased prevalence of red tree voles in old-growth forests is therefore most likely associated with the availability of individual tree structures for nest building, whereas interconnected branches at nest sites is likely of less importance. Thinning approaches that stimulate older forest structure may therefore have long-term positive effects on red tree vole populations.

To mound or not to mound: Assessing the effects of mounding on the recovery of understory communities in disturbed treed peatlands

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Abstract: In peatlands, micro-topography is a major driver of understory plant community composition. Disturbance in peatlands can result in a loss of micro-topographic variation, primarily through the loss of hummocks. Mounding can re-establish micro-topographic variation and has been shown to be an effective restoration technique in drained peatlands. This study examines the effects of mounding on the recovery of the understory vegetation on seismic lines. Seismic lines are linear corridors of deforested treed peatlands (approx. 3-8 m wide), that are created during oil and gas exploration. Regeneration on seismic lines can be slow and mounding is being explored as a technique to facilitate restoration. Our objectives were to assess and compare the recovery of vascular understory diversity, abundance, and composition on unmounded and mounded seismic lines and determine how this recovery varies with micro-topographic position. In particular, we examined three micro-topographic positions: top of the hummock, slope of the hummock, and the level ground adjacent to each hummock. Recovery was defined as similarity to the understory vegetation in undisturbed peatlands. Results show both unmounded and mounded seismic lines had significantly higher diversity than the undisturbed peatlands, regardless of micro-topographic position. Total understory cover was significantly lower in the slope and level position than at the top of the hummocks for both unmounded seismic lines and undisturbed sites; cover on mounded seismic lines did not differ among micro-topographic positions. In addition, total understory cover on the top of hummocks was significantly lower on mounded seismic lines than on unmounded seismic lines; however, neither differed significantly from those of undisturbed peatlands. Our results show that recovery may vary by micro-topographic position; future analyses will examine compositional differences between these sites. The results of this study can inform restoration efforts in boreal treed peatlands.

Spatially varying selection pressures and introgression with limber pine structure genetic diversity within peripheral populations of southwestern white pine

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Abstract: Quantifying standing levels of genetic diversity across natural populations of organisms is a crucial first step to understanding future responses to environmental change. Attribution of these patterns to historical evolutionary process, moreover, provides further information crucial for management. Here, we quantify genome-wide patterns of genetic diversity across the natural range of southwestern white pine (*Pinus strobiformis*) using tens of thousands of genetic markers generated by reduced representation DNA sequencing. We then examine the role of two evolutionary processes to the generation and maintenance of observed patterns – spatially varying selection pressures based on climate and introgression with a closely related species (*P. flexilis*). Overall, genetic structure among populations of southwestern white pine is low, although there is multilocus evidence of geographic groupings that divide the range of southwestern white pine into a northerly group of peripheral populations and a southerly group of core populations. Within the peripheral populations, there is evidence of long-term introgression with *P. flexilis*, with genome-wide levels of introgression forming a north-to-south cline. Geographic clines in genetic diversity, moreover, are discordant with those from

morphological data, suggesting the action of natural selection acting upon introgressed variants. Thus, standing levels of genetic diversity in the peripheral populations of southwestern white pine are affected by natural selection acting upon novel allelic combinations generated in part by patterns of historical introgression. Integration of these results with those emerging from landscape genomic scans for selection across the peripheral populations will also be discussed.

Evaluating comparative growth responses of spruce and aspen in thinned mixedwood stands to historical drought episodes

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Abstract: Spruce and aspen mixedwood stands are an important component of boreal forest in western north America, and there is increasing evidence of their sensitivity to climate change, and summer drought in particular. However, sensitivity to climatic shift, and the specific timing and duration of drought events, is expected to differ between species. Understanding how management interventions in mixedwood stands, such as brushing and thinning, influences stand dynamics and species-specific responses to drought events remains an important challenge in mixedwood forestry ecology. We evaluated the relative impact of drought on spruce and aspen growth in boreal mixedwood stands in northern British Columbia, using increment cores collected from long-term silviculture trials. Our analysis focused on addressing three related questions: 1) Is the growth of spruce influenced more negatively by drought events compared to Aspen? 2) Do thinning treatments influence the response of spruce and aspen to drought events? 3) Do past growth dynamics influence the response of spruce and aspen to thinning treatments? Our results indicate that both stand composition and relative density influence the sensitivity of spruce and aspen to drought events. Both aspen and Spruce exhibited strong negative growth impacts in response to climate perturbations, and high drought years in particular. However, there was relatively weak correspondence between the years where spruce exhibited poor growth and the years when aspen growth was constrained by climate. These differences in climate sensitivity reflect both the differences in the seasonal phenology of the two species, and species-specific differences in the duration over which drought events influence growth. We discuss our findings in context of the projected resilience of boreal mixedwood forests to increases in the magnitude and frequency of summer drought, and discuss the potential to partially mitigate climate impacts through shifts in species composition and stand density.

Impacts of climatic change on the health of high mountain forests: The case of widespread dwarf mistletoes in timberline pine species

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Abstract: Two species of dwarf mistletoe (DM) were studied in the high mountain forest of Nevado de Toluca, Mexico. These forests are dominated by populations of *Pinus hartwegii*, which currently present high levels of deterioration (forest fires, pests, parasitic plants and wood extraction). The objective of the research was to determine the infestation levels of DM in the pine forest. For this, 1,622 sampling sites were established along an altitudinal transect. The sampling sites (0.1 ha, 35.6 m diameter) were distributed systematically at an equidistance of 200 m, to guarantee a minimum sampling intensity (1.25%). At each site the UTM geographical coordinates, altitude, slope, and slope exposure were recorded and all trees with DBH (diameter at breast height 1.30 m above the ground) ≥7.5 cm were measured; regeneration (<7.5 cm DBH) was recorded, as well as the measurement of the basal diameter of all the cut trees. Two species of DM were identified: yellow (*Arceuthobium globosum* subsp. *Grandicaule* Hawksw. & Wiens) and black (*Arceuthobium vaginatum* (Humb. & Bonpl. Ex Willd.) J. Presl subsp. *Vaginatum*) using available taxonomic keys. Data analysis indicated that 43% of the *Pinus hartwegii* is infested with DM. The infestation by DM is distributed in all diameter classes. The black mistletoe is distributed between 3100 and 4100 masl, while the yellow mistletoe is established between 3400 and 3800 masl. The southern and western exposures (the region with the highest rainfall, and have had the largest changes in temperature in the last 30 years), are the slopes with the largest infestation. It is also a region with the lowest slopes that are more accessible to human pressure. The research suggests an effect of anthropic disturbance and climate change on the distribution and levels of DM infestation on the Nevado de Toluca pine forests.

Changes in lichen biomass following 10 years of warming climate in the Mackenzie Valley of northwestern Canada

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Abstract: Lichen-rich forest and peatland environments form critical habitat for boreal woodland caribou (*Rangifer tarandus caribou*). Listed as threatened under Canadian and Northwest Territory (NWT) Species at Risk Acts, the national recovery strategy identifies habitat disturbance as the primary factor affecting the sustainability of a population. Fire and anthropogenic disturbances are currently incorporated in population sustainability models and recovery strategies for boreal woodland caribou but there is limited understanding of the effect of climate change on critical habitat attributes. This is particularly important in the Mackenzie Valley of the NWT, which is one of the regions exhibiting the greatest temperature increases in Canada and, due to the prevalence of ice-rich permafrost, is also a region where the consequences of this warming may be most dramatically evident. In 2007-2008 a series of 69 permanent monitoring plots was established, throughout the Mackenzie Valley, on the sensitive landscape features of peat plateaux (permafrost-containing bogs), areas of permafrost thaw within the peat plateaux (collapse scars), and low productivity upland forests occurring on mineral soils. A series of 15 transects was also established at the interface of peat plateau and collapse scar features. These plots and transects were re-measured in 2017-2018, following 10 years of climate warming. Field-based measures of lichen abundance and lichen mat thickness were coupled with lichen biomass samples, to develop biomass prediction equations. Modelled lichen biomass significantly (α=0.05) declined from peat plateau, to upland forest, and from upland forest to collapse scar environments. We did not see such dramatic effects of climate warming on lichen biomass when not associated with permafrost collapse. However, these results indicate that climate warming causing any substantial permafrost collapse in the ice-rich, lichen-dominated peat plateau environments will affect lichen biomass and, potentially, caribou habitat quality.

Long-term effects of timber harvesting on coarse woody debris volume and size distribution, and the impacts on marten habitat in northern British Columbia

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Abstract: Coarse woody debris (CWD) is an important component of forest ecosystem functionality, and there is increasing recognition that CWD dynamics need to be considered when planning forest management. Coarse woody debris provides structural diversity, permits nutrient cycling, influences species composition, soil and sediment transport, and provides important habitat for diverse species, especially pine marten, *Martes americana*. Martens use CWD as predator-escape cover, denning and nesting sites and to access prey. The ability of CWD to perform its functional role depends on the amount and distribution (i.e., size, decay state, orientation, and position) of the pieces, the additions of new CWD, and losses through decay. Timber harvesting greatly influences these dynamics. The long-term effects of timber harvesting on CWD loading and size distribution were analysed in North American northern temperate hemlock-cedar forests as part of the Date Creek Silvicultural Systems Experiment in British Columbia, Canada. Coarse woody debris volume, diameter and length distribution, height above the ground, and decay stages were compared in stands of varying amounts of overstory basal area removal: 100% (clearcut); 60%, 30%, 0% (unharvested control); 25 years after harvest. Stands with 30% and 60% basal area removal had similar CWD characteristics, though the 30% removal stands were the most analogous to unharvested stands. These stands had more CWD in lower decay stages and the pieces were larger than CWD in the clearcuts. Coarse woody debris in the clearcuts tended to be closer to the ground, smaller and more decayed. These results suggest that tree retention during harvesting partially retains higher structural diversity of CWD, an important characteristic of marten habitat. Our results also demonstrate that forest management practices influence both CWD size and input dynamics over multiple decades, and we discuss the concomitant impact on wildlife habitat at the landscape scale.

Temperature-sensitivity to drought-induced mortality of Mexican pine species

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Abstract: Forests in many semi-arid locations around the globe are threatened by drought compounded by warmer temperatures. Yet, current projections of vegetation change do not represent mortality adequately and likely could be substantially underestimating the vulnerability to large-scale forest die-off. Progress is being made to increase our understanding regarding the drivers of mortality but, information is very limited regarding the resiliency to drought and warmer temperatures of similar species in the same genus that occur across natural temperature gradients such the Sierra Madre mountains of northern Mexico. Estimates of drought and heat induced tree mortality are needed to provide predictions of present forest vulnerability to have sufficient confidence to guide future management decisions. We conducted two drought by heat (ambient and +4ºC treatments) experiments with five predominant native pine species of the Sierra Madre mountains of Mexico (*Pinus engelmannii*, *P. greggii*, *P. montezumae*, *P. pseudostrobus*, *P. strobiformis*) and *Pinus edulis* found predominantly in the semi-arid southwestern U.S. in constructed experimental chambers and along a natural elevation gradient created by the Santa Catalina Mountains near Tucson, Arizona. After 60 days of experimental conditions, all of the Sierra Madre species died in the drought treatment in both the ambient and hotter chambers. Survival of watered saplings was 100% in the ambient chamber, but a few saplings could not cope with warmer temperatures in the hotter chamber and succumbed even though water was not limiting. These results are novel in that they suggest warmer temperatures can be a dominant driver of mortality regardless of water amount but, alternatively, amount of water can also be the dominant driver of mortality. These results also highlight more complexity in heat and drought mortality drivers than previously considered.

Fire in peatlands erase linear disturbances and restore caribou habitat

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Abstract: Alberta's boreal forests are highly fragmented by seismic lines, narrow linear features (~3–12 m wide) that are cleared of woody vegetation for the purpose of petroleum exploration. Many seismic lines have failed to be reforested even after 50 years post-disturbance, especially within treed peatlands that are preferred habitat for threatened woodland caribou (*Rangifer tarandus caribou*). The mechanized creation of seismic lines simplify microtopography and depress the soil surface leading to failures in tree recruitment due in part to inundation by high water table. These linear features subsequently act as pathways for other vertebrates to enter caribou habitat and ultimately increasing caribou predation. Methods to reforest seismic lines are expensive (>$12,000/km) and do not account for wildfires which can destroy restoration investments (planted trees), yet also initiate early seral conditions that favor recovery. Here we compared burnt and unburnt treed peatland seismic lines with adjacent (paired) forest controls in northeast Alberta, Canada. Tree regeneration more than doubled on burnt seismic lines compared to unburnt seismic lines and was higher than that in the adjacent forests illustrating that fires clearly are assisting with forest recovery. Specifically, tree regeneration varied from 28,500 stems/ha in burnt lines, 11,440 stems/ha in unburnt lines, 18,210 stems/ha in adjacent burnt forest, and 9,520 stems/ha in adjacent unburnt forest. We suggest that natural recovery (passive restoration) of seismic lines can be expected post-fire in treed peatlands and therefore active restoration, through silviculture and tree planting, should be applied strategically and with respect to considerations of wildfire frequency to save limited restoration dollars.

Accelerating restoration: The challenges and successes of the nation's largest collaborative restoration project

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Abstract: The 2.4 million acre Four Forest Restoration Initiative (4FRI) is the largest collaborative forest restoration project in the United States. The objective of 4FRI is to restore ecological resilience and function across 2.4 million acres of northern Arizona's ponderosa pine forest and to attract appropriately sized industry to the region and increase the pace and scale of our efforts to meet the objectives above. The presentation will define restoration and focus on the wide variety of restoration projects occurring across the

4FRI footprint. The presentation will conclude by examining the challenges facing 4FRI implementation of restoration projects. There will be a discussion of the challenges that face implementation, how are we getting to success with these challenges, and where there is more work to be done.

Testing for hybridization in one- and two-needled pinyon pines in the Southwest

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Abstract: Pinyon pine (*Pinus edulis*) experiences among the highest mortality rates of forest species after prolonged periods of drought, which are expected to increase in intensity with climate change. A close relative, *Pinus monophylla*, is adapted to more arid environments. Both species are dominant in the Southwest and play an important ecological role in supporting biodiversity. Despite occupying different ecological niches, they have a contact zone with overlapping distributions, facilitating potential hybridization. Moreover, the types *californiarum* and *fallax* have complicated taxonomic delimitation, as both have one needle per fascicle like *P. monophylla,* but share other features with *P. edulis.* In this study, we have morphological and next-generation genomic data to test for hybridization, detect the direction of gene flow, and determine the extent of the hybrid zone. This hybridization could lead to drought tolerant traits being conferred across species barriers, resulting in drought resistant hybrids. We examined the entire southwestern range of these four pine taxa, ultimately discovering the extent of hybridization and its consequences. We used the fixation index (F_{ST}) to determine population differentiation by genetic structure. Population clustering was determined using a Discriminant Analysis of Principal Components (DAPC) in R. A Bayesian analysis of population clustering was performed in the software STRUCTURE. Our F_{ST} and DAPC results support *P. edulis* and *P. monophylla* being independent species, *californiarum*-type possibly being a result of hybridization between the two, and *fallax*-type possibly being its own species. Our STRUCTURE results suggest *californiarum*-type and *fallax*-type share the same chloroplast genome, contradicting the nuclear data's suggestion that *fallax*-type was a separate group. This contrasting chloroplast-nuclear data support the hypothesis of hybridization and may even imply possible hybridization between *P. monophylla* and *fallax*-type.

Fine-scale spatial patterns of post-fire tree regeneration in western US ponderosa pine forests

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Abstract: Ponderosa pine forests of the western United States have experienced an increase in wildfire occurrence in recent decades, generating interest in understanding how they will regenerate post-fire. We synthesize results from three recently published papers that examined fine-scale spatial patterns of post-fire tree regeneration in ponderosa pine forests of Arizona, Colorado, and South Dakota. Two of the papers examined regeneration spatial patterns in large high-severity patches. These papers collectively utilized data from thirty 4 ha plots distributed across five fires, and yielded several key findings: (1) Ponderosa pine seedlings tended to be spatially aggregated in large high-severity patches. Moreover, while the density of seedlings tended to decline as distance from surviving trees increased, spatial patterns did not likewise change along this gradient; (2) Ponderosa pine seedling locations were either positively or neutrally influenced, but never negatively influenced, by the locations of post-fire regenerating trees of other species (i.e., ponderosa pine seedlings and seedlings/suckers of other species displayed aggregated or random spatial patterns, but not patterns of repulsion); (3) The influence of topographic gradients on ponderosa pine seedling locations was inconsistent, perhaps because our sampling strategy was not optimized to characterize these relationships. The other paper examined regeneration spatial patterns in areas that burned with highly heterogeneous mixtures of severity. Data were collected in three 4 ha plots in Colorado's Hayman Fire. This paper found that (1) conifer seedlings (comprised primarily of ponderosa pine) were spatially aggregated; (2) conifer seedling locations were negatively influenced by the locations of surviving trees; and (3) conifer seedling locations were inconsistently influenced by suckers of other species and by topography. Our results should help managers better predict post-fire regeneration outcomes for recent and future wildfires and prioritize post-fire management investments to achieve the greatest payoff.

Persistence of mixedwoods in montane and ecotone environments under a changing climate

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Abstract: Montane and subalpine forests of the eastern US are dominated by spruce (*Picea*) and fir (*Abies*) species and surrounded by mixedwood transition zones. Management of mixedwoods in these subalpine ecotones is subject to considerable uncertainty under climate change. Simple models predict retreat of subalpine forests, but diverse observations report that spruce and fir are recovering in these zones, suggesting overlooked opportunities for mixedwoods conservation and management. In this research we ask whether spruce-fir mixedwoods are changing across subalpine areas throughout the eastern US. We used mixed models to test hypothesized drivers of change, including stand dynamics, disturbance, and historic and changing patterns in climate and atmospheric deposition. Models allowed effects to vary across three regions of the Smoky Mountains and West Virginia (WV), the Adirondacks and Green Mountains, and the White Mountains and Maine (ME). We analyzed dense time series of Landsat data from 1984 to 2012 to map trends in subalpine mixedwood composition using Google Earth Engine. We used re-measured Forest Inventory and Analysis (FIA) data to infer underlying demographic processes. We found that the conifer component in subalpine mixedwoods increased more than it decreased over 28 years. This pattern dominated montane ecotones of the Northeast, but differed by geographic zone. Spruce-fir abundance increased with elevation and latitude, and decreased with deposition of S and N. Spruce-fir increases declined with distance from a source population, but increased with time since disturbance. Increasing temperatures negatively affected spruce-fir abundance in the South, but conversely favored gains in spruce-fir from NY to ME. FIA data showed spruce-fir species increasing in overstory and sapling basal area in each region. This recent expansion of ecotonal mixedwoods highlights areas for potential recovery and management from WV to ME, but forests remain sensitive to future changes at their southern extreme.

Silvicultural principles utilized in restoration of Klamath Federated Tribes pine and mixed-conifer forests

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Abstract: Klamath Federated Tribes have adopted and, in collaboration with the Fremont-Winema National Forest, a program to restore their historic reservation forest to a fire-resistant state. This forest is dominantly frequent-fire forests of ponderosa pine and mixed-conifer that was naturally subjected to frequent, low severity wildfire. Much of the forest retains at least moderate numbers of old, fire-resistant pine trees, but forest densities have increased over historic densities by 2 to 3X. The mixed-conifer forests are the highest priority for restoration as conditions have changed much more rapidly in these more productive forests than in those of pure ponderosa pine. Restoration prescriptions begin with retention of all old trees regardless of species or size; there are no diameter limits on young trees. Old trees are not only retained but nurtured by removal of all ground and ladder fuels and most or all competing younger trees for a distance of twice the drip line of their crowns. The remainder of the stand is thinned to reduce its density to a target basal area, increase mean diameter, and shift composition toward more fire-resistant species, such as ponderosa pine. All marking is done using a cluster-based rule to encourage the development of a more spatially heterogeneous forest. Treatment of activity fuels is also a goal. Very large project areas (currently 100,000 acres or more) are undertaken so as to rapidly restore the entire historic reservation.

Natural disturbance and stand structure of old-growth northern white-cedar forests, northern Maine, USA

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Abstract: Natural disturbance histories and stand structures derived from old-growth forests are often used to guide forest management prescriptions. Although such information is readily available for a number of forest types, it is lacking for others, such as northern white-cedar (*Thuja occidentalis*) forests, despite this forest type's wide distribution, ecological value, and economic importance in eastern North America. We applied dendrochronological methods to seven old-growth northern white-cedar stands

within the Big Reed Forest Reserve of northern Maine, USA, to reconstruct the frequency and severity of past natural disturbances. The prevalence of internal rot (well-known for this species) precluded the construction of age-class distributions. Overall, 63% of cedar trees contained internal rot, and the probability of rot increased with increasing diameter. However, evidence from growth releases reveal pulses of low- to moderate-severity canopy disturbances that occurred sporadically. Surprisingly, these disturbance pulses did not appear to be synchronized among stands. The mean disturbance rate was 7.3% of canopy area disturbed per decade, and pulses rarely exceeded 25% per decade. Based on the subset of complete cores (i.e., no internal rot), 49% of the current canopy trees showed one growth release before achieving canopy status, 23% showed two releases, and 7% showed three releases. Of the 21% that showed no release, most simply showed persistent slow growth that eventually placed them in the canopy. Structure in these stands is similar that reported from other old-growth conifer forests in the region: mean living tree basal area of 41.3 $m^2 \cdot ha^{-1}$, density of 611 trees ha^{-1}, and coarse woody debris volume of 173 $m^3 \cdot ha^{-1}$. Taken together, these findings suggest that multi-aged silvicultural treatments incorporating periodic harvests of low to moderate intensity, retention trees or patches, and protection of coarse woody debris would be appropriate for sustaining or restoring this forest type.

Modeling aerial dispersal of eastern spruce budworm moths during summer migration

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Abstract: Unlike passive aerial transport that depends only on wind speed and direction, the aerial dispersal of insects and animals is an interactive process in which the individual expresses agency, both acting on and driven by its environment. Dispersal of birds, bats, and insects may frequently occur in numbers and at scales that are observed with weather radar. Using an individual-based model of dispersal behavior, combined with independent weather model outputs at high spatial and temporal resolution, we developed a methodology by which the resulting flight trajectories are then compared with weather radar observations to calibrate dispersal model parameters. Applied to numerous individuals on a regional domain, the calibrated model can then express emergent results indicating collective aerial migration across a landscape. We applied this approach to model eastern spruce budworm (*Choristoneura fumiferana* [Clem.]) migration events during the current outbreak period in Québec. Our rule-based flight model was developed from decades of empirical aerobiological research and is coupled with an established phenological model, BioSIM. We used the Weather Research and Forecasting (WRF) model to drive high-density agent-based simulations of spruce budworm moth nocturnal dispersal activity over a three-week period in July 2013. Flight model results were calibrated and validated using available weather radar observations in an area centered on the St. Lawrence River. Overall results are consistent with observed regional patterns of eastern spruce budworm dispersal from defoliated areas with known spring feeding activity, and significantly advance our understanding of the spatiotemporal variability and interannual dynamics of the current eastern spruce budworm outbreak in the eastern North American boreal forest. Our quantitative parameter-estimation methodology reduced uncertainty in several flight-oriented biophysical parameters and may have broader application to other species where weather radar observations of dispersal events are available.

Spatiotemporally explicit modeling of forest phenology using weather and climatology

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Abstract: Using 35 years of Landsat images for northeastern Minnesota, USA, and more than a decade of phenocamera observations in the Boundary Waters Canoe Area Wilderness, we present analyses and hindcasts of forest phenology. Various studies of forest phenology from both of these perspectives have employed logistic, harmonic, or other curves fitted to long-term observations but then used only that mean curve in subsequent analyses. We have developed a method to explain latent information in the curve residuals, those observed departures from the mean phenology, using seasonal and interannual deviations from the long-term climatology at the same location. While the long-term mean phenology is useful in a diagnostic sense, these phenoclimatological relationships use meteorological measurements at the land surface on a daily basis, allowing us to generate model-based predictions of expected forest phenology (ahead of satellite image availability) that account for interannual variability in weather and climate conditions. At the spatial scale and resolution of Landsat observations, these phenoclimatological relationships advance our understanding of vegetation responses to atmospheric conditions on temporal scales from weeks to seasons. These methods can help improve the representation of

forest phenology in weather and climate models, especially its spatiotemporal variability, leading to more realistic effects of vegetation state on energy, carbon, and moisture fluxes at the land–atmosphere interface.

Augmenting Growth Models for *Pinus strobiformis* Seedlings Using Dimensional and Spectral Variables from Unmanned Aircraft Systems

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Abstract: Common garden studies are used in forestry to detect genetic variation within species, including resistance to drought and disease. To detect phenotypic variation, these experimental designs traditionally require manual measurements, visual inspections, or both. Obtaining these measurements is resource intensive and potentially a limiting factor with respect to scale. Unmanned aircraft systems (UAS) are a relatively new method of monitoring plants that have the potential to be more efficient and objective than traditional techniques. We surveyed common garden boxes containing southwestern white pine (*P. strobiformis*) seedlings in Arizona, USA twice, one year apart, using multispectral and thermal infrared enabled UAS. Dimensional variables (i.e. height, crown area, volume) were estimated for the seedlings using products from structure from motion (SfM). Mean seedling spectral responses, including seven vegetation indices and crown temperature, were extracted using a vegetation mask and buffered point vectors. The heights and diameters of the seedlings were manually measured during the same growing seasons as aerial surveys. The objective of the study was to predict the one-year increase in seedling size using only the seeding dimensions from the previous year and remotely sensed variables, which are inexpensive to acquire compared to ground-based measurements. We provide evidence that when modeling seedling size, height, root collar diameter, or slenderness are not necessarily preferred response variables, but the longitudinal area is. We found that including remotely sensed variables increases the predictability power of linear regression models, and that dimensional variables were generally better indicators of growth than spectral variables. The longitudinal area of the seedlings from the previous year was a good predictor variable for several responses, which suggests that this metric may be well suited for describing the physical structure of young tree seedlings. Our methods were also effective for remotely detecting seedling mortality that occurred between UAS surveys.

Tree proximity enhances natural root grafting in two hybrid poplar clones

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Abstract: Root grafting in trees is a well-recognized phenomenon allowing nutrient and photosynthate redistribution between connected roots, that can later influence tree growth. This study assessed the influence of spacing in root graft formation and growth of planted hybrid poplars. Tree growth metrics, including diameter at breast height (DBH), basal diameter and stem height, were measured in 15-year-old hybrid poplars planted at three spacings (1 x 1 m, 3 x 3 m and 5 x 5 m) and three sites in Abitibi-Témiscamingue, Québec, Canada. Root number, root diameter and root age were characterized after hydraulic excavation of root systems and with dendrochronological analyses within one site and two spacings. Our study showed that for both clones, larger spacing (3 x 3m) was significantly related to higher above- and belowground growth, but they didn't benefit from the greater spacing (5 x 5m). Root grafts were present and were only found between trees spaced 1 m from each other while no grafts were observed in the 3 x 3m spacing. Root grafts were relatively young and were still at the beginning of their formation (1-6 years). Grafted trees had greater stem volumes (0.18 m^3. $stem^{-1}$), wider roots cross-sectional areas (18.86 cm^2) and greater root numbers (12) than non-grafted trees: 0.07 m^3. $stem^{-1}$; 10.62 cm^2; 9 roots ($p < 0.001$; $p < 0.001$; $p=0.0065$). These results suggest that close spacing led to root grafts and lower tree growth. Bigger trees with wider roots and with a denser root biomass also facilitated the formation of root grafts between neighboring trees in hybrid poplars.

Implications of intraspecific variation in drought tolerance for the response of *Pinus edulis* to climate change

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Abstract: Populations of pinyon pine (*Pinus edulis*) have experienced high mortality during drought events in the US Southwest, and many models predict a significant range contraction in this species. However, long-term field studies of growth and mortality at sites in northern Arizona demonstrated significant intraspecific variation in performance during wet versus dry decades, allowing us to identify drought tolerant and drought intolerant trees. We used a moisture manipulation experiment in a common garden to assess whether the offspring of drought tolerant trees also performed well in the driest conditions in the common garden. We found that: 1) seedlings had similar patterns of growth and mortality as their maternal trees and their siblings suggesting that drought tolerance is inherited, 2) seedlings of drought tolerant trees performed better than those of drought intolerant trees under low moisture conditions as expected, but they also performed better under high moisture conditions, 3) drought tolerance was strongly associated with ectomycorrhizal fungal species composition, with drought tolerant trees consistently associating with ascomycete fungi in the genus *Geopora*, 4) members of the genus *Geopora* tolerated dry soil conditions better than other genera of ectomycorrhizal fungi, and 5) neutron radiography showed that root colonization by *Geopora* increased water flow velocity in drought tolerant seedlings, but had the opposite effect in drought intolerant seedlings. These results indicate that intraspecific differences in drought tolerance and fungal associations interact to influence pinyon responses to drought and could mitigate the effects of large scale *P. edulis* mortality across the Southwest.

Recovery of soil mesofauna and microbial communities following even- vs uneven-aged management in mixedwood boreal forests

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Abstract: Uneven-aged management has become increasingly popular over the past few decades in order to sustain a wide range of ecosystems services. Although we have a good understanding of the impacts of even- and uneven-aged management on vegetation composition, productivity and different groups of fauna, little information is available on the soils mesofauna and microbial communities especially over the long-term. This study compares the soil mesofauna (springtails) and microbial communities (bacteria and fungi) of boreal mixedwoods under even- vs uneven-aged management. The different treatments included recently clear cut or partially harvested stands, 20 year old clear cuts, 20 year old partial cuts and unlogged stands. This study also aimed at determining the main environmental factors driving these communities (vegetation, stand structure, soil properties). During the summer of 2016, we assessed vegetation composition, stand structure, coarse woody debris, topography, and collected litter and soil samples (first 15cm) in all treatments. From a subset of the litter and soil samples we assessed the diversity and composition of the springtail communities and from all soil samples we assessed the diversity and composition of the microbial communities (bacteria and fungi) by new generation DNA sequencing. From the soil samples we also determined the physical (water-holding capacity, texture) and chemical properties of the soils (nutrients, pH). Harvesting treatments did not affect species richness of springtail, bacterial and fungal communities, but they affected their composition. For soil mesofauna and microbial communities, partially cut stands had compositions more similar to unlogged stands than clear cut stands even 20 years later. Results of the difference in soil mesofauna and microbial communities between logging treatments as well as the main factors responsible for these changes will be presented and implications of these results for forest management will be discussed.

Long-term impacts of even-aged and uneven-aged forest management on the composition of ground beetles.

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Abstract: In northern mixed forests, uneven-aged management initially better maintains habitat and ecological legacies for biodiversity than even-aged management. Yet key issues remain unresolved including whether biodiversity in even-aged stands recovers once forest canopy is re-established and whether biodiversity recovers from successive silvicultural interventions that occur in two-pass harvesting. We evaluated the long-term impacts of uneven and even-aged management on the abundance and composition of ground beetles, a diverse and speciose group of animals. We compared beetles in (1) partial cuts harvested with a single pass in 1995; (2) partial cuts harvested twice in 1995 and 2015; (3) clear cuts harvested in 2015; (4) clear cuts harvested in 1995; and (5) uncut mature stands (control) in Haute Mauricie, Québec, Canada. We collected insects from May to September 2018 using 120 pitfall traps and 60 interception traps. Preliminary results suggest that the abundance of ground beetles does not differ between partial cuts with a single pass made in 1995, older clearcuts made in 1995 and uncut controls. However, recent partial and clearcuts significantly reduced the abundance of ground beetles. This suggests that both even-aged and uneven-aged management maintain similar ground beetle abundance after 20 years. However, even 20 years after the harvest, compositional differences in ground beetle assemblages persisted between even- and uneven aged stands.

Edge influence on composition and structure of a longleaf pine woodland following wind disturbance

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Abstract: Forest edges are an important legacy of natural and anthropogenic disturbances. Edges of forest fragments are influenced by adjacent non-forested ecosystems, resulting in compositional and structural differences at the edge. Edge influence is the altered biotic and abiotic interactions that occur along the edge-to-interior gradient in disturbed forests. Few studies have analyzed edges created by natural disturbance, particularly in woodland forest structures, which contain fewer trees ha^{-1} than forests and are typically less light limited. The goal of our study was to examine edge influence of a tornado-created edge in a longleaf pine (*Pinus palustris* Mill.) woodland. In 2011, an EF-3 tornado impacted a restored longleaf pine woodland, resulting in a distinct woodland edge. To quantify distance of edge influence into the stand, nine transects were installed perpendicular to the tornado swath, with 11 plots on each transect at variable distances from the edge. Biotic and abiotic response variables were measured at the appropriate spatial scales. To determine the distance of edge influence, the magnitude of edge influence was calculated at each distance, and compared to the reference woodland using a non-parametric randomization test. Edge influence on forest structure was negative (reduced values at edge), with a maximum distance of 70 m. Ground flora richness and diversity experienced a positive edge influence (increased values at edge), with higher richness and diversity in the tornado swath and edge, however, ground flora communities at the edge were not compositionally distinct from the tornado swath or the interior. Results of this study add to our understanding of edge influence on woodland forest structure and naturally created edges.

Does involvement in boundary organizations improve knowledge coproduction, relationships, and communication between scientists and managers? A case study of the Southwest Fire Science Consortium

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Abstract: Boundary organizations, such as the Southwest Fire Science Consortium (SWFSC) funded by Joint Fire Science Program, have been established to bridge scientists and managers. The goal is to increase the amount of science used in management decisions and to inform what type of scientific information managers need for their work, in turn facilitating effective forest and fire management. To explore if and how SWFSC fosters interactions between scientists and managers, we conducted interviews with scientists and managers involved with SWFSC. Specifically, we examined the correlation between level of engagement in SWFSC and (1) methods of science delivery used by scientists, (2) manager and scientist coproduction of knowledge, and (3) improved relationships and communication between managers and scientists. Scientists with greater engagement in SWFSC reported more experience with collaborative methods of scientific delivery and coproduced knowledge, as well as improved relationships and communication with managers since interacting with SWFSC. Managers who reported improved relationships and communication with scientists had greater levels of engagement with SWFSC. However, unlike scientists, several highly engaged managers reported their relationship had not changed since working with SWFSC because they already had worked closely with scientists. Both

managers and scientists reported interactions had improved because SWFSC provided opportunities to network, which led to increased connections and collaborations and broke down perceived and actual barriers. Findings from this research indicate that boundary organizations, such as SWFSC, can play an important role in fostering relationships, communication, and knowledge coproduction between managers and scientists. In changing ecological and political conditions, these increased interactions can lead to improved approaches for managing forests and fire.

Modeling the natural dynamics of boreal mixedwoods stands following fire

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Abstract: Natural disturbances, i.e. fire and insect outbreaks, play an important role in natural forest dynamics, which, on long time scales, are characterized by changes in stand composition and structure. Modeling is therefore an interesting tool for better understanding and predicting forest development following disturbances. The aim of this study was to evaluate the ability of the SORTIE-ND simulator model to reproduce natural dynamics of the boreal mixedwoods of eastern Canada as well as the effects of the most recent (1970-1987) spruce budworm outbreak. In 1991 and 2009, we sampled all trees (including seedlings and saplings) in 431 quadrats located at the Lake Duparquet Teaching and Research Forest in western Québec. These quadrats (16 × 16 m) were distributed in seven stands originating from different fires representing a chronosequence of post-disturbance stand development. The 1991 inventory data were used for parametrization of SORTIE-ND and to simulate short (i.e., 18 years) and long (i.e., 100 years) term natural dynamics. We compared the simulated short-term stand composition and structure with those observed in 2009 using a chronosequence approach. We also assessed the impacts of the spruce budworm outbreak on stand dynamics (long-term simulation) using principal component analysis. For the short term simulation, our results show that there is no significant differences between simulated stand composition and structure and empirical observations of 2009. As for the long term simulation, our results show that the recent spruce budworm outbreak has modified the composition and structure of mixedwood stands. We conclude that SORTIE-ND is able to reproduce the natural dynamics in boreal mixedwoods and that from an ecosystem management perspective it is a reliable tool to understand forest natural dynamics.

Beyond the tipping point in dry conifer forests of the US Southwest: post-fire Gambel oak shrubfields as alternative stable states

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Abstract: The goal of forest restoration in dry conifer forests of the Southwest is often to promote resilience to extreme events, such as uncharacteristic high-severity fire. One consequence of high-severity fire in dry conifer forests of this region is a rapid transition of forests to oak-dominated shrubfield. Whether these shrubfields represent a successional stage for conifers or are otherwise permanent alternative stable states remains uncertain. We provide centennial-scale perspectives on fire and vegetation change in the Southwest to provide context for potential future ecosystem dynamics following high-severity fire. Gambel oak shrubfields in the Jemez Mountains persisted for hundreds of years in the presence and absence of frequent fire. Patch sizes of historical shrubfields averaged less than 20 ha with a maximum size of 368 ha. By contrast, high-severity fire patches in the Jemez Mountains following several recent fires reached over 10,000 ha, leaving large swaths of forest deplete of conifers and dominated by resprouting shrubs. Restoring surface fire regimes and associated historical forest structures may reduce the rate and patch size of forest-to-shrub conversions.

