Research Work Unit Description **Ref: FSM 4070**	**1. Number** RMRS - 4157	**2. Station** Rocky Mountain Research Station
	3. Unit Location Flagstaff and Tucson AZ, Fort Collins and Woodland Park CO, Moscow ID, Missoula MT, and Logan UT	

4. Research Work Unit Title/Program

Forest and Woodland Ecosystems (FWE) Science Program

5. Program Manager (Name and address)

Alison Hill, Research Program Manager, Southwest Forest Science Complex,

2500 South Pine Knoll Drive, Flagstaff, AZ 86001-6381.

Signatures	Title	Date
Recommended:	Program Manager	4/6/2021
	Assistant to Staff Director	
Torah Patel-Weynand	Staff Director	6/01/21
Approved:	Station Director	6/29/2021
Concurred: ALEXANDER FRIEND Digitally signed by ALEXANDER FRIEND Date: 2021.07.01 19:22:38 -04'00'	Deputy Chief for Research	

6. Area of Research Applicability

Local at each location, regional, multiregional, national, and international.

Much of FWE's research is physically located in the western U.S. FWE scientists respond to requests from land managers and the public for information and scientific insight with locally and regionally relevant research on the ecology, sustainability, and rapidly evolving disturbance regimes of western ecosystems and on issues concerning several threatened and endangered indigenous species. Additionally, FWE's research and many of its scientists are recognized nationally and internationally. FWE's work on the effects of fire on above- and below- ground biota; soil biodiversity and health; the consequences of climate variability on ecosystem health and disturbance regimes; plant genetic diversity; the influence of climate and disturbance on water available to and use by forests; forest

insects and pathogens; and relating ecosystem carbon dynamics to forest health and productivity are all of global significance. FWE also develops and uses models that facilitate the exchange of descriptive and predictive information between FWE scientists, land managers, and other academic and non-academic partners and to extend its research from one locality to another, from one ecosystem to a similar ecosystem on another continent, and to scale-up from the ecosystem level to the landscape or continental scale.

7. Estimated Duration

10 years, April 30, 2021 to April 30, 2031.

8. Mission

The Forest and Woodland Ecosystems Research Program (FWE) of the Rocky Mountain Research Station provides the best available science to manage, sustain, and enhance forest and woodland ecosystems in the interior mountain West.

9. Justification and Problem Selection

The forests and woodlands of the interior mountain West comprise more than 50% of the National Forest System lands of the United States. These lands provide the American people with clean water, clean air, lumber and fiber, sense-of-place, and recreation opportunities, as well as providing wildlife with habitat and forage. While the work of FWE focuses on the Northern, Rocky Mountain, Intermountain, and Southwest Regions of the Forest Service, our research and its impacts, products, and applications extend to the rest of the U.S., the bordering lands in northern Mexico and southern Canada, and other parts of the world.

Forest and woodland ecosystems of the western U.S. are extremely variable, ranging from open, dry oak and piñon-juniper woodlands at low elevations in the south to dense, wet Douglas-fir and mixed-species forests in the north or at high elevations in other parts of the region. The structure and composition of these forests vary over a wide range of spatial and temporal scales from tree-fall gaps, to stands, watersheds, landscapes, and entire biomes, and from seasons, to years, decades, centuries and millennia. The condition of these ecosystems at any of these scales is dependent on climate, topography, and disturbance history, including fire, parasites and pathogens, insect epidemics, invasive species, extreme weather events, past and current land use and timber harvesting. The severity, extent, and frequency of disturbance—the “disturbance regime”—in tandem with ecosystem condition, processes and characteristics, govern impacts and are critical to ecosystem health, resilience, and stability.

The resources and ecological services provided by western U.S. forests and woodlands have always been immensely valuable to the American people. But now these forests face unprecedented risks due to an intersection of forest densities that often exceed the historical range of variability, changing climate, changing disturbance regimes, and

increasing demands for extractive and non-extractive ecosystem services. Many well intended actions have resulted in unintended consequences. For example, fire suppression and timber harvesting (or lack of harvesting) in many parts of the western U.S. have led to landscapes that are now crowded with small trees and heavy fuel loads. This, in turn, has led to significantly altered ecological processes and disturbance regimes and ultimately to increased tree mortality. In addition, the introduction of exotic plants, insects, and pathogens have led to broad-scale changes in many ecological characteristics, including increased surface fuels and tree mortality. These have further exacerbated the severity of fires. The combination of altered fire regimes and a warming climate, which results in earlier snow melt and longer, more severe fire seasons, has led to increased native insect and pathogen eruptions and extensive tree mortality in some ecosystems. Disturbance regimes in the western U.S. are changing rapidly and will continue to pose an increased risk to ecological sustainability and economic activities.

The entwined combination of forest conditions that do not reflect the historical range of variability, changing disturbance regimes, changing climate, and increasing human population with concomitant increasing development complicates the sustainable management of western U.S. forests and woodlands. Because the nature of specific disturbances and ecological responses can vary significantly in both the short term (days to months) and the long term (years to decades) over this broad and diverse geographical region, FWE takes a necessarily broad and diverse approach to address information needs and knowledge gaps to develop solutions to complex, multifaceted management challenges.