Phenotyping disease resistance in trees with a hyperspectral imaging platform

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Abstract: Screening trees for disease resistance or susceptibility is labor intensive and subjective. Recent developments in hyperspectral sensors have opened the door for automatic phenotyping. In this experiment, we developed an automatic workflow

using a 400-1000 nm range hyperspectral camera to screen southwestern white pine (*Pinus strobiformis)* for white pine blister rust (*Cronartium ribicola*). Spectral information of the pine seedlings revealed: (i) whether plants were infected, and (ii) what the degree of symptom severity was. With a supervised classification scheme, we were able to label infected pines with a 90% overall accuracy (kappa 0.8) for a single date. However, using a subset of 2 out of 271 bands (520 and 631 nm) we approached this accuracy with an 88.9% overall accuracy (kappa 0.78). These results show the potential of hyperspectral imaging for wavelength selection. The selected bands can be used to develop a cheaper multispectral camera. Besides this binary classification, we also predicted the degree of infection. The overall classification accuracy of 72.6% was promising. However, there was a high false negative and false positive rate caused by inseparability of the intermediate severity classes. Combining these classes increased the overall classification accuracy to 88.1% (kappa 0.58). An 82.1% accuracy (kappa 0.5) is obtained with the Plant Senescing Reflectance Index, PSRI, using bands 500, 680, and 750 nm. Preliminary results showed that we are able to identify non-symptomatic infected trees, demonstrating the potential for early detection.

Dead or dying? Quantifying the point of no return from hydraulic failure in drought-induced tree mortality

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Abstract: Determining physiological conditions that cause tree die-off could help reduce large uncertainty in global predictions of future terrestrial carbon sinks. We directly tested for the lethal threshold in hydraulic failure—an inability to move water due to drought-induced xylem embolism—in a pine sapling experiment. In the greenhouse, we exposed loblolly pine (*Pinus taeda*) saplings (n=83) to drought-induced water stress ranging from mild to lethal. Before re-watering to relieve drought stress, we measured native hydraulic conductivity and foliar color change. We monitored all measured individuals for survival or mortality. Here we show a lethal threshold at 80% loss of hydraulic conductivity (PLC), a point of hydraulic failure beyond which it is more likely trees will die, than survive, and describe mortality risk across all water stress levels. Foliar color changes lag hydraulic failure, best predicting when trees have been dead for some time, rather than when they begin dying. Our direct measurement of native conductivity, while monitoring the same individuals for survival or mortality, quantifies a continuous probability of mortality risk from hydraulic failure. Remarkably, some individuals survived extreme (>90 PLC) hydraulic failure. Observations from active xylem staining and microCT indicated the importance of water supply to the vascular cambium for survival of extreme drought stress. In a follow-up experiment, our preliminary results indicate that despite a three-fold increase in the xylem tension associated with mortality, a similar level of hydraulic failure (~80 PLC) is lethal for *Juniperus virginiana*, eastern redcedar. We discuss the potential (and limitations) of generalizing our findings, especially as continuous predictors of mortality risk, and outline future work necessary to understand when trees begin dying. Predicting tree die-off events and understanding mechanism requires knowledge not only of when trees are dead, but when they begin dying, passing the point of no return.

Historical range of variability, vegetation departure, herbivory, precipitation, and restoration objectives of open forests

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Abstract: Open forests historically were widespread in the United States. Here, I define open forest composition and structure along with probable extent, in comparison to current forest structure and composition in the eastern United States, using historical and contemporary tree surveys. I also provide several lines of evidence indicating that herbivory and precipitation do not appear to be influential on forest composition and structure at landscape scales. For these analyses, I examined Southeastern Cooperative Wildlife Disease Study and Quality Deer Management Association deer densities, tree stocking, and Palmer Drought Severity Index for the eastern US. Lastly, I discuss restoration objectives and considerations.

Unlocking published figures of deer density and historical forests using GIS

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Abstract: Figures in publications contain valuable data, which may be unavailable in formats that contain original values such as tables and GIS layers. Here, we demonstrate two techniques to recover data from published figures through conversion to GIS layers. We applied eCognition to increase automation of the digitization of white-tailed deer density maps during circa 1982 and 2003 in the United States. We used GIS processes and regression to convert bar charts to numerical values of tree composition in historical forests of Indiana townships. These methods may allow retrieval and analysis of other published figures without archived data.

Seed and water availability drive post-fire response of a coastal serotinous pine

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Abstract: Serotinous tree species require high-severity fire for seedling recruitment, yet competing resource values often prevent the use of natural fires. Instead, foresters use other silvicultural treatments, including prescribed fire, to promote serotinous tree resilience. Applying appropriate silvicultural prescriptions requires detailed knowledge of post-fire stand dynamics, including drivers of post-fire tree regeneration, production of viable seeds, and susceptibility to disease, yet these factors are unknown for many species. In this study, we quantified post-fire stand dynamics on semi-arid coastal sites dominated by serotinous Bishop pine (*Pinus muricata*). Bishop pine population persistence is threatened by altered fire regimes, increasing drought, and the non-native pitch canker pathogen, and some land managers are actively using prescribed fire to prevent extirpation. We used a chronosequence of prescribed burns to characterize post-fire stand development, sampling 50 plots that burned in one of five fires since 1982. We modeled post-fire Bishop pine density as a function of time since fire, pre-fire tree cover, and microclimate conditions using generalized linear models. We also modeled seed viability and pitch canker prevalence as a function of time since fire by comparing across fire years. Post-fire regeneration density declined with time since fire, likely reflecting processes such as density-dependent mortality and competition with understory vegetation. Pre-fire tree cover and topographic wetness index exhibited positive relationships with post-fire regeneration density, suggesting that seed and water availability are important drivers of post-fire densities. Finally, we found that availability of viable seeds increased with time since fire, however, older sites also exhibited greater disease prevalence, which may have important implications for stand resilience to future fire and drought conditions. Our results highlight important drivers of post-fire regeneration in an understudied, fire-adapted pine forest and will inform management efforts to implement a prescribed burning program to promote resilience in Bishop pine stands.

Tracing the fate of carbon and nitrogen reserves: Exploring storage and remobilization in trembling aspen (*Populus tremuloides* Michx.)

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Abstract: Allocation and remobilization of carbon and nitrogen reserves in trees remains poorly understood, but are essential for predicting tree growth and mortality, as storage pools provide buffers when demand exceeds supply. However, it is not well known 1) to what extent reserves in one organ are/can be remobilized for use in other organs, and 2) the role distance from the reserve source may play in constraining the availability of stored resources during spring flush or carbon limiting conditions, such as defoliation and drought. To address these questions, we explored reserve remobilization in trembling aspen in response to spring leaf flush and after defoliation. Aspen seedlings, half of which were pulse labeled with $^{13}CO_2$ and $^{15}NH_4{}^{15}NO_3$ before dormancy, were reciprocally grafted prior to leaf flush to create seedlings with either root-labeled or stem-labeled carbon and nitrogen reserves. A subset of seedlings was harvested 18 days after early leaf expansion to measure non-structural carbohydrates and isotopic signature within organs, while the remaining seedlings were defoliated and harvested three weeks later. Following leaf flush, labeled carbon and nitrogen were

remobilized in only one direction: belowground to aboveground. Furthermore, distance from the roots did not appear to affect the proportion of carbon and nitrogen imported for leaf growth in the seedlings. The use of storage reserves varied depending on timing of leaf production. More of the carbon stored in shoot and root reserves was used for early leaf production compared to later leaf production. Additionally, root stored nitrogen was used more than shoot stored nitrogen for later leaf production compared to early leaf production. Under carbon limiting conditions, defoliated seedlings experienced a shift in use of stored reserves by comparison. We discuss these results in the context of carbon and nitrogen transport pathways, as well as limitations to the remobilization and transport of reserves.

Thinning and prescribed fire effects on ground flora in mixed pine-hardwood stands

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Abstract: In temperate forest ecosystems, enhancement of native biodiversity is becoming an increasingly popular management goal. In these systems, biodiversity enhancement efforts are commonly focused on the ground flora (typically defined as stems ≤ 1 m height) because this stratum often has the potential to harbor greater plant diversity than the overstory. Disturbances, such as thinning and prescribed fire, can alter understory growing conditions and may increase ground flora richness, diversity, and cover. Here, we report results from a larger project that was established on the Cumberland Plateau in Alabama, USA to analyze vegetation and fuel response to silvicultural thinning and prescribed fire. Specifically, we analyzed the effects of thinning without fire and thinning in combination with prescribed fire at two fire rotations (four burns on a three year return interval and two burns on a nine year return interval) on ground flora richness, diversity, and cover in mixed pine-hardwood stands. Additionally, we analyzed annual changes in ground flora assemblages over three growing seasons in frequently burned stands (stands burned on a three-year rotation). Ground flora richness, diversity, and cover were greatest in stands that were thinned and burned every three years, and these measures were negatively correlated with litter depth and positively correlated with exposed mineral soil in a non-metric multidimensional scaling solution. Ground flora composition changed over the three years between prescribed burns. Forb cover and richness were highest in year one and gradually declined as woody plants became increasingly abundant. Managers that wish to enhance native plant diversity in mixed pine-hardwood stands may consider thinning and frequent burning to promote ground flora richness, diversity, and cover.

The effects of forest diversity on tree survival following multiple insect outbreaks

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Abstract: Coincident with recent warm and dry conditions, native bark beetles have killed conifer trees across 22.5 M hectares of forest in the western United States. Tree mortality caused by outbreaks of bark beetles can dramatically change ecosystems, leading to changes in timber supply, water quality, recreation, and real estate value, among other things. Most bark beetles are specific to one or a few host tree species and favor stands with abundant large diameter host trees. Thus, a common management goal to mitigate the effects of current and future bark beetle outbreaks is to promote species and structural diversity. In the Interior West, much of the tree mortality has been concentrated in subalpine forests, where the mountain pine beetle (MPB; *Dendroctonus ponderosae*), spruce beetle (SB; *D. rufipennis*), and western balsam bark beetle (WBBB; *Dryocoetes confusus)*, have caused extensive mortality of pine, spruce and fir, respectively. While many subalpine forests are composed of a mix of pine, spruce, and fir, it remains poorly understood how species and structural diversity affects tree survival in the face of multiple bark beetle outbreaks. Here I make use of the spatial and temporal regularity of the USFS Forest Inventory and Analysis (FIA) sampling design to examine the effects of diversity on tree and plot-level tree survival in stands affected by multiple outbreaks. I found that 37% of plots with MPB, SB, or WBBB host trees were affected by bark beetles, while 5% were affected by multiple outbreaks. Model selection suggested survival rates were not influenced by species or structural diversity, but were lower in areas where multiple outbreaks occurred. These results highlight the importance of managing forests in the context of multiple insect outbreaks.

Gaps and hotspots in the state of knowledge for pinyon-juniper communities

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Abstract: Pinyon-juniper (PJ) communities cover a large area across North America and provide critical habitat for wildlife, opportunities for recreation, and rich cultural resources. PJ communities occur across a variety of environmental gradients, disturbance regimes, structural conditions and species compositions, including three species of juniper and two species of pinyon. PJ communities have experienced substantial changes in recent decades and identifying appropriate management strategies for these diverse systems is a growing challenge. Here, we present on the compilation of 441 studies to characterize patterns in research on PJ communities through time, across geographic space and climatic conditions, and among focal species. We will also describe the state of knowledge on three focal topics: 1) historical stand dynamics and responses to disturbance, 2) land management treatments and their effects, and 3) potential future responses to changing climate. We identified large and potentially important gaps in our understanding of pinyon-juniper communities both geographically and topically. While the effect of drought on *Pinus edulis* was frequently addressed, few studies focused on the effects of drought on *Pinus monophylla*. The largest proportion of studies that examined land treatments only measured their effects for one year, and grazing was a common land use that was rarely controlled for with ungrazed reference sites. We found only 39 studies that had information on the impacts of anthropogenic climate change and were concentrated on *Pinus edulis*. These results provide a synthetic perspective on research in PJ communities that can help resource managers identify relevant studies for their concern and location and help researchers recognize important knowledge gaps.

Monetizing the Health Impacts and Economic Value of Using Wood Biomass as a Renewable Energy Source

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Abstract: Fuels-reduction treatments such as mechanical thinning extract small diameter wood, reduce fuel load and subsequent fire intensity. Utilizing small diameter wood and slash from treatments as a renewable energy source presents an opportunity to offset treatment costs and enhance forest health, environmental quality and local economies. This project will examine the environmental and health benefits of using harvested wood as a renewable energy source to generate electricity and reduce air pollutants from coal- or gas-fired power plants in Arizona. Our objectives are to 1) quantify pollutants emitted from pile burning of small-diameter wood removed from fuels-reduction treatments, and 2) quantify pollutants emitted from electricity production using fuel sources of wood, coal, and natural gas. The results will permit us to assess the economic value and human health burden of pollutant emission associated with electricity production, and inform state and federal agencies, local utilities, stakeholders and the bioenergy industry of the value of forest bioenergy. To assess the scenarios, we plan to utilize modeling software such as the Environmental Benefits Mapping and Analysis Program – Community Edition (BenMap-CE), the Estimating Air Pollution Social Impact Using Regression (EASIUR), the Co-benefits Risk Assessment (COBRA), and the Air Pollution Emission Experiment and Policy (APEEP); these models estimate the human health and environmental costs of power generation with respect to types and amount of air pollutants and population size. By calculating the negative or adverse effects (referred to as damages) on human health and the environment caused by electricity production, we will be able to determine the benefits of using woody biomass as a renewable energy resource in Arizona.

Cottonwood clonal transgenerational plasticity and response to climate variation

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Abstract: The capacity for tree populations to cope with climate change depends upon the amount of genetic variation and plasticity in natural populations. Transgenerational plasticity in natural tree populations has received relatively little attention. By expanding on the development of *Populus trichocarpa* as a model system, we can potentially discern intergenerational plant responses to warming temperatures. *P. trichocarpa* holds great significance in natural ecosystems and managed plantations. It has also been a model for

understanding genetic effects on phenotype. We hypothesize that environmentally induced epigenetic variation will be passed to clonally reproduced *P. trichocarpa*. To test this hypothesis, we quantify the effects of planting clones in two contrasting climate conditions for a decade before cloning a second time and planting in new common gardens. The contrasting environments were a warmer, drier garden in Corvallis and a cooler, wetter garden in Clatskanie, Oregon. Eight female genotypes and four male genotypes were chosen to represent warm and cool source regions. Clonal replicates of each of these trees were grown in the Northern Arizona University greenhouse and then transplanted into a warm, dry garden at Walnut Creek Center for Education and Research (WCCER), and a cooler, wetter garden at the Flagstaff Arboretum. Several weeks after planting, data was taken on the respective heights and leaf number of the offspring trees. Both genotype and previous growing environment affected height and leaf number. Understanding the epigenetics and transgenerational effects of three-generations of clonal reproductions of *P. trichocarpa* will give a better understanding of their potential to acclimate and adapt to climate change.

Dasometric parameters estimation from data acquired with terrestrial laser scanner (TLS): Development of a methodology applied to temperate forests in Mexico

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Abstract: Terrestrial laser scanning (TLS) has great potential as a remote sensing tool, since it is efficient for the fast and reliable acquisition of three-dimensional (3D) data in point clouds, creating a wide range of applications in recent years. Beyond the interactive measurement of 3D data, this technology represents a field of research with high priority in Mexico, especially in studies of both climate change, and biodiversity. The use of TLS is being adapted in forest inventories and in the development of local volume and biomass equations, among many other applications in forest ecosystems studies around the world, and as an alternative in non-destructive source of information capable of generating new knowledge in the field of forest ecology. The aim of this study was to develop an alternative methodology to the traditional measurement of dasometric variables, using and combining the TLS technology with free-use software, to accelerate the process of measuring and predicting these variables, in one *Abies religiosa* ((Kunth) Schltdl. & Cham) stand located to the north of the Monarch Butterfly Biosphere Reserve in Michoacán, Mexico. We studied 38 trees to adjust the models of the following variables: basal diameter, total height and height at the base of the crown. The results show that with this methodology it is possible to perform basic dasometric measurements directly from the point cloud. We have had the opportunity to explore and to adapt the use of TLS in Mexico to generate clouds of points of forest plots, as well as the use of applied computational tools. It has been possible to observe that the proposed method is precise and relatively simple one, which allows using this tool in future studies in temperate forests in Mexico in order to understand the dynamics of these ecosystems.

Wildfires and inland mountain forests: is nonforest vital to forest resilience?

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Abstract: In past work with repeat aerial photography of early and late 20th century conditions, we were consistently surprised by the large amount of historical nonforest (e.g., grasslands, shrublands, sparse woodlands, bare ground), and changes to its pattern and abundance in the modern era. Here, we examine in greater detail the abundance and granularity of historical nonforest of several western provinces, and the role that it potentially plays in the wildfire resilience of intermingled forests. Theory and empirical studies affirm that historical forested landscapes of the western US were hierarchically organized, and that there were cross-connections between levels. At fine-scales, patches were often composed of clumped and gapped trees, which nested within meso-scale forest successional patchworks, which themselves nested within broad patchworks of nonforest. We take a closer look at those linkages, and recent changes to them. Using recent MTBS burn severity data from one province rescaled to match the granularity of the aerial photogrammetric data, we quantitatively compare the pattern and abundance of historical nonforest to that created by recent wildfires. Our results provide a clearer idea of the structure and organization of historical forest landscape resilience for this province, and they foreshadow changes that we can expect to these forests with changes in the regional climate.

Evaluation of the evapotranspiration in a managed temperate forest using the Eddy covariance method

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Abstract: Evapotranspiration is an important component of the hydrological cycle and the energy balance. It plays an important role in ecosystem productivity and carbon fixation. This component is highly variable in space and time since it is controlled by numerous biophysical factors. Our objective was to analyze the evapotranspiration variability by the analysis of water vapor flows and measurements of microclimatic characteristics. The study was carried out in a temperate forest dominated by *Pinus patula* under forest management for timber production in central Mexico. The evapotranspiration data was obtained using the eddy covariance technique, simultaneously measuring solar radiation, air temperature, relative humidity, precipitation, soil moisture, and soil temperature. All measurements were made from October 1, 2017 to September 30, 2018. Flux data processing was performed using Li-COR´s EddyPro software. For gapfilling, we used the ReddyProc online tool. To determine the origin of the signal, we performed a footprint analysis using the Kljun methodology. The correlation analysis between environmental variables and evapotranspiration was implemented in R software. During the study period, total evapotranspiration was 1068 mm, and it varied from 1.5 - 5.5 mm day^{-1}. The evapotranspiration varied seasonally in relation to the cold fronts season, and the dry and rainy seasons. The net radiation and the vapor pressure deficit explained most of the evapotranspiration variability, and water availability is not a factor that limits this process. We suggest subsequent studies that involve the analysis of CO_2 fluxes, water use efficiency, and ecosystem productivity to better understand the ecosystem processes and identify appropriate sustainable forest management practices.

Observational and experimental approaches to understanding conifer regeneration in managed stands of Western conifers

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Abstract: Uncertainties related to tree regeneration have emerged as critical knowledge gaps in western US silviculture. Many questions arise directly and indirectly from the anticipated effects of a changing climate, but silvicultural treatments applied in novel contexts also present situations where the natural regeneration events precipitated by treatment and their impact on subsequent stand development are not well understood. In this talk, I will discuss several related studies of conifer regeneration in managed stands that incorporate observational and experimental study designs to better understand the effects of silvicultural treatments. Our group has gravitated toward combining experimental tree planting and seed sowing with intensive environmental monitoring at microsite scales as a means of building silvicultural knowledge that will maintain its relevance in a variety of novel scenarios.

Optimizing plantation tree species composition for multiple ecosystem services under different management scenarios

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Abstract: A core challenge to using the ecosystem services framework is how to value trade-offs between often incommensurate services in a way that is helpful for landowners with a diverse set of objectives and priorities. In this talk we use the management decision of selecting species composition (monocultures versus species mixtures) in plantations of coastal Pacific Northwest as case study to identify ranges of species compositions that minimize trade-offs between seven ecosystem services. In addition, we determine species compositions that optimize ecosystem services under three different sets of priorities designed to reflect the management objectives of investment forestry, conservation forestry, and multi-use forestry. This study highlights the ways management priorities can change the total flow of ecosystem services. We collected data from trees and understory plants in 43 plots in stands with similar management history in an industrial plantation. The tree species composition of plots included monocultures and all possible two and three species mixtures of western hemlock, Douglas-fir, and red alder. We derived proxies for seven different ecosystem services from

the field data and using a response surface model and a simple optimization process determined the species composition that maximized over-all ecosystem service potential and potential ecosystem service output under the three hypothetical management regimes.

Growth and physiological differences between trees that survived and died from an extreme drought in California

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Abstract: Globally, forests are becoming more vulnerable to drought and drought-biotic agent interactions, with large die-off events occurring. In central and southern California, four years of consecutive drought from 2012-2015 caused massive, widespread tree mortality. More frequent and extreme drought conditions are predicted with a changing climate and better data and prediction tools are needed to anticipate the impact of these disturbance events. Our study examines whether early warning signals can be detected from tree rings, which combined with climate relationships, site conditions and stand structure, could identify predisposing factors to tree mortality. We collected cores from trees that survived and trees that died during the most recent California drought to retrospectively quantify tree growth and physiology over time using tree ring and stable $\delta^{13}C$ isotope analyses in ponderosa pine (*Pinus ponderosa*), singleleaf pinyon (*Pinus monophylla*), incense cedar (*Calocedrus decurrens*), and white fir (*Abies concolor*). Drought-mediated bark beetle attacks drove mortality in pines and fir, whereas incense cedar mortality was largely due to suppression from larger, overstory trees. For pines and white fir, dead trees initially grew slightly faster than surviving trees, but growth was similar between response groups for the last 45 years in pinyon pine and 25 years for ponderosa pine and white fir until death. In contrast, incense cedar live and dead trees initially had similar growth, but diverged around 1935, with trees that died having consistently slower growth compared to trees that survived the drought. Our isotope analysis is in progress, and we will report results of annual differences in $\delta^{13}C$ from 1956−2016 between live and dead trees for the four species in our study. This analysis will improve understanding of site and climatic factors associated with long-term tree growth and physiological patterns, and identify possible predisposing characteristics leading to greater susceptibility to drought-related disturbance events.

Characterizing light across a strip shelterwood in a mixed conifer forest

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Abstract: A knowledge of how light varies within gaps is fundamental to understanding variation in survival and growth of regenerating trees. Simple indices based on a small number of instantaneous measurements by portable sensors or cameras are widely used to characterize light levels. However, the effectiveness of these indices for estimating growing season light is influenced by stand characteristics and local weather conditions. We conducted a study in two small (50 m wide by 150 m long) clearings in a mixed stand of the interior cedar hemlock zone of southern British Columbia to evaluate several commonly used light estimation techniques, including: 1) hemispherical photography, 2) LAI-2000 plant canopy analyzer, and, 3) midday measurements of % PPFD (hourly average) under sunny and overcast skies in a strip-shelterwood system. While diffuse indices from hemispherical methods (LAI-2000 and photograph) performed poorly, direct and total indices from photography gave lower variability (lower rmse) and stronger correlations (higher r^2). Sky conditions under which light measurements were recorded influenced the relationships between PAR sensor indices and growing season light; for example, measuring light around midday on a sunny day provided stronger correlations than overcast day measurements. Moreover, rather than using one midday light measurement on a sunny or an overcast day, an average of two measurements increased r^2 and reduced bias while measuring light three times on a sunny day (morning, noon and afternoon) gave the highest r^2. Several indices also correlated strongly with monthly light levels, measured from May-September. Based on the finding that indices that accounted for direct beam contribution gave the best outcomes, we suggest that canopy conditions (degree of heterogeneity), stand orientation and gap sizes should be considered in selecting an instantaneous light index for studies in high latitude forests.

Invasive species legacy effects on functional traits of Fremont cottonwood from sites with and without co-occurring tamarisk

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Abstract: In addition to climate change, invasive species are a major factor in global change. Since its introduction in the early 1800s, tamarisk (or saltcedar; *Tamarix* spp.) has overtaken many of the riparian corridors of the southwestern United States. Even when it is removed, tamarisk leaves a chemical and biological legacy in the soil which presents unique challenges in restoration of native vegetation to riparian areas. Although tamarisk often displaces native cottonwoods and willows (*Populus* spp. and *Salix* spp., respectively), some individual cottonwoods and willows can survive with co-occurring tamarisk. Preliminary studies have shown that cottonwoods and willows from sites with tamarisk (hereafter "experienced") survive better and grow faster when grown in tamarisk legacy soils than cottonwood and willows from sites without tamarisk (hereafter "naïve"). However, we have not yet identified any functional traits that contribute to these differences. This study investigates the functional traits of Fremont cottonwood (*P. fremontii*) from sites with and without co-occurring tamarisk (i.e. experienced and naïve) grown in two types of soil legacies, tamarisk and agriculture. We used a fully-factorial design to test the hypotheses that 1) experienced cottonwoods will have different functional traits than naïve cottonwoods, 2) tamarisk legacy soil will also significantly affect cottonwood functional traits, and 3) that there will be a significant interaction between cottonwood source population and soil legacy type. We identified two major patterns: 1) Experienced cottonwoods, especially when grown in tamarisk legacy soil, showed an increase in root allocation; 2) Experienced cottonwoods growing in tamarisk legacy soil showed greater water use efficiency. Our data suggest that experienced cottonwoods have physiological and resource allocation patterns that better equip them for growing in tamarisk legacy soil. We encourage land managers to use experienced cottonwoods as vegetation stock in restoring areas following tamarisk removal.

Canopy density patterns at the catchment scale homogenize with decreased hydrologic downslope subsidy

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Abstract: In mountainous headwater catchments, downslope flow of subsurface water could mitigate the impact of dry periods in convergent topographic areas, buffering downslope forest communities from soil moisture stress during drought. Here we investigated changes in landscape-scale vegetation patterns at five forested headwater catchments in the Coweeta Hydrologic Laboratory in the southern Appalachians. We used a *ca*. 30-year Landsat Thematic Mapper (TM) image record of normalized difference vegetation index (NDVI) spanning a period of recorded warming since the mid-1970s**.** We then related spatial and temporal canopy patterns to seasonal water balance, streamflow recession behavior, and low flow dynamics from the long-term hydrologic records. All hydrologic metrics indicated increased localized water use, decreased hydrologic connectivity, and reduced downslope subsidy from ridge to stream during low-flow periods. Contrary to expectations, upslope leaf area index (LAI) increased more than downslope LAI over time, coincident with warming. Downslope vegetation appeared to respond to more frequent drought stress driven by a set of interacting processes resulting in decreased hydrologic connectivity and downslope subsidy. These processes have led to a change in canopy density patterns in which hillslope-scale NDVI has been homogenized along hydrologic flow paths over time. Trends in the ratio of NDVI in upslope and downslope topographic positions were also supported by long-term tree basal area increment, litterfall, and sap flux data in one of the reference watersheds. This study suggests that the vegetation downslope may be experiencing lower growth than upslope vegetation, due to their strong dependency on upslope water subsidy.

Comparing tree spatial patterns between and within remnant ponderosa pine forests in Fort Valley and Long Valley Experimental Forests, Arizona, USA

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Abstract: Forest spatial patterns influence a number of ecological processes in dry forests, therefore understanding and replicating spatial patterns is critically important in order to make these forests sustainable and more resilient to fire and other disturbances. The objectives of the study were to: 1) establish definitive characteristics for the grouped arrangement of ponderosa pine trees in old-growth stands; 2) compare overall tree spatial pattern between limestone and basalt soil sites, and 3) determine how spatial patterns change as a function of tree densities within and between sites. We stem mapped all trees >40 cm dbh within two large relict (minimally-logged) pure ponderosa pine study sites at Long Valley (73-ha) and Fort Valley (32-ha) experimental forest in northern Arizona, USA. We also modelled 10,000 individual iterations of each study site incorporating field data parameters and then sampled each iteration using 4-ha plots. Using cluster analysis and field data we found that an inter-tree distance (ITD) of 9-11 m best separated single trees and groups within our study sites. Using a fixed 10 m ITD we found the more productive Long Valley site had higher tree densities and larger groups, but differed only slightly in terms of singles and groups ha^{-1}. By subsampling within each site we were able to compare areas with similar tree densities at both sites. Simulation results indicated that when tree densities are equal, the spatial patterns were very similar between the two sites, suggesting that tree spatial patterns variability is directly a function of tree densities and only indirectly related to site productivity. Our findings suggest that it is important to consider microsite variability within sites and adjust spatial patterns according to the desired tree densities to produce heterogeneous and resilient landscapes.

Human-fire-ecosystem interactions in the pine forests of the binational Madrean Archipelago and implications for regional connectivity of ecosystem services

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Abstract: Pine forests constitute a key component of the rich biodiversity found in the Sky Island mountains that make up the Madrean Archipelago of northwestern Mexico and southwestern United States. Located at watershed headwaters, these forests provide important ecosystem goods and services to human communities in the arid lowlands. International collaborations and perspectives are imperative to understanding Madrean pine forest ecology and designing successful conservation strategies. The Sky Island mountain ranges also provide a unique setting to study how anthropogenic land uses and forest management impact disturbance regimes and the resulting ecosystem function; mountains in the ecoregion are biogeographically similar, but the region is divided in half by the international border, where contrasting land uses and fire management approaches have developed over time and contributed to regional variation in fire regimes and habitats. In this presentation we will give an overview of recent and ongoing research on forest ecology and fire ecology in the Madrean ecoregion, and the development of science partnerships across institutions and nations. We will touch upon the results of ongoing studies including: 1) spatial and temporal patterns of contemporary (1985-2011) fire regimes of region, 2) human-climate-fire interactions and effects on ecosystem services, 3) relationships between fire patterns and avian abundance, and 4) how spatial heterogeneity in recent burned areas functions to facilitate persistence and migration of *Pinus* spp.

Advancing understanding of forest responses to novel climate and disturbance regimes through the quantification of ecological memory

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Abstract: Forest ecosystems face rapidly changing climate and disturbance regimes over the coming century. Recent work has demonstrated forest demographic processes may exhibit ecological memory to climate extremes and disturbance events such as droughts and insect attack. That is, forest demographic responses to current disturbance events may be shaped by responses to past events. Understanding ecological memory and its role in the formation of resistant and resilient forest systems is critical to developing adaptive management plans aimed at maintaining forest function under novel conditions. In particular, ecological memory may serve as a linking mechanism between thresholds, tipping points, and critical transitions allowing for improved understanding of the accumulation of physiological stress over the lifespan of a forest contributing to catastrophic tree mortality or the formation of an alternative stable state following a single disturbance event. We introduce EcoMem, a newly-developed package for the **R** computing environment, that allows users to quantify the memory of ecological processes to a range of environmental variables. The package uses a Bayesian hierarchical framework to estimate latent memory functions for continuous and binary (e.g., disturbance chronology) variables making no *a priori* assumption on the function's shape or form. The utility of the package to advance understanding of forest demographic responses to changing climate and disturbance regimes is demonstrated through its application to continental-scale tree-ring and inventory data from the Canadian boreal forest. Results indicate that boreal tree growth (a proxy for vigor) exhibits decadal-scale memory to past water deficits and insect defoliation events with both variables having a negative effect on growth. Ecological memory functions are uniquely parameterized for regionally-dominant species and applied to long-term inventory data to improve prediction of drought- and pest-induced tree mortality across Canada.

Ecological silviculture for management and restoration in longleaf pine forests – concepts to application

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Abstract: While other southern pine species are predominantly managed for economic objectives, longleaf pine-dominated forests typically have multiple management objectives in addition to production of forest products, including suitable habitat for game and non-game wildlife species, high biological diversity, and aesthetics. These diverse and more conservation-oriented objectives make ecological silviculture practices a logical fit for managing the once dominant and now rare longleaf pine forest ecosystem. Early knowledge of the species' biology led to recommendations for managing longleaf pine using even-aged silvicultural systems. Natural longleaf pine forests, however, are generally multi-aged, and the most frequent disturbance events occur at small spatial scales. These two factors counter the general recommendation for even-aged management of longleaf pine forests and, given the conservation objectives, argue for approaches that utilize ecological silviculture concepts. Recent research on the biology of longleaf pine, especially during the regeneration phase, also provides better understanding for managing the species in an ecological silviculture context. In practice, ecological silviculture in longleaf pine maintains a continuous forest canopy, fosters multiple age classes and a heterogeneous structure, utilizes frequent prescribed fire and individual tree selection harvest methods, and operates from a long-term management perspective. Silvicultural manipulations are patterned after small-scale disturbances that are predominant in the natural disturbance regime. An iconic example of applying ecological silviculture principles to longleaf pine is found in the Stoddard-Neel approach that was developed in the mid-twentieth century in north Florida and south Georgia, and also an adaptation of that approach as practiced at Ichauway, a private reserve in southwest Georgia that is home to the Jones Research Center. The scientific insights supporting ecological silviculture of longleaf pine will be highlighted, and examples of operational restoration and management will show application of concepts and how this management provides resilience in the face of major disturbance events.

Fire, wind and water: drivers of restoration in longleaf pine

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Abstract: Longleaf pine woodlands and savannas are a conservation priority in the southeastern U.S. Longleaf pine ecosystems are some of the most biologically diverse temperate forest types in North America and harbor a suite of rare biota, with 31 federally-listed species and numerous candidate species. Reduced to less than 4% of its historic extent, longleaf pine is an increasing focus of restoration interest. Longleaf pine occurs across a wide edaphic gradient that ranges from xeric to hydric soil types. These highly

productive systems depend upon a regime of frequent fire to maintain their structure, function, and persistence on the landscape. Competition, both inter- and intra-specific, also plays an important role in structuring longleaf pine woodlands. Interactions between site type and hydrology, fire management, competition, natural disturbances, and the unique characteristics of longleaf pine as a species create challenges for conservation, restoration, and long-term management of longleaf pine. Historically poorly understood, over the last 30 years researchers and restoration practitioners have advanced the knowledge of these systems and refined best practices for restoring and managing longleaf pine for a range of objectives. We present case studies that incorporate current understanding of longleaf pine ecology into restoration and management.

Drivers of variability in mixed conifer forest conditions prior to and following fire regime disruption on the Mogollon Rim, AZ

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Abstract: As a result of fire regime disruption, southwestern mixed conifer forests have experienced significant changes following Euro-American settlement, including increased tree density and species shifts. Variability in forest structure and composition strongly affect ecosystem function and wildlife habitat; however, there is a lack of empirically-based biogeographic understanding of how variation in forest structure and composition results in different ecosystem conditions and developmental pathways. This knowledge gap is particularly acute for pre-settlement forests with intact fire regimes and presents a problem that impedes the development of appropriate management and restoration projects. Utilizing field plot measurements and dendrochronological data from sites in dry mixed conifer forests on the Mogollon Rim in northern Arizona, we reconstructed historical forest structure and composition prior to Euro-American settlement (ca. 1879). Our results indicate that by 2014, basal area and trees per hectare had increased by an order of magnitude. Additionally, we observed changes in species composition, with a decrease in the relative importance of *Pinus ponderosa* and *Quercus gambelii* accompanied by an increase in the relative importance of *Abies concolor*. Using environmental variables describing climate (temperature, precipitation, and vapor pressure deficit), topography (elevation, slope, aspect, and topographic position), and soils, we explore sources of variation in the forests prior to and following Euro-American settlement. We identify key relationships and drivers of fine- to mid-scale variability in these forests that can help to inform appropriate management and restoration goals.

Effects of forest tent caterpillars on boreal mixedwood soils and forest regeneration

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Abstract: The boreal mixedwood forest (BMF) is among the most productive ecosystems in eastern Canada. Although fire is the main disturbance agent in the BMF, forest tent caterpillar (FTC) outbreaks periodically intervene to influence forest dynamics. As a larva, this defoliating insect mainly feeds on trembling aspen. During outbreak period, FTC creates canopy gaps that allow solar radiation to penetrate the canopy, which could increase the growth rate of tree seedlings and saplings. In addition, during the outbreak period, FTC corpses and feces litter the forest floor which could increase soil nutrient availability. Depending on the nutrient requirements of the species present in an infected stand, an increase in soil nutrient availability could induce changes in soil-regeneration dynamics and favor the growth of some species to the detriment of others. Eventually, this effect could also induce a modification of the future composition of the stands. However, relatively little is known about these effects in boreal mixedwood stands and, in the context of natural disturbance-based ecosystem management, it is important to better understand how FTC outbreaks influence the dynamics and regeneration of the boreal mixedwood forest. Preliminary results point towards a lower soil C:N ratio, higher nitrogen concentration, and lower phosphorous, calcium and magnesium concentrations in stands infested by FTC. Abundance of aspen saplings was also significantly higher in defoliated sites whereas conifer saplings were found in lower numbers compared to stands clear of FTC. The results of this study could therefore allow the development of novel silvicultural approaches that take into account effects of insect outbreaks on soil properties and forest regeneration.

Response of woody species regeneration to morality caused by hemlock woolly adelgid (*Adelges tsugae*) in the southern Appalachian Mountains

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Abstract: *Adelges tsugae* (hemlock woolly adelgid, HWA, an invasive insect native to Japan), was introduced to the United States in the early 1950s and has caused widespread mortality throughout much of the range of *Tsuga canadensis*. In 2017, we resampled 30 long-term vegetation monitoring plots in Great Smoky Mountains National Park that were established in 2003 across five forest ecogroups that contained *T. canadensis*. Because these plots were established prior to the spread of HWA within the park, we used plot data to examine how the loss of *T. canadensis* affected forest regeneration in forests that contained varying amounts of *T. canadensis* prior to the arrival of HWA. We hypothesized that compositional changes in the seedling and sapling strata would be correlated with the pre-HWA importance of *T. canadensis* in the overstory and the relative dominance of *Rhododendron maximum* (a pervasive ericaceous shrub) in the understory. We also hypothesized that species diversity metrics would differ across year depending on ecogroup and the relative dominance of *R. maximum*. Non-metric multi-dimensional scaling revealed that the seedling and sapling strata of plots with greater pre-HWA importance of *T. canadensis* and lower basal area of *R. maximum* generally exhibited greater compositional change between 2003 and 2017. The degree and direction of change in species richness, evenness, and Shannon-Wiener diversity index varied between strata and with ecogroup, but metrics for both seedlings and saplings displayed a negative relationship with the relative dominance of *R. maximum*.

The genus *Chamaedorea* in Mexico

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Abstract: In Latin America 130 species of the *Chamaedorea* genus are known, of which 54 are found in Mexico. *Chamaedora's* greatest diversity is located in the states of Chiapas, Oaxaca and Veracruz; these small palms are of high structural value in tropical forests, providing understory structure and contributing to the dynamics of soil formation and conservation. Twenty-one of the 54 *Chamaedorea* species present in Mexico have high commercial value. They are used for ornamental purposes, so they represent a source of income for the communities where they grow wild. Due to the volume of foliage extraction, it is necessary to propose strategies of *ex situ* use, which allow their sustainable use. Mother plants were established in the nursery and different management protocols were applied, with the purpose of stimulating vegetative growth and the production of viable seeds that guarantee propagation. Our results found positive effects of applying a management protocol that includes phytosanitary supervision, soil with good drainage and abundant organic matter, a container of adequate size for the development of the root, programmed irrigations and the application of biostimulants to the foliage of the plants. These practices contributed to positive foliar growth and the development of new structures, increasing the number and length of the leaflets in the species *Chamaedorea tepejilote*. Therefore, we conclude that the *ex situ* management tasks are successful in achieving successful foliage production and that the time in which a plant can undergo programmed foliage cutting can probably be reduced.

Identifying range-wide patterns of genetic resistance to save a species threatened by a non-native disease and climate change

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Abstract: Southwestern white pine (*Pinus strobiformis*), is a large, long-lived conifer native to the U.S. and Mexico, and is very susceptible to white pine blister rust (caused by the non-native fungal pathogen *Cronartium ribicola*). The species has a major gene

(*Cr3*), that has been discovered at low frequency in some populations, that imparts complete resistance to the disease but may be overcome in the future by virulent strains of the pathogen. Partial resistance has also been documented in the species and allows infected individuals to survive with disease symptoms. Despite the fact that resistance is found to occur in southwestern white pine, little is known about the type, frequency, and geographic pattern of resistances across its range. Here, early results from a range-wide assessment (446 families from 104 populations) of major gene and partial resistance is presented, where most seed collections are from areas not yet heavily impacted by the disease. Seedlings were artificially inoculated with *C. ribicola* spores and scored for disease symptoms and patterns of growth. All populations show high infection, however, early results indicate that there is a significant ($P < 0.05$) relationship between the probability of canker development and geographic origin of maternal parent. Moreover, we identified variation in partial genetic resistance in the species at low frequencies (7%-11%) and have identified several *Cr3* families. By making selections from families with identified resistance we can test their durability, stability, and usability in field trials and these selections can then be used in proactive management of *P. strobiformis* stands identified as likely to see the arrival of white pine blister rust. These results will provide guidance to refine genetic conservation efforts and future seed collections for reforestation and restoration.

Inducing sucker regeneration of seedling-origin trembling aspen (*Populus tremuloides* Michx.) in boreal forest restoration

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Abstract: Aspen is an early successional, fast-growing tree species native to North America. A critical characteristic of the species is its resiliency to aboveground disturbances, producing dense stands of sprouts (suckers) from its root system, making it an attractive option for boreal forest restoration. A common method to introduce aspen to restoration sites is as planted seedlings; however, little is known about how seedling origin stands will respond to disturbances and whether aspen's regeneration potential will result in maintaining this species and/or forests in these reconstructed landscapes. The objective of this study was to assess the suckering response of 15 to 27-year-old seedling-origin aspen planted on boreal forest restoration sites and explore how stand and site characteristics such as competition impact the suckering. Aspen readily suckered following the complete removal of the aboveground stems, and both the initial number of aspen as well as the total aspen basal area in a plot were strong indicators of the number of suckers produced following stem removal. The type of competing vegetation (graminoid vs. forb) did not affect the number of suckers or their size. In areas where competing vegetation was removed with herbicide, suckers were smaller indicating potential residual herbicide effects. Stand age did not impact the number or size of sucker regeneration; however, the proximity to nearby intact forest stands did. Regeneration plots that were isolated by roads or other intensive mining activities had generally taller suckers than regeneration plots that were located near forests, a result of increased browsing pressure. This research indicates that younger seedling-origin aspen stands can regenerate via root-suckers and cutting it could be a valuable management tool to increase stem density on low-density sites. However, the suckering response will depend on initial stand and site conditions and on pressures such as herbivory during the early recovery phase.

Operational and economic viability of biomass harvesting in hardwood uniform shelterwood

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Abstract: The decline in Ontario's forest industry combined with the increasing demand for low-carbon renewable energy has resulted in the need to develop policies and programs aimed at developing a more diversified forest bioeconomy. Woody biomass as a renewable energy fuel option for heating and combined heat and power can be beneficial because it uses by-products and residues from forest management, restoration, and forest fuel reduction treatments. In the tolerant hardwood forest region, biofibre harvesting can provide a local, sustainable source of renewable biofuel and potentially other higher value bioproducts, as well as a means to improve the quality of the degraded forests across the region. The study aims to determine the economic feasibility of biofibre harvests, at the stand level, by quantifying the volume of product recovered compared to the costs associated with the harvest, as determined by time of motion studies. The study took place across a range of forest conditions (species composition and volume) and directly compared the regeneration cut phase of a shelterwood harvest with and without additional utilization of residual, previously unmerchantable material. Implementing harvesting techniques to recover unmerchantable material resulted in an additional ~60 m^3 ha-1 of bioenergy feedstock, pulp and small sawlogs. This additional volume resulted in greater revenue ($1800 CDN) per hectare for the contractor. Harvest cost per hectare, based on operator time of motion studies, were not significantly different, despite significant

differences in individual machine productivity. Net profitability was highly variable across stands but was mostly dependent on the total merchantable volume harvested. These early results indicate that harvesting unmerchantable material is both operationally and economically viable at the stand scale to help support a diversified forest industry as well as important silvicultural goals.

An introduction of larches in northwestern Russia

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Abstract: Larches are a quite sustainable, easy-to-manage, non-demanding, and multipurpose species native to northern regions. Significant research has been done analyzing adaptation of naturalized larch populations in Bulgaria. Moreover, other scientists addressed larch reproduction features in the Republic of Khakassia, Russia. One of the ways to reproduce larch species in conditions that differ from their natural ones is to grow seeds in those new conditions, and subsequently, the seeds from trees that grew in new conditions and shown best results. The main objective of this research study was to detect the best species for reproduction and breeding of larches in northwestern Russia where the climate is different from the larches' natural habitat. An introduction of larches in northwestern Russia is one way to mitigate the aftermath of some global problems that we presently face, such as climate change, deforestation, and decreasing biodiversity. Seven larch species were represented in the study (i.e., *Larix sibirica, L. sukaczewii, L. decidua, L. polonica, L. dahurica, L. maritima, and L. japonica*). Research data was collected at the Botanical Garden of St. Petersburg State Forest Technical University and Okhta Experimental Base. Data was analyzed utilizing the comparative analysis of seed and cone characteristics (i.e., quality, quantity, crop, age, size, and sowing qualities) of trees from different sites (single tree/stand) and with various parameters (height, diameter, crown cover). The results showed that *Larix sukaczewii*, *sibirica*, and *decidua* of mature age with developed structure demonstrated the best characteristics and can be adapted as a reliable seed source for sustainable reproduction of larches in the northwestern region of Russia. The results can be used to inform further adaptation research by scientists. Additionally, the results can be implemented by foresters and breeders in North American forests to start growing larches in similar climate conditions.

The role of stress and release events on growth and defense patterns in a western U.S. pine

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Elevated global temperatures and recent droughts have contributed to widespread bark beetle-associated pine mortality in the western U.S. Many recent studies highlight the importance of retrospective growth and defense measures to assess pine resistance to bark beetle-attack, with increased allocation to growth and defense often associated with greater resistance. However, information is lacking on the responsiveness of growth and defense to the potential mitigating effects of thinning and burning treatments during a prolonged and intense drought. Here we compare changes in growth and defense patterns in sugar pine (*Pinus lambertiana*) associated with both short and long-term responses to treatments that preceded a prolonged drought in California. In our study examining the short-term effects of thinning (even-thinning and variable density thinning) and burning treatments during drought, we found that growth rather than defense in the year prior to mortality was most informative of tree survival independent of treatment. Competition had a consistent negative relationship with growth in surviving trees and growth generally decreased over the duration of drought. In another study examining the longer-term effects of prescribed burning in different seasons on growth and defense in living sugar pine, we found that growth following a late season fire was lower than both the early season burn and untreated stands. This difference in growth declined over time and by onset of drought 10 y later, trees in both the early season and late season fire stands had greater growth than the control. Trees that experienced late season fire increased allocation to defense in the year after treatment and was greater than both the control and early season fire treatments. However, we did not observe differences in defense among treatments during drought. Our results highlight that treatments can effectively increase tree vigor over short and long time periods depending on the treatment implemented.

Single moderate-severity wildfires create the spatial pattern characteristic of resilient forests but increase large tree mortality

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Abstract: A century of fire suppression has left fire-dependent forests of the western United States increasingly vulnerable to wildfire, drought, and insects. Forest managers are trying to improve resilience using combinations of mechanical thinning and prescribed fire. Unfortunately, available funds are insufficient to treat more than a small fraction of the needed area each year. An alternative is to let wildfires burn under low- to moderate-fire weather. Historically, repeated low- to moderate-severity fires organized forests into patterns of individual trees and small clumps of trees separated by openings of varying sizes. We examined post-fire forest structure using airborne lidar data to determine whether a single wildland fire following an extended fire-free period could produce forest structures resembling historic conditions. We studied forest structures resulting from these "initial" fires in a forest with a history of timber management (2008 American River Complex fire, Tahoe National Forest) and in a wilderness area (2009 Big Meadow fire, Yosemite National Park). Another area in Yosemite NP that had experienced 2+ predominately low- to moderate-severity fires under a restored fire regime served as a reference area. We identified visible overstory trees from the lidar data and examined their patterns in terms of individuals, tree clumps, and openings. We found that moderate-severity fire effects in the initial fires produced similar patterns to the reference area, while low-severity fire failed to adequately break up pre-fire closed canopies and high-severity fire produced large, historically uncharacteristic openings. Results hint that increasing burn severity may disproportionately remove larger (>32 m height) trees from the canopy, which future research should follow up on. Our study suggests that initial fires allowed to burn under conditions likely to produce mixed severity fires can reproduce spatial patterns resembling historic conditions resilient to fires and drought but possibly at the disproportionate expense of larger, 'backbone' trees.

An evaluation of landscape-scale fire-induced change in Washington State, USA

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Abstract: In many parts of the western United States, landscape patterns of forested vegetation are dynamically shaped by wildfires. Following decades of fire exclusion in this region, wildfires are tending to burn larger, more contiguous patches, which can set the stage for subsequent large wildfires in maturing forests. Although increased severity of wildfires is of concern, there is also a need to understand how recent wildfires create low- and moderate-severity burn mosaics that can contribute to greater landscape resilience to future wildfire events. We studied the effects of 11 wildfires (58,354 ha, 1984-2015) on the Colville National Forest, in northeastern Washington State. We used Landsat imagery to estimate burn severity (RdNBR). Forest structure was measured using LiDAR data and photogrammetric digital surface models (DSMs) derived from biannual 40 cm-resolution Hexagon Program imagery. For four fires (41,087 ha) occurring in 2015, we had pre- and post-fire DSMs, which allowed us to detail changes created by wildfires. We evaluated fragmentation of forest canopies after wildfires by comparing geo-registered pre- and post-fire DSM images and quantifying changes in the forest canopy and openings. Prior to the 2015 fires, most of the forests displayed dense, continuous canopy cover, a result of long-term fire exclusion. Low-severity burns created fine-scale patterns of typically enclosed canopy gaps, while moderate-severity fire broke continuous canopies into numerous spatially-disjoint, fine- and meso-scale canopy clumps separated by variably sized openings. High-severity burn patches created contiguous openings disrupted by smaller patches of live canopy cover. These patterns were also apparent in the older fires; however, many fire-created openings were now occupied by young tree or shrub vegetation. Our results offer a rare opportunity to examine the creation of multi-scale forest structural complexity and spatial variability following fire across landscapes and relate them to forest type, pre-fire canopy structure, and biophysical patterns.

Climate change effects on forest fire hazards in the wildland-urban-interface of Bhutan

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Abstract: As forest managers in North America adapt to increasing fire risks in the wildland-urban-interface (WUI), it will be informative to compare with similar efforts abroad. In the Himalayan Mountains of Bhutan, for example, fires play a formative role in blue pine *(Pinus wallichiana)* ecosystems but are also changing with shifting land-use patterns. Our research has investigated the climatic, social, and ecological drivers of fire behavior and risk. The most recent study examined fire hazards in the WUI, focusing on two valleys in Bhutan (Thimphu and Jakar) where expanding human settlements and infrastructure are surrounded by blue pine forests. Data characterizing fuel profile and other risk factors were collected from 102 field inventory plots. We then applied FlamMap, a spatially-explicit wildfire simulation model, to simulate forest fire behavior under four climate scenarios. Climate scenarios were based on climate change projections for the Himalayas (symbolizing scenarios of monsoon failures and warmer temperatures) and built with extreme values of temperature and relative humidity from the years 1996 to 2017. The FlamMap output indicators used for assessing fire behavior were flame length, rate of spread, crown fire activity, burn probability, and fire size. After integrating FlamMap output into a common fire hazard index, we created a fire hazard map showing the areas most susceptible to forest fires. FlamMap predicts a likely two-fold increase in fire hazards in the WUI for both study areas due to climate change. The capital city of Thimphu has greater fire hazards than Jakar; fire hazards are spatially variable over both study areas. Our results highlight parallels between increasing forest fire hazards in the Himalayan Mountains and those unfolding in western North American. Results can be used to better plan suburban development to minimize fire risks in the WUI and adapt forest management efforts in the face of climate change.

Quantifying spatial drought-resistance trait variability of dominant tree species during severe drought

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Abstract: Anthropogenic climate change is anticipated to have large consequences for forest ecosystems, particularly through elevated temperatures and shifts in precipitation regimes. In particular, drought events in the southwest US are expected to increase in intensity, severity, and duration under current climate change projections. Unfortunately, native southwestern forest tree species that are unable to acclimate to these climatic changes in time will be maladapted to the new environmental conditions. To investigate trait acclimation potential in response to drought, we investigated the extent to which drought-resistance physiological traits differ in *in-situ* mature quaking aspen (*Populus tremuloides*) and ponderosa pine (*Pinus ponderosa*) forest stands in the San Juan National Forest in Colorado across an elevation gradient during a severe drought year (2018). We quantified key drought-resistance traits of xylem resistance to embolism, specific leaf area (SLA), turgor loss point (TLP), leaf area-to-sapwood area ratio, and hydraulic safety margin at the low, middle, and upper elevation limits for each species. We compared the spatial patterns of traits across elevation from drier/hotter low elevation plots to wetter/cooler high elevation plots. We observed substantial variation in some drought-resistance traits (particularly leaf area-to-sapwood area ratio, xylem resistance to embolism, and TLP) in both species that are likely to help buffer drier populations during severe drought. However, the degree of trait variation differed between the two species, emphasizing that the limits of plasticity and acclimation may vary across species and clades.

Reintroducing fire into productive mixed-*Quercus* stands: effects on taxonomic, functional, and structural diversity

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Abstract: Although myriad interacting forces control stand dynamics and successional patterns, fire exclusion is a principle factor responsible for the mesophication and homogenization of structure and composition of eastern North American *Quercus* forests. Evidence suggests periodic fire contributed to the development and maintenance of *Quercus* forests across varying spatial and temporal scales, with the increase in the abundance of shade-tolerant species and onset of *Quercus* regeneration problems correlated with fire exclusion/suppression efforts in the mid-1900s. As such, reintroduction of fire, with frequency and intensity informed by historic fire regimes, is actively integrated into forest management plans. The success of burning in *Quercus* forest types is often assessed by its impact on species diversity and/or abundance of specific species. Taxonomic diversity, although useful to describe post-disturbance changes to vegetation, does not quantify the potential effects of disturbance on ecosystem function, a particularly important component in the context of managing forests for resilience to contemporary forest threats. Despite the role functional

diversity has in the production of ecosystem goods and services, functional attributes and diversity have rarely been utilized to describe disturbance effects on forest vegetation in eastern US forests. In 2008, a study examining the response of productive Appalachian hardwood forests to repeated prescribed burning was initiated. Eight, 5 ha mixed-*Quercus* stands were identified in western North Carolina. Treatments (n=4) included control and prescribed burning conducted on a four-year return interval (RRXF). The effects of RRXF relative to unburned stands on taxonomic, functional, and structural diversity were assessed for woody vegetation from the seedling, sapling, subcanopy, and overstory strata. Between year 0 (pretreatment) and year 7, substantial changes in structure and taxonomic and functional diversity were observed as a consequence of RRXF. Results will be discussed in the context of using fire to restore ecological complexity in these diverse and productive forest ecosystems.

Monitoring and adaptive management in the Four Forest Restoration Initiative

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Abstract: The monitoring and adaptive management plan of the 2.4 million acre Four Forest Restoration Initiative represents the culmination of substantial collaboration between the USDA Forest Service and its various stakeholders. Given the scope and scale of the anticipated restoration activities, it was necessary for the monitoring and adaptive management plan to contain a commensurately broad set of monitoring questions that address wide-ranging topics at both fine and broad scales. In this presentation, we will discuss the overall structure of the monitoring and adaptive management plan along with some of the challenges discovered during its implementation. We will also review a selection of the collaboratively developed monitoring questions, indicators, triggers, and responsive adaptive management actions. Finally, we will provide some examples of monitoring efforts currently underway.

Anthropogenic impacts on pine woodland recovery after catastrophic wind disturbance

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Abstract: Forest recovery after disturbance is shaped by the spatial arrangement of residual plants and propagules and their abilities to compete in altered biophysical conditions. Post-disturbance management actions that interact with natural disturbance legacies may alter forest recovery processes. The goal of this study was to assess the effects of catastrophic wind disturbance, salvage logging, and prescribed fire on plant succession and development in longleaf pine (*Pinus palustris*) woodlands of the Alabama Fall Line Hills. A mixed study design was used to monitor physical site conditions, woody regeneration, and understory vegetation before (2016 and 2017) and after (2018) a prescribed fire conducted across sites differentially impacted by an April 2011 EF3 tornado and a subsequent salvage logging operation. Before the prescribed fire in 2018, unlogged wind-disturbed sites exhibited the highest diversity of saplings and ground flora, which was counteracted by salvage-mediated habitat homogenization (i.e., deadwood extraction). Although ground flora assemblages remained distinct after prescribed fire, sapling density was significantly reduced. Furthermore, unlogged and salvaged wind-disturbed sites exhibited increased foliar cover of graminoids and increased densities of longleaf pine saplings after the prescribed fire. Continued use of prescribed fire is recommended to enhance longleaf pine regeneration and the production of fine fuels (grasses and needles) and leaving some wind-disturbed areas unlogged is recommended to maintain ground flora diversity.

Balancing ecosystem processes: dynamics of tree regeneration in frequent fire woodland ecosystems of the eastern USA

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Abstract: Woodland ecosystems of the eastern United States are generally characterized by open stand structure and abundant herbaceous vegetation, which often become target conditions for restoration. Frequent, low-intensity prescribed burning is widely used to restore and then maintain woodland ecosystems. Through time, however, maintaining the woodland structure will also require replacement of canopy trees as stands age and mortality occurs, thus necessitating successful tree regeneration. The regeneration

process is complex but can be generalized into stages: 1) initial seedling establishment, 2) seedling persistence/survival following establishment, and 3) eventual sustained growth for canopy replacement (i.e., recruitment). Frequent, low-intensity surface fire regimes used to maintain woodland ecosystems (commonly at 3 to 5 year fire return intervals) affect each stage of the regeneration process, although the effects vary according to species-specific regeneration traits. We provide examples from studies across the eastern US to contrast tree regeneration of upland oak (*Quercus* spp.), shortleaf pine (*Pinus echinata*), and longleaf pine (*Pinus palustris*) within woodland ecosystems. In general, frequent fire improves site conditions for seedling establishment for all three species groups. Although each species group exhibits traits that allow for persistence with frequent fire, differences among these traits suggest that chronic effects of repeated fire may differ among the species. Finally, the species differ greatly in recruitment potential with frequent fire. Taken together, regeneration success with frequent fire can be expected to vary among these species groups; incorporating the regeneration process into woodland management thus requires consideration of appropriate fire regimes, including variable fire frequencies, for the ecosystem of interest.

Using regeneration ecology to understand development and maintenance of shortleaf pine-oak mixedwoods of Missouri, USA

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Abstract: Shortleaf pine (*Pinus echinata*) – oak (*Quercus* spp.) is the most common mixedwood forest type in Missouri, where shortleaf pine is the only native pine species and oaks typically dominate upland forests. Compared to historical conditions, the abundance and extent of shortleaf pine within the state has decreased, contributing to interest in shortleaf pine restoration and mixedwood management. In the absence of forest management or certain disturbances, contemporary shortleaf pine stands commonly transition to mixedwoods due to ingrowth of hardwoods, and existing mixedwoods commonly transition to hardwood stands as pines age without replacement. Thus, securing shortleaf pine regeneration has been a recent challenge in the region. Understanding the regeneration processes that favor shortleaf pine vs. oak species can help inform managers as to approaches for successful mixedwood management. Shortleaf pine and upland oaks have several similar regeneration traits, including allocation of growth to root development, slow initial shoot development, and the ability to sprout following disturbance. However, they also differ in important ways. Upland oaks accumulate rootstocks and advance reproduction through repeated dieback-sprouting in the understory, whereas shortleaf pine does not develop abundant advance reproduction under shade. The abundance of existing hardwood rootstocks commonly results in problematic competition for shortleaf pine established from seed or planted. Successful regeneration of shortleaf pine requires seed contact with mineral soil followed by sustained growth of established regeneration. Deliberate silvicultural practices that release shortleaf pine from competitors, using herbicide, mechanical methods, or properly timed fire, can overcome challenges with establishing mixedwood forests in Missouri.

Can group-selection with legacy-tree retention change compositional trajectories in traditionally managed northern hardwoods?

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Abstract: Forest managers and scientists have proposed group-selection as a complementary system to traditional, uneven-aged management in temperate hardwoods to counteract declines in overstory diversity and dominance by shade-tolerant species caused largely by long-term implementation of single-tree selection. Results from experimental group-selection harvests in northern hardwoods have been mixed, and growing interest in preserving aspects of ecological memory through legacy retention have led some to consider including ideas from retention forestry into group-selection systems. The Yellow Birch Legacy-Tree Project is a group-selection experiment established in 2003 which incorporates yellow birch (*Betula alleghaniensis* Britt.) legacy-trees into harvested canopy gaps of varying size in a northern hardwoods forest in the Upper Peninsula of Michigan. We surveyed woody vegetation in 49 group-selection openings and 20 single-tree selection reference sites 15 years post-harvest to (1) examine long-term trends in seedling and sapling abundance and diversity, (2) evaluate the initial and contemporary effects of gap size on regeneration, and (3) assess the overall efficacy of group-selection with yellow birch legacy-tree retention in regenerating mid-tolerant and intolerant species, especially yellow birch. Despite shade-tolerant sugar maple (*Acer saccharum* Marsh.) dominating regeneration layers across

treatments, we observed modest increases in diversity within openings that may alter long-term canopy composition over several cutting cycles. We found that gains in diversity and evenness in canopy gaps persisted through time and that large gaps (22 m radius) were the most diverse compared to reference sites. Canopy gaps contained significantly higher densities of shade-intolerant and mid-tolerant seedlings and saplings compared to reference sites, although most diversity occurred in shorter height classes. Legacy retention within group-selection systems holds promise for maintaining ecological memory and structural complexity through time, but further treatments such as scarification may be necessary to shift compositional trajectories more in favor of shade-intolerant and mid-tolerant species.

Drought thwarts ponderosa pine regeneration pulse

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Abstract: Trees in dry forests often regenerate in episodic pulses when wet periods coincide with ample seed production. Factors leading to ultimate success or failure of such regeneration pulses are poorly understood. We investigated impacts of stand basal area on survival and growth of the 2013 cohort of ponderosa pine seedlings in northern Arizona. The 2013 cohort is a regionally distinct, large regeneration pulse produced by heavy seed production in 2012 followed by heavy summer rains in 2013. We measured survival and growth of seedlings from this cohort in six stand basal areas (0, 7, 14, 23, 34, unthinned-66 m^2 ha^{-1}) maintained in a long-term stand density experiment. Our measurements spanned 55 months and five growing seasons (April 2014- November 2018). Survival over five years averaged 2.5%, decreased over time, and varied among basal areas. Mean survival duration was longer (11-15 months) at intermediate basal areas than in clearings and high basal areas (5 months). The 7, 14, and 23 m^2 ha^{-1} basal areas appear to have enough five-year-old seedlings (~2600 ha^{-1}) for successful cohort recruitment into the overstory because of a combination of high initial seedling establishment and relatively high survival. In contrast, regeneration failed completely (0% survival) in the 34 and unthinned-66 m^2 ha^{-1} treatments, and is low in the 0 m^2 ha^{-1} treatment (666 seedlings ha^{-1}). Survival was highest in the first three years during wet years and lowest in the last two years when drought was most severe despite seedlings being oldest. Low survival of four- and five-year-old seedlings occurred during two consecutive years of drought, including the driest fall on record. Seedlings in all basal area levels had no net height growth in the last two years of drought, in part due to stem browsing. Results indicate control over regeneration success by stand basal area, drought, and herbivory.

Interactions between drought stress and induced defenses determine mortality of ponderosa pine to bark beetles

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Abstract: Interactions between drought stress and induced defenses and their role in tree mortality from bark beetles are poorly understood. We performed a factorial experiment on 48 mature ponderosa pines (*Pinus ponderosa*) in northern Arizona over three years that manipulated a) tree water stress by cutting roots; b) bark beetle attacks by using pheromone lures; and c) phloem exposure to biota vectored by bark beetles by inoculation with recently captured, dead beetles. Tree responses included resin flow from bark wounds, phloem terpene composition (mono- and sesqui-terpenes), xylem water potential, leaf gas exchange, and survival. Phloem contained 21 mono- and sesqui-terpenes, which were dominated by (+)alpha pinene, (-)limonene, and delta-3-carene. Bark beetle attacks (mostly *Dendroctonus brevicomis*) and biota carried by beetles induced a general increase in concentration of phloem monoterpenes, whereas water stress did not. Bark beetle attack induced an increase in resin flow for unstressed trees but not water stressed trees. Mortality was highest for beetle-attacked-stressed trees. Compared with trees that lived, trees that died had lower xylem water potential, leaf gas exchange, and resin flow, but greater induction of phloem terpenes. Results show that ponderosa pine mortality from bark beetle attack occurs when water stress constrains quantitative resin flow despite induction of phloem terpene defenses.

Regeneration patterns reveal contraction of ponderosa forests and little upward migration of pinyon-juniper woodlands

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Abstract: A severe drought at the turn of the century caused widespread tree mortality in forests and woodlands in the southwestern United States. The magnitude and extent of mortality of ponderosa pine (*Pinus ponderosa*) and pinyon pine (*Pinus edulis*) has raised concerns about the persistence of these tree species under climate change conditions. We investigated post-drought tree regeneration and potential species migration in three community types along local elevation gradients: pinyon-juniper woodlands, ecotones, and ponderosa forests and three soil parent materials (SPM; sedimentary rock, flow basalt, and volcanic cinder). We assessed regeneration by measuring cone production, tree seedling density, and sapling density. We found evidence that ecotone sites are losing their ponderosa component and transitioning to pinyon-juniper woodland communities. Ponderosa seedling and sapling density was low in ecotones of all SPMs. We found little regeneration of all species in all communities on cinder SPM, despite cone densities that were often similar to those on the other SPMs. The gravelly, dark colored surface of cinder-derived soils create harsh conditions for seedling establishment, including low soil moisture and high daytime soil surface temperatures. These harsh conditions are likely to intensify under climate change. In ponderosa forest communities, we found evidence of constrained regeneration of ponderosa pine, and little indication of an upward migration of pinyons and junipers. Ponderosa seedlings >1yr old were sparse in most ponderosa sites, and ponderosa sapling density was about half the recommended level for local pre-European settlement reference conditions. Pinyon and juniper cone, seedling, and sapling densities were very low in ponderosa forests, indicating little to no upward migration of these species.

Drivers of ponderosa pine regeneration following wildfire in the western United States

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Abstract: In the past decade, there has been a marked increase in the number of research publications examining post-fire ponderosa pine regeneration in ponderosa pine dominated forests across the western US. However, there has not yet been a thorough review of these research publications. We employed systematic mapping and reviewing principles to synthesize the science surrounding the regeneration of ponderosa pine following wildfire, with a focus on identifying, characterizing, and discussing important fire, abiotic, and biotic drivers of regeneration patterns. We defined three subcategories of fire drivers that included fire severity, distance to live trees, and time since fire. Distance to live trees was a strong driver of regeneration. With very few exceptions, most studies demonstrated a strong positive relationship between presence and/or density of regeneration and proximity to living, mature trees. Conversely, other variables like severity and time since fire had varying impacts on regeneration across the publications analyzed. We defined two subcategories of abiotic drivers consisting of topography and climate. Within topography, increased elevation was a strong driver and within climate, average precipitation was a strong driver for ponderosa pine regeneration following wildfire. Other specific topographic and climate drivers did not have consistent trends or were understudied. Finally, we identified three subcategories of biotic drivers: pre-fire overstory structure, understory vegetation, and ground cover. Areas subjected to pre-fire thinning treatments tended to have greater levels of post-fire tree regeneration than unthinned areas. In contrast, there were no clear patterns on how specific understory vegetation or ground cover drivers interact with post-fire ponderosa pine regeneration; this may be due, at least in part, to the low number of publications that examined them. We conclude by identifying research gaps and management recommendations for post-fire ponderosa pine regeneration following wildfire.

Post fire impacts across varying species and topography in an existing forest dynamics plot network located in Santa Rosa CA following the 2017 Tubbs Fire

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Abstract: Following the Tubbs Fire (Sonoma Co., CA, October 2017), a complete resurvey of a previously established plot network was conducted in order to gain deeper insight into the post-fire recovery strategies of each woody species present. The network, consisting of fifty 20x20 m plots, located at the Pepperwood Preserve in NE Santa Rosa, CA (38.57 N, 122.68 W), was established in 2013 and designed in order to monitor long-term changes in forest dynamics with respect to disturbance and climate change. Plots are stratified across the varying topographic gradients present on the preserve, and evenly represented by evergreen and deciduous oak woodland sites. Thirty woody plant species are represented in the network, including ten species of *Quercus*. All stems with a diameter at breast height (dbh) >1cm were measured and tagged with a unique ID number. Additionally, all saplings >50 cm tall and <1 cm dbh were tagged and measured. All seedlings (<10 cm) and juveniles (11-50 cm) were tallied by species both pre- and post-fire. We quantified fire severity in the Tubbs Fire across different vegetation types, and post-fire mortality and regeneration of tree species in all permanent plots at the Pepperwood Preserve. The fire burned 14,895 ha, with >25% in both medium and high severity. Chaparral and knobcone pine stands mostly burned at high severity, while other vegetation types experienced a fairly even distribution of fire severity. The fire killed 50% of saplings and 27% of trees (dbh ≥1cm), with higher mortality in high severity patches. Coast live oak, black oak, madrone, and California bay exhibited very high levels of topkill combined with basal resprouting. Douglas-fir, which lacks resprouting ability, exhibited high mortality, especially in saplings at high severity. The results provide a baseline to examine potential vegetation change due to high-severity fire, especially in high-severity stands of Douglas-fir.

Differential moisture dynamics and flammability among tree species' litter: implications for mesophication in once fire-prone North American forests

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Abstract: Long-term fire exclusion has impacted many landscapes across North America, changing vegetation structure and altering ecological functions. One hypothesized impact is the mesophication of once fire-prone eastern forests (e.g., oak woodlands and savannas). Mesophication is a feedback cycle whereby shade-tolerant, moisture loving, but fire-sensitive species, i.e., mesophytes, replace fire-tolerant, sun-loving, "pyrophytic" species in the prolonged absence of fire. Proposed mechanisms include mesophytic species dampening forest floor conditions and reducing fire potential, thereby facilitating conditions suitable for mesophytes to persist. To examine this process, we evaluated the potential role of mesophyte litter on moisture retention and flammability through laboratory experiments. Litter of mesophytic species absorbed more water or dried more slowly than pyrophyte litter across a study of 17 southeastern US species. Red maple (*Acer rubrum*) litter became the wettest at saturation and dried the slowest of all species studied. Water uptake was related to litter surface area:volume, thickness, and density, while drying response was related to metrics of leaf size and the level of litter 'curling'; thin dense leaves became more moist, while large curling leaves with deep sinuses dried more rapidly as a litter bed. Fire behavior experiments elucidated the role of mesophyte moisture retention on reducing flammability in mixed litter beds. Incorporating litter of sweetgum (*Liquidambar styraciflua*), winged elm (*Ulmus alata*), and dogwood (*Cornus florida*) into oak (*Quercus* spp.) and hickory (*Carya* spp.) litter increased moisture retention and reduced flammability. These mesophytic species were also less flammable than their pyrophytic counterparts when their litter was burned under similarly dry conditions. Changes to forest floor litter composition may be involved in the mesophication process through impacts on moisture dynamics and fire potential.

Sixty years of community change in oak savannas of southern Wisconsin

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Abstract: Less than one percent of presettlement oak savannas exist today across the Midwest. Understanding how savannas respond to changing environmental conditions is critical to their continued presence on the landscape. Fire plays a critical role in savanna maintenance and altered fire regimes can considerably change species composition. Also, winter temperatures have warmed in the Midwest, and may influence savanna communities. To examine plant community change over the past 60 years, we resurveyed savannas in Wisconsin that were originally surveyed in the 1950s. Identical methodology was used at both times to survey understory and canopy plant communities. Landowners provided information about land use and fire histories. With these data, we examined how savannas changed over the past 60 years and how community change related to management and climate change. Both savanna canopy and understory plant communities changed considerably over the past 60 years. Fire frequency was very low or absent for most sites between survey timepoints. In the absence, or near absence, of fire over the past 60 years, many savannas are showing signs of mesification, with a decrease in oak dominance and canopy replacement by more mesic tree species. Also, canopy density increased between the 1950s and today, with an average of 56 (±35) additional trees per acre. In the understory, most of the prairie species

present in the 1950s are gone and replaced by species typical of forests and disturbed woodlands, including an increase in the problematic invasive species *Rhamnus cathartica*, *Zanthoxylum americanum*, and *Celastrus orbiculatus*. Most of the sites surveyed in the 1950s still exist on the landscape today, but active management is required to restore and maintain savanna structure and species composition into the future.

Experimental warming and increased CO_2 impact cone production in black spruce

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Abstract: Climate change, through increased temperature and carbon dioxide (CO_2), could potentially have large impacts on boreal forest tree reproduction. Resource budget models propose that because carbon is not stored, increased CO_2 may have a direct effect on reproduction, while a contrasting hypothesis states that temperature is the main cue driving reproduction. We are using an experimental approach to study the expected impact of climate change on conifer reproduction at the Spruce and Peatland Response Under Changing Environment (SPRUCE) project. The SPRUCE experiment is located in the S1 bog at the Marcell Experimental Forest at the southern edge of the boreal zone in north-central Minnesota. The experiment consists of above and belowground warming conducted in a total of ten open-topped octagonal enclosures (12 m wide, 8 m high) with paired temperature (from +0°C (unheated control) to +9°C, in 2.25°C increments) and carbon dioxide (ambient and elevated ~400 and ~900 ppm respectively) treatments. Canopy vegetation is dominated by black spruce (*Picea mariana*). To quantify cone production on black spruce trees, we count all new cones that are visible using binoculars while standing in a location to see the crown of the tree. During a relatively high cone year, overall black spruce cone production was three to four times higher in the elevated CO_2 treatment compared to ambient CO_2, while there was little impact of temperature. We also detected an interaction between temperature and CO_2 under the highest temperature treatment, where trees produced the fewest cones on average under these conditions. Our findings suggest that elevated CO_2 may have a large direct effect on cone production.

Do wildfires follow fire-prone forest restoration principles?

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Abstract: Wildfires across the western US are modifying forest structure and composition at rates far exceeding planned fuel reduction and restoration treatments. This "work" of wildfires can be beneficial or harmful, depending on the resultant fuel beds, community structure and composition, and habitat patchworks. One way to evaluate wildfire effects, and the need for post-fire management, is to assess the degree to which they follow restoration principles. We investigated recent wildfires in Montana, California, and Washington, USA—with respect to post-fire fuel loadings, forest structure, and tree regeneration and transitions to non-forest—to assess the work of wildfires relative to restoration principles. Fires reduced surface fuel loadings, but this initial effect was offset by post-fire inputs from the overstory. Fires caused reductions of canopy fuels and tree biomass that increased with time since fire, and along unburned-once burned-reburned fire history gradients. In Montana, environmental variables related to topographic position and the severity of the initial fire were most important in explaining post-fire regeneration and transitions to non-forest. In Washington, regeneration density was lowest in dry forests, but high overall, and was related to post-fire weather and proximity of seed sources. Transition to non-forest should be expected in some patches following both initial fires and short-interval reburns, and is characteristic of native fire regime variability, and thus frequently restorative. We see evidence for restorative effects of wildfires, but these effects appear short-lived, especially for surface fuel loadings. Individual wildfires are not sufficient on their own to meet fire-prone landscape restoration goals. Unplanned wildfires present an opportunity for managers to reestablish frequent fire regimes using subsequent mechanical and prescribed fire treatments that build on the work of wildfires.