FWE's knowledge discovery, development, modelling, and syntheses inform management and policy decisions made by local, regional, national, and international clients and partners. Furthermore, our science, and the knowledge generated from it, informs scientific programs and studies worldwide. FWE's work is integral to and notably strengthens the following four USDA Strategic Goals FY 2018-2022:

> (1) Ensure USDA programs are delivered efficiently, effectively, and with integrity and a focus on customer service,
>
> (4) Facilitate rural prosperity and economic development,
>
> (5) Strengthen the stewardship of private lands through technology and research, and
>
> (6) Ensure productive and sustainable use of our National Forest System Lands.

Similarly, all Forest Service Strategic Plan 2015-2020 Goals are supported, with our research investment directly contributing to the strategic goals:

1) Foster resilient, adaptive ecosystems to mitigate climate change;
2) Mitigate wildfire risk;
3) Provide abundant clean water;
4) Advance knowledge; and

5) Transfer technology and applications.

FWE findings support the 2014-2017 Rocky Mountain Research Station Strategic Framework Research Priorities:

1) Disturbance Ecology,
2) Fire Sciences,
3) Human-Landscape Interactions,
4) Inventory & Monitoring,
5) Resilient Landscapes,
6) Species Endangerment, and
7) Water & Watersheds. (https://www.fs.usda.gov/rmrs/rmrs-strategic-priorities)

Finally, by researching how climate variability and related disturbances impact natural and managed ecosystems, FWE's research accords with the multi-agency US Global Chance Research Program's encouragement of "research to support decision making relevant to managing *[climate change-related]* risks".

Program personnel support the priorities of the USDA, FS, RMRS, and the US Global Chance Research Program by organizing formal and informal teams among RMRS Research Programs and by collaborating with States, universities, non-governmental organizations, other federal agencies and stakeholders to address the most relevant issues facing the National Forest System, Bureau of Land Management, National Park Service, U.S. Fish and Wildlife Service, federal policymakers, and allied State, tribal, local, non-governmental, and private land managers, policymakers, and individuals. Positive outcomes for the American people, such as clean water and clean air and/or the successful restoration and maintenance of sustainable forests and woodlands, can only be assured through the active partnering of research and management to jointly develop research questions and science-based strategies for addressing society's priorities. FWE's contribution to this shared effort falls principally within the scope of the following four Research Focus Areas to inform contemporary and future policy, planning, restoration, and land management decisions.

Focus Area 1: Discover and provide scientific knowledge of ecological and physical processes and their interactions under a changing climate.

Focus Area 2: Advance our predictive capabilities about forest and woodland dynamics in a period of increasing climate variability to promote sustainable, resilient and productive natural ecosystems.

Focus Area 3: Discover and develop knowledge of plant and soil carbon and water dynamics to changes in vegetation, disturbance regimes and management strategies.

Focus Area 4: Develop, assess, and provide scientific knowledge of vegetation treatments to restore and promote the resiliency and productivity of complex landscapes under changing environmental conditions and conflicting societal priorities.

Experimental Forests and Ranges

The Forest Service's network of long-term experimental areas, commonly referred to as Experimental Forests and Ranges (EFRs), is the largest and longest-lived ecological research network in the United States. FWE scientists serve as scientists-in-charge (SIC) of 7 of the 14 Experimental Forests and Ranges in the Rocky Mountain Research Station's territory. The sites have been established progressively since the early 1900's. This network provides an incredible wealth of records and knowledge of ecological change in natural and managed forest and grassland ecosystems across the United States. The network provides a home for long-term science and management studies in most major vegetation types of the United States.

Black Hills Experimental Forest
https://www.fs.usda.gov/rmrs/experimental-forests-and-ranges/black-hills-experimental-forest
SIC**:** Mike Battaglia

Boise Basin Experimental Forest
https://www.fs.usda.gov/rmrs/experimental-forests-and-ranges/boise-basin-experimental-forest
SIC: Justin Crotteau

Coram Experimental Forest
https://www.fs.usda.gov/rmrs/experimental-forests-and-ranges/coram-experimental-forest
SIC: Justin Crotteau

Deception Creek Experimental Forest
https://www.fs.usda.gov/rmrs/experimental-forests-and-ranges/deception-creek-experimental-forest
SIC: Terrie Jan

Fort Valley Experimental Forest
https://www.fs.usda.gov/rmrs/experimental-forests-and-ranges/fort-valley-experimental-forest
SIC: Warren K. (Keith) Moser

Manitou Experimental Forest
https://www.fs.usda.gov/rmrs/experimental-forests-and-ranges/manitou-experimental-forest
SIC: Paula Fornwalt

Priest River Experimental Forest
https://www.fs.usda.gov/rmrs/experimental-forests-and-ranges/priest-river-experimental-forest
SIC: Terrie Jain

Research Natural Areas

Research, observation, and educational uses of Research Natural Areas (RNA) are the responsibility of the Rocky Mountain Research Station. The RNA network protects some the finest examples of natural ecosystems for scientific study and education and for maintenance of biological diversity. These sites are representative of common ecosystems

in natural condition; as such they serve as baseline or reference areas. RNAs are managed to maintain the natural features for which they were established and to maintain natural processes. They are excellent areas for studying ecosystems or their component parts and for monitoring succession and other long-term ecological change. FWE employees facilitate research in RNA's in two of the four national forest regions. John Byrne is the RMRS Regional RNA Coordinator for Region 1 (105 RNAs) and Laurie Huckaby is the RMRS Regional RNA Coordinator for Region 2 (40 RNAs).