The role of carbon depletion in conifer physiological resistance to drought

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Abstract: Identifying how trees succumb to drought and which physiological traits influence drought resistance is an on-going challenge in western forests. During drought, theory predicts that trees with high hydraulic safety (resistance to cavitation under drought stress) will survive. We leveraged the California "hot drought" of 2012-2016—more severe than any observed in the previous 1200 years—as a natural experiment to assess how living and dead trees differed in growth and wood anatomy relative to climate. We sampled living and dead *Pinus ponderosa* and *P. jeffreyi* in multiple stands that experienced extensive drought-induced mortality in the Sierra Nevada. Xylem cell "thickness-to-span" (T-S)—the ratio of tracheid wall thickness to tracheid diameter—was higher in drought-killed trees than living trees. Annual growth in living trees increased slightly or stayed constant during and following the drought, while dead trees rapidly decreased growth prior to mortality. However, trees that eventually died grew much faster on average than trees that survived. We then tested the hypothesis that high hydraulic safety through xylem lignification comes at a greater carbon (C) expense, which may limit other C-intensive processes such as pest defense and radial growth. We measured total lignin and carbon concentrations in annual rings. Dead trees were found to have higher average lignin concentrations than living trees, and varied annually in lignin concentration more than living trees. Results demonstrate the C budget implications of drought defense and suggest that drought-induced xylem cell wall thickening may induce a positive feedback loop of C limitation under drought.

Drought and heat wave effects on trees: a piñon pine experiment

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Abstract: Climate change, global warming, and extreme weather events are not synonymous although very interrelated and many scientists are using complex models, high performance computing, and supercomputers to understand the interrelations between these phenomena that have become known as the Anthropocene. Unfortunately, there is a general lack of information on how to inform global change models with parameters, such as interactions between increased air temperature, drought, and heatwaves and their individual and collective effects on important ecosystems for scientists to appropriately understand cause and effect. For example, ecoclimate teleconnections have been documented in recent studies but the "causes and effects" of these global change highways have not yet been completely mapped out. As a result, there remains a great need of controlled experiments for scientists to use to determine, for example, the effects of pinyon (*Pinus edulis*) juniper (*Juniperus* sp.) woodland mortality of the semi-arid U.S. southwest on the carbon balance in other parts of the world. In an effort to improve our understanding and modeling ability of causes and effects of tree mortality we present the results of an experiment on pinyon pine seedlings exposed to drought, above ambient air temperature, and heatwaves. These results include decreased time to mortality with increased temperature and decreased soil moisture. Time to mortality, air temperature, soil moisture, and heatwaves and their relationship are important parameters for global models to accurately predict the effects of climate change, global warming, and extreme events on the longevity of "PJ woodlands" and other important teleconnected ecosystems. Additional information from this experiment regarding important parameters such as NDVI, stomatal conductance, and soil temperature are also invaluable information for improving model accuracy regarding carbon sinks and sources, biomass, afforestation, deforestation, and teleconnections between ecosystems and across the globe.

Complex climate change effects on growth and mortality in upland forests and peatlands of northwestern Canada

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Abstract: Recent climatic warming has led to an increased rate of permafrost thaw and is affecting forest and peatland ecosystems in northern Canada. As temperature is predicted to increase in the next century, plant growth is expected to increase with latitude. However, regional growth is also mediated by complex interactions among local ecological factors. This study assesses the status of upland forests and peatlands through plot-based measurements of tree growth and mortality over the past 10 years, and examines the drivers of these observed changes. Our study builds on existing long-term research in a network of 69 permanent plots along the Mackenzie River Valley of the Northwest Territories. The plot network spans over 1000 km, encompassing four ecoclimatic zones and three permafrost zones, while contrasting three plot types along a topographic gradient: peatlands containing permafrost (peat plateaux), peatlands where permafrost has thawed (collapse scars), and adjacent forests occurring on mineral soil (upland forests). Results indicate that decadal changes in biomass, as well as aboveground stand biomass, vary among ecoclimatic regions and plot types. Multiple linear regressions show that the regional and local site factors mediating climate effects on growth and mortality vary among plot types and across latitudes. In upland forests, increased growth is most strongly associated with mean annual temperature and a greater depth to permafrost, whereas mortality is associated with an increase in the heat-moisture index. In peat plateaux, growth is most strongly correlated with annual solar radiation, followed by mean annual temperature, whereas mortality declines with increasing soil bulk density. Increasing water table depth is the main driver of recruitment in collapse scars. Our results show that local site factors are important and complicate the climate-growth relationship in upland forests and peatlands underlain by permafrost.

Consider forest resilience and long-term risk in rules for regeneration of forests on public lands

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Abstract: Canadian provincial regulators have adopted strict regeneration standards that must be achieved by any agency harvesting timber on public lands. In the four western provinces, the stated reason for such standards is to sustain wood supply. The provincial standards place high value on full stocking and uniform distributions of trees that optimize stand yield - particularly of conifers, often in monocultures. Much of this is achieved by planting programs and subsequent competition control, with expenditures of ~ $300 M per year. Such composition and distributions of trees are chosen because they are associated with higher estimates of final yield in empirically driven stand growth models used to estimate final yield linked to annual allowable cut. In this paper, we argue, however, that estimation of final yield must be influenced by the substantial long-term risk of loss of timber due to insects, diseases, wildfire, and climate change. We argue that in this disturbance landscape, these risks of timber loss increase substantially with simple and uniform conifer stands. Instead, the ~$300 M investment each year should be used to re-establish stands and forests with mixtures of species, but with compositions and structures that also support stand resilience. This could be achieved by planning mixed species composition, and stand structure and layout to achieve higher levels of resistance and resilience to disturbance. Regeneration rules should be reworked to initiate stands that minimize spread of fires and insects, and projections of forest yield and other values should include a realistic suite of risk factors affecting forests.

Cyanolichens from the edge: Dispersal patterns of cyanolichens into harvested openings 25 years after disturbance

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Abstract: The long-term survival of lichens in managed forests depends on their ability to disperse between suitable forest patches and to establish and reproduce in the surrounding regenerating forests. How well the lichens can colonize young trees in logged openings is not well known. In fact, dispersal and establishment of lichens, which are comprised of two partner organisms, is complex and not well understood. We sampled cyanolichens on 25 year old regenerating trees at varying distances from the forest edge, into openings of different sizes, and into openings surrounded by mature or old growth forest, to understand the effective dispersal distances of this group (which includes the federally-listed *Nephroma occultum* and *Lobaria retigera*, and the provincially-listed *Dendriscocaulon intriculatum*, *Lobaria oregana* and *Nephroma isidiosum*). This study was part of the Date Creek Silvicultural Systems Experiment in the interior cedar-hemlock forests of northwest British Columbia, Canada. Overall, total cyanolichen abundance declined as distance from the unharvested edge increased, with fewer lichens occurring at distances >50 m into logged openings. Listed species colonized regenerating trees at lower rates, and in some cases, with shorter effective dispersal distances than less sensitive species. The age class of the surrounding forest modified the dispersal patterns for 11 out of 17 species, with six species showing higher abundance when surrounded by old growth and five species higher abundance surrounded by mature. We detected a small additional influence of opening size on colonization for total lichen abundance and for the abundance of four out of five common species; openings >0.6 ha (clear-cuts) had fewer colonies per tree. These results will aid in the design of silviculture strategies to conserve the remarkable populations of cyanolichens in the managed forests of northwest British Columbia.

Long-term response of forest bird communities to retention forestry in northern temperate coniferous forests

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Abstract: BC's forests are rapidly becoming dominated by managed stands. Retention forestry aims to maintain structural and functional continuity in these stands. While short-term benefits to forest dwellers are well documented, few studies have assessed patterns over decades. Initiated in 1992, the Date Creek Research Forest in northwest BC includes four replicates of four retention levels: 0% (clearcut), 40%, 70% and 100% (unharvested control). These stands, with retention designed to mimic typical insect and wind disturbance, are now entering the canopy closure seral stage. We followed breeding bird communities over 25 years. Community similarity to controls decreased as retention decreased; communities changed over time, with those in clearcuts changing most. Patterns in species abundance varied with habitat preference. Conifer-forest species declined after harvest, with some responding linearly to retention level while others responded similarly to 40%, 70% and 100% treatments; Pacific Slope Flycatcher, Pacific Wren and Brown Creeper remained significantly less abundant in some treatments by year 24. Open-habitat and generalist species increased most in clearcut and somewhat in 40% retention stands, with generalists moving in immediately and open-habitat species by year 10; some shrub specialists remained abundant in harvested stands in year 24. Mixed-forest species reached highest abundance at 40% retention in years 2 and 10, and dropped to control levels by year 24. Although conifer-forest, open-habitat and generalist species treated retention stands as intermediate between clearcuts and controls, mixed-forest species perceived them as a different, preferred habitat for a decade. We conclude that most forest birds perceive 70% retention stands as similar to unharvested forest, that aggregated 40% patch retention partially or fully mitigates impacts for conifer-forest birds, and provides new habitat for other species, and that communities are still changing at early canopy closure. High levels of retention can help soften the changing landscape.

Is it possible to migrate whole ecological communities?

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Abstract: The predicted and realized impacts of climate change are particularly challenging for management of whole ecological communities. Climate change is having a differential effect on different components of ecological communities, effects that are not yet fully understood and that limit the effectiveness of management strategies. Because climate change will cause a decoupling of suitable habitat for many species, assisted migration has been proposed as a strategy for establishing new populations in areas that will have the appropriate conditions in the future. When considering whole communities, assisted migration, although a useful management tool for species of commercial or ecological interest, might not be feasible when a large number of species, belonging to different taxonomic groups, need to be moved to new sites. One alternative is to consider Units of Assisted Migration of Species Assemblages.

Under this proposal, useful (mostly for economic reasons) species and keystone species are migrated to facilitate colonization of as many species as possible from the ecological community to be established. For example, several studies have shown that nurse plants increase diversity by creating microclimatic conditions and by attracting birds and other seed-dispersing animal species. Based on available evidence from Central-Western Mexico, we discuss the potential and limitations, and propose criteria for planning trials, for establishing Units of Assisted Migration of Species Assemblages for temperate forests in the mountainous region of the Mexican Transvolcanic Belt.

Ectomycorrhizae effects on forest regeneration in severely burned areas

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Abstract: With severe fire becoming more common due to a hundred years of fire exclusion and changes in climate, it is becoming more important to begin to understand the drivers of forest regeneration within large, high severity burn areas. Soil composition, specifically surrounding ectomycorrhizae content in the soil, is a good indicator of a site's probability of recovery. We looked for differences in ectomycorrhizal composition from the forest edge to the center of the large, high severity burn patch to identify if ectomycorrhizae, as a soil component, are driving forest regeneration. By understanding the soil factors that contribute the most to forest regeneration, it is feasible to identify areas where forest regeneration will be successful on its own and areas where additional inputs will be necessary to aid in forest regeneration.

Biome-specific responses of carbon, water, and energy fluxes to climate-driven stress and disturbance across the New Mexico Elevation Gradient (NMEG)

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Abstract: Water limited ecosystems in the southwestern US include a range of biomes (e.g., desert grasslands to coniferous forests) that provide ecosystem services for a rapidly growing population that is expected to reach 94 million by 2050. While annual carbon uptake in these water-limited ecosystems is relatively low compared to more temperate ecosystems, collectively these biomes store a significant amount of carbon on a regional scale (up to 350 g C m^{-2} y^{-2}). It is therefore of great interest to not only understand hydrological, biogeochemical, and ecological processes in these environments, but also the response of these processes to both climate stress and disturbance. Climate changes in the past decade alone includes a 1.5 degree C increase in temperature above historic averages, and recent drought that has increased tree mortality, fire, and insect outbreaks across the region. We use a 12-year record from 2007-2018 of continuous measurements of carbon, water, and energy fluxes made across a network of flux towers along an elevation/aridity gradient in New Mexico (the New Mexico Elevation Gradient (NMEG)) to quantify how dynamic carbon, water, and energy fluxes across these diverse biomes have responded to these observed changes in climate and climate-driven disturbances. We also compare measured total carbon uptake through photosynthesis (Gross Primary Productivity, GPP) to the maximum potential GPP calculated for each site, and relate the decreases in light-use efficiency across the gradient to biome-specific thresholds of soil moisture and VPD. We relate these observations to plant functional types across the gradient and use them to predict the impact of a hotter climate and changing precipitation regime on carbon dynamics in the region.

Burn, grow, repeat: evaluating ecological consequences of reburn fires within Alaskan boreal forests

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Abstract: Climate is the primary driver of fire regimes in Alaskan boreal forests, where warmer and drier conditions are correlated with the contemporary trend towards larger and more severe fires. Repeat fires – fires that burn across previously burned areas at shorter-than-expected return intervals – have increased in recent decades. Reburn fires are significant for fire management, where past fires serve as fire breaks that are factored into active fire planning - and significant ecologically, because changes in fire frequency and

severity can alter successional trajectories, species composition, and hydrology and permafrost dynamics, with complex feedbacks to fire behavior. Numerous fire plots established by the National Park Service have burned multiple times in the past decade(s). We re-measured boreal forest plots in Denali and Wrangell-St. Elias National Parks to assess the differences in vegetation communities in once and twice burned sites and with varying times since fire. We identified changes in vegetation by growth form and species related to time since fire and number of fires that suggest that short-interval repeat fires shift boreal vegetation communities significantly away from pre-fire or once-burned composition to non-analog conditions, within our comparative data set. Companion analysis of spatial patterns and fire behavior of reburn fires suggests that repeat fire effects on ecosystems are persistent and that reburn-induced shifts in vegetation communities do not pose a barrier to future, short-interval fire occurrence.

Measuring fire severity with satellites: New developments in the era of cloud-based computing

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Abstract: Satellite-inferred fire indices such as the delta normalized burn ratio (dNBR) can provide consistent maps of fire severity across multiple fires and across large spatial domains. However, these dimensionless indices are often difficult to understand and interpret in terms of on-the-ground fire effects. This said, satellite-inferred metrics are usually highly correlated to field-based measures of fire severity in forested systems, thus providing opportunities to directly model and map field-based fire effects as a function of spectral indices. Recently, it has become possible to produce extensive, cross-jurisdictional fire severity atlases due to the novel availability of cloud computing platforms, such as Google Earth Engine (GEE). In this study, we model a field-based measure of fire severity, the composite burn index (CBI), as a function of several Landsat-derived spectral indices from over 200 fires in the United States (including Alaska) and Canada, thereby making our model applicable to most fire-prone forested regions in North America. We also incorporate climate variables into the model to account for the variation in these relationships across climatic domains. Results show that the relationship between CBI and spectral indices is strong-to-informative in most forested systems of North America, with the notable exception of forests in the Southeastern US. Furthermore, the inclusion of multiple spectral indices improves model fit compared to models built with just one index; climate variables further enhance the model. We also implemented our model within the GEE platform, thereby allowing for the rapid mapping of CBI across hundreds of fires; we illustrate the procedure with an example from Canada, where fire severity atlases do not exist. Although much remains to be learned, mapping CBI provides researchers and practitioners a more direct link to on-the-ground fire effects, such as tree mortality and fuel consumption, compared to dimensionless spectral indices.

General Land Office Survey data as tools for shortleaf pine (*Pinus echinata*) restoration

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Abstract: In the eastern USA, attention has been placed on the creation and maintenance of mixed pine (*Pinus*)-hardwood systems. This emphasis is motivated by efforts to increase biodiversity and enhance stand-level resilience. In the southern USA, efforts have focused on establishing mixed loblolly pine (*Pinus taeda*) or longleaf pine (*Pinus palustris*) stands. Historically, shortleaf pine (*Pinus echinata*) has received less attention than other *Pinus* species. Only recently has it garnered interest and is considered a desirable species throughout its range. The prevailing concern in restoring pine-hardwood systems requires improved ecological and silvicultural knowledge that will help create and maintain this stand composition. A greater comprehension is particularly necessary for the comparatively less understood regeneration and site requirements of shortleaf pine. The primary objective of this study was to determine where shortleaf pine was found historically to prioritize efforts of restoring this species to its historical range. To evaluate forest characteristics prior to widespread European settlement, we utilized records of the General Land Office (GLO) Public Lands Survey System for the Bankhead National Forest in northern Alabama from the 1820s. These documents provided insight of vegetation-environment conditions before European settlers modified the landscape. These records, however, only recorded pine species to the genus level. Of the 1,772 witness trees noted, 215 (12%) were pines. Hapludult soils were the most common at sites where pine was recorded. For documented pine individuals, no significant difference in topographic position (i.e., ridgetop, mid-slope with north-east aspect, mid-slope with south-west aspect, low slope) was found based on the G^2 statistic. We hypothesized our findings are the consequence of surveyors not classifying pines to the species level in an area where multiple pine species with different ecological requirements occur. These findings are part of a larger project to quantify historical forest conditions from multiple sites in Alabama.

Adaptive Silviculture for Climate Change: Next steps forward

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Abstract: Under increasing uncertainty, climate-adaptive forest management strategies are critical for sustaining ecosystem services to society. Three common adaptive silviculture options discussed in the context of climate change are (1) resistance: maintaining relatively unchanged conditions over time; (2) resilience: encouraging an eventual return to reference conditions while permitting limited short-term changes; and (3) transition: actively facilitating change to encourage adaptive responses. The Adaptive Silviculture for Climate Change (ASCC) project has established partnerships to begin applying silviculture options aimed at enhancing the adaptive capacity of urban forest ecosystems to the environmental, social, and economic implications of climate change. This includes designing adaptation and mitigation strategies that enhance carbon storage and other ecosystem services, promote urban forest health, protect high-value urban trees, and create resilience to invasive species, while incorporating a more explicit social dimension through local community education and engagement. The ASCC Network is also in the process of developing a data management plan, which will allow the Network to use cross-site data to answer overarching project questions and dive into forest growth-and-yield modeling to extend ASCC-developed adaptation strategies to a landscape setting under different climate change scenarios. In this final presentation of the special session, we will discuss current cross-site research efforts taking place across the network, lessons learned from the study so far, and the next steps forward as a collaborative, on-the-ground, operational-scale research network of replicated sites testing ecosystem-specific climate change treatments across this gradient of adaptive approaches.

Pseudotsuga menziesii in Mexico: current state, in situ protection vs. assistant migration

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Abstract: Since the last glaciation, suitable climatic habitat for Douglas-fir is shifting in Mexico. The gradual increase in temperature forced this species to migrate from south to north and towards higher altitude in the mountains, which resulted in a fragmented distribution. Mexican Douglas-fir populations have differentiated morphologically from the coastal and interior Pseudotsuga menziesii varieties in the United States to become distinguishable based on multiple traits. In the central part of Mexico, the species exists in small isolated stands. The geographic pattern of morphological differentiation found and common garden tests suggest a wide variation between populations in adaptive traits for Mexican P. menziesii. Reproductive success (ratio of sound seed to seed potential) is low (15 to 30%) for most populations, particularly for those from Central Mexico, with 65 to 80% empty seeds. Loss of reproductive efficiency seems to be related to high inbreeding levels, although pollination effectiveness and insect damage had additional impacts in some locations. A reduced number of parents participated in the pollination, but there may be problems with phenological synchronization in the dispersal of the pollen. The participation of a reduced number of individuals in the reproductive events may lead to a reduction of genetic diversity in these populations, which puts the persistence of the population at risk if there is no genetic exchange among the individuals that contain it. Germplasm collection for use in assisted gene flow and migration approaches, including artificial reforestation, should be considered in these locations. Special management plans are required to save the genetic resources of Mexican Douglas-fir, the protection of contemporary populations from grazing, illegal logging and pests, and establishing and managing refugia at locations where future climates may be suitable.

Succession after reclamation: Identifying and assessing ecological indicators of forest recovery on reclaimed oil and natural gas well pads

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Abstract: To address a lack of understanding of long-term successional trajectories of reclaimed oil and natural gas sites, we sampled 30 reclaimed and adjacent reference sites in Alberta's boreal forest ranging from 7-48 years post-disturbance. The objectives of this study were to: i) measure above- and below-ground ecological properties to determine if certified reclaimed wellsites were on a positive successional trajectory for recovery, and ii) determine which properties were significantly influenced post wellsite

reclamation and were thus good ecological indicators for recovery. Multi-response permutation procedures and non-metric multidimensional scaling illustrated separation between reclaimed and reference site plant community compositions. When accounting for forest type, seral stage, and time since last disturbance, there was further separation of sites, with only two sites (7%) resembling the community structure of reference sites, and 18 sites (60%) resembling treeless grasslands, two of which were >35 years post disturbance, indicating an arrested recovery trajectory. The remaining 30% of sites are likely on a positive trajectory towards recovery. We used a joint generalized estimating equation (JGEE) to determine if reclamation had a significant effect on soil bulk density and pH, noxious plant cover, canopy cover, grass cover, woody debris, LFH, introduced plant richness, and live tree basal area. Our data indicate impacts can be long lasting and may remain for half a century or more post reclamation, potentially flat lining the recovery trajectory.

Ecological silviculture for boreal mixedwood forests: Possibilities, challenges and benefits

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Abstract: Retention harvesting has become a popular approach to ecosystem- or natural disturbance-based management around the world. Its aim is to sustain a diversity of ecological, economic, and social values in managed forest landscapes. While variable retention, with low levels of retention, is a common practice in aspen and mixedwood forests of the boreal region of Alberta, Canada, few studies have documented forest regeneration or examined possibilities for silvicultural interventions in such systems. The EMEND (Ecosystem Management Emulating Natural Disturbance) study examined variable retention harvesting for a range of boreal mixedwood forest stand types in northwestern Alberta. This wide range of retention levels is reflective of natural stand conditions since most mixedwood (broadleaf-conifer) and conifer-dominated forest stands of this region are multi-aged, demonstrating a past mixed fire regime. Retention harvesting was found to be effective for facilitating conservation and recovery of biotic communities towards the mature forest condition, but there are no clear thresholds of retention appropriate for all taxonomic groups. Post-harvest regeneration of broadleaf species (trembling aspen and balsam poplar) by root-suckering was boosted by abundant broadleaf species prior to logging, but was reduced by increasing levels of their retention. For seedling-origin white spruce, forest floor disturbance coupled with increasing number of adjacent seed trees promoted natural regeneration, but dense retention of spruce had a negative effect. Using the Mixedwood Growth Model, we projected stand growth and dynamics based on data collected 15 years after retention harvest. The projected stand structure, composition, and yield suggest a variety of next-step silvicultural options are possible for sustaining multi-cohort stands in boreal mixedwoods.

Positive results of an early intervention strategy to suppress a spruce budworm outbreak after five years of trials

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Abstract: Eastern North America is undergoing another major spruce budworm (*Choristoneura fumiferana* Clem., SBW) outbreak, and we are testing an early intervention strategy (EIS) to suppress SBW populations in New Brunswick, Canada. A consortium of government, industry, research and other partners termed the Healthy Forest Partnership (HFP) have conducted this project for 5 years (2014-2018) with $18 million of government and industry funding. Strategies include short-term applied control measures designed to suppress SBW populations, longer-term understanding effects of natural enemies and factors affecting outbreak initiation, and improving decision support capabilities to facilitate planning. Application of EIS includes intensive monitoring of SBW populations to detect 'hot spots' of low but rising populations, targeted biological insecticide treatments, and proactive public communications and engagement on project activities and results. This is the first attempt of area-wide (all areas within the jurisdiction of the province of New Brunswick) management of a native forest insect population. Following 5 years of over 420,000 ha of EIS treatments of low but increasing SBW populations, second instar larvae (L2) SBW levels across northern NB are considerably lower than populations in the adjacent province of Québec. Treatments increased from 4,500 ha in 2014, to 56,600 ha in 2016, and to 199,000 ha in 2018. SBW populations in blocks treated with *Bacillus thuringiensis* or tebufenozide have consistently declined by 38-96% and generally have not required treatment in the subsequent year. Area requiring treatment increased up to 2018, but SBW populations across northern New Brunswick, based on intensive L2 sampling, showed over 90% reductions in 2018. We expect that this may be a temporary decline,

but it is counter to continued increases in Québec. Successful results to date resulted in the HFP EIS team being approved for $75 million of federal government (Natural Resources Canada) funding to continue trials from 2018-2022.

The potential impacts of insect induced salvage harvests in mixed forests: the case study of emerald ash borer in New England forests

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Abstract: Forest insects and pathogens (FIPs) have significant impacts on U.S. forests, each year affecting an area nearly three times the area of all wildfires and timber harvesting combined. In the face of climate change and current trade policies, we expect an increase in both numbers of FIPs and their impacts on our forests. FIPs selectively eliminate tree species, thereby directly altering forest structure and composition. FIPs also have significant indirect impacts on forests by altering management practices, often initiating pre-emptive and salvage harvesting. With collaborators, we surveyed family forest owners (FFOs) in the northeastern U.S. and 88% of respondents indicated they would consider harvesting their trees if they were infested with FIPs. This salvage harvest response to FIPs represents a potentially significant shift in the timing, extent, and species selection of harvesting in the Northeast. Here we used information from the landowner survey, regional forest inventory data, and the emerald ash borer (EAB) invasion to examine the potential for FIPs to alter harvest regimes and affect regional forest conditions. We found that 45% of the FFO forest area in the Connecticut River Watershed in New England is likely to be harvested in response to EAB. This harvest represents an 80% increase from typical harvest rates in FFO woodlands. Also, 16% of the total carbon will be removed in these salvage harvests, with 84% of that carbon from species other than ash, creating a forest disturbance that is up to three-times the magnitude of the expected disturbance from EAB alone.

Advancing ecological understanding to inform restoration in long-needle pine ecosystems of New Mexico

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Abstract: Rapid increases in aridity, area burned, and fire severity in New Mexico have increased the urgency for restoration of long-needle pine ecosystems, many of which haven't burned for over 120 years. Information derived from tree rings has been important for understanding the ecological role of fire and informing and supporting restoration. Recent advances in tree-ring methods (e.g., spatial calibration/validation of landscape-scale spatially-systematic fire-scar networks with fire atlases) have provided important new information to inform and adaptively gauge the progress of restoration efforts. We present multiple studies from long-needle pine ecosystems from throughout New Mexico that advance our knowledge of variability in area burned, fire-climate relationships, fire season, and long-term ecological trajectories after high-severity fire in a warming climate. We include examples of what can be considered successful fire-regime restoration in the Gila Wilderness and the Santa Fe Municipal Watershed wildland urban interface, as gauged by metrics derived from historical fire regimes. The combination of tree-ring and modern records of fire suggest that long-needle pine ecosystems in New Mexico should be most resilient to future climate variability with a restored fire regime dominated by frequent, low-severity fire.

Summer frosts best predict tree growth than mean annual temperature in Québec's boreal plantation forests

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Abstract: Increase in frost damage to trees due to earlier spring leaf-out could outweigh the expected increase in forest productivity caused by climate warming, decreasing the productivity of tree plantations and possibly compromising sustainable management of the boreal forest. The impact of growing-season frosts on height growth of three spruce species (white, black, and Norway spruce) and different seed sources was quantified in two experimental plantations established in the Canadian boreal mixed forest along a south-north gradient. Our objectives were first to determine if species and seed sources showing increased asynchrony between spring dehardening and air temperature would show more frost damage and would grow less than the better-acclimated local seed source and, second, if growing-season frosts could best predict tree growth than mean annual temperature. We analysed the relationship in the bud break timing, air temperature and photoperiod of 255 trees and 10 000 bud observations with a Markov chain model to determine if earlier leaf-out increased exposure to frost. Then, we used linear mixed effect models to regress height growth to frost ring chronologies built from stem analyses of 163 trees. The non-native species (Norway spruce) froze the most and had the lowest growth at both sites. At the northern site, frost caused the greatest growth reductions in white spruce. Black spruce had a late leaf-out and was less affected by early spring frosts, allowing it to grow at its maximum potential at both sites. The local seed source outperformed the non-native and southern seed sources and model selection based on AIC identified that minimum temperature in May was the best climate variable predicting height growth, highlighting that extreme climate events are important drivers of tree growth and assisted migration might not be as promising to increase future forest productivity in frost prone environments under climate change.

Assessing the resilience of tropical dry forest productivity to hurricanes disturbance

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Abstract: Recent scientific evidence suggests that high resilience of tropical forests to hurricane disturbance results from their ability to recover to pre-disturbance conditions rather than resisting hurricane effect. In tropical dry forests, hurricane disturbance has immediate negative effects on forest productivity due to biomass loss caused by high-speed winds, but fast recovery may occur due to plant re-growth supported by increased precipitation. We evaluated tropical dry forest resistance and recovery (the two resilience components) to hurricane disturbance by analyzing litterfall patterns over a 35-yr period in five small watersheds in the Chamela-Cuixmala Biosphere Reserve on the Pacific Coast of Mexico. This region had not experienced hurricane landing in more than 60 years, but a Category 2 Hurricane (Jova) struck the area in 2011, followed by a Category 4 (Patricia) in 2015. Hurricane-induced litterfall after both events largely exceeded the amount produced in any month of the pre-disturbance period, suggesting low resistance (a measure of change during the event relative to the pre-disturbance condition). After Jova, recovery (the ability to restore function relative to the changes during disturbance) was fast, with increasing levels of productivity over the next four years. This positive response is partially explained by a combination of favorable post-disturbance conditions like unusually high dry-season rainfall, large hurricane-induced flux of P-enriched litter, and high re-sprouting capacity of damaged plants. After Patricia, recovery was slower and productivity decreased by half, a pattern likely explained by the greater destruction of the forest canopy and the drier conditions following the storm. Our long-term data allowed us to assess the resilience capacity of tropical dry forests to multiple disturbances (droughts, hurricanes) and discuss the implications of changing precipitation regimes for forest productivity and management.

Modeling high-severity fire, drought, and climate change impacts on ponderosa pine regeneration

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Abstract: We created a model to investigate the effects of high-severity fire and drought on ponderosa pine regeneration using a water balance approach. Climate envelopes were constructed to simulate conditions during the flowering, seed production, germination phase, seedling growth in the season following germination, and seedling growth in the two years following germination. The model was tested against observed regeneration at five sites in the Southwest that experienced high-severity fires during a drought from ca. 1945 to 1956. For validation purposes, single fire events, as occurred at each field site, were simulated by altering maximum and minimum temperatures and runoff conditions in declining stages of severity for seven years. To evaluate long term fire and climate impacts, four sensitivity tests were conducted on climate records from 1914 through 2009: (1) a climate control with no modifications to temperature and precipitation inputs; (2) a permanently burned condition simulation; (3) a simulation where climate conditions were altered based on IPCC future climate change projections; and (4) a simulation with both climate change and fire modifications.

The sensitivity tests suggest that regeneration rates are reduced by 43% in post high-severity fire environments because of changed conditions during germination and post-germination establishment phases. Our model suggests that high-severity fire reduce germination because the fire-induced microclimate changes result in increased numbers of killing frost days and increased mortality of seedlings post-germination. These same microclimate conditions result in reduced water availability to seedlings in the summer and fall following germination. The model shows that impacts of climate change may differ across the forest climate envelope, with forests on the dry end of the climate envelope likely experiencing severe reduction in regeneration events while forests on the wet/cold end of the climate envelope potentially experiencing benefits from warmer climate conditions that lead to increased regeneration at these locations.

Hazardous fuels reduction using simple biochar kilns

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Abstract: Forest managers use hazardous fuels treatments to reduce the severity and intensity of wildland fire. Pile burning is a common and inexpensive approach to treating hazardous fuels after a mechanical treatment. However, pile burning is limited by current fire danger and air quality restrictions. Further, pile burning often consumes organic soils and reduces future productivity of forest stands. A novel approach to this challenge is the use of low cost flame-cap biochar kilns to reduce hazardous fuels while making biochar in forest settings from excess woody biomass. A primary benefit of this approach is accessibility; almost anyone can do it, often with materials and equipment they have on hand. This method allows for small scale biochar production across a wide variety of uses and users. Instead of open pile burning of forest residues, we put the fire in a box, or a flame-cap kiln, which reduces damage to the soil and protects air quality. We apply a fraction of the biochar on-site while a portion is available for application on nearby agricultural lands. This reduces wildland fire hazard by converting forest residues into biochar, and the addition of biochar to the soil can increase the drought tolerance of remaining vegetation. We have conducted seven simple kiln workshops in six Utah Counties with more than 200 attendees to date. We have successfully pyrolyzed five different forest feedstock types including two invasive tree species. The Utah Biomass Resources Group is scaling-up this method to increase the pace and scale of hazardous fuels reduction by these methods. By creating methods for biochar production that land managers can easily access, the use of biochar can grow, which will lead to increased carbon sequestration, increased soil productivity, and improved air quality.

Large-scale forest restoration stabilizes carbon under climate change in the Southwest U.S.

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Abstract: Higher tree density, more fuels, and a warmer, drier climate have caused an increase in the frequency, size, and severity of wildfires in Western U.S. forests. There is an urgent need to restore forests across the western U.S. To address this need, the U.S. Forest Service began the Four Forest Restoration Initiative (4FRI) to restore four national forests in Arizona. The objective of this study was to evaluate how restoration of ~400,000 ha under the 4FRI program and projected climate change would influence carbon dynamics and wildfire severity from 2010 to 2099. Specifically, we estimated forest carbon fluxes, carbon pools and wildfire severity under a moderate and fast 4FRI implementation schedule and compared those to status quo and no harvest scenarios using the LANDIS-II simulation model and four projections of climate change. We found that the fast-4FRI scenario showed early decreases in ecosystem carbon due to initial thinning/prescribed fire treatments, but total carbon storage increased by 11 – 20% over no harvest by the end of the simulation. This increased carbon storage by 8 – 14 million metric tons, depending on the climate model, equating to removal of carbon emissions from 67,000 – 123,000 passenger vehicles per year until the end of the century. Nearly half of the additional carbon was stored in more stable soil pools. However, climate models with the largest predicted temperature increases showed declines by late century in ecosystem carbon despite restoration. We estimated that ~40% of the harvested carbon, up to 1.5 million metrics tons, will remain sequestered in wood products throughout the simulation period. Our study uses data from a real-world, large-scale restoration project and indicates that restoration is likely to stabilize carbon and the benefits are greater when the pace of restoration is faster.

3-PG model parameterization for longleaf pine forests to estimate long-term growth responses under different climate change scenarios

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Abstract: The 3-PG (Physiological Process Predicting Growth) model is a process-based model that integrates climate, physiology, and stand attributes to predict net primary production (NPP), stand dynamics, stand transpiration, and soil water balance. Because of their resistance to disturbance and drought, longleaf pine (*Pinus palustris*) forests may offer a pathway to increase the resilience of southern forests to changing climate. The objective of this research is to incorporate species-specific functions and modify model structure to enable the use of 3-PG to predict growth of longleaf pine forests under varying climate and forest management scenarios. The long-term datasets used in parameterization are from sites located across the natural range of longleaf pine. Datasets include plantation data from the Harrison Experimental Forest, T. R. Miller Mill Company, the Palustris Experimental Forest, The Nature Conservancy, Virginia Department of Forestry, the Southwide Southern Pine Seed Source Study, and the Longleaf Pine Throughfall Reduction Experiment (LPTRE). We developed model functions for NPP allocation, canopy conductance response to vapor pressure deficit, seasonal patterns of needle fall, specific needle area, density-independent mortality, self-thinning, specific gravity, and the fertility rating. To date, parameter estimates generated for longleaf pine are different from the other southern conifers, which proves the need for species-specific longleaf pine parameterization. The model will be tested against data from measurement plots covering a range in stand characteristics. Stand transpiration predictions will be validated using measurements from the LPTRE. We aim to predict how growth and water use of longleaf pine will respond to projected changes in climate and compare the results to published predictions made for loblolly pine and slash pine using the 3-PG model.

Climatic and stomatal controls on sap flow partitioning between transpiration and stem water storage in a large boreal tree

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Abstract: Despite increased knowledge of whole tree water uptake using in-situ methods such as sap flow systems, information about patterns of water use within large trees remains limited. Temporal lags and discrepancies between canopy measurements and xylem sap-flow measurements have been reported, highlighting the importance of water storage along the stem in large trees as well as microclimatic conditions dictating water flow in the canopy. Properly assessing the partitioning between flux and storage and between canopy parts requires accurate sap flow measurements. Using 12 heat ratio method sap flow sensors distributed along the stem and 8 sensors in the canopy of a large mature boreal aspen (*Populus tremuloides*), we examined the temporal dynamics of hourly and daily sap flow, partitioning in the crown, and the separation into water storage and transpiration stream and the relationships with microclimate variables. Over 30 days, hourly upper-stem sap flow rates were significantly lower than basal-stem rates, suggesting substantial stem water storage. The partitioning between the transpiration stream and water storage in the sap flow rates varied with cardinal orientation across the stem. As a result, the strength of the correlation between hourly stem sap flow rates and climatic conditions changed with distance from the canopy. The sap flow rates of the lower branches in the canopy were significantly lower than the main trunk, showing an inequal repartition of the water flow between the lower and upper parts of the canopy. Although the HRM sap flow sensors provide reliable estimates of total tree water use, the results show a substantial variation between cardinal orientations in sap flow measurements. This highlights the importance of measuring and separating the transpiration stream and stem water storage in sap flow measurements, especially when correlating to climatic conditions and modelling water fluxes at both the individual tree and the landscape scale.

Integrating forest restoration, climate adaptation, and proactive fire management: Rogue forest restoration

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Abstract: Wildfire is intrinsic to North American forests, yet conditions after a century of fire exclusion and extractive logging, aggravated by climate change, are increasing fire impacts. Even with aggressive fire suppression, fires increasingly threaten natural and human communities. Innovative approaches are needed to integrate forest adaptation with proactive fire management by implementing strategic forest thinning and controlled burning with broad stakeholder support. To guide this, we developed the Rogue Basin Cohesive Forest Restoration Strategy (Strategy) for 1.9 million ha in the Klamath Mountains in southwestern Oregon. Dry, mixed conifer forests of the Klamath Mountains, like other systems with long-needle pines, were historically dominated by short fire-interval fire regimes. However, southwestern Oregon forests are relatively productive and feature diverse and abundant native shrubs and hardwoods. Restoration in the region is aided by a relatively robust timber infrastructure and regional workforce. The Strategy takes a unique approach to developing an activity map to illustrate trade-offs among objectives. The Strategy identifies forest to protect from either treatment or fire, then prioritizes needed treatments to reduce wildfire risk to these and other values. Outputs quantify forest density reduction, change in wildfire risk, and resulting jobs and timber revenue, allowing comparison of management scenarios. We are building a coalition to support the strategy by clarifying the benefits and associated costs of landscape-scale forest restoration. Successive unprecedented fire/smoke years have galvanized support for proactive, beneficial management, which can include aggressive fire suppression. However, the effort competes with calls to double down on fire exclusion through technological developments and roading that is expected to improve suppression effectiveness in the modern fire environment. In frequent-fire forests globally, severe wildfire threatens human communities and sensitive habitats, thus the need for integrated management that manages fire to protect the full range of values benefits for people and nature.

Putting ecological forestry into practice: historical fire and future applications in Lake States pine forests

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Abstract: A key challenge to maintaining resilient landscapes is adapting to and maintaining dynamic ecological processes. In fire-dependent ecosystems this includes identifying and defining mechanisms through which fire influences forest structure and functionality. In the Lake States region, understanding of how disturbance probability is related to forest age, or fire frequency relates to forest structure is based primarily on proxy data (e.g., tree patterns based on Euro-settlement era survey data). We used dendrochronological methods to determine how fire history and stand structure, including cohort structure, tree density, and spatial patterning, are linked within Lake States mixed conifer forests in Wisconsin. We found relatively short mean fire return intervals (MFRIs) ranging from 6–13 years with little variation in fire frequency among sites. Current density of red pine-dominated forests are 3–37 times historical (ca. 1860) densities (μ=12 x) and almost entirely spatially random, whereas historically forests were spatially aggregated at stand scales. Stands also contained multiple and/or loosely defined cohort structures suggesting very different controls operating historically than currently. Our findings suggest density-independent regulation of tree populations was important, with establishment limited not by overstory density or mortality, but rather mortality of seedling and saplings with frequent fires as a primary forcing agent in these stands. Heterogeneity that helped maintain ecosystem resilience in these ecosystems historically came from frequent fire disturbance processes that affected stand-scale forest resistance. This was likely the historical dynamic across fire-adapted transitional pine forests of the Lake States.

Great Basin forests on the edge? Science & spin

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Abstract: From topography to climate, mountain forests live an edgy existence. Constrained by the geometry of peaks that narrow into thin air at summits and atmospheric lapse laws that dictate decline in temperature with increasing elevation, the common projection under warming is for species to shift upward. As they follow favorable climatic space, available land area diminishes, warmer-adapted species encroach from below, and mountain species face inevitable "elevational squeeze", which at worst could lead to extinction. Examples from contemporary as well as paleo-ecological studies corroborate this expectation. Packed into this literature, however, are examples of situations where this did not occur. While the geometry of mountains ensures a limit to area at some upper elevation, the complexity of topography also offers abundant opportunity for escape and refuge from ambient climate stresses. Complex topography further catalyzes climate processes below the synoptic level that affect species according to their ecology. These include meso-climates (processes at regional or inter-mountain scales), topoclimates (dictated by complex topography and elevation, such as differing solar radiation on different aspects or cold-air drainage), and microclimates (local processes often decoupled from those at larger scales, such as wind shelters or forest-canopy effects). I present a round-up of examples from Great Basin mountain ecosystems where species have moved up (as expected), down, around, not at all, or otherwise responded to climate change. As spin on the science, I address in parallel contemporary concerns about fake news, distrust of science, climate denial, and the grave dangers that can result. In particular, I focus on our role as scientists, and how we can, but don't always, control our storylines. While it is the responsibility of scientists to ensure that science is reported objectively, factors in our own community often drive bias into our messaging with ultimate harmful consequences.

Multiple dimensions of mesophication: a case study from Coweeta Hydrologic Lab

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Abstract: Forest "mesophication" has been defined as the process by which shade-tolerant, fire-sensitive trees have replaced heliophytic (sun-loving), fire-tolerant trees. Furthermore, it is hypothesized to be a self-reinforcing process, whereby cool, damp, and shaded conditions and less flammable fuel beds continually improve conditions for shade-tolerant mesophytic species while deteriorating conditions for shade-intolerant, fire-adapted species. One dimension of this process, water, has been investigated in recent studies and results show that mesophytic trees have greater rates of litter interception, stem flow, and transpiration than many oak and non-mesophytic species, lending support to the idea that mesophytic species are associated with or can influence local conditions towards greater moisture. Here, we conduct a landscape-scale analysis in the highly diverse (>40 tree species) Coweeta Basin in the southern Appalachian Mountains. We asked whether the broad functional grouping of "mesophytic species" that typically have deep functional sapwood, transpire at high volumes (diffuse-porous xylem), and have sensitive stomatal regulation to drought was predictable across environmental and spatial gradients. We developed functional group predictive models using multiple environmental/landscape metrics. We measured tree species composition and diameter across 617 permanent vegetation plots, and calculated an importance value, a combination of basal area and density. Metrics associated with environmental condition and landscape position were determined from a combination of field measurements, remote sensing, and GIS. We found strong correlations among the importance of mesophytic species and environmental variables. For example, these trees were negatively correlated with solar radiation, southern exposure, and high terrain convexity, and positively correlated with precipitation and soil wetness index. Ring-porous trees, including five oak species, were negatively correlated with precipitation and soil wetness index, and positively correlated with southern exposure and solar radiation. We conclude that functional groups were predictable across hydrologic gradients, and discuss the utility of incorporating this framework into hydrologic models.

The case for nursery-grown aspen seedlings in post-fire landscapes

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Abstract: Aspen is a broadly distributed forest tree with exceptionally high ecological value in western US landscapes. Despite its extensive ecological amplitude, however, aspen tree mortality is becoming apparent in many core areas of the species range in the western US. These mortality events are largely due to increasingly severe and frequent drought conditions, but are exacerbated by excessive ungulate herbivory and conifer expansion. Natural aspen regeneration can occur through root suckering or seedling establishment, but management practices rely primarily on suckering following clearfelling. The use of seedlings for restoration has not been fully explored, but offers the opportunity to enhance genetic diversity and promote adaptation to changing climates. Post-fire

landscapes may provide ideal settings for restoration using nursery-grown aspen seedlings. Seedlings could be used to increase genetic diversity in existing stands and/or to establish new stands in locations where fuelbreaks or post-fire sediment stabilization are needed. We discuss the opportunities, barriers, and research needs regarding the production and outplanting of aspen seedlings in post-fire landscapes.

Effects of maternal climate and artificial seed warming on variation of *P. strobiformis* seed mass and germination

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Abstract: Climate projection models for the southwestern USA consistently forecast an increasingly hot and arid future climate that is expected to yield conditions that challenge the successful establishment and survival of forest trees. Tree trait studies that incorporate data from across an entire species' range are rare yet required in order to assess the evolutionary potential of species to endure climate change. *P. strobiformis* occurs across high and low elevations of mesic and semi-arid sites in the USA and Mexico, where it serves as an important source of food for wildlife and as a mediator of watershed dynamics. Seed mass correlates strongly with germination rate, seedling tolerance to abiotic stress, and survival past the seedling stage. Seed mass is a trait that thus is closely related to the vulnerability of seedlings during the life-stage when tree mortality rates are highest. Timing of germination is also a critical fitness-related trait because environmental conditions endured by germinants vary widely across the germination time frame. Studies of other tree species have shown that seed mass, percent germination success, and germination timing are influenced by within-canopy temperature variation of the seed microclimate as well as mean annual and seasonal temperatures of locations where maternal trees grow. I will discuss results from a large-scale seed collection effort spanning the range of *P. strobiformis* in the USA and western Mexico, focusing on characterizing the influence of maternal environmental climate on seed mass and germination, and the influence of experimental warming of developing seeds on seed mass and germination.

Designing restoration-based treatments using a collaborative approach

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Abstract: The purpose of the Collaborative Forest Landscape Restoration Program (CFLRP) is to encourage the collaborative, science-based ecosystem restoration of priority forest landscapes. The Four Forest Restoration Initiative is the largest of the CFLRP projects and involves a diverse group of engaged stakeholders. Restoration-based project planning in a collaborative framework is distinct from the approach used by federal agencies in the past. While similarities exist such as full compliance with National Environmental Policy Act and Forest Plans, identification of the desired condition, and development of a proposed action that addresses the desired condition, many differences still exist that add complexity to the project and the relationships involved. Some of these differences include the process of developing operating norms for interaction between stakeholders and federal agencies and a more thorough consideration of the perspectives of individual stakeholders. From a project planning perspective, the most considerable difference might be the process of developing a proposed action that addresses the purpose of the project, the ecological need on the landscape, is compliant with applicable Forest Plans, and addresses the diverse values of our stakeholders. Case studies and lessons learned are presented where various strategies were employed to meet the purpose of the CFLRP while being responsive to the values of the project stakeholders regarding potentially contentious issues such as large tree retention as well as dwarf mistletoe management.

Cambial plasticity in Southwest ponderosa pine and Douglas-fir: How much can tree growth bend to future drought stress?

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Abstract: Warming temperatures and decreasing precipitation over the last couple of decades in the Southwest US have been linked with declining tree growth, reduced canopy leaf areas, and high tree mortality rates (from greater drought stress and associated insect outbreaks) among forests of the Southwest. Thus far, the most severe impacts have been noted in vegetation growing in lower and mid-elevation zones. In this study, we focus on ponderosa pine and Douglas-fir growing in a higher elevation forest of the Jemez Mountains. At this location, a multi-decade record of radial growth based on dendrometer data illustrates both the variability of inter- and intra-annual growth rates, as well as seasonal timings of growth between these two species. These data reflect the adaptive capacity of cambial activity in its response to climate, and weather, and can be used to assess potential responses of tree growth to stressors arising from climate change. Further insights can be gained by a more direct examination of the role of intra-annual climate drivers as they impact the cambium and tree-ring formation at monthly and sub-monthly scales on a cell-by-cell basis. In this study, we use standard xylogenesis techniques to gain insights into wood production and tree-ring development from a cellular perspective. We collected microcores every one to two weeks from five ponderosa pine and five Douglas-fir during three growing seasons (2016 through 2018). This sequence of years provided a stark contrast in initial growing season conditions; the winter of 2017-8 was extremely dry, whereas winter precipitation for the previous two growing seasons was about average. This work also will improve the precision of dendroecological reconstructions of the historical seasonality of fire activity and precipitation in the Southwest.

Do trends in climate influence the increase in high-severity wildfire in the southwestern US from 1984 to 2015?

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Abstract: Over the last 30 years, in woodland and forested ecosystems across the southwestern US, there has been an increasing trend in fire activity. Altered land use practices and more recent changes in precipitation patterns and warmer temperatures are widely thought to contribute to departures in fire regimes toward more frequent and larger fires with more extreme fire behavior that threatens the persistence of the various forested ecosystems. We examined fire-climate relationships in these vegetation types in Arizona and New Mexico using an expanded satellite-derived burn severity dataset that incorporates over one million additional burned hectares analyzed as extended assessments to the MTBS project's data and five climate variables from PRISM. Fire-climate relationships were identified by comparing annual total area burned, area burned at high/low severity, and percent high severity regionally with fire season (May-August) and water year (October-September), temperature, precipitation, and vapor pressure deficit (VPD) variables. The high severity indicators were also derived for each fire individually to see if climate-fire relationships persist at the scale of the individual fire. Increasing trends toward more arid conditions were observed in all but two of the climate variables. Furthermore, VPD-fire correlations were consistently as strong or the strongest compared to temperature or precipitation indicators alone, both regionally and at the scale of the individual fire. Thus, our results support the use of VPD as a more comprehensive climate metric than temperature or other water-balance measures to predict future fire activity. Managers will have to face the implications of increasing high severity fire as trends in climate toward warmer and drier conditions become an increasingly dominant factor in driving fire regimes towards longer and more intense fire seasons across the Southwest.

Forest response to adaptive silviculture treatment in northern Minnesota: Assessing variations in below-canopy microclimate conditions

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Abstract: Climate change is expected to significantly impact the health and productivity of mixed-pine forests of the western Great Lakes region. Managers face increasing challenges to sustaining forests due to high uncertainty associated with forest response to climate change. The Adaptive Silviculture for Climate Change (ASCC) project was developed to provide operational-scale research opportunities to demonstrate and test adaptive forest management strategies across a gradient of adaptation approaches aimed at climate climate. The first of the five initial ASCC sites is located on the Cutfoot Experimental Forest – Chippewa National Forest in northern Minnesota, USA (MN-ASCC). The silvicultural tactics implemented on the MN-ASCC site include standard thinning, variable density thinning (thinned matrix, ½-acre "skips", and ½-acre gaps), and regeneration harvesting (irregular shelterwood combined with ½-acre gaps), creating a range of overstory conditions. We are studying the microclimate effects of different forest overstory conditions created by adaptive management approaches on initial seedling performance by quantifying below-canopy

microclimate and tracking seedling performance. Microclimate measurements included hourly sampling of soil temperature, soil moisture, air temperature, and relative humidity over the entire 2017 and 2018 growing seasons (May – September), along with estimations of leaf area index, canopy openness, and photosynthetically active radiation from hemispherical photography. Additionally, understory vegetation and regeneration are being monitored and tested against microclimate variables across the treatments to better understand the mechanisms and potential for each treatment to meet overall management goals related to stand structure and regeneration. This presentation will highlight variations associated with different stand structures and below-canopy microclimates within each adaptive silviculture approach, as well the initial response of seedling regeneration to changes in overstory conditions.

Fuels management in northern mixedwoods in light of an uncertain climate future

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Abstract: With projected increases in Maine's summer temperatures and growing season length, there are concerns for changes in disturbance regimes such as fire frequency and severity. Given Maine's historically long fire return intervals, minimal research has addressed fuels mitigation and resulting stand development outcomes. To address these concerns, we utilized an existing U.S. Forest Service study located on the Penobscot Experimental Forest in Bradley, ME, USA. Stands of northern mixedwood (*Picea–Abies*–hardwood) composition were treated in 2018 with strip-cutting using: 1) stem-only harvesting (SOH), 2) stem-only harvesting with prescribed burning (SOHB), and 3) whole-tree harvesting (WTH). Our objectives were to: 1) evaluate effects of common harvest methods (SOH and WTH) and prescribed burning (SOHB) on fuels/deadwood structure, and 2) compare tree regeneration composition across treatments. Prior to prescribed burn application, we measured fuels by size class (1-hr, 10-hr, 100-hr, and 1000-hr size classes), fuel height, litter and duff depth, as well as density of tree regeneration ≥15 cm in height to <1.3 cm diameter at breast height. Overall, harvesting resulted in a 73 (± 14.4 standard deviation (SD)) percent average reduction in aboveground woody biomass. The greatest reduction (89 (± 5.2 SD) percent) and lowest fuel height resulted from WTH. There were few differences observed in litter and duff depths across harvesting treatments. Density of tree regeneration increased in all treatments, compared to pre-harvest estimates, and was dominated by hardwoods (mostly *Populus* spp.). Post-burn data were recently collected in late fall and analysis is ongoing. Results will inform forest managers about structural and compositional outcomes of slash/fuels management in northern mixedwoods.

Implementing a landscape-scale stakeholder-derived NEPA project in a complex world: It takes a village (and the villagers don't always get along)

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Abstract: The Four Forest Restoration Initiative (4FRI) is a collaborative effort to restore forest ecosystems on portions of four National Forests along the Mogollon Rim in northern Arizona. The Record of Decision (ROD) for the first Environmental Impact Statement (EIS), covering restoration activities on nearly 600,000 acres within the Coconino and Kaibab National Forests, was signed in April 2015. Implementing the first several projects under the 4FRI EIS has presented numerous challenges. One of the biggest challenges stems from the fact that district-level implementers and resource specialists had relatively little involvement during the planning process. In part to help alleviate this issue, an Implementation Plan (Appendix D) and an associated Design Features, Best Management Practices, and Mitigation Measures (Appendix C) document were added to the EIS. Despite a general lack of site-specific information to guide their development, these documents proved quite site-specific and prescriptive, limiting silvicultural options on the ground. Lessons learned from the planning side include gathering more district-level input during the planning process and building more flexibility into implementation. Lessons learned from the implementation side include actively seeking out project planners when needed for clarification/interpretation, engaging collaborators early on during implementation to learn about sticking points and encourage buy-in, and accepting that definitely being able to do a lot of good work now is oftentimes better than hoping to do a little bit of great work later.

Reconstructing historical outbreaks of mountain pine beetle in lodgepole pine forests in the Colorado Front Range

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Regional-scale mountain pine beetle (Dendroctonus ponderosae) outbreaks in the first decade of the 2000s affected millions of ha of lodgepole pine (Pinus contorta) in western North American forests. In Colorado, 1.4 million ha exhibited high mortality. These events prompted questions about whether historical outbreaks reached the scale of this event. We aimed to reconstruct past outbreaks in lodgepole pine forests in the northern Colorado Front Range, to determine whether past outbreaks of similar local extent to the 2000s outbreak have occurred, and to look for possible mountain pine beetle interactions with fire. We identified logs and snags of beetle-killed trees based on beetle infestation signs and subsequent tree effects, collected cross-sections, and determined death dates through tree ring analysis. We detected four mortality events since the 1880s, including an outbreak in the 1910s that was as geographically extensive as the 2000s outbreak in our study area. Tree mortality in all events was related to stand age and size structure with beetle-killed trees being around 230 years of age and 36 cm in diameter. In our study area, it takes about 200 years for a lodgepole pine to reach the size suitable for mountain pine beetle. Study stands established from the 1500s to the 1700s and some experienced partially stand-replacing events and periods of cohort establishment in the 1700s and 1800s. These were likely the cohorts that exhibited widespread mortality during the 1910s and 2000s outbreaks at both landscape and stand scales. The data show that extensive outbreaks have occurred in the past in the northern Colorado Front Range. Awareness of the disturbance histories in forests and the legacies of past events advances understanding of their ecology and will inform researchers and managers in developing management strategies to foster sustainable delivery of ecosystem services and resiliency as climate change manifests.

Resilience of Oregon white oak to reintroduction of fire

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Abstract: Pacific Northwest oak woodlands and savannas are fire-resilient communities dependent on frequent, low-severity fire to maintain their structure and understory species diversity, and to prevent encroachment by fire-sensitive competitors. The re-introduction of fire into these transformed ecosystems is viewed as essential to their restoration, yet can be fraught with unintended negative consequences. We examined response of mature Oregon white oak (*Quercus garryana* Douglas ex Hook.; Garry oak) to "first entry" woodland restoration burns following a long fire-free period. Thirteen to twenty-five months post-burn, topkill of oaks was minimal (3%) and mortality was rare in three prescribed burns, despite high levels of crown scorching (mean=92%) and irrespective of proportional duff consumption around oak bases (mean=21%). Percentage of crown scorch volume was the strongest predictor of oak crown dieback, but response was highly variable, especially ≥80% scorch. Comparison of our results with FOFEM, a common fire effects model, revealed high model inaccuracy, likely due to the lack of a species-specific equation for prediction of Oregon white oak mortality. The results of this study indicate that Oregon white oak is highly resistant to mortality in restoration burns, even following long fire-free intervals. Prescribed fire is not contraindicated in areas with extant mature oaks, and may promote oak regeneration via basal sprouting.

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Abstract: The incidence and severity of droughts are increasing worldwide with climate change. Maintaining tree diversity is a commonly proposed strategy to foster forest resilience to changing climate. However, we lack evidence indicating whether more diverse communities are more resistant to changes in productivity in response to changing resource availability, and experimental tests have been mostly conducted in grassland systems. Here, we present an investigation into the effects of a severe and sustained drought in 2018 in central Europe on a large field experiment examining the relationships between tree diversity and ecosystem function. Utilizing a pool of 12 species to construct independent gradients of tree species richness and functional diversity, the experiment consists of four blocks with 102 plots in each block. In every block, there are 30 monoculture plots and 42, 24, and 6 plots with two,

four, and six tree species each. In each plot, 49 trees were planted at 45 cm spacing on a 7x7 grid to facilitate early interactions among individuals. Annual inventories document tree mortality and growth for individual trees in a core area of each plot. In August 2017, hyperspectral reflectance data was collected from a UAV. From April to July in 2018 temperatures were 2 degrees warmer than normal and precipitation substantially reduced. We therefore measured a number of canopy parameters every two weeks throughout the drought: community leaf area index, leaf abscission and canopy reflectance. We will present an analyses of canopy responses and test the hypothesis that more diverse tree communities exhibit higher resistance to changes in the measured parameters in response to the drought. In addition, we will test the strength of the relationship between UAV-based NDVI, ground-based LAI and canopy mortality. Finally, we will show how tree diversity - annual above ground productivity relationships were influenced by the drought.

Fire ecology of southeastern pine savannas and woodlands

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Abstract: The long-needled pine ecosystems of the southeastern United States are commonly called forests, but most are more accurately portrayed as savannas or woodlands because their canopies are usually open enough to allow a dense, grass-dominated groundcover. The pines that characterize these communities, depending on geography and site conditions, include longleaf pine (*Pinus palustris*), slash pine (*P. elliottii*), South Florida slash pine (*P. densa*), pond pine (*P. serotina*), shortleaf pine (*P. echinata*), and marginally, pitch pine (*P. rigida*). Hardwoods are mostly restricted to the ground or shrub layer on the most frequently burned sites, but heterogeneity in burn patterns, soil moisture, and other factors sometimes allows pyrogenic oaks such as turkey oak (*Quercus laevis*), bluejack oak (*Q. incana*), sand live oak (*Q. geminata*), sand post oak (*Q. margaretta*), post oak (*Q. stellata*), blackjack oak (*Q. marilandica*), or southern red oak (*Q. falcata*) to reach the midstory or sometimes a low canopy. Other trees found in some long-needled pine communities or ecotones with hardwood forest include mockernut hickory (*Q. tomentosa*), black oak (*Q. velutina*), and cabbage palm (*Sabal palmetto*). The typical fire regime in pine savannas and woodlands across the region is frequent, low-severity, surface fire, often with low site-level variability. Fire-return intervals under a natural lightning regime range from one year to 10 years, occasionally longer, but weighted toward shorter intervals. Paleoecological and other evidence suggests fire has been important in parts of the Southeast for millions of years. Most species, including many endemics, in southeastern pine ecosystems possess fire-adaptive strategies and traits. Some components of lightning fire regimes are more commonly mimicked by fire managers than other components. For example, fire managers generally agree about the importance of frequent fire, whereas the appropriate season(s) to burn is more controversial. Most dominant plant species of fire-prone ecosystems in this region experience greater fitness when burned during the natural lightning-fire season than in other seasons. Although practical considerations often dictate controlled burns that differ substantially from lightning fires, a precautionary approach would attempt to mimic the evolutionarily relevant fire regime whenever feasible.

Does burning the O-horizon following long-term fire exclusion accelerate mesophication?

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Abstract: Over the last century, the forests of the southern Appalachians have experienced a significant reduction in fire frequency. Fire exclusion has likely contributed to forest mesophication, where fire adapted anisohydric species (e.g., oaks, *Quercus* spp.) decline, while fire sensitive isohydric species (e.g., maples, *Acer* spp.) increase. We propose that litter characteristics and mycorrhizal symbionts representative of the two water use strategies can potentially accelerate mesophication upon the reintroduction of certain types of fire after long exclusion. The oak litter characteristics that make it conducive to carrying fire and important for maintaining a fire regime also slow decomposition. In addition, oaks are associated with ectomycorrhizal symbionts that are less efficient decomposers. Consequently, in the absence of repetitive fire, an O horizon (duff layer) is more likely to form in areas dominated by oaks. While litter fuels rarely result in tree mortality even in isohydric species, a smoldering O horizon destroys both fine and coarse roots causing high mortality, which is often delayed a few years. This pattern would be reversed in areas dominated by maples and other mesic species as their more labile litter and arbuscular mycorhizzae symbionts should result in little fine fuel or duff accumulation and less post-fire mortality. We report on an investigation of the patterns of duff consumption and tree mortality after the 2016 Southern Appalachian wildfires. We sampled areas burned in the Rough Ridge and Rock Mountain fires in 2017 and 2018. Immediate post-fire mortality was low, and the fires were classified as low-severity. We inferred pre-fire conditions within the burns by sampling in unburned areas adjacent to the fires stratified by topography and aspect. Delayed mortality rates in burned areas were

more than double the unburned mortality rates and more than 70% of duff was consumed in the fires. We expect mortality to peak in 2019 as mortality rates in other forests subject to duff consumption see most death occurring 2-3 years post fire. While fire is a crucial component of Southern Appalachian ecosystem function, burns that consume the duff layer could have the undesired consequence of accelerating mesophication.

System for evaluating the socioeconomic impact of temperate forest management for timber production in Northern México

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Abstract: There is a need for having systems for evaluating the socioeconomic impact of the management of temperate forest for timber production in ejidos and communities in Mexico. A study in Ejido San Diego de Tezains, Durango was carried out in order to design a system including variables to be periodically evaluated, to understand changes in those variables in order to identify their impact on socioeconomic indicators. Once the system was applied in San Diego de Tezains, a baseline was established for monitoring the socioeconomic impact of timber production at this ejido. After that, the evaluation system was adapted to be applied in the Ejido El Largo, in Chihuahua, México, and it was established as the baseline for evaluating the socioeconomic impact of timber production at that ejido. The system is integrated by principles, criteria, indicators, and verifiers for monitoring the socioeconomic impact of the use of temperate forests for timber production in ejidos and communities from Northern México. The results show that at both ejidos, forest management for timber production generates most of the jobs and is the main economic activity by providing most of the income of people living in those ejidos. The economic benefit obtained from timber production by the ejidos is used also for improving socioeconomic status of families by supporting education, health, and communication services.

Long-term effect of fire severity on ponderosa pine regeneration niches and fungal communities

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Abstract: Wildfires in southwestern US ponderosa pine forests have recently increased in size and severity, leaving large, contiguous patches of tree mortality. These wildfires can potentially alter ponderosa pine regeneration niches and fungal community composition, including pine-symbiotic ectomycorrhizal (EM) fungi. We investigated the long-term (13 years post-wildfire) effect of fire severity on: 1) ponderosa pine regeneration niches (e.g., abiotic and biotic characteristics surrounding naturally regenerating ponderosa pines), 2) EM and saprotrophic fungal sporocarp (fruiting) communities, and 3) ponderosa pine root tip EM colonization and community composition on the 2000 Pumpkin Fire, Arizona, USA. Plots were located in unburned (including high tree densities, ranging from 560-1160 trees/ha), moderate-severity (including post-fire surviving tree densities ranging from 120-490 trees/ha), and high-severity (100% tree mortality) burned areas. Results show high-severity burn plots have regeneration niches with different understory plant community composition and soils with different textures, but similar total carbon and nitrogen, nitrate, phosphate, and ammonium concentrations compared to unburned and moderate-severity plots. High-severity burn plots also had unique sporocarp community composition, a shift in dominant sporocarp functional groups, and 4-7 times lower EM sporocarp species richness compared to unburned and moderate-severity plots. Regenerating ponderosa pines had similar EM colonization and richness among treatments, yet ponderosa pines in the interior of high-severity burn patches had a different EM community composition and a lower relative abundance of EM species compared to moderate-severity burn plots. These results suggest that large patches of high-severity fire have long-term consequences to ponderosa pine regeneration niches and associated fungal communities, which could influence regeneration success.

Using thermal and chlorophyll fluorescence imaging to compare the physiological responses of resistant and susceptible seedlings to infection by an invasive pathogen

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Abstract: Determining the physiological consequences of plant-pathogen interactions for the host species underpins our capacity to predict future impacts at the ecosystem scale. This is especially relevant when considering combined impacts of climate change and plant diseases. Will infected trees be more susceptible to mortality in future? In this experiment, we compared the physiological responses of 10 families of southwestern white pine (*Pinus strobiformis*) to infection by *Cronartium ribicola*. Our objectives were to quantify the physiological impact of infection and to determine the extent to which partial and complete disease resistance was reflected by needle-scale physiological responses. One hundred seventy five seedlings from 10 families, from range-wide seed collections and covering a range of resistant and susceptible families, were germinated in the greenhouse, and half were inoculated with *C. ribicola*. Seedlings were then monitored for 12 months. Top-down thermal infrared (TIR) images were captured monthly as part of a high-throughput phenotyping platform along with hyperspectral imagery, with stomatal conductance measured on a subset of seedlings. Chlorophyll fluorescence imaging of single-needles was conducted at 6-8 week intervals and A-Ci curves were measured at the beginning and end of the experiment. Overall, photosynthesis was inhibited by infection with *C. ribicola*, with a significant reduction in ϕ_{PSII} among all infected seedlings. However, the degree of depression in ϕ_{PSII} was highly variables among families and not significantly different between resistant and susceptible families. Similarly, stomatal conductance was significantly lower in infected seedlings, although variance among families was very high. In contrast to needle-scale measurements of chlorophyll fluorescence and stomatal conductance, the seedling to air temperature difference (T_l-T_a) was not different between infected and uninfected seedlings. To follow on from this experiment, we are now conducting a drought experiment with the remaining resistant families to examine the combined effect of drought and disease on the physiological functioning of this species.

Going long and going big to tackle climate change adaptation: The value of long-term and large-scale management experiments

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Abstract: Designing, implementing, and maintaining large-scale and long-term management experiments is a huge challenge. Forest management partners who are willing and able to go big and go long in the name of research are few. Administrators must see beyond the next congressional cycle when setting priorities for research. Scientists must be creative, often on shoe-string budgets initially, and innovative at selling silvicultural research to larger funding sources. Despite these challenges, pursuing and staying the course with large-scale, long-term management experiments can pay huge dividends in often anticipated ways. Perhaps there is no better example of this payoff then in the context of climate change adaptation approaches in forests. These experiments, often designed to address questions about growth and yield, productivity, forest health, and regeneration, can prove powerful in assessing climate adaptation strategies through, for instance, retrospective analysis of tree ring data or assessing the conditions that resulted in diverse, mixed-species regeneration. They are also invaluable for informing the development of newer *grand experiments* aimed at future climate adaptation. In this talk, I will highlight how long-term and large-scale management experiments designed for other purposes have been used to inform and develop climate change adaptation strategies, using several important regional forest types as examples. These include long-running *Levels of Growing Stock* experiments and large-scale structural and compositional restoration experiments. Moreover, I will highlight how the wealth of knowledge and experience gained from these experiments has been instrumental in designing some of the largest climate change adaptation experiments on the planet.

Natural models for ecological silviculture: what it is and why it matters

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Abstract: Ecological silviculture is an approach for managing forest ecosystems, including trees, other organisms, abiotic components, and their interactions based on emulation of natural models of disturbance and development. In doing this, ecological silviculture is used to sustain or restore the structure, composition, and function of ecosystems while managing for multiple services, inclusive of timber and other commodities. Considering ecological silviculture as a unique operating paradigm is still controversial among some researchers and managers, who may view it as nothing more than a tweaking of classic, timber-focused, silviculture, i.e., new terms for old ideas. While ecological silviculture is grounded in the rich tradition of classic silviculture, we will discuss why it is different from the latter and uniquely positioned to be responsive to emerging global drivers of forest management. Specifically, we will place ecological silviculture in the context of forestry in the 21st century, including the exponential increase in understanding of forest ecosystems, the continued divergence of the global forest estate into production and conservation forests, and the rise of forest certification and non-traditional forest stewards. We will present the scientific underpinnings of ecological silviculture based on principles of continuity, complexity/diversity, timing, and landscape context and how these principles translate into silvicultural systems. We will show how ecological silviculture is well suited to adapting forest to changing conditions, especially climate change, but also invasive pests, changing markets, and changing societal expectations. Finally, we will introduce the symposium talks that will demonstrate application of ecological silviculture principles, as an operating paradigm, in different forest settings.

Belowground consequences of a hemlock woolly adelgid infestation in New England hemlock forests

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Abstract: Eastern North American landscapes are being transformed by widespread hemlock (*Tsuga canadensis*) decline and mortality caused by hemlock woolly adelgid (HWA, *Adelges tsugae*). Despite HWA's substantial impact on tree health, we lack a clear understanding of how hemlock loss alters soil microbial communities and, in turn, soil biogeochemical processes. Toward this goal, we used a recent HWA-induced outbreak (since 2008) in an eastern hemlock stand at Harvard Forest (Petersham, MA, USA) to determine whether microbial communities differ between HWA-infested and uninfested sites as well as quantify and characterize soil biogeochemical responses across a gradient of HWA infestation (0-100% defoliation). We found that highly infested sites (>75% defoliation) had greater soil moisture content, lower root biomass, lower organic soil mass and a reduced organic layer depth. Soil respiration was lowest at sites where hemlock replacement by black birch (*Betula lenta*) occurred (100% defoliation), suggesting a net effect of stand replacement on soil C efflux. In contrast to biogeochemical responses, total microbial, bacterial, and fungal biomass did not vary across the HWA infestation gradient. However, there was a decline in the abundance of fungi to bacteria (i.e., F:B ratio) suggesting a shift to a more bacterial-dominated community across the HWA infestation gradient. Taken together, our results indicate that aboveground HWA infestation has far-reaching belowground impacts, initiating substantial changes in biogeochemical processes shortly after infestation occurs, and suggests that forests affected by HWA may not remain a carbon sink following reorganization of stand structure.

Linking tree growth responses to antecedent drought and physiological mechanisms in the southwestern US

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Abstract: Drought stress affects tree growth and physiology across the southwestern US, with major implications for forest functioning and carbon fluxes under future climate change. We present results from two studies of tree drought physiological response at different scales, including a synthesis of ponderosa pine (*Pinus ponderosa*) response to repeated drought events across the western US, and novel measurements of bomb-spike radiocarbon and stable isotopes in sapwood non-structural carbohydrates (NSC) in aspen (*Populus tremuloides*) growing at two sites of differing moisture stress. Given observed legacy effects of drought in tree growth—multi-year impacts of drought on tree growth—an obvious question is: what is the impact of compounded droughts occurring during the recovery period from previous drought? We show ponderosa pine is more strongly impacted by a second or third drought occurring during a given five year period. Additional changes in growth-climate sensitivities induced by compounded drought differ in both direction (sign) and their impact on legacies across ponderosa populations, likely related to evolutionary histories. Drought

legacies may result due to slow recovery of NSC following drought, however, NSC pools in trees are built up and drawn down over multiple years, resulting in multiple "pools" of NSC with different cycling rates. Then, how does drought affect the size and age (time since fixation) of NSC pools? We show total NSC in dry site aspen is both reduced and of older age compared to trees at a wet site, illustrating differences in radial mixing of NSC pools across years, likely controlled by moisture stress. These results highlight how variation within species may modify the broad regional footprint of compounded drought legacies, and how the histories of non-structural carbohydrate dynamics may explain differences in the legacy effects (and climatic memory) we observe across space.

Effect of altitude on soil organic carbon stocks in *Pinus hartwegii* Lindl forests at central Mexico

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Abstract: Alpine forest soils are considered important in mitigating climate change because their large stocks of organic carbon (OC) which can be retained for long periods of time. This is not only due to the nature of the soil, but also to the prevailing environmental conditions as altitude increases. The extremely low temperatures at high-altitude forests affect the processes of incorporation and release of soil organic carbon (SOC). The objective of this research was to determine the soil organic carbon (SOC) stocks along an altitudinal gradient (from 3,400 to 4,000 m) in the *Pinus hartwegii* forest in the Nevado de Toluca, in central Mexico. SOC stocks of top-soil (15 cm deep) were measured in soil samples collected every 100 m elevation by the oxidation-reduction method. The results show a significant effect (P=0.0176) of altitude. In the first altitudinal floor (3,400 to 3,600 m) a stable C pattern was observed; at 3,700 m it had a slight decrease and from 3,800 to 4,000 m an increase in the amount of stored C was observed. The study indicates that mean SOC stock at the highest altitude site sampled (4,000 m) was 173.1 Mg ha^{-1}, significantly higher than at the lowest altitude (3,400 m), with 146.8 Mg ha^{-1}. Soil organic matter (SOM) content was also significantly (P<0.0001) higher at 4,000 m (22.8% ± 0.33%). The highest accumulation of C, at higher altitude suggests that low temperatures drive the SOC stocks in alpine forests. Therefore, the expected increase in temperature from global warming could cause the release of OC stored in alpine soils into the atmosphere, reinforcing climate change.

Spatial variability of carbon and nitrogen pools on the forest floor across a landscape of temperate managed forests in Mexico

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Abstract: The forest floor litter forms specific carbon (C) and nitrogen (N) pools that are influenced by forest type, canopy structure, and forest management practices. These pools can vary significantly over short distances. Spatial information is therefore necessary to evaluate the C sequestration potential and inform sustainable forest management practices. The study was carried out in a temperate forest in central Mexico dominated by *Pinus patula* under forest management for timber production. A chronosequence approach was used to evaluate the influence of canopy structure on the spatial variation of the forest floor C and N pools. Forty-one inversed Y-shaped inventory plots in an area of 900 ha within an Intensive Carbon Monitoring Site were analyzed. Two layers of the forest floor (leaf litter and fermented layers) were evaluated and the C and N concentrations were determined in the laboratory. Both layers were statistically compared considering two years (2013 and 2018). The Moran's I, geostatistics, and geographical information system techniques were applied to reveal the spatial pattern of C and N pools. In order to explain the spatial variability derived from canopy structure, hemispherical photographs were taken and tree variables were measured. The data was processed in ArcGis®, GapLight Analyzer®, and R® software. A topographic map for the region was used to interpolate and map forest floor C and N pools by Inverse Distance Weight. The RMSE between interpolated and measured values at monitoring plots was also evaluated. The variability among different sampling sites was statistically different (P<0.001). Different levels of variability of C and N pools across the landscape, between 2013 and 2018, and between forest floor layers were detected. Our results suggest that the spatial variability of the forest

floor C and N pools is a function of canopy structure, which is deeply influenced by forest management practices such as thinning intensity.

Quantifying the multivariate controls of deadwood and soil gas emissions in a second-growth northern hardwood forest

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Abstract: Alternative forest management practices emulating natural disturbance have emerged to improve the resilience and sustainability of forest ecosystems. Certain features of old growth forests are associated with higher structural complexity and enhanced provision of ecosystem functions in comparison to younger secondary growth forests. Structural complexity was manipulated within a maturing second-growth forest site via the creation of gap openings and addition of woody debris on the forest floor. Our aim was to test whether these features accelerate the development of a managed forest and recover key characteristics associated with late-successional forests. To assess the relationship among deadwood addition, soil biotic activity and forest C dynamics, we monitored soil and wood CO_2 exchange throughout two growing seasons (2016 – 2017) and soil CH_4 and N_2O fluxes for the 2017 growing season. Soil CO_2 flux was greatest near moderately to highly decayed wood, and the amount of variation in flux between gap and closed canopy conditions varied depending on the proximity to and decay status of the deadwood. In gap openings, soil flux was significantly greater near highly decayed wood compared to less decayed wood, which could be linked to higher soil water content. Inversely, in closed canopy conditions, the soil CO_2 flux tended to be highest in soils sampled away from highly decayed wood. Estimated soil CH_4 fluxes varied seasonally and ranged from -25.65 to 16.24 μmol m^{-2} s^{-1} and N_2O flux ranged from -0.58 to 0.65 μmol m^{-2} s^{-1}. Wood CO_2 flux did not vary between gap openings and closed canopy conditions nine years after treatment implementation. These results suggest a complex interaction of soil microenvironment, wood characteristics and forest management, and point to the shifting influence of wood at different decay stages. Understanding the multivariate controls of soil CO_2, CH_4, and N_2O production and uptake is essential to quantify the contribution of woody debris to atmospheric gas exchange.

Collaborative scientist-manager partnerships: The National Adaptive Silviculture for Climate Change (ASCC) Network

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Abstract: The Adaptive Silviculture for Climate Change (ASCC) project is a collaborative effort that has established a series of experimental silvicultural trials across a network of different forest ecosystem types throughout the United States. Scientists, land managers, and a variety of partners co-developed the five initial experimental sites as part of this multi-region study to research long-term ecosystem responses to a range of climate change adaptation approaches. The core team of scientists and managers that compose the National ASCC Network are working together to research impacts to forest ecology in rapidly changing conditions, and evaluate management strategies to best cope with these changing conditions into the future. The big question ASCC is poised to answer is: What actions can be taken to enhance the ability of a system to cope with change while continuing to meet management goals and objectives? Silvicultural treatments at each ASCC study site were developed using a modified process from the *Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers* and contain treatments that approximate three general climate adaptation options: (1) resistance: maintaining relatively unchanged conditions over time; (2) resilience: allowing some change in current conditions, but encouraging an eventual return to reference conditions; and (3) transition: actively facilitating change to encourage adaptive responses. Here we will provide an overview of the ASCC experimental design and discuss the contributions and key strengths of this collaborative science-management partnership, setting the stage for the other session presentations to provide details on the implementation and data collection currently taking place across the network.

White spruce silviculture in the boreal mixedwood forest – why are we only choosing a single option?

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Abstract: White spruce (*Picea glauca*) is a common, highly productive, and high value late successional species found across the boreal mixedwood forest. It naturally regenerates from seed, either immediately after disturbance or often in the understory of trembling aspen stands. It is also a species that is potentially at risk from a drier future climate across much of its range. Management regulations generally require the replacement of species harvested immediately after harvest even though this may not resemble a common natural successional pathway. This results in white spruce almost always being planted after harvest in conjunction with mechanical site preparation. Subsequently, vegetation management including the use of herbicides in some jurisdictions is applied to increase growth rates and ensure stands meet performance expectations. As a result, these new spruce stands tend to be productive but uniform across the landscape. We believe that a range of management approaches for white spruce are needed and justified. We will address six practices that have been tried but have not been widely adopted in the boreal mixedwood forest: 1) harvesting with advanced regeneration protection, 2) understory planting of white spruce, 3) natural regeneration using seed tree systems, 4) precision vegetation control with localized treatment applications, 5) intensive management of spruce plantations, and 6) commercial thinning of spruce plantations. These options range from lower to higher intensity relative to current management and each has limitations associated with it. But there are also opportunities to implement these practices given the appropriate management goals and site conditions. Our goal is to expand the range of viable management options for white spruce in the boreal mixedwood resulting in a forest with a range of future management options to face global change.

Invertebrate responses a decade following prescribed burning and retention harvest in the western boreal forest of Canada

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Abstract: Over the last two decades, green-tree retention (GTR) has been used in northern and temperate forests as an alternative harvest prescription to clear-cutting. This management model is implemented to retain post-harvest legacies (e.g., living mature trees, standing/downed woody material) inspired by those left after natural disturbances, particularly wildfire. Much research has focused on comparing post-harvest faunas to those of unharvested reference conditions to assess faunal recovery, but little is known about how stands harvested through GTR recover compared to equivalent stands that recovered after fire. As part of the Ecosystem Management Emulating Natural Disturbances (EMEND) project, we compare responses of three invertebrate groups (spiders, carabid beetles and rove beetles) to retention harvest and prescribed burning over a period of 10 years. Species composition in stands recovering after harvest and burning was more similar than either was to clear-cuts or reference unharvested controls over time; however, each taxon showed different responses, with carabid and rove beetles exhibiting more complete recovery than spiders. Although species richness decreased over time in all stands, it was highest in burned sites and lowest in unharvested controls for both carabids and rove beetles; however, spider richness was highest in controls. Although there are significant differences between forest harvest and fire as disturbances, results suggest some features are retained following retention harvest that support more similar species composition with those observed after prescribed burning than after clear-cutting. Because post-disturbance faunas remain different from those in unharvested controls after a decade, longer observations are required to better understand recovery trajectories. Nonetheless, results to date show that faunas of GTR and burn treatments have recovered toward targets better than in clear-cuts. Because of variation in recovery among the three taxa, observations support multi-taxa evaluations of retention harvest in support of forest management more sensitive to faunal conservation.

Litterfall production and decomposition rates in a reforested area in Central Mexico

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Abstract. Reforestation has been widely used as a forest restoration strategy in Mexico, where tree survival and growth have been the only measures of restoration success. However, ecological restoration´s main goal is to reverse the degraded land through the functions, processes, structure and ecosystem diversity recovery. Litterfall and decomposition are two ecological process in forest ecosystems; which are the main source of organic matter where the nutrient incorporation and cycling are the most important functions. We examined the litterfall production and decomposition in reforestations of *Pinus greggii*. The study was carried out in three reforested areas (R5, R12, and R14, with 5, 12, and 14 years-old) and in a reference site (RS, a patch of natural forests). Ten sampling sites were established randomly to measure the litterfall (monthly), while the decomposition process was evaluated by the litter-bag method in four sampling points in each reforestation age and in the RS. The reforestation age was positively correlated with litterfall production. The highest litterfall production was recorded in R14 (0.3099 kg m^{-2} $year^{-1}$) while the lowest in R5 (0.0436 kg m^{-2} yr^{-1}). The highest and lowest decomposition rates corresponded to RS (k= 0.676) and R14 (k= *0.229*). These results reflected the highest C and N release in RS, and the lowest in R12 and R14, respectively. While reforested area showed an increase in litterfall recovery over time, decomposition rates and nutrient release (C and N) showed opposing results compared to the RS, which could be associated with the decomposer communities.

Biomass recovery following a major hurricane in secondary tropical forests

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Abstract: Natural disturbances, such as hurricanes in the Mexican tropics, are part of the dynamics of tropical forest growth. However, the potential for biomass recovery after hurricanes is still unknown, making it difficult to quantify the value of ecosystem services such as carbon sequestration. This study seeks to clarify the rate of biomass recovery in tropical forests hit by large hurricanes. To address this issue, we calculated the growth rate of biomass accumulation over eight years in early, intermediate, and old-growth successional stage secondary forests across the southern Yucatan peninsula, Mexico that were hit by Hurricane Dean on August 21, 2007. Before the hurricane, the forest biomass content was 92.79, 192.19, and 353.43 Mg ha^{-1} in early succession, intermediate succession, and old-growth forests, respectively. Two years after hurricane impact, the forest biomass continued to decrease to 51.60%, 40.71%, and 16.18% across the forests successional stages analyzed. Eight years following Hurricane Dean, the forest biomass had recovered to 67.10 Mg ha^{-1} in early succession, 151.87 Mg ha^{-1} for intermediate succession, and 330.31 Mg ha^{-1} for the old-growth forests. These represent an annual growth increment of 1.58 Mg ha^{-1} yr^{-1} in forests in early succession, 2.07 Mg ha^{-1} yr^{-1} in intermediate succession, and 9.27 Mg ha^{-1} yr^{-1} in old-growth forests. Our results showed that the effect of the hurricane on forest biomass was more accentuated in secondary forests in the early successional stage. The effect of hurricanes on forest biomass recovery may last for long periods of time. In this study, secondary forests after eight years of severe damage caused by a Category 4 Hurricane are still recovering to their pre-hurricane biomass content, which has to be considered in the design of conservation and forest management strategies.

Invasion of non-native plants in gaps created by reduced-impact logging activities

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Abstract: Non-native plant invasions frequently occur following human-caused disturbances in forest ecosystems. Canopy openings and disturbed soil conditions may facilitate such invasions and reduce successful tree regeneration of desired species. In forest areas where timber is harvested using selective harvesting and reduced impact logging, more than 90% of the trees are left standing after logging. The remaining dense canopy may not provide enough light for non-native plant invasion. However, there has been no research on this topic, nor has research been conducted linking the presence and abundance of non-native understory plants with successful tree regeneration. We examined non-native plant invasion and native tree regeneration success in three post-harvest compartments including 1 year, 3 years and 5 years post-harvest. We installed three different plots in skid trails, harvesting gaps, and non-harvested forests in each post-harvest forest to record understory plant abundance and characterize the light environment using leaf area index (LAI). We found that that there was no interaction between sampling categories (non-gap, gap, and skid trail) and post-harvesting year (1, 3, and 5 years post-harvest). We found that LAI was significantly different between year 1 and year 5 and between skid trail and non-harvested forests. Skid trails generally had the lowest LAI value across the post-harvest sites and the LAI declined

from gaps to skid trails in all post harvesting years, except 1-year post harvest, where the non-harvested areas (gaps) and non-gaps were not significantly different. We found five non-native plants in the 1- and 3-year post-harvest sites with the average weight of non-native plants contributing only 0.24% of the overall plants. No non-native plants were found in 5-year post-harvest sites.

Ecological classification of the river floodplain forests of the Shiawassee National Wildlife Refuge, Saginaw County, Michigan, USA

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Abstract: Forest management often benefits from a sound understanding of the range of ecological conditions of forests across the landscape. In Lower Michigan, the Shiawassee National Wildlife Refuge (SNWR) is undergoing several projects that depend on filling the knowledge gap of understanding the natural forest vegetation prior to extensive modification by agriculture and recreation. Approximately 50% of the 4,000 ha SNWR is forested, yet the forested areas remain some of the most poorly understood ecosystems within the Refuge. Forest ecological classification systems (ECSs) are a valuable tool in this regard because of their iterative process that simplifies the complex, multi-factor nature of ecosystems and places forest sites within an ecological hierarchy. An ECS that identifies volumetric and spatially explicit ecological units defined by physiography, hydrology, soil, and vegetation will provide a detailed framework that is critical for well-informed and purposeful management. A preliminary ecosystem map was created and 61 randomly stratified plots were used to test our initial classification. Our current ECS has identified and described 11 unique and repeatable forest ecosystems within SNWR. Silver maple (*Acer saccharinum* Linnaeus) is the dominant overstory species across a majority of the forested areas of SNWR, however, consideration of other biophysical components allowed for the identification of three unique silver maple dominated ecosystems. Ecosystem units were contrasted using biophysical variables obtained in the field and canonical correspondence analysis. Forest community composition is shown to be most influenced by elevation, flood duration, water table depth, and soil texture. These results highlight that the simultaneous consideration of physiography, hydrology, soil, and vegetation proved most effective over single-factor approaches in the identifying, defining, and mapping of local forest ecosystem units at SNWR.

Restoring Wisconsin's critically imperiled pine barrens: how does prescribed fire alter soil properties linked to aboveground communities?

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Abstract: Human settlement and subsequent land use change, namely fire exclusion and suppression, have resulted in substantial decline of pine barrens, which are now considered critically imperiled both globally and regionally. In the Moquah Barrens (Wisconsin, U.S.), the Forest Service is using prescribed fire to restore and expand pine barrens habitat. We monitored pre- and post-fire soil conditions at 112 study plots following four large-scale (430–780 ha/unit) prescribed burns to understand how edaphic conditions change following fire. After the first year of prescribed burns, we observed a pattern of increasing hydraulic conductivity with decreasing time since fire, indicating that prescribed burns alter soil water retention in a way that may favor native pine barrens plant communities. We also found that pyrolysis and ash formation altered chemical and physical conditions of the forest floor and mineral soil. Cation concentration (K, Ca, Mg) of wildland fire ash was positively related to soil pH, a pattern that persisted one year after fires. Soil nutrients exhibited a range of responses to fire; some showed ephemeral increases or decreases which had dissipated by one year post-fire, while other changes were persistent one year after fires. Plant root simulator probes suggested that nutrient supply rates generally declined by one year after fires, suggesting either a) rapid uptake of fire-released nutrients by recovering plant communities, or b) leaching of pyrogenic nutrient inputs through sandy soils. Collectively, our findings indicate that fire-driven changes in soils are likely to influence restoration outcomes of open pine barrens habitat.

Two new maximum stand density indices based on an exponential equation applied to mixed-species forests in Mexico

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Abstract: Two new maximum stand density indices (SDIs) based on exponential density decline as a function of quadratic mean diameter were developed for and applied to mixed-species forests from Durango, Mexico. The exponential-based density-diameter relationship was compared with the power law density-diameter relationship (Reineke's model) in the linear and nonlinear forms. The developed SDIs were based on the intercept and slope parameters (i.e., density-dependent intercept parameter or density-dependent slope parameter) and they were applied to 22 species combined and to six species groups in mixed-species forests. The dataset used in the fitting included 202 fully stocked circular plots at maximum density, with 22 species in mixed-species forests. The SDIs were validated with a dataset of 122 circular plots. The fitting statistics of the exponential equation outperformed those reported by the potential equation for both nonlinear and linear forms. The SDIs based on the exponential equation showed a curvilinear trend based on the maximum SDI in graphical log–log scale. Also, the SDIs generated two Density Management Graphics (DMGs): the first DMG showed a variable intercept and common instantaneous mortality rate, and the second DMG showed a common intercept and variable mortality rate. When applied in a thinning schedule for mixed-species forests, the SDIs based on the exponential equation suggested greater average removal of trees per hectare, volume, or basal area than those based on the potential equation. The fitting of exponential and potential equations for species or species groups showed that the density–size relationships for all species combined had the most statistical support.

Emulating natural disturbance dynamics through the application of irregular shelterwood systems in Québec's temperate mixedwood forest

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Abstract: Because of its proximity to inhibited areas, the temperate mixedwood forest of Québec (Eastern Canada) has been used for decades for wood production, fishing, hunting, and other recreational activities. More recently, ecological forestry has become the new paradigm through ecosystem management because of its capacity to address multiple economical, ecological, and social objectives. Using natural forest landscape structure and dynamics as a reference, ecosystem management aims at maintaining ecosystem functions and resilience by reducing the gaps between managed and natural forests. This talk will focus on the silviculture of temperate mixedwood forests, and more specifically on that of balsam fir (*Abies balsamea*) – yellow birch (*Betula alleghaniensis*) stands, where spruce budworm outbreak (*Choristoneura fumiferana*) is the main driver that causes intermediate disturbances interspersed between stand-replacing fires. By emulating the impact of spruce budworm causing partial mortality on ~30-40-yr cycles, we pose the hypothesis that irregular shelterwood systems could mimic regeneration patterns, and maintain species composition, as well as structural and species diversity. First 5-yr results from a study in balsam fir – yellow birch stands show that irregular shelterwood treatments could regenerate the three target species (red spruce (*Picea rubens*), balsam fir, and yellow birch). They also indicated that continuous cover irregular shelterwood, the least intense treatment, offers the greatest potential to reach compositional and structural goals. Clearcut was the least efficient treatment for maintaining structural attributes, regenerating the conifers, preventing hardwood expansion, and conversion to hardwood-dominated compositions. Even though results are relatively short term, irregular shelterwood appears to be a sound alternative to clearcut systems that could help with conciliating wood production, ecological, and social objectives.

Silviculture for resistance and resilience in the temperate mixedwood forest of Eastern Canada

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Abstract: The temperate mixedwood forest of Eastern Canada constitutes an ecotone where temperate and boreal forest tree species coexist under a variable disturbance regime that ranges from light (e.g., background mortality) to severe (e.g., catastrophic fires). In a context where global changes can affect growth and regeneration processes at a faster pace than the adaptive capacity of species, some species like the boreal conifers are anticipated to lose habitat in the mixedwood forest. These changes risk altering the composition, structure, and productivity of this ecosystem. Adaptive silviculture strategies focusing on a portfolio of resistance, resilience, and transition options could help today's forest to face future stressors in a context of uncertainty. This talk will explore different silvicultural options of resistance and resilience that could help mixedwood forest stands adapt to future unknown conditions caused by global changes. Resistance options include treatments and modalities that will promote tree vigor and species diversity, like mixed precommercial and commercial thinnings in stands of young and intermediate ages. In mature and late-successional stands, treatments that sustain species and structural complexity, including irregular shelterwood and hybrid selection systems, could promote resilience. To illustrate this, we will present a concrete example for late-successional yellow birch (*Betula alleghaniensis*)–conifer stands, where a range of hybrid single-tree and small group selection cutting intensities was assessed to emulate gap dynamics. First 8-yr results show that hybrid selection cutting could regenerate yellow birch, while maintaining high plant and structural diversity. We found an increased risk of impact on structural attributes such as large trees (>29 cm) above 40% removal of basal area. Enrichment planting could be necessary to preserve the declining red spruce (*Picea rubens*). While some silvicultural systems could be used as coarse filter approaches to sustain diversity and ecosystem functions, fine filter measures may be needed.

Sensitivity to climate warming: Piñon pine seed cone production and recruitment patterns across the Colorado Plateau

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Abstract: Dryland ecosystems across the western US are currently experiencing warmer temperatures coupled with climate-driven increases in disturbance. This may result in biome-level vegetation shifts to alternate vegetation types if there is a failure of trees to regenerate. Yet tree regeneration patterns vary across the landscape due to physiographic factors, such as elevation, aspect, and soil type, which alter water and energy balance, as well as biotic factors such as nurse plant availability, which alter microclimate conditions. Further, multiple population processes are required to successfully achieve tree regeneration, including seed production, seedling establishment, and juvenile survival – all of which may be differentially affected by local climatic conditions. Here we present results from studies assessing how seed cone production, tree establishment, and juvenile survival vary across broad physiographic gradients among populations of piñon pine (*Pinus edulis*), a widespread dryland conifer in the U.S. Southwest. Piñon pine seed cone production, seedling establishment, and juvenile survival were all strongly affected by physiographic factors that increase tree water stress, suggesting that regeneration failure is more likely in areas with hotter and drier climatic conditions. Piñon pine establishment and survival were also highly dependent upon the facilitative effects of overstory trees and shrubs for providing favorable microsites for seedling establishment, particularly in areas with greater grass cover, which appear to compete with piñon pine juveniles. Thus, following recent disturbance events such as drought-induced tree mortality, regeneration failure is likely to occur in areas without sufficient remaining overstory tree or shrub cover, especially at locations with high grass cover and hotter and drier climatic conditions.

Tracking ecosystem disturbance and recovery using PhenoCam imagery

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Abstract: Photographs are remarkably powerful documents with which the state of a landscape scene can be permanently fixed in time. Repeat photography enables tracking changes in that state over time, and quantification of the magnitude and timing of both gradual and abrupt changes in state. In an ecological context, gradual changes would include shifts in species composition over years to decades, whereas abrupt changes would include disturbances such as fire or insect defoliation. The frequency at which images are recorded determines the precision with which the timing of abrupt changes in state can be identified. The PhenoCam network uses

digital camera imagery to track vegetation phenology in a diverse range of ecosystems across North America. With over 20 million visible-wavelength images, the PhenoCam archive currently encompasses about 2000 site-years of data from over 500 cameras. The image time series from a handful of cameras are more than 15 y in length, and many image time series are a decade in length. These data are providing important information about the sensitivity of terrestrial vegetation phenology to interannual variation in weather and other environmental factors. However, PhenoCam imagery can also be used to track ecosystem disturbance, and recovery from disturbance. I will provide examples of how PhenoCam imagery has been used to track disturbances resulting from spring frosts, insect outbreaks, fires, and wind storms and hurricanes, as well as gradual forest mortality resulting from drought. Because of the high frequency of PhenoCam imagery—generally sub-daily—the timing of abrupt disturbances can be identified with high precision, facilitating attribution. With the data volumes now being accumulated, even "rare" disturbance events are being observed with some regularity. Importantly, the archived imagery allows researchers to detect the onset of disturbance events months or even years after they have occurred.

Fire legacies drive complexity in eastern ponderosa pine stand structure and biodiversity

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Abstract: The legacies of fire drive forest stand structure and biodiversity via complex interactions between time-since-fire and fire severity for unknown periods of time. However, due to increasing changes in disturbance regimes, it is becoming more difficult to characterize fire legacies or determine how long they persist. We used a space-for-time substitution to compare post-fire forest stand, habitat structure, and biotic communities within 10-year-old and 27-year-old mixed-severity fires that occurred in an eastern North American ponderosa pine forest. Specifically, we sought to 1) quantify the relative strengths and interactive effects of time post-fire and fire severity on habitat structure, and 2) determine how long fire legacies influenced forest stand structure and biotic communities. We evenly stratified 112 sampling plots by fire severity (unburned, low, moderate, and high) and time-since-fire (10 years and 27 years). We recorded live tree and snag densities, tree cavity data, tree diameters, and coarse woody debris at both times-since-fire, and we also recorded biotic community composition (bird and understory woody plant) at the 27-year-old fire. Fire severity explained >14 times the amount of variation in forest stand and habitat structure than time-since-fire, but we also found the interaction of severity and time post-fire was a significant driver of forest stand and habitat structure. Unburned patches significantly differed from all burned patches. At 10 years post-fire, low and moderate severity patches did not significantly differ, but they did differ from high severity patches. However, 27 years post-fire, low and moderate severity patches differed, whereas moderate severity patches were similar to high severity patches. We found no difference between 10-year- and 27-year-old low severity burned patches. Fire legacies persisted decades after the mixed-severity wildfire in ponderosa forest, fostering distinct structures, communities, and species in burned versus unburned patches and across fire severities. We discuss how spatiotemporal asynchrony in fire severity drives forest stand structure, habitat structure, and biodiversity.

Recent and projected future trends in post-fire regeneration for two conifer species in the southern Rocky Mountains

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Abstract: While plant species distribution models (SDMs) commonly focus on the ranges of mature individuals, the presence of individuals in early life stages may better predict species' climatic tolerances and thus the potential for future range shifts in a warming climate. We used extensive field inventories (c. 1,300 field plots spanning 22 fire events) of the presence and abundance of two dominant seed-obligate conifers (ponderosa pine [*Pinus ponderosa*] and Douglas-fir [*Pseudotsuga menziesii*]) in the southern

Rocky Mountains to predict regeneration success for each species following wildfire. We then combined these models with terrain variables and statistically downscaled climate data to spatially model recent (1981 – 2015) and future (2020 – 2099) post-fire abundance throughout the southern Rocky Mountains. Our models predicted substantial shifts in suitable climate space for each species across the region. Fire, one of the dominant controls on global patterns of vegetation, is likely to facilitate shifts in tree species distributions in a warmer, drier future.

What's beneath Pando? Community forest ecology gauges recovery or ruin

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Abstract: The famed Pando aspen (*Populus tremuloides* Michx.) clone is putatively 'the world's largest organism,' although its status is rapidly changing. This iconic 43 ha forest of genetically identical stems is threatened by ungulate herbivory, recreation, developers, and past management. Previous work at Pando has documented decades of poor regeneration success attributed to browsing deer and cattle. Without demonstrable change in stewardship the clone faces extensive failures that will substantially reduce its size, potentially leading to system collapse. We set out to understand how evolving management actions are affecting species composition in the understory plant community. Specifically, we were interested in overall plant diversity, nonnative invasions, and species abundances related to long-term disturbances in the context of current herbivore exclosures. Twenty vegetation plots were established in conjunction with previous mensuration and herbivory sample locations in three protection regimes. The unprotected area is subject to cattle and deer browsing, a partially protected area inadvertently allowed deer browsing only, and the totally protected area excluded all ungulates. Results indicate that in five years since fencing has been erected differences in plant communities are emerging. We found a total of 68 distinct species (54 herb; 14 woody) across the entire clone, with the greatest diversity occurring under lower canopy cover. Direct and indirect effects are likely at play. Some plants are targeted by browsers, some spread by hikers or cattle, and others are facilitated by increased or decreased sunlight related to widening canopy gaps or rapid aspen recruitment in protected zones, respectively. Results presented here are preliminary, though we intend to remeasure plant communities over time to fully understand Pando's recovery or collapse. Wider issues of forest, recreation, and wildlife policy will play into understory diversity futures beneath Pando's broad canopy, as well as aspen forests at-large.

Variation in soil moisture, temperature, and grass cover in a burned and unburned PJ woodland: Effects on a rare plant

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Abstract: Chapin Mesa milkvetch (*Astragalus schmolliae*) is a globally rare and potentially federally listed plant that is only found on Chapin Mesa. The majority of the population is managed by Mesa Verde National Park and Ute Mountain Ute tribal lands. This pinyon-juniper obligate grows in deep loamy soils and relies on winter moisture to replenish deep soil moisture required for spring emergence. We placed temperature sensors at a 10 cm depth and soil moisture sensors at 10 and 35 cm depths in burned and unburned plots. Summer soil temperature was 5°C warmer in burned vs. unburned plots. Shallow soil moisture water content was less in burned vs. unburned plots, however there was no difference in deep soil moisture water content. The plant had a positive response to the fire for the first 11 years, increasing the overall density within the burned areas, however this trend has shifted and now there is a negative effect in the burned area with recent density counts below that of unburned sites. We propose that the shift from a positive to negative burn effect is primarily due to competition from grasses. Cheatgrass, smooth brome, and Western wheatgrass have increased to >60% cover in the burned area and may be inhibiting seedling survival as well as the expected succession towards a woodland. As fire risk increases with climate change, managers may be able to assist post-fire succession by choosing a seed mix that benefits succession. Bunch grasses, forbs, and shrubs should comprise the bulk of a post-fire seed mix for the Chapin Mesa area.

Tree islands of Florida's dynamic southern coastal plain

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Abstract: With the recent acceleration in the rate of sea-level rise, mangroves have encroached into coastal prairies of the southern Everglades, with profound effects on landscape structure. While the march of mangroves across the former grassland is recognized as a process of great interest for Everglades restoration, the effects of mangrove invasion into the myriad tree islands that dot the coastal landscape are not well known. In 2016-17 we sampled vegetation and soils in tree islands and the adjacent coastal wetland matrix east of Shark River Slough, including sites previously sampled by our research team in 1996. Our objectives were to determine whether mangrove encroachment into the marsh was paralleled by mangrove invasion into the tree islands, and to learn whether these forests were nutrient "hot spots", similar to tree islands in the freshwater Everglades. We examined soil profiles within the forests and the adjacent wetland matrix, and analyzed soil and leaf chemistry. Our data showed that in the two decades between surveys red mangrove (*Rhizophora mangle)* had become established in nearly all islands, but mesic tropical hardwoods (e.g., *Metopium toxiferum, Calyptranthes pallens, Coccoloba diversifolia*) persisted, continuing to produce the fleshy fruit important in the diet of avian visitors. We also found that soil salinity was similar in tree islands and adjacent wetlands, but organic matter content and phosphorus concentrations were elevated in the forest soils. Leaf N:P ratios were significantly lower in the leaves of red mangrove in the tree islands than the marsh, indicating that the phosphorus limitation that characterizes many Everglades wetlands was ameliorated in these forests. As saltwater flooding in the lower Everglades increases in magnitude, managers must consider the influence of mangrove invasion on carbon storage, nutrient cycling, and provision of wildlife habitat by coastal tree islands.

Legacies of forest cuttings on the soil-plant-microbes complexes

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Abstract: In temperate forests of North America, even-aged or uneven-aged management systems have direct impacts on the soil-plant-microbe forest complex. These direct impacts are increasingly recognized as important in the alteration of numerous forest ecological functions, however, little is known on the legacies of these management systems in the temporal dynamic of the soil-plant-microbes complex. To examine temporal patterns, soil parameters, litter, as well as plant and fungi community composition and abundance were assessed in unmanaged forests and along a chronosequence (< 5 years, 15 years, 30 years) for even-aged and uneven-aged managed forests. In total, 189 permanent plots were installed in 63 sites (random stratification with paired-treatment, n=9). We observed that numerous physicochemical and biological soil traits experienced large fluctuations shortly after forest cutting (< 5 years). Furthermore, the temporal dynamics of some traits (e.g. pH, cations (Ca^{2+}, Mg^{2+}, K^{+}), mineralizable N, N, C/N, Al^{3+}) were still affected on a long term, since they did not recover to the unmanaged forest level more than 30 years after treatment. Additionally, our results reported a decrease in functional and phylogenetic β diversity of plants and a significant decrease in total herbaceous plant covert (-50%) along the chronosequence. This situation was especially true in even-aged managed systems. The exploration of the relationships between plants or fungi communities (i.e. total soil fungi diversity and changes in abundances of AMF families) in association with the changes in soil propriety along the chronosequence revealed the importance of soil parameters. To reinforce this conclusion, a greenhouse experiment successfully demonstrated altered tree productivity as a result of forest cutting legacy. Our results can help with mitigation of management impacts and restoration efforts for temperate ecosystems.

Assisted migration of pines and *Abies religiosa* in the Native Indian Community of Nuevo San Juan Parangaricutiro and Monarch Butterfly Biosphere Reserve forests

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Abstract: Suitable climatic habitat of forest tree species will shift upwards in altitude in Mexican mountain regions, due to climatic change. The speed at which conifer populations migrate by natural means, is not fast enough to keep coupled to the climate for which they have evolved. Assisted migration, e.g. the relocation of genotypes by planting them in new locations that match projected suitable climatic habitats, is needed, both for commercial forest plantations and for conservation purposes. We tested assisted migration in the Mexican Transvolcanic Belt. Several provenances collected along altitudinal gradients of four Mexican pines of commercial relevance (*Pinus devoniana, P. leiophylla* and *P. pseudostrobus*), were planted in field common garden tests placed at contrasting altitudes

(2100, 2400 and 2700 m a.s.l.), in the forest of the Native Indian Community of Nuevo San Juan Parangaricutiro, Michoacán state. Six to ten *Abies religiosa* (sacred fir) provenances collected along an altitudinal gradient were planted at two high elevation sites inside the core zone of the Monarch Butterfly Biosphere Reserve (MBBR). The high elevation common gardens also tested the use of nurse plants as protection against extreme temperatures. Results of pine tests indicate that an assisted upwards migration of 300 m in altitude, in order to approach a realignment of the populations to the climate projected for the decade centered around the year 2030, appears to be a viable strategy with which to accommodate the effects of climate change **in the** Mexican Transvolcanic Belt, although there is a loss in growth of about 5 % per each 100 m of shift upwards in altitude. Similarly, a shift upwards in altitude up to 400 m of *Abies religiosa* seedlings is feasible, if planted under local shrubs (such as *Baccharis conferta*) as needed protection, with a survival averaging 81%. That would require planting the nurse plants in advance.

Climate-change trajectories and forest dynamics following treatments in warm/dry mixed-conifer forests of San Juan Mountains in southwest Colorado

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Abstract: Some warm/dry mixed-conifer forests are at increasing risk of uncharacteristically large, high-severity fires. As a result, managers have begun ecological restoration efforts using treatments such as mechanical thinning and prescribed fire. Empirical information on the long-term impacts of these treatments is limited, especially in light of potential climate change. We assessed changes in forest structure and composition five-years following three alternative restoration treatments in a warm/dry mixed-conifer forest: (1) thin/burn, (2) prescribe burn, and (3) control. We used the Climate-Forest Vegetation Simulator (Climate-FVS) model to quantify potential forest trajectories under alternative climate scenarios. Five years following treatments, changes in forest structure were similar to initial post-treatment conditions, with thin/burn being the only treatment to shift and maintain forest structure and composition within historical reference conditions. By 2013, the thin/burn had reduced basal area (11.3 m^2 ha^{-1}) and tree density (117.2 tree ha^{-1}) by 56% and 79% respectively, compared to pre-treatment values. In the burn, basal area (20.5 m^2 ha^{-1}) and tree density (316.6 tree ha^{-1}) were reduced by 20% and 35% respectively, from 2002 to 2013. Mortality of large ponderosa pine trees (the most fire-resistant species) throughout the duration of the experiment averaged 6% in the burn compared to 16% in the thin/burn treatment. Changes five years following treatments were largely due to increases in sprouting species. Shrub and sapling densities were approximately two to three times higher (respectively) in the thin/burn compared to burn and control, and dominated by sprouting oak and aspen. Under climate simulations, the thin/burn treatment was more resilient in maintaining forest conditions compared to burn and control, which approached meager forest conditions (3-4 m^2 ha^{-1}). These results indicate that restoration treatment that includes both thinning and burning can maintain forest integrity over the next few decades.

Effects of prescriptive rescaling on pattern and process in southwestern ponderosa pine-dominated forests

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Abstract: In 1987, Urban et al. defined landscape ecology as being, "motivated by a need to understand the development and dynamics of pattern in ecological phenomena, the role of disturbance in ecosystems, and characteristic spatial and temporal scales of ecological events". In this influential paper, they went on to discuss how resource management may introduce "novel perturbations" that can differ in spatial or temporal scale from those observed in natural conditions and regimes, and suggest that resource management should be scaled to mimic natural patch dynamics, which they call "prescriptive scaling". The effects of natural and prescriptive scaling on spatial pattern and process were examined in three pine-dominated case study landscapes of northern Arizona: (1) an uninterrupted frequent fire landscape in Grand Canyon National Park; (2) a landscape initially treated 20 years ago with thinning and repeated burning just north of Flagstaff; and (3) an experimental landscape at Coulter Ranch treated over a century ago that has remained relatively untreated since. Using these landscapes, I describe the structured hierarchy (e.g., tree-patch-stand-watershed-landscape) and present comparisons of structural fragmentation and diversity (patch richness and evenness) observed for each landscape. I discuss the role of novel perturbations observed for each landscape and explore how characteristic spatial patterns effect simulated wildfire behavior using FlamMap as an example ecosystem process. Lastly, I discuss how these pine-dominated case-study landscapes provide insights into the success of resource management practices, potential resilience to anticipated climate related

disturbances, and suggest that "prescriptive rescaling" should be explicitly recognized and considered in future management and restoration planning and practice.

Nine-year tree regeneration response and spatial patterning in variable-sized experimental gaps in northern Wisconsin, USA

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Abstract: While it is generally accepted that shade-intolerant species have a growth advantage under high light, and shade-tolerant species have the advantage under low light, results of field studies are inconsistent. We conducted a field experiment testing the response of tree regeneration to experimental gaps of different sizes. Previously we reported that overstory gaps significantly increased height and growth rates of both shade-tolerant *(Acer saccharum, Ostrya virginiana)* and midtolerant species *(Fraxinus americana, Carya cordiformis, F. nigra, Tilia americana)* in gap sizes ranging from 50 to 380 m^2 four years after gap harvest. Here we revisit these patterns and evaluate the distribution of growth rates of regeneration nine years post-treatment. The Flambeau Experiment is designed to test the effects of canopy openings and dead wood on ecosystem processes in northern hardwood forests. This study focuses on 15 replicates of each of 3 sizes of experimental gaps (50, 200 and 380 m^2). Ten main plots (80 x 80 m) were fenced to exclude deer, and gaps were created in half of the fenced plots. Height, growth, and diameter at breast height of saplings and stump sprouts were measured nine years post-treatment. Individuals were monitored within quadrants oriented on the cardinal directions within the expanded gap and the gap/closed canopy transition zones to allow analysis of the effects of aspect and edge influence on tree regeneration. Mixed modeling approaches will be used to analyze species survival, growth, and abundance by spatial location, gap size, deer exclusion, and canopy cover. We will use point pattern analysis to investigate the spatial patterns of mapped midtolerant saplings in harvested gaps and the surrounding forested edge environment. We hypothesize that while initially shade-tolerant and midtolerant species displayed similar competitive abilities, nine years post-treatment, the patterns will have changed. Growth of midtolerant species appear to be accelerating and may lead to a stronger chance of gap capture.

Regional patterns of quaking aspen health and mortality across northern Minnesota ecoregions: Implications for forest management

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Quaking aspen trees are valuable both ecologically and economically. Sudden Aspen Decline (SAD) brought on by drought and climate change impacts has the potential to threaten Minnesota quaking aspen populations. Understanding current trends in aspen health and mortality can help researchers and forest managers create mitigation and adaptation strategies. Comparative analyses between larger ecoregions were performed to identify spatial patterns in quaking aspen health and mortality between and within ecoregions. Previous data from USDA Forest Inventory and Analysis were used to develop baseline estimates and for comparison with research plot results. Aspen populations were assessed in 2017 and 2018 across both a rainfall gradient and ecological transitions in northern Minnesota by measuring DBH, crown health estimates (0, 25, 50, 75, 100%), pathogen presence, and physical damage. A total of 88 plots (8477 individuals) were sampled across the ecoregions in northern Minnesota. It was found that fragmented regions of Aspen Parkland were healthier (or just as healthy) relative to stand age as stands in the Laurentian Mixed Forest Province to the east. The Prairie Parkland Province displayed the highest mortality rates among the provinces with the Eastern Broadleaf Forest intermediate. Variations among the ecoregions were found in the distribution and the strength of relationship between mortality factors and their influence on quaking aspen health and mortality. Age-related vulnerability to mortality factors was a leading driver of lower health rates, with variations among the ecoregions in which specific mortality factors were more prevalent. These results question preconceived notions of lower comparative Aspen Parkland stand health. They also show the value of age-related mortality characterizations across specific ecoregions as they could identify early deviating trends as possible SAD events brought on by drought or climate change impacts as opposed to an age-related mortality pattern.

Is phloem transport limited under drought and does it matter for plant survival?

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Abstract: Anthropogenic climate warming is projected to result in more frequent and severe droughts accompanied by increased temperatures in this century. Such global-change-type droughts have been linked with large-scale tree mortality, and followed by increasing number of studies on mechanisms of tree mortality to allow more accurate predictions of vegetation cover changes. These studies emphasize the role of the hydraulic integrity of the water transport tissue, the xylem, or the available carbohydrate reserves in determining which trees die and how fast. Drought responses of the phloem, the carbohydrate transport tissue, could hold the key to combining these two aspects. The phloem is the pathway that distributes carbohydrate reserves to all plant parts, and it relies on water extracted from the xylem transpiration stream to facilitate carbohydrate transport. Drought impacts on phloem transport, however, have attracted attention only recently. This is because studying phloem transport is challenging. Phloem tissue is relatively small and delicate, and it has often been assumed not to be impacted by drought, or having insignificant impact on plant function or survival compared to the xylem. New experimental evidence and theoretical considerations, however, suggests that drought responses of the phloem might hold the key for predicting plant survival time, or revival capacity after drought. For example, osmotic adjustment of phloem water potential to match the declining water potential of the xylem during drought may increase carbohydrate concentration, and viscosity of the phloem sap enough to significantly reduce phloem transport capacity, and potentially promote plant mortality. In this talk I review the newest results from theoretical and anatomical studies, isotopic labelling experiments, and scalable fluid mechanics experiments to discuss the impacts of drought on the phloem, the means plants can use to avoid these, and answer the question whether phloem transport matters for plant survival under drought.

How do deciduous forests of North America respond to climate change?

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Abstract: Projected warming and changes in the patterns of precipitation are expected to influence spring and autumn vegetation phenology and length of the growing season in many ecosystems. Understanding how full-year vegetation phenology vary with space and time will help us to identify vulnerable regions and habitats. However, how spatial and temporal variations in climate interact with ecosystems through the growing season is not fully quantified. We analyzed 504 site-years of daily vegetation activities at 101 sites from the PhenoCam network. The sites cover a broad range of ecosystems and climates, representing the temperate deciduous biome. Within a hierarchical framework, we designed a piece-wise linear model to describe vegetation activity during the green-up, growing and green-down seasons. A multivariate joint model was used to quantify how environmental and meteorological anomalies influence both timings and rates of the spring and autumn phenology. Spring phenology was overwhelmingly explained by two energy drivers: temperature and solar radiation. Variations of autumn phenology, however, were controlled by energy and moisture drivers: summer temperature, vapor pressure deficit, and annual precipitation. We predicted how spring and autumn phenology are sensitive to climate anomalies using the historical climate data. Our results showed that sensitivity of spring phenology to temperature anomalies is higher in warmer sites than the rest. While the effect of vapor pressure deficit was not a universally significant factor across all sites, the effect increased with increasing mean annual precipitation. We predicted that wet sites were significantly vulnerable to vapor pressure deficit anomalies. The residuals covariance matrix showed that greenness, timing, and rate of the green-down were strongly related to the green-up phenology. The findings may have implications for current studies that use univariate models or underestimate moisture drivers to explain full-year vegetation phenology.

Thresholds, feedbacks, or linear relationships? Environmental drivers of tree species turnover across an ecoregion-scale ecotone in the Upper Midwest

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Abstract: Ecotones are transition areas between adjacent ecological systems and may be especially sensitive to climate change. Ecotone response to climate change often depends on a suite of factors, including multiple environmental controls, individual species response, and additional processes such as disturbance. Thus, it is difficult to predict ecotone response to climate change without understanding the underlying factors that control the ecotone. One way to learn more about ecotone controls is to examine the relationship between the rate of transition from one system to the other (turnover) and the rate of transition in key environmental variables spatially across the ecotone. Linear relationships with climate indicate that ecotone response to climate change is easy to predict, although this may not be common. More likely, thresholds or feedbacks exist or interactions with other environmental variables affect the shape of the relationship. Furthermore, turnover-environment relationships may vary along the ecotone. Here we examine historical turnover-environment relationships in the Tension Zone, an ecoregion-scale ecotone in Wisconsin. Using data on tree species occurrence in the mid-1800s obtained from the U.S. Public Land Survey, we use generalized linear mixed models to examine whether the relationship between various environmental variables—representing climate, topography, hydrology, and soil—and the turnover from southern to northern species across the Tension Zone is linear or non-linear. We examine the variables separately and together, including interactions. To determine whether turnover controls vary along the Tension Zone, we complete this process separately for 15 transects across the Tension Zone, interspersed along the ecotone. If the best models are non-linear, we infer that thresholds or feedbacks control turnover across the ecotone. We discuss the implications for predicting climate change response in the region.

Quantifying the demographic vulnerabilities of pinyon-juniper woodlands to climate change using landscape-scale population models

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Abstract: Although climate change induced disturbance and drought are causing widespread mortality in pinyon-juniper woodlands across the western U.S., the long-term resilience and viability of North American pinyon-juniper woodlands are generally unknown because we lack information on other key demographic processes. In particular, we lack an understanding of recruitment and growth rates that will determine where, and over what time scales, pinyon-juniper can recover from mortality events. Using data from >5,000 re-censused Forest Inventory and Analysis (FIA) plot across the western US, we developed spatially-explicit, size structured demographic models of survival, growth, and recruitment of seven pinyon and juniper species across their ranges. These structured population models allowed us to estimate resilience and long-term population growth. Preliminary results indicate that while the majority of populations are nearly stable (10 yr. $\lambda>0.9$), rapid population decline ($\lambda<0.9$) is more common than rapid growth ($\lambda>1.1$). In some species, vital rates and population growth rates vary systematically across species' ranges. For example, two-needle pinyon (*Pinus edulis*) growth and survival decline with latitude, leading to a lower population growth rates, on average, at its southern range limit. In contrast, Utah juniper (*Juniperus osteosperma*), individual growth rates and population growth rates decline at more northern latitudes and low elevations. Our results highlight that the vulnerability of pinyon-juniper woodlands is likely to be idiosyncratic and species-specific, but landscape-scale demographic models will be valuable tools to anticipate future vulnerabilities of forests to climate change.

Restoration with balsam poplar cuttings and the effects of disturbance on plant community composition in Blue Rapids Provincial Recreational Area, Alberta, Canada

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Abstract: Off-highway vehicle (OHV) use in natural areas results in changes in the physical, chemical and structural properties of the OHV trails and their surrounding ecosystems. Within Blue Rapids Provincial Recreation Area (BRPRA), Alberta, Canada, numerous unmanaged OHV trail crossings traverse wet areas and watercourse features. Wet areas have low resilience and long recovery times following disturbances. This project focused on the revegetation of 15 enhanced crossings in BRPRA, including: an investigation of three different balsam poplar (*Populus balsamifera*) tree cutting planting treatments to identify the most effective method for restoring native future canopy vegetation; and exploring how vegetation differed on restored trails, adjacent edges, and forests across two years post-restoration. We used three different types of experimental cutting treatments: unrooted (from dormant cuttings), rooted (from dormant cuttings, rooted in a greenhouse), and direct plant (from greenwood). We measured initial diameter at planting day and monitored survival and height growth for the first and second growing seasons. In addition, we conducted vegetation surveys to compare the plant community composition on different trail positions. The rooted treatment showed overall better survival and height growth. All three treatments were recommended, since each one might be practical to specific needs of different restoration programs. Initial diameter of the cutting influenced survival during the first growing season and height growth in both growing seasons; optimal diameters ranged from 4 to 8 mm. Restored OHV trails and their associated edges had different plant communities when compared to adjacent forested areas. Therefore, the planting of native woody species could be an option to help accelerate plant succession on these trails, although, this cannot yet be predicted. Longer-term monitoring of the enhanced OHV trails can help inform their successional trajectories.

Increasing trends in high-severity fire in the southwestern USA from 1984 to 2015

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Abstract: In the last three decades over 4.1 million hectares have burned in Arizona and New Mexico and the largest fires in documented history have occurred in the past two decades. Changes in burn severity over time, however, have not been well documented in forest and woodland ecosystems in the southwestern US. Using remotely sensed burn severity data from 1621 fires (>404 ha), we assessed trends from 1984 to 2015 in Arizona and New Mexico in (1) number of fires and total area burned in all vegetation types; (2) area burned, area of high-severity, and percent of high-severity fire in all forest and woodland areas; and (3) area burned, area of high-severity, and percent of high-severity in seven different grouped forest and woodland vegetation types (Ecological Response Unit [ERU] Fire Regime Types). Number of fires and area burned increased across the Southwest regardless of vegetation type. The significant increasing trends held for area burned, area of high-severity, and percent of high-severity fire in all forest and woodland ecosystems. Area burned and area burned severely increased in all seven ERU Fire Regime Types while percent of high-severity fire increased in two ERUs: Mixed Conifer Frequent Fire and Mixed Conifer with Aspen/Spruce Fir. Managers must face the implications of increasing, uncharacteristic high-severity fire in many ecosystems as climate change and human pressures continue to affect fire regimes.

Shedding light on drought tolerance in Californian oaks illuminates potential changes in woodland community composition along aridity gradients

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Abstract: Drought can cause major damage to plant communities. Although species-specific damage thresholds are not yet fully determined, recent findings indicate that post-drought recovery of gas exchange in conifer and angiosperm plant species can be predicted by properties of the xylem water transport system. Consequently, quantifying the capacity of plants to resist embolism (i.e., air blockage) formation in the xylem seems to be essential for understanding species distributions along aridity gradients and predicting future drought damage and mortality patterns. However, many questions remain. For example, little is known about within-species variation in capacity to resist embolism and its drivers. Even less is known about within-species variation in tissues other than stems, despite results suggesting that roots, stems, and leaves can differ in vulnerability. In this presentation, I will discuss how my research examines variation in vulnerability to embolism in leaves and stems within and between oak species that occupy sites with varying aridity, as well as the implications for woodland communities under future climates. Specifically, I will discuss how we are using newly developed visual techniques to observe embolism formation in leaf and stem xylem of Californian oaks. This line of

research has shown that xylem vulnerability to embolism varies between North American oak species distributed along aridity gradients. We also show that there is no local adaptation and only minor phenotypic plasticity in leaf/stem xylem within one oak species, even from populations distributed across very broad climatic gradients. These results are suggesting that oak populations are highly adapted to extreme drought events. However, high levels of potentially heritable variation within populations could contribute to adaptive responses under future climate change. Consequently, our results offer insight into how knowledge of plant physiological variation, coupled with predictions of specific changes in the environment might impact the future distributions of oak woodlands.

Burn severity assessment using Sentinel-2 and Planetscope spaceborne data in a context of salvage logging in the boreal forest of Eastern Canada

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Abstract: In a context of global climate change, natural extreme events such as forest fires will increase in frequency and severity. Such changes will have major impacts on the use of salvage logging to harvest affected forest landscapes. The work presented here is within the framework of a national effort to monitor and characterize burn severity in order to optimize salvage logging operation efficiency. This study aims to characterize burn severity at three different scales using *in situ* (Composite Burn Index [CBI] plots) as well as high (Planetscope) and medium (Sentinel-2) resolution spaceborne imagery. In this study, we assess the burn severity (initial assessment) of two recent fires (5000 and 9764 ha) in the crown-closed boreal forest of the same ecological region of the Québec province. Such fires were selected in order to analyze spring (2017) and summer (2018) fire severity variability and post-fire environmental characteristics. We conducted an extensive field campaign of 90 plots (2017 fire) and 50 plots (2018 fire) where the CBI, char height, soil, and vegetation characteristics were collected in order to calibrate remotely sensed data. CBI data has proven to be a strong severity metric for both observed fires, with R^2 of 0.86 and 0.71 with linear regressions with Sentinel-2 derived dNBR for the 2017 and 2018 fires, respectively. Preliminary results of the object-oriented classification, as well as calibration with *in situ* data, are proving to be effective in rapidly characterizing burn severity and could improve the standardization and efficiency of the salvage logging management assistance efforts.

Modeling forest carbon dynamics in managed and non-managed temperate forests in Mexico

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Abstract: Understanding the effects of forest management and natural disturbances is essential for predicting forest carbon (C) dynamics, informing climate policy-making, and improving forest management. Process-based ecosystem models (PBEM) are powerful tools that provide guidance on uncertain future forest productivity or unexpected problems to decision makers, and information for public debate about the management of terrestrial ecosystems. In this study, measured forest biomass C stocks and eddy covariance tower data in Mexican temperature forests managed for timber production, as well as non-managed forest, were used to calibrate and parameterize the process-based forest ecosystem model, PnET-CN. The calibrated model was used to evaluate the effects on carbon dynamics of historic forest management, natural disturbances, and alternative management scenarios. We quantified above-ground biomass (AGB) stocks and the C fluxes of gross primary productivity (GPP), net ecosystem production (NEP) and net primary production (NPP). In general, PnET-CN simulated the expected trajectories in C fluxes (GPP, NPP, and NEP) and stock (AGB) following stand regeneration of *Pinus patula* managed forests. The predicted annual GPP, NPP, and NEP increased with time since disturbance. Simulated GPP increased with stand age, reaching a maximum (2230–2511 $gCm^{-2}\ yr^{-1}$) 14 and 15 years after fire and harvest, respectively. Simulated NEP was initially negative with a higher net C loss after fire than after harvesting. The NPP in regenerating stands was more dynamic due to the scheduled thinning. Simulated AGB in mixed managed forest was 15% higher than in monoculture. These findings illustrate the importance of forest management and natural disturbances on carbon dynamics when applying simulation models over time periods to estimate regional productivity rates and carbon budgets. This PBEM was able to quantify the impact on carbon of various management scenarios and can be used for future scenario analyses to support sustainable forest management and climate mitigation actions.

Changes in fuels with post-fire succession in a jack pine (*Pinus banksiana* Lamb.)-dominated forest of northern Lower Michigan

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Abstract: Changes that occur in fuels with succession in fire-prone forests of the Lake States are not well documented. We sampled permanent forest plots established in the footprint of a 9,700 ha stand-replacing burn that occurred in an approximately 35 year-old jack pine-dominated forest in northern Lower Michigan in 1980. Data collection within these plots in 1986, 1996, and 2017 provided an opportunity to assess aboveground fuel dynamics over time since fire and across different ecosystem types. Plots were classified into one of eight landscape ecosystems using variables related to physiography, soils, and vegetation. Total number of stems of jack pine (overstory, understory, and groundcover) decreased over time, with canopy cover greater in 1996 than 1986 or 2017. Significant differences in the average diameter of coarse woody debris (CWD) ($P=0.018$) and total plot counts of CWD ($P<0.001$) were observed from 1986 to 2017, with significant interactions between time and landform. No significant changes were detected for fine woody debris counts or litter depth over time, while duff thickness significantly increased ($P<0.001$). Ground vegetation heights and abundance did not change. Changes in vegetation composition featured a decrease in jack pine seedlings and an increase in oak and maple seedlings with time since fire. This study improves our understanding of fuel dynamics with succession and provides a basis for modeling potential fire behavior at various points during post-fire forest recovery.

Livestock exclusion impacts the persistence of native and exotic plants in California oak savannas and importance of microhabitat differences

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Abstract: Oak savannas in California have been highly altered by the introduction of herbaceous species from the Mediterranean, including winter annual grasses that currently dominate most sites. Although these species arrived more than two centuries ago, the effects of management and disturbance on remnant native plant assemblages remains largely unresolved. Oak trees create unique, persistent microhabitats beneath and at the edge of their canopy. This variation may interact with disturbances such as livestock grazing to produce heterogeneous outcomes. We investigated these issues using repeated mapping efforts and vegetation surveys connected to a long-term livestock exclusion experiment. First, we intensively mapped populations of several species of native perennial grass to address how livestock grazing might affect boundaries between native- and exotic-dominated patches. Mapping took place inside and outside of grazing exclosures, replicated at two locations with different soil conditions. Mapping was done at two time points five years apart. Second, we conducted repeated vegetation surveys at the same set of grazing exclosures, explicitly considering areas beneath and outside the canopy of different oak species. We found that boundaries of mapped native grass populations fluctuated over five years, depending on site and grazing treatment. At the lower fertility site where native grasses were initially less abundant, grass populations expanded greatly, especially in the presence of livestock grazing. Population boundaries were more static in the high fertility site, where native grasses occupied more area initially, but native grass cover shrunk within grazing exclosures. Grazing also affected oak understory microhabitat differently; native species were much more abundant beneath oaks when livestock were excluded. Our work demonstrates the importance of context in predicting the impacts of livestock exclusion in oak savannas. It further illustrates that there will be significant heterogeneity in outcomes when using grazing as a restoration tool in a setting such as oak savanna.

Structure of a ponderosa pine forest on tribal lands in the southwestern US

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We examined the current structure of a ponderosa pine-dominated forest on the Hualapai tribal lands in Arizona. From nine 0.04 ha plots within each of five 25 ha research sites that were previously installed for a study of surface fire history, we collected forest

structure and composition data, which included tree-ring samples from over 600 living trees. Preliminary results suggest the forest is numerically dominated by younger ponderosa pine, primarily from a cohort that established around 1919. Gambel oak, pinyon pine, and Utah juniper are also present in the forest, with each showing a more balanced distribution of ages and sizes. Compared to forests on public lands, forests on Native American lands have generally been managed using uneven-aged silvicultural systems for longer periods. Although few older ponderosa pine trees are present in the Hualapai forest, current uneven-aged management practices may set this forest up to be more resilient as climate warms, impacting carbon stocks. Future resiliency may be further improved given that prescribed fires, which approximate the frequent surface fire regime of the past (pre 1887) have been implemented in this forest since the 1960s.

What is regenerating after mountain pine beetle attack in a novel region in Alberta?

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Abstract: Natural disturbances are an integral part of forest ecosystems and drive successional change. The boreal forest is adapted to stand-replacing fires, which have different ecological impacts than less severe disturbances, such as insect attacks. In recent years, mountain pine beetle (MPB), a bark beetle native to western North America, has undergone an unprecedented range expansion into lodgepole pine forests in west-central Alberta. MPB influences the canopy, but does not necessarily provide suitable conditions for pine regeneration. It is crucial to understand what may regenerate after MPB attack in stands with no previous record of MPB attack. The objective of this study was to assess natural regeneration after MPB across a range of site types and levels of MPB mortality within west-central Alberta. We used model selection to examine which factors best explained tree regeneration after MPB attack. While almost 60% of the post-MPB sites assessed had evidence of tree regeneration, regardless of species, less than ten percent of sites had any evidence of pine regeneration. On sites that had some evidence of pine regeneration, the median density was 250 tph (ranged from 250 to 1,500 tph). On sites that had evidence of any tree regeneration, the mean density was 3,300 tph (ranged from 80 to 22,940 tph). There was evidence of higher amounts of pine regeneration in sites with poorer moisture and nutrient regimes, especially those with pre-existing pine advance regeneration. Sites with richer moisture and nutrient regimes, broadleaf advance regeneration, and spruce in the canopy were less likely to experience pine regeneration. This was likely due to unsuitable regeneration microsites, shading, and competition. Without intervention, these stands will likely transition away from pine, to broadleaf and other conifer species. Thus, richer quality sites should be prioritized for lodgepole pine rehabilitation in Alberta.

Stand-replacing fire in California's conifer forests: Spatial scale and why it matters

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Abstract: There is ongoing disagreement over the natural range of variation in stand-replacing, or high-severity, fire within western yellow pine and mixed-conifer forests. Often absent from this conversation is a discussion of the critical importance of the spatial scale of contiguous patches of stand-replacing fire, and the ecological consequences of variability in this spatial scale. Using examples from contemporary fires in the Sierra Nevada of California, I illustrate how traditional ways of comparing stand-replacing effects among different fires often fail to account for important variation in aggregate distance to seed sources for conifer regeneration within stand-replacing patches and describe a new statistical metric (stand-replacing decay coefficient or SDC) that can capture this variation. I then describe how the spatial scale of stand-replacing patches can influence two important ecological metrics: snowpack hydrology and understory plant diversity. Evidence from these examples suggests that within-stand heterogeneity created by fine-grained stand-replacing fire and other forest management practices is not only consistent with the natural range of variation based on other lines of evidence but may maximize snowpack retention and plant diversity at the stand scale. Current trends in burn severity in California conifer forest suggest that we are moving away from fine-scale heterogeneity and towards coarse-scale heterogeneity which may have cascading ecological effects.

Throughfall reduction decreased transpiration, canopy stomatal conductance, and the hydroscape area in longleaf pine

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Abstract: Increasing temperatures and extreme precipitation events with prolonged droughts are predicted for the southeastern U.S., which could lead to a greater risk of drought-related mortality in trees. Understanding how trees respond to drought is essential to predict how forests will respond to climate change. Our objective was to examine the impact of experimentally induced drought on water relations of longleaf pine *(Pinus palustris*). The impacts of approximately 40% throughfall reduction (TR_{40}) and ambient throughfall (TR_0) on water relations and growth were examined over three growing seasons in a longleaf pine plantation growing on a xeric site in Georgia. Between September and November 2016, an extreme natural drought occurred (77 days without rain) with the Palmer Drought Severity Index falling to -4.6. During the natural drought, predawn (Y_{PD}) and midday (Y_{MD}) leaf water potential declined to -3.1 MPa and -3.8 MPa, respectively. Average monthly canopy stomatal conductance (G_S) and monthly transpiration on a ground area basis (E_G) declined to near zero for two months. Throughfall reduction treatment over the three years reduced soil moisture and Y_{PD}. The hydroscape area, which is a metric of iso/anisohydry or stomatal regulation of leaf water potential, was decreased from 1.8 to 1.6 MPa^2 by TR_{40} indicating stomatal control of Y_{MD}. Reductions in G_S in TR_{40} resulted in decreases in annual E_G of 19% and transpiration per unit leaf area of 16%. Neither the natural nor the experimentally imposed drought had a significant effect on mortality, which was on average 2.8%. However, TR_{40} decreased stand volume and growth efficiency, defined as the ratio of annual net primary productivity to maximum leaf area index. Based on hydroscape area and leaf water potential at the turgor loss point, longleaf pine exhibited isohydric behavior during severe drought and in response to TR_{40}.

Integrating management into models of forest function at local to continental scales

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Abstract: Forests are central to the Earth system, and human management of forests is therefore critical to simulate in Earth system models. Doing so requires: 1) a theoretical basis for understanding how social and economic factors influence forest management decisions, 2) an approach to build this understanding into ecological models, and 3) information about how forest management strategies vary across space and time. We demonstrate how ecological assessment can interface between social and economic theories that define forest goods and services, and ecological theories for quantifying forest function. In other words, social and ecological assessment can be used to construct socioeconomic theories of forest management and function. But our understanding of forest function is scale-dependent and largely based on the stand scale. Do ecological theories of forest function based on stand scale observations break down at larger 'macrosystem' scales, and does management play a role? We demonstrate a path forward for incorporating forest management and disturbances into a scalable model – namely ED2 – to predict the effects of changing management policy, disturbance regimes, and climate on forests across the continental United States. Such an analysis cannot be undertaken without maps of different forest management strategies and we demonstrate how the Breaks for Additive Season and Trend (BFAST) algorithm can be used to map forest management in two study regions: the U.S. Pacific Northwest and the Southeast. Results demonstrate a way forward for integrating large-scale forest management into models of Earth system function.

Woody fuel heat subsidies: can we accelerate pine woodland and barren restoration during dormant season burns?

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Abstract: Semi-open to open pine systems were historically common on sandy glacial deposits throughout the Great Lakes region of North America but are now rare and of global biodiversity significance. Twin challenges limiting restoration of these systems

following the opening of the canopy are: a) reversal of the "mesophication" process related to the development of an organic duff layer, and b) the persistence of hardwood regeneration from belowground stump and root reserves following hardwood encroachment. We partnered with the Chequamegon-Nicolet National Forest to investigate the how mechanical brush cut fuel treatments, coupled with late dormant season controlled burns, influenced restoration objectives in the Moquah Barrens (Wisconsin, U.S.). Here we overview the effects of experimental fuel treatments on fuel consumption patterns, soil heating, and subsequent hardwood regeneration across a range of restoration stages following four large-scale (~400 ha each) late dormant season controlled burns conducted in 2016 and 2018. Woody fuel loads ranged from very low on grassland and fuel removal treatments (~1 ton/ac [0.45 Mg/ha]) to high on brush cut and fuel addition treatments (5-15 tons/ac [2.3-6.9 Mg/ha]), providing sharp contrasts in fire behavior, fuel consumption, and aboveground fire severity. Nonetheless, direct duff consumption was minimal (~0.4 cm), and mineral soil heating was largely decoupled from fire behavior due to the insulating effects of the overlying duff. Likewise, densities of hardwood sprouts regenerated to pre-fire densities within one year post-burn, regardless of fuel treatments. Our results suggest that multiple, repeated fires during the dormant season would be required to meet restoration objectives. These findings buttress a growing body of evidence that burns applied during the growing season, particularly when duff moisture is lower and ambient soil temperature is higher, could more effectively achieve restoration objectives within semi-open to open pine systems of the Great Lakes region.

Processes underlying restoration of temperate savanna and woodland ecosystems – Summary and Discussion

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Abstract: Temperate woodlands and savanna are among the most threatened ecosystems globally, but represent unique restoration challenges as primarily disturbance-dependent systems falling between closed canopy forest and open grasslands. In this symposium we pull examples from different temperate woodland and savanna ecosystems across the North American continent to examine the processes and unique challenges affecting the restoration success for these systems. Key processes include natural disturbances such as fire and herbivory, competitive interactions among life forms, water balance, and nutrient cycling. Here we present the major take-home messages and conclusions from the series of papers presented within the symposium as an entry point into a broader discussion of commonalities and differences across case studies to inform restoration practices of temperate semi-open systems of North America.

Maximizing growth and avoiding mortality: Seedling phenology in a high elevation white pine

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Abstract: High elevation tree species in water-limited environments must time development to avoid mortality and maximize growth. While genetic variation and phenotypic plasticity enable trees to adapt or acclimate to some environmental changes, multiple studies suggest that trees do not possess sufficient variation to cope with projected changes in climate. The western United States is predicted to experience earlier snowmelt and onset of spring, and increased drought, which could disrupt the synchrony between environmental cues and growth. Southwestern white pine (*Pinus strobiformis*), which grows in isolated high elevation sky islands across the southwestern United States and Mexico, is an ideal species for investigating phenology and altered environmental cues. Through a common garden experiment with 22,154 seedlings (from maternal trees across the species' range) planted in three consecutive years at three different elevations, our research group has studied the impacts of precipitation and temperature extremes on seedling phenotypes and mortality. To investigate possible relationships among phenology, tree mortality, and maternal origin, we assessed the impacts of garden treatments and seed source environmental variables on seedling phenotypes from the spring and fall of 2018. Preliminary results suggest local adaptation to the source environment may impact phenology at the gardens as the source population explains more variation in phenology than garden climate or a drought treatment. Ultimately, we will use this phenotype data for a genome wide association study. Our results will help identify *P. strobiformis* populations putatively more adapted to grow in particular environmental conditions and the role phenology has on seedling survival.

Multi-century histories of fire and people in resilient ponderosa pine and mixed conifer forests of the southwestern United States

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Abstract: People have lived within long-needle pine forests of the Southwest for centuries. Droughts and wildfires recurred many times in the past, but ancestral Pueblo populations managed to live within these forests, with no known history of catastrophic fires destroying their villages. In recent decades, however, very large and high intensity wildfires are burning over these landscapes and the ruins of ancestral villages, as well as in modern housing developments. How did Puebloan people live within fire-prone landscapes at relatively high population densities for centuries, in what was essentially a sustainable human-natural system? We have attempted to answer this question over the past decade with an inter-disciplinary research team of tree-ring scientists, paleoecologists, anthropologists, archaeologists, and ecological modelers. In this presentation, I will focus on findings from our work in the Jemez Mountains of northern New Mexico. Here, our research aimed at reconstructing human population numbers, fire regimes, and forest changes over the past 700 years. We found that during maximum population periods of the 14th through 17th centuries, there were high frequencies of small extent fires in areas distant from villages, and almost no fires adjacent to villages. Frequent fire ignitions by people, fuel wood gathering, small tree harvesting for roof timbers and other uses, trails, and agricultural fields imparted a spatial heterogeneity of fuels that promoted frequent, low intensity, small extent fires. Although the past is not a perfect guide for the future, the history of people, forests, and fires in the Jemez Mountains provides useful insights for restoring and living within resilient, long-needle pine landscapes today.

Identifying lags between annual CO_2 uptake and aboveground biomass increment: A synthesis across six AmeriFlux sites

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Abstract: A key process in forest carbon sequestration is the transfer of carbohydrates made during photosynthesis (i.e., CO_2 uptake) to long-lived woody biomass. One might assume that the magnitude of CO_2 uptake and biomass growth track one another closely on an annual basis. However, recent studies have shown these metrics are somewhat decoupled on an annual basis because the duration of biomass growth tends to be shorter than the period of CO_2 uptake, with the most pronounced difference late in the growing season. Once stem biomass growth stops in a given year, late-season photosynthate is allocated to storage pools (i.e., non-structural carbohydrates) that can be used to kick-start growth the following spring - corresponding to a measurable lag between late-season CO_2 uptake and biomass growth. In this study, we investigate growth lags using over 90 site-years of data across six mid- to late-successional forests within the AmeriFlux network. We compare time-series of CO_2 flux integrals from eddy covariance measurements to the woody biomass increment calculated from tree rings and repeated diameter measurements. We hypothesized that shifting the start of the CO_2 flux integral from the conventional beginning of the calendar year into the previous growing season would improve the relationship with woody biomass increment at all sites. We found that late-season CO_2 flux (i.e., September and October) accounted for a quarter of the annual gross-primary productivity at the sites investigated. When these late-season fluxes are integrated into the following growing season, relationships between CO_2 flux and woody biomass increment improve at most sites, up to a three-fold increase in correlation (from r=0.24 to 0.71). Our study demonstrates that lags in allocation of non-structural carbohydrates can be important contributions to biomass growth, and consideration for growth lags may improve forecasts of forest carbon sequestration.

Pest and disease impacts and control in declining forests

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Abstract: In the last 10 years, outbreaks of pest organisms and their negative impacts on natural forests have increased significantly. Such organisms can be differentiated between those that historically have behaved like pests (e.g. *Dendroctonus* spp., *Neodiprion* spp., *Zadiprion* spp., *Scolytus* spp.) from those normally found at endemic levels (*Ocoaxo* varians, *Lophodermium* sp, *Andricus quercuslaurinus*, *Antiteuchus innocens*, *Cronartium quercuum quercuum*, *Phytophthora cinnamomi*, *Toumeyella pinicola*). The principal hosts are species of temperate forest (*Pinus* spp., *Abies religiosa*, *Quercus* spp.). As for the affected area, there is an accumulated total in Mexico of around 1,500,000 ha, with the transition zones (semiarid to temperate) being the most affected. The measures that are carried out to achieve their control are mostly silvicultural activities, by means of which about 5,500,000 cubic meters of timber have been extracted; and application of pesticides, these activities are conducted in accordance with the national regulations on the matter.

Drought and warming response of chemical defenses in mature *Pinus edulis*

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Abstract: Increases in the frequency and duration of heat and drought stress will directly and indirectly affect forest pests and pathogens with important consequences for tree mortality and ecosystem function. It is well known that severe drought stress decreases tree chemical defenses and increases susceptibility to biotic agents. The severity and duration of drought stress necessary to promote critical shifts in defensive chemistry under field conditions, however, remains unclear. Furthermore, we lack a mechanistic understanding of the trade-offs that result between non-structural carbohydrates (NSCs) and carbon-based defensive chemistry (e.g., monoterpenes) in the face of warmer droughts. Here we provide four years of needle and phloem + xylem monoterpene concentrations and their relationship with NSCs from mature piñon pine (*Pinus edulis*) from a large-scale drought and warming field experiment. Results showed no effect of heat alone on total monoterpene concentrations relative to ambient; however, total monoterpene concentrations increased with increasing drought stress (that ranged from -0.6 to -3.1 MPa pre-dawn water potential (ψ)), suggesting that the threshold at which total monoterpene defenses start to decline in piñon pine occurs at water potentials < -3 MPa. Total monoterpene concentration was negatively correlated to starch and positively correlated to glucose + fructose content, implying a contribution from starch hydrolysis to monoterpene synthesis under stress conditions. Individual compounds responded differentially to the treatments; however, NSC content alone could not explain shifts in select compounds known to influence bark beetle performance and success. Our results suggest preferential shifts in carbon allocation patterns and/or terpene synthase responses at key points within the monoterpene biosynthetic pathway in response to physiological drought stress. Future work should provide a deeper mechanistic understanding of drought-induced changes in individual monoterpene compounds and provide data on how these changes correspond with bark beetle choice and behavior.

Strategically placed landscape fuel treatments decrease fire severity and promote recovery in the northern Sierra Nevada

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Abstract: Strategically placed landscape area treatments (SPLATs) are landscape fuel reduction treatments designed to reduce fire severity across an entire landscape with only a fraction of the landscape treated. Though SPLATs have gained attention in scientific and policy arenas, they have rarely been empirically tested. This study takes advantage of a strategically placed landscape fuel treatment network that was implemented and monitored before being burned by a wildfire. We evaluated treatment efficacy in terms of resistance, defined here as the capacity to withstand disturbance, and recovery, defined here as regeneration following disturbance. We found that the treated landscape experienced lower fire severity than an adjacent control landscape: in the untreated control landscape, 26% of land area was burned with >90% basal area mortality, according to the remote-sensing-derived relative differenced Normalized Burn Ratio (RdNBR), while in the treated landscape only 11% burned at the same severity. This difference was despite greater pre-treatment fire risk in the treatment landscape, as indicated by FARSITE fire behavior modeling. At a more local scale, monitoring plots within the treatments themselves saw greater regeneration of conifer seedlings two years following the fire than plots outside the treatments. Mean seedling densities for all conifer species were 7.8 seedlings m^{-2} in treated plots and only 1.4 seedlings m^{-2} in control plots. These results indicate that SPLATs achieved their objective of increasing forest resistance and recovery.

Effects of various climate scenarios on jack pine (*Pinus banksiana* Lamb.) barrens and wildfire in northern Lower Michigan

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Abstract: Jack pine (*Pinus banksiana* Lamb.) barrens were historically common in northern Lower Michigan, where open, low-fuel barrens persisted within dense, high-fuel jack pine forests. This structure was maintained by stand-replacing wildfires prior to 20th century fire suppression. Modern forest management prioritizes jack pine plantations for endangered Kirtland's warbler habitat, but barrens are rarely included and warbler management has altered the landscape in many ways. Barrens can host rarer grassland species and potentially create wildfire fuel breaks, but increased temperature and/or precipitation related to climate change may preclude barrens creation or encourage encroachment of trees into the open barrens. To investigate effects of climate change on barrens distributions, we used LANDIS-II to model the landscape and quantify changes in fire severity and barrens distribution attributable to climate change. We compared historical and current climates with three representative concentration pathways (rcps) each of two general circulation models (GCMs; CanESM2 and CCSM4). We found that the business-as-usual emissions scenarios (rcp 8.5) of both GCMs and the lower emissions scenario (rcp 4.5) of CanESM2 produced changes to barrens distributions, had higher fire severity, shorter fire rotations, more fires, and altered stand-age distributions of jack pine stands when compared to landscapes modeled using historical and current climates. Both GCMs predict increased temperatures, and the CanESM2 GCM predicts increased precipitation. Our results suggest that these climatic shifts may cause pronounced effects on barrens and the fire regime of the region, even including reduced coverage of jack pine and barrens overall. Alongside management for Kirtland's warbler habitat, there has been interest from local land managers to restore historically-relevant landscape structure in the region. This has encouraged management agencies to retain or restore barrens on the landscape, however our results suggest that such efforts may be more difficult in the long term as climate conditions continue to change.

Mechanisms of persistence of resprouting shrubs and grasses in a semi-arid mesquite savanna following extreme fire

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Abstract: Southern Great Plains savannas are experiencing shrub encroachment, which negatively impacts biodiversity and productivity for livestock and wildlife. One common restoration practice is prescribed fire, but morphological and physiological adaptations provide tremendous resilience to many savanna shrubs. Recent studies using extreme fires have demonstrated there may

be a threshold of intensity that overcomes shrub resprouting, but also increases managers' concerns about potential loss of desirable grasses. We examined the effects of prescribed fires on resprouting honey mesquite shrubs (*Prosopis glandulosa*) and two grasses (curly mesquite (*Hilaria belangeria*) and Texas winter grass (*Nassella leucotricha*)), while manipulating fire intensity and shrub stem exposure. Fire intensity, stem exposure, and soil moisture impacted whether foliage resprouted twelve weeks post-fire. Seventeen percent of the shrubs with their stems exposed to high-intensity fires resprouted, while 58% of shrubs that experienced high-intensity fires without stem exposure resprouted. Ninety-six percent of shrubs that experienced low-intensity fires regenerated foliage within twelve weeks, regardless of stem exposure treatment. Higher soil moisture at the time of burning increased the amount of foliage present twelve weeks post-fire. We measured stem sap flow during and following the fires to assess whether heat-mediated disruption in water transport could contribute to post-fire mortality. Two weeks post-fire, 75% of tagged *Hilaria* individuals had not resprouted in high fire intensity treatment plots. All monitored *Nassella* resprouted, regardless of fire treatment. Differences in grass mortality are potentially due to bud depth; *Hilaria* buds were measured an average of 0.5 cm below the soil surface, whereas *Nassella* buds are located at an average depth of 1.8 cm. Soil may serve as an insulator, protecting the buds of resprouting shrubs and grasses. An increased understanding of the physiological mechanisms leading to fire-induced shrub mortality will increase effectiveness of prescribed fire as a management tool for reducing or reversing shrub encroachment.

Coerced resilience in fire management

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Abstract: Mechanisms underlying the loss of ecological resilience and a shift to an alternate regime with lower ecosystem service provisioning continues to be a leading debate in ecology, particularly in cases where evidence points to human actions and decision-making as the primary drivers of resilience loss and regime change. In this paper, we introduce the concept of coerced resilience as a way to explore the interplay among social power, ecological resilience, and fire management, and to better understand the unintended and undesired regime changes that often surprise ecosystem managers and governing officials. Philosophically, coercion is the opposite of freedom, and uses influence or force to gain compliance among local actors. The coercive force imposed by societal laws and policies can either enhance or reduce the potential to manage for essential structures and functions of ecological systems and, therefore, can greatly alter resilience. Using a classical fire-dependent regime shift from North America (tallgrass prairie to juniper woodland), and given that coercion is widespread in fire management today, we quantify relative differences in resilience that emerge in a policy-coerced fire system compared to a theoretical, policy-free fire system. Social coercion caused large departures in the fire conditions associated with alternative grassland and juniper woodland states, and the potential for a grassland state to emerge to dominance became increasingly untenable with fire as juniper cover increased. In contrast, both a treeless, grassland regime and a co-dominated grass-tree regime emerged across a wide range of fire conditions in the absence of policy controls. The severe coercive forcing present in fire management in the Great Plains, and corresponding erosion of grassland resilience, points to the need for transformative environmental governance and the rethinking of social power structures in modern fire policies.

Drought and annual grass invasion limit Great Basin pinyon-juniper woodland recovery after fire by reducing nurse shrub availability

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Abstract: In western US woodlands, warmer temperatures are expected to increase the frequency and severity of disturbance events, including fire and drought-induced tree mortality. After stand-replacing disturbance, woodland recovery depends on successful regeneration, but for many dryland tree species, recruitment is largely limited to favorable microsites where abiotic stress is reduced. Changes in microsite availability in response to climate change, coupled with the influence of invasive species, represent indirect

impacts on dryland tree species with potentially important implications for woodland persistence. Here, we present results from multiple studies that explore the direct and indirect effects of climate warming and invasive species on the post-fire regeneration dynamics of singleleaf pinyon pine (*Pinus monophylla*). Experimental evidence indicates that big sagebrush (*Artemisia tridentata*) microsites allow pinyon to overcome a population bottleneck at establishment and are thus crucial for recruitment in areas without tree cover. A lack of consistent differences in interaction outcomes across broad climatic gradients suggests that nurse shrub facilitation of pinyon pine may be relatively insensitive to climate change. However, other research suggests that climate warming and annual grass invasions are likely to reduce the post-fire availability of sagebrush nurse shrubs in some portions of the landscape. In warmer and drier sites with depauperate perennial grasses, fire can initiate invasive grass/fire cycles and reduce shrub cover, an outcome that will become more widespread as suitable habitat for invasive grasses expands. Sagebrush seed availability is constrained after large fires especially where pre-fire tree cover was high, and drought after fire directly limits sagebrush seedling establishment. These results suggest that the effects of climate change on nurse shrub availability will vary over environmental gradients and have indirect impacts on pinyon pine recruitment, contributing to the growing body of evidence that ecologically-important species interactions should be incorporated into projections of vegetation responses to climate change.

Modelling vegetation understory cover using LiDAR metrics for habitat characterization

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Abstract: The capacity of LiDAR to capture the three-dimensional forest structure has conferred large advantages to forest managers, conservationists and researchers in their attempts to manage the forest efficiently and sustainably. In this paper we examine LiDAR metrics and analysis approaches to generate effective predictions of understory vegetation structure in support of wildlife habitat characterization. We examined four separate LiDAR metrics that attempt to measure understory structure directly but use different methods for controlling for sampling density. We used separate mixed effects models with each of the four LiDAR metrics along with covariates to predict ground-based measures of understory vegetation density. We compared this approach to machine learning using Random Forests. We found that all four LiDAR metrics of understory structure produced good predictions of ground-based measures with conditional R-squared values of >80% and symmetric mean absolute error of 0.152 to 0.159 based on k-folds cross validation. The lowest error and highest R-square values were associated with the fractional cover LiDAR metric, which is calculated as the number of LiDAR vegetation returns for an understory vertical stratum divided by the sum of understory and ground returns. In contrast, the selected random forest model had 60 variables, an R-squared value of 74.4% and a symmetric mean absolute error rate of 0.129 based on k-folds cross validation. Based on highest variance explained, best error characteristics, and ease of interpretation and application, we recommend using the mixed effects model with fractional cover to generate spatial estimates of understory cover. Nonetheless, mixed effects models with all four LiDAR metrics and random forest produced good predictions that would be suitable for many ecological and forest planning applications. With error rates of around 15%, these spatial predictions will introduce some uncertainty into predictions of wildlife habitat and fire behavior, which should be factored into decision making.

What depth of capping treatment supports optimal tree growth in Athabasca Oil Sands overburden reclamation?

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Abstract: Oil extraction in the Athabasca Oil Sands has led to the removal of over 760 km^2 of boreal forest. Successful reclamation of these areas requires a return to an equivalent capacity forest. Placement of surficial soil materials (capping treatments) aims to create a good rooting media for planted trees, and plays a crucial role in the success of reclamation efforts. Using varying depths and composition ratios of capping treatments on reclaimed sites in the Athabasca Oil Sands, I sought to assess the effects of capping treatment on reclamation success. I compared the growth of planted trembling aspen (*Populus tremuloides*) and white spruce (*Picea glauca*) over 19 years, and at 9 and 13 years post-planting. At 19 years, I was able to observe a trend towards higher growth in the thick capping treatment (100 cm), but only for the fast-growing, early-successional aspen. The slower-growing, mid-successional spruce did not display any difference among the treatments at the time of last sampling. New reclamation standards for an even thicker capping treatment (150 cm) did not show improved growth, as compared to the 100 cm depth, in either species at 9 years. I conclude

that investing in the thick capping treatment (100 cm) is justifiable at sites where aspen are planted, but not where white spruce are planted; further investment in the thickest capping treatment (150 cm) is unnecessary.

Tracking ecosystem response to repeat burns in boreal forests with satellite-derived measures of fire intensity

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Abstract: Wildfire activity in Alaskan boreal forests has been increasing in extent and frequency over the past two decades, with critical consequences for future fire and resource management. Fire is a dominant driver of numerous interrelated aspects of the boreal environment, including permafrost dynamics, carbon sequestration, wildlife habitat availability, and the rate and nature of vegetation recovery. To investigate how patterns of burn intensity and reburn frequency interval act upon and are mediated by landscape vegetation composition across Alaska, we evaluated changes in satellite-observed fire radiative power (FRP), which is a quantitative measure of fire intensity proportional to the amount of biomass consumed. We combined remote sensing data and derived products in Google Earth Engine, a cloud-computing platform that enables the rapid integration and processing of vast amounts of geospatial data. We extracted 1 km resolution Moderate Resolution Imaging Spectroradiometer (MODIS) pixels in Alaska from 2002 to 2016 for which the detected FRP value indicated the presence of fire at the time of satellite overpass. We calculated the constituent proportions of 30 m 2001 Landfire Existing Vegetation Type landcover data within each pixel extent to link fire parameters to vegetation fuel classes. We additionally associated information about the dates and characteristics of prior burns from the Alaska Interagency Coordination Center's Alaska Fire History Database, which contains mapped fire perimeters and ancillary data from 1940 to present. Analysis of the resulting compiled datasets indicates that key boreal forest classes display distinctive FRP responses to the timing and frequency of repeat burns.

Bottom-up control of C emissions from boreal wildfires

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Abstract: The boreal forest biome encompasses ~30% of the global forested area and stores approximately one third of terrestrial C stocks. Climate warming and drying in this globally important biome has led to an increase in fire extent, frequency, and severity. This changing fire regime could strongly alter the structure and function of boreal ecosystems, shifting them across a C cycle threshold and causing a positive feedback to climate warming. Recently, substantial progress has been made in understanding the characteristics of forests, landscapes, and fires that lead to large C emissions. However, we still lack a comprehensive understanding of the network of interactions among the dominant drivers of C emissions and the generalizability of these interactions among different ecoregions of the boreal forest. In this study, we synthesized data on pre-fire C pools, C emissions from fire, and the potential drivers of these emissions from over 400 sites in six ecoregions of North America's boreal forests after unprecedentedly large fires. We found that southern boreal ecoregions stored proportionally more C aboveground than belowground, exhibited higher rates of C accumulation over time, and had lower C emissions compared to northern boreal ecoregions. We used structural equation modelling to assess the network of interactions among drivers of emissions. We found that stand age and landscape gradients in moisture affected the presence of black spruce and pre-fire above- and below-ground C pools, which in turn drove C emissions. In all ecoregions, C emissions were not impacted by fire weather indices and were primarily limited by fuel, but the relative influence of aboveground versus belowground fuels was ecoregion specific. Results from this study are crucial for predicting ecoregion specific estimates of C pools vulnerable to combustion and modeling C emissions as the intensification of disturbance from boreal wildfires increases.

Incorporating best available science information into the 4FRI proposal and initial planning efforts: a stakeholder's perspective

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Abstract: The Four Forest Restoration Initiative 2010 proposal was developed based on a foundation of ecological restoration science, combined with more than two decades of collaborative work across the Mogollon Rim in northern and eastern Arizona. The use of best available science information (BASI) by an agency and multi-stakeholder collaborative effort incorporates ecological science with the collaborative stakeholder's social, economic, and political values. The ecological science supporting 4FRI includes multiple lines of evidence including forest reconstruction using dendroecological methods, historic inventory plot remeasurement, and use of historic documents and photography. The available science improved multi-stakeholder understanding of northern Arizona's current forest conditions, and the ecological departure from historic conditions that has led to a higher risk of high severity wildfire. The science informed a collaborative prioritization effort (small-diameter wood utilization study) that had high support from a diverse stakeholder group. This effort set scope and desired conditions included in the 2010 CFLRP proposal. Following CFLRP selection, the 4FRI collaborative and forest service team continued to use the best available ecological science to inform the initial planning process that covered approximately 1 million acres in the western half of the 4FRI landscape. Stakeholder participants contributed to this with additional social and ecological values, also providing technical capacity for additional spatial analysis layers. Additionally, a stakeholder-developed monitoring plan was included in its entirety into the EIS. Stakeholder values were well-incorporated by the Forest Service into the first EIS, however, lessons-learned included a reluctance of Forest Service to include stakeholder-developed data or analysis layers due to security or data validation reasons. Additionally, the collaborative group evolved to have less stakeholders with technical capacity, which further isolated Forest Service analyses. Future work should include increased co-production of efforts, and continued opportunities to share data and analysis information.

Balancing economic and ecological priorities in forest restoration

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Abstract: The broad mix of socioeconomic and ecological goals of federal forest restoration programs creates a complex prioritization problem for managers. For instance, goals to reduce ecological departure in dry forests may or may not contribute to reducing wildfire risk to communities or contribute economic benefits to timber-dependent communities. Although budgets and policy documents call for specific priorities to different restoration goals, decision support tools that could support this implementation are largely ad hoc, and lack key features to ensure that projects are being located in areas to maximize restoration benefits while meeting multiple management goals and operational feasibility. Restoration programs in other ecosystems face similar challenges, and the problem of prioritizing activities and analyzing tradeoffs has been explored using spatial optimization and production possibility frontiers (PPF). These tools can reveal where restoration conflicts and opportunities exist on heterogeneous landscapes, and how the joint spatial distributions of both stressors and ecosystem services leads to tradeoffs and opportunity cost of specific restoration choices. PPF analyses can also help stakeholders grasp how economic principles can be leveraged for resource management as part of restoration programs. For instance, spatially correlated restoration opportunities, i.e., co-located stressors and ecosystems services, create opportunities to achieve multiple restoration goals. In this talk we demonstrate a spatial optimization framework to analyze tradeoffs among economic and ecological restoration priorities on the 4FRI restoration project. The work advances the use of decision support tools to prioritize restoration activities and understand pathways to achieve efficient long-term restoration goals.

Using interdisciplinary research across scales to manage for healthy species and forests

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Abstract: Forests and tree species are under increasingly complex threats to their long-term viability. Understanding both the ecological and social complexity inherent in these wicked problems requires research across disciplines and scales to integrate knowledge and find appropriate management strategies. Our cross-scale, interdisciplinary approach to understand how species respond to these complex threats will allow for more informed land management. Climate change and an invasive tree disease, white pine blister rust (caused by the fungal pathogen *Cronartium ribicola*), threaten the viability of our model species, *Pinus strobiformis*. Our research goal is to provide a cross-scale view of the interactions in this system and ultimately, provide management recommendations based on the best available science. For example, understanding how adaptive traits (growth, phenology, disease resistance) vary by population source location and environmental stressors such as drought will yield insight into management prioritization. Similarly, understanding how disease influences plant physiology or understanding the spatial pattern of disease resistance in the landscape may also lead to improved management strategies, as managers select trees to remove or retain. We aim to provide managers with the tools they need to make decisions about species management while incorporating cutting-edge research. This talk will focus on synthesizing research results to date in the context of applications for management.

Genetic erosion and management options for conservation of Picea chihuahuana populations at Durango-Chihuahua

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Abstract: The need of genetic diversity for evolution and the relationship between heterozygosity and population fitness are important reasons for conserving genetic diversity. Loss of genetic diversity can be harmful to the short-term viability of individuals and populations, and to the evolutionary potential of populations and species. The rare tree species Chihuahua spruce (*Picea chihuahuana* Martínez) is endemic to Mexico. About 42,600 individuals are distributed in about forty isolated relict populations in the Sierra Madre Occidental. The populations are fragmented and can be classified into three geographical clusters, each group separated by a distance of about 300 km. The total accumulated area covered by *P. chihuahuana* populations is less than 300 ha. Several factors threaten P. chihuahuana, including the low reproductive capacity resulting from high levels of self-fertilization and mating between closely related individuals. The predicted reduction and eventual disappearance of a suitable habitat *for P. chihuahuana* due to climatic change imposes a further extinction risk. The principal aim of this study was therefore to estimate genetic erosion populations of *P. chihuahuana* by comparing genetic diversity. The results led us to make management proposals for conservation of *P. chihuahuana*. If genetic diversity reflects diversity in the whole genome, genetic erosion was not found, except for very small populations. Continuous monitoring in situ of the size and genetic diversity of populations is important. Several in situ and ex situ conservation actions could be, such as i) conservation by limiting livestock and controlling forest fires, ii) identifying potentially suitable locations and, then, establishing new populations with minimum viable populations size, iii) establish provenance trials and traditional progeny tests as genetic archives, iii) assisted gene flow to facilitate local adaptation to climate, and iv) storage of seeds in gene banks.

Has climate warming shifted the pendulum from expansion to contraction in Great Basin pinyon-juniper woodland?

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Abstract: Pinyon-juniper woodlands of the Great Basin are typically managed from the perspective that they have increased in extent and density since the late 1800s, such that these native tree species are considered invasive and restoration consists of large-scale tree removals. This perspective stands in sharp contrast with other regions that have experienced pronounced diebacks of pinyon pine, associated with hot droughts, insect outbreaks, and anthropogenic climate change. We report on recent trends in woodland dynamics

for the Nevada Great Basin, integrating information from a remote sensing analysis using the Landsat archive (1984-2016) with a resampling study (2005-2015) of 98 field plots across 11 mountain ranges. The remote sensing study found that recent drought-related die-off, wildfire, and management treatments have balanced expansion, resulting in little net regional change in tree cover. Across the 34,000 km^2 study area, 12% showed canopy cover decline, 13% showed canopy cover increase, and 75% showed no significant change. Areas experiencing canopy cover loss were more common at lower elevations and on sites with greater climatic water deficits. The field study found substantial tree mortality, an order of magnitude greater than reported background levels, with stem mortality and canopy dieback more likely in hotter, drier sites and in localized patches of higher tree density. Thus, the recent landscape change trajectory suggests a shift from overall reforestation and expansion, to an ecoclimatically driven pattern of contraction from unfavorable sites, occurring simultaneously with new tree colonization at higher elevations and on wetter slopes. Also, species-specific differences in drought-related mortality and tree regeneration following canopy dieback suggest that future woodlands may become more dominated by juniper at the expense of pinyon, with important implications for biodiversity and cultural resources. The dominant management paradigm for Great Basin pinyon-juniper woodlands needs to become more forward-thinking in anticipation of future climate-driven landscape change.

Elucidating the roles of the genome, epigenome, and environment in trait distributions on a complex landscape

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Abstract: Understanding proximate causes of plant phenotypes involves understanding the interactions among the genome, epigenome, and environment in a particular time and place. Complex interactions across time and space in turn determine the ultimate, evolutionary cause of particular relationships between traits and the underlying genomes, epigenomes, and environments. Our group is dissecting the causes of phenotypic variation in southwestern white pine (*Pinus strobiformis*), across a complex landscape, along with genetic, epigenetic, and modeling techniques to better understand the emergent properties of the processes of selection and gene flow operating at variable scales. We are using field environmental manipulations, multiple common gardens with environmental manipulations, greenhouse and chamber experiments, and pathogen exposure to gain insight into the distribution of trait variation and its disparate sources. For now, we have examined effects of source population (latitude, elevation, and rain shadow effects), maternal tree, artificial warming during cone development, common garden variation, water reduction, temperature in growth chambers, and pathogen inoculation on morphological, physiological, phenological, and epigenomic traits. First, we will focus on details of a cone warming treatment imposed in the tree canopy during seed development and how it relates to source environment variation for the species. Second, we will explore the phenotypic effects, and lack thereof, of seed warming on a spectrum of plant traits. And third, we will summarize the relative effect sizes of source population, maternal tree, artificial warming during cone development, common garden variation, water reduction, temperature in growth chambers, and pathogen inoculation on tree traits. Later in the project we will be positioned to dissect the potential genetic sources of variation through genome wide association studies. Then we will use simulation modeling to connect information on the control of traits by the genome, epigenome, and environment to predict future species distributions under environmental change.

It matters what you measure: Identifying carbohydrate storage pools available for remobilization in aspen

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Abstract: Nonstructural carbohydrate (NSC) storage is an important source of carbon which trees must often rely upon during periods of low carbon gain or high demand, such as during or following a disturbance. Unfortunately, remobilization remains poorly understood in trees. In particular, it is often not known 1) which NSC pools (bark versus sapwood) supply the majority of remobilized carbon and 2) to what extent these NSC pools can be depleted—and therefore which portion of NSC pools constitute available carbon. It also is unclear whether NSC mass or concentration is a better measure of the size of the storage pool, as it relates to a tree's ability to recover following disturbance. A better understanding of these issues is needed to accurately quantify NSC storage and determine

when tree growth, survival, or recovery is limited by carbon availability. To address these questions, we used light deprivation to starve root segments (1-3.5 cm diameter) collected from a mature aspen stand that were capable of resprouting. Mature root segments were harvested after all sprouts had ceased growth and died. We found that initial starch mass, not concentration or total NSC, was the best predictor of subsequent sprout growth. In total, four times more NSC mass was remobilized from the root bark than the sapwood, indicating the importance of the bark in carbon storage, a role that is often overlooked. After resprouting, almost all starch had been remobilized from both bark and sapwood (<0.6% w/w remaining). In contrast, a large portion of sugars appears unavailable for remobilization, particularly in the bark (12% w/w remaining). These findings suggest that to determine whether plant processes like resprouting are limited by storage, we should consider differences in storage pool size, not just concentration, and carefully determine which compounds are actually components of the storage pool.

Public attitudes towards longleaf pine ecosystem restoration using prescribed fire

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Abstract: Historically, fire has been an important element of native longleaf pine (*Pinus palustris*) forests in the southern United States. This research explores public interest in restoration of this threatened ecosystem and forest landowners' failure to apply prescribed fire, a key restoration practice. We report on a three-phase project across eight states with the following objectives: (1) to assess the amount of longleaf planting on private lands motivated by disaster mitigation decisions; (2) to identify if prescribed fire has kept pace with increased demand for planting longleaf following disaster events, and (3) to identify landowners' and public interest in ecological restoration using science-based prescriptions, and how managers may use this information to increase prescribed burning. To address these objectives, we collected data from key informant interviews and a public telephone survey. Results demonstrated several important predictors of social barriers to prescribed burning, types of landowners most likely to burn in longleaf ecosystems, an identification of an economic threshold for designing cost-share policy options, and "best marketing practices" (BMPs) for recruiting and retaining landowners to educational efforts. Comparisons were made between rural and urban human populations. We conclude with a discussion about ways to increase dialogue among stakeholders to help them understand the risks and benefits of appropriate ecosystem management using fire. Findings can be applied to programs that increase prescribed burning in general and to increasing the range of native forest, a positive climate change adaptation.

Seed depredation inhibits longleaf pine seedling establishment at mast seed availability

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Abstract: Midstory hardwoods are traditionally removed in longleaf pine regeneration treatments. However, recent evidence demonstrating midstory hardwood facilitation on longleaf pine seedling survival has brought this practice into question on xeric sites. Currently, it is unknown whether midstory hardwoods facilitate longleaf pine seedling establishment. Two factors influencing longleaf pine seedling establishment are seed contact with mineral soil and seed depredation. Midstory hardwoods may have contrasting effects on germination because hardwood litter could impede mineral soil access and conceal seeds from predators and improve micro-environmental conditions. In this study, we tracked longleaf pine seed depredation and germination in artificially seeded plots (11 seeds/1m^2) in a factorial design fully crossing hardwood retention or removal with vertebrate seed predator access or exclusion in the Sandhills Ecoregion of North Carolina USA. Seed depredation averaged 78% across treatments and was greatest in unexcluded plots. Seed depredation was not affected by hardwood retention. Longleaf pine averaged 3.6 germinants /4 m^2 across treatments, and was six times more abundant where vertebrates had been excluded. Hardwood removal had a strong positive effect on seedling germination, likely due to the removal of litter, but only when vertebrates were excluded. Our results indicated midstory hardwoods are not facilitating longleaf pine seedling establishment. Nevertheless, our results indicated that hardwood removal may not increase longleaf pine seedling establishment, as seed depredation diminished the effectiveness of hardwood removal under mast seed availability. Collectively, these results indicate that seed predators may exert a greater influence on longleaf pine seedling establishment than previously recognized.

Chasing tree die off: Improving our ability to forecast regional tree mortality in response to extreme drought

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Abstract: Warmer temperatures under drought conditions are causing extensive tree die off events globally, particularly in dryland systems and at the margins of species distributions. Pinyon-juniper woodlands have recently experienced particularly severe and spatially extensive episodes of drought and beetle-induced mortality across the western US. Several post-hoc climate metrics have been developed to quantify mortality in these systems, but in order improve our ability to forecast near term regional die-off events, independent field tests of these metrics are warranted. We tested the predictive ability of three climate-derived metrics in explaining adult and juvenile tree mortality in pinyon-juniper woodlands across a broad geographic gradient of drought severity in 2018: Forest Drought Severity Index (FDSI), Standardized Potential Evapotranspiration Index (SPEI), and threshold values of warm season vapor pressure deficit (VPD) and annual precipitation. We also tested for mediating impacts of canopy cover on juvenile survival using heat balance equations. FDSI and SPEI were better predictors of above average tree mortality (relative to previously reported rates of background mortality, or >3% of all trees within a stand) than absolute values of VPD or precipitation, suggesting the importance of local adaptation to climatic stressors. Our results provide necessary field tests of several established metrics to predict mortality and improve our ability to forecast regional tree die-off in response to extreme drought. Juvenile survival may be a bottleneck to woodland regeneration, particularly at water-stressed sites. Improving our predictive ability to forecast tree die-off is necessary to plan for and implement adaptive management actions that sustain ecosystem services and increase resilience to future drought events.

Restoring Colorado Front Range forests: Knowledge co-production and tools for shared stewardship

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Abstract: In Colorado, scientists, land managers, and stakeholders worked together to co-produce a science informed process to apply site specific ecological restoration principles for Front Range ponderosa pine and dry mixed conifer forests. In developing the restoration framework published in RMRS-GTR-373, we applied forest science in multiple use landscapes to advance desired conditions, restoration principles, and monitoring metrics rooted in complex working landscapes. Taking ecological theory to practice, a new step-by-step restoration process helps integrate science-based approaches and simplify complex management decisions. New decision support tools have been developed to better connect forest and fire management actions on small hillslopes with desired outcomes for increasing forest resilience across larger landscapes. These decision support tools are being implemented in collaborative place-based adaptive management frameworks to apply forward looking strategies for restoration, while balancing the need for fire risk reduction to other critical values like water supplies and infrastructure. Co-development and publication of this knowledge has been followed by a large targeted outreach campaign, and through surveys and evaluations of our outreach, we continue to improve strategies for integrating restoration science into forest and fire decision management frameworks.

Modernizing restoration: Innovation and efficiencies in the implementation and adaptive management process

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Abstract: The United States Forest Service (USFS) has identified the modernization of forest products delivery systems as a strategic priority moving forward. In conjunction, much of the USFS restoration in dry forest of the western United States is being planned and implemented through collaborative efforts involving a wide array of stakeholders. As collaborative forest restoration efforts are being implemented, the USFS and stakeholders are tasked with developing and applying innovative, landscape scale monitoring and adaptive management plans that assess effectiveness of restoration treatments for a variety of forest structural and spatial conditions.

To facilitate adoption of new business practices in preparation, implementation, and adaptive management of restoration thinning projects, The Nature Conservancy in Arizona has entered into a Stewardship Agreement with the USFS. The objective of this partnership is to co-develop and test various innovative processes, apply technology and remotely sensed datasets, and develop a standard set of business practices that will accelerate the pace and scale of restoration in the Four Forest Restoration Initiative (4FRI). These efforts and initial results and lessons learned will be presented to better understand how the USFS and stakeholders can accelerate restoration efforts in the face of unnaturally severe wildfires, while obtaining desired forest conditions that match 4FRI collaboratively derived restoration plans.

Limited recovery of ground beetle communities in partial and clearcut in boreal mixedwood stands 15 years post-harvest

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Abstract: Developing sustainable approaches to forest management that maintains species over the long-term will be a cornerstone in our responses to global declines in biodiversity. Here we evaluate the long-term recovery of ground beetle communities following a diverse range of partial and clearcutting strategies aimed at emulating natural disturbance dynamics in eastern boreal mixedwood forests at the SAFE (Sylviculture et aménagement forestier écosystémique) experiment in northwestern Québec. We have analyzed catch rates of ground beetles (>30,000 individuals and >60 species) collected in pitfall traps 5, 10, and 15 years post-harvest from partial cut, clearcut, and uncut stands from three forest ecosystems representing typical post-fire succession for this region. Using both compositional and individual species responses, we observed clear reductions in forest carabids associated with reduced basal area across ecosystems. Moreover, we see little evidence of beetle recovery within either partial cut or clearcut stands over the 15 years sampled. However, we also have observed overall increases in ground beetles over the 15-year sampling, which correlate with longer-term regional increases in temperature. This trend is in marked contrast to recent reported declines in insect abundance elsewhere. The complex interactions between retention and ecosystem type over 15 years also suggest that long-term changes in biodiversity will likely play out differently across larger regions.

Investigating the mechanisms by which pre-commercial thinning increases black spruce growth in different climates and on different soil types

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Abstract: In Québec (Canada), pre-commercial thinning (PCT) is a common silvicultural practice applied to young black spruce (*Picea mariana*) stands. PCT consists of removing competing vegetation and smaller black spruce stems in order to reduce rotation intervals. Our objectives were to provide insights on the mechanisms driving forest productivity following PCT in different climates (warm/dry vs. cool/wet) and on different soils (clay vs. till), totaling three distinct site types. Our study measured tree size, indices of soil N fertility and moisture availability, canopy openness, and foliar characteristics in 24 plots. In all site types, PCT decreased total basal area but increased QMD as well mean DBH of dominant trees. Across all plots, soil N mineralization rates measured in 2016 were positively related to foliar N concentrations of one-year-old needles collected in 2017. However, PCT either had no effect, or decreased, soil N mineralization rates within various site types in both sampling years. Annual precipitation, drainage class, potential evapotranspiration, and climate moisture index all indicated that Abitibi till sites were more prone to summer moisture deficits. Accordingly, PCT increased forest floor moisture in Abitibi till sites only. Average canopy openness was higher on PCT than in control treatments at each site type. The gradient in canopy openness was greatest on Abitibi clay sites (12-37%) and correlated negatively with DBH values. We conclude that PCT increases the mean diameter of residual black spruce trees, not from higher soil N fertility, but rather from lower competition for resources. On dryer sites, PCT seems to benefit tree growth by increasing soil moisture availability. Differences in the mechanisms by which black spruce respond to PCT across different site types will be vital in preparing forest applications for future global environmental change.

Mechanical site preparation influences resource use efficiencies of planted black spruce independently from climate on boreal sites of northeastern Canada

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Abstract: In boreal Québec (Canada), mechanical site preparation is widely used to promote survival and growth of black spruce (*Picea mariana*), by reducing competition from ericaceous shrubs that ostensibly reduce soil N fertility. However, silviculture is expected to interact with climate to influence treatment effects and thus productivity of black spruce, which occupies a large gradient of climate regimes in northern Québec. To better understand the mechanisms controlling these interactions, we measured needle-surface gas exchange, foliar nutrition, forest floor N dynamics, and black spruce growth in scarified and non-scarified plots 18 years after treatment. Replicated plots (n=5) were located in a relatively warm, dry (Abitibi) and a relatively cool, wet (Côte Nord) boreal climate. In both climates, average tree height in scarified plots was twice that of control plots. The average relative growth rate over the last two years was 36% higher in scarified plots than control plots. Black spruce trees planted in scarified plots showed significantly lower photosynthetic nutrient-use efficiency and significantly higher water-use efficiency compared to control plots. This is in keeping with higher soil N fertility expected from the removal of ericaceous shrubs, and higher soil moisture demand expected from larger trees. It is also consistent with our finding of higher soil N mineralization rates and lower soil moisture content on scarified plots. We conclude that after 18 years, scarification has similar effects on black spruce growth in both climates, but prioritizes efficient use of either N or water depending on the limiting resource. Given that scarification decreases nutrient stress but increases moisture stress, we predict that scarification will eventually be more beneficial in cool, wet climates, where ericaceous shrubs are more abundant, but moisture availability is greater. Identifying these types of climate-by-silviculture interactions will contribute to management strategies that alleviate stresses and mitigate the impacts of climate change.

Plant strategies for nutrient acquisition – an unconsidered dimension of forest "mesophication"

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Abstract: Research on forest mesophication has largely focused on fire exclusion, shade, and moisture as drivers of forest change. As a result, "mesophytes" are categorized as tree species with functional traits associated with fire intolerance, shade tolerance, and high water use. A critical but missing piece is the traits associated with nutrient acquisition, which facilitate nutrient cycling and a self-reinforcing feedback in forests undergoing mesophication. Many mesophytic tree species (e.g., *Acer* and *Liriodendron tulipifera*) associate with arbuscular mycorrhizal fungi, which improve the ability of plant roots to scavenge existing mineral nitrogen in soils. The availability of mineral nitrogen is promoted by the leaf litter of arbuscular mycorrhizal trees, which tends to be nutrient-rich and decompose rapidly, thereby creating a feedback that favors mesophication. In contrast, many fire-adapted tree species (e.g., *Quercus* and *Carya*) associate with ectomycorrhizal fungi that mine organic nitrogen directly from organic matter, thereby competing with, and suppressing, decomposers. The mineralization of nitrogen is further reduced because these tree species tend to produce litter that is nutrient-poor, thereby creating a feedback that excludes mesophytes. Thus, we argue for a broader view of functional traits associated with mesophication in order to understand its core ecological drivers. For example, the low flammability and high moisture characteristic of mesophytic leaf litter co-occurs with traits that promote rapid nutrient cycling between plants and soils. To consider land use change and mesophication across the Eastern forests, we present a nutrient-based framework including how fire exclusion, nitrogen deposition, and disturbance-induced nitrogen fixation can increase nitrogen stocks and facilitate forest mesophication.

Quantifying climate change impacts on vegetation-mountain pine beetle interactions using a dynamic global vegetation model

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Abstract: Insect outbreaks have been key drivers of tree mortality and can lead to substantial changes in regional and global carbon cycles and climate feedbacks. The current insect-induced tree mortality models do not have a sufficiently sophisticated representation of vegetation-insect interactions**.** In this talk, we describe our efforts to construct a mechanistic mountain pine beetle model in the Functionally Assembled Terrestrial Ecosystem Simulator (FATES) model that is used to represent ecosystem demography in the U.S. Departments of Energy's Earth system models for the mountain pine beetle. We used a computationally efficient Insect Mortality and Phenology (IMAP) model to capture individual-level variability and we assessed the impact of future warming and droughts on the risks of insect outbreaks. In our model, mountain pine beetle populations emerge in one-hectare habitat patches and attack trees locally within the patch. All patches are assumed to have endemic populations of beetles with demographics governed by weather fluctuations. At endemic levels, local mountain pine beetle populations are assumed to persist in weakened trees. Once beetle populations exceed the endemic threshold, they attack vigorous host trees and their dynamics are governed by host availability in addition to weather. In the FATES-IMAP model, the rate at which mountain pine beetles attack host trees depends on the incipient-epidemic threshold, which is the minimum density of beetles on a per hectare basis that is required to overcome a single well-defended host tree. We used the model to assess the impact of warming, CO_2 fertilization, droughts, and their interactions on mountain pine beetle outbreaks. Our modeling results show that future warming is likely to increase the intensity of insect outbreaks during droughts, while CO_2 fertilization can partially mitigate the impact of warming.

Landscape impacts of fire and climate change in the Southwest

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Abstract: Complex interactions among climate, vegetation, and fire are expected to transform landscapes over the coming century, intensifying and creating new management challenges. The SW FireCLIME project is a science-management partnership focused on landscape impacts of fire and climate change in the Southwest. Goals of the project have been to synthesize our current scientific understanding of climate, fire, and vegetation dynamics, critically evaluate how fire regimes and fuels may shift across Southwest landscapes as climate changes, and assess the implications of changing regimes for management programs. Outcomes to date include a synthesis of climate-fire-vegetation interactions in the Southwest and a modeling assessment of management impacts on desired conditions in the Jemez Mountains and the Kaibab Plateau. In addition, a new Vulnerability Assessment tool has been built, which is a flexible, powerful tool that managers can use to identify at-risk resources and guide adaptive management. In this presentation, we will give an overview of the SW FireCLIME project, using ponderosa pine and mixed-conifer ecosystems of the Southwest as an example throughout.

Evidence and impacts of negative fire-vegetation feedbacks in the North American boreal forest biome

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Abstract: Annual area burned in North American boreal forest ecosystems is projected to increase over the course of the current century in direct response to climate change. These projections, however, generally do not account for post-fire vegetation changes, which can modify landscape flammability and thus change the likelihood of future burning through fire-vegetation feedbacks. Here,

we investigate the existence and impact of fire-vegetation feedbacks in North American boreal forest ecosystems using fire history, MODIS tree cover (MOD44B), and climate datasets. We explicitly quantified the relative importance of vegetation as a control of annual fire activity, the magnitude and duration of post-fire vegetation change, and the presence and magnitude of fire-vegetation feedbacks. Our study domain was the entirety of the North American boreal forest biome (4.24×10^6 km^2) from 1950-2016. We found strong evidence for the existence of negative fire-vegetation feedbacks across North American boreal forest ecosystems. When comparing areas that burned only once in the past 36 years (1981-2016) to areas that burned multiple times, we found the distributions of single- and re-burned areas were significantly different ($P<0.05$). Furthermore, we estimate the magnitude of this negative feedback accounts for a decrease in area burned of ≈ 27,000-36,000 km^2 ($2.7\text{-}3.6\times10^6$ ha, 4-5% of total area burned). Annual-scale burning also caused tree-cover loss of up to 40%, with this reduction in tree cover relative to pre-fire levels lasting for decades (35-55 yr). Together, these findings underscore how negative fire-vegetation feedbacks have a significant and detectable influence in altering forest cover and future area burned. Such fire-driven decreases in landscape flammability will likely be influential in mediating the impacts of 21st-century climate change on fire regimes, at least until fire-conducive climate conditions exceed ranges experienced over the past several decades.