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10. Approach to Problem Solution

Discover and provide scientific knowledge of ecological and physical processes and their interactions under a changing climate (Research Focus Area 1).

Managing forests and woodlands in the face of future uncertainties requires fundamental knowledge about how they have changed and are likely to change into the future. This requires knowledge about underlying ecological and physical processes in relationship to disturbance agents, exotic species, climate variability, and management strategies. The cumulative effects of land-use history are currently intersecting with climatic changes to alter and intensify many disturbance regimes. When combined with urban expansion into wildlands, the altered or novel disturbance regimes place ecosystems, human population centers, and economic activities at risk from high-severity disturbances. RMRS and FWE have the expertise and reputation as primary generators of scientific knowledge of ecological and physical processes and how they respond to climate variability and change.

FWE conducts research to understand contemporary, historical, and potential future forest and woodland dynamics, disturbance processes, and disturbance interactions at various spatial and temporal scales. With this understanding, our goals are to provide managers with knowledge of 1) the natural regulating roles of disturbance agents and how they interact with ecological conditions and management actions, 2) how climate and management practices affect disturbance regimes, and 3) the ensuing consequences to ecosystem resilience, stability, products, and services. The research from Focus Area 1 provides managers and policy makers with the scientific foundation to enhance and sustain the productivity and resilience of forests and woodlands and to ensure that they have the capacity to adapt to changing future conditions. Work in this focus area also provides the foundation for much of the research FWE conducts in Focus Areas 2, 3, and 4.

FWE performs baseline studies, empirical field studies, and controlled laboratory experiments to investigate disturbance agents—both native and exotic—their interactions, rates of change, and their impacts on soils, plants, and ecosystem services at the levels of individual plants, vegetation communities, stands, and landscapes. Research efforts within Focus Area 1 address the following four topic areas:

1(a). Develop an improved understanding of the effects of drought, fire, and extreme weather events on forest and woodland ecosystems. FWE's research includes characterizing historical

fire regimes; determining of historical ranges of variability at multiple scales; quantifying fuels accumulation and distribution; understanding how fire alters vegetation, soils, and fuels; modeling the effects of alternative future management strategies; and modeling disturbance interactions.

1(b). Develop an improved understanding of native and invasive insect and pathogen disturbance agents. These include improving the knowledge base regarding insect and pathogen interactions with fire, climate, other environmental factors, and each other at tree, stand, and landscape scales; their ecological roles as natural regulators of forest processes; factors affecting forest and woodland resilience to them; predicting interactions with climate; and developing resilience to exotic and emergent species.

1(c). Develop an improved understanding of forest responses to varying climatic processes (e.g., temperature and precipitation regimes, extreme events): including tree population dynamics (e.g., growth, mortality, and regeneration), tree and shrub species distribution changes, physiological responses, interaction with management actions, and effects on carbon sequestration.

1(d). Develop an improved understanding of the sources of forest and woodland ecosystems' capacity to adapt. Research here overlaps considerably with other Focus Areas but focuses specifically on genetic and epigenetic (gene expression under variable conditions) bases for individual and population resilience, physiological responses to temperature and drought, and forest and woodland responses across wide geographic ranges and management systems.

Deliverables and Due Dates

FWE scientists listed over 100 products anticipated within 10 years in FA1. Selected deliverables, some of which combine several related items and others that are more specific, include the following:

2019-2023:

- Investigate the valued but poorly understood western larch/mixed-conifer forests in Montana regarding disturbance regimes, fire history, fire behavior, and stand development under changing climate conditions to provide information to develop adaptive management strategies.

- Determine the long-term effects of slash pile burning on wood decomposition rates and below-ground processes and fungal diversity to identify possible alternatives to slash pile burning of unmerchantable material.

- Characterize the historical ponderosa pine forest structure, influences of structural conditions on understory vegetation, and how structure is affected by fire exclusion, re-introduced fire (high-severity and prescribed), and biomass harvesting to provide sustainable and productive management strategies.

- Provide managers with information to ensure retention of the five-needle pine species, which are threatened in Western landscapes by climate change, bark beetles and exotic pathogens. This includes providing information about genetic differentiation, phenotypic

plasticity, landscape-scale gene flow, continental-scale genetic variability, landscape-scale adaptive variation, and resistance to mountain pine beetle and white pine blister rust.

- Provide knowledge of spruce aphid (an exotic) biology, ecology, impact, and population response to weather regimes (the key factor contributing to outbreak severity).

- Synthesize the current state of knowledge and managers' knowledge needs for aspen ecology, health, and management to provide managers with comprehensive information in one outlet.

- Predict the effects of recent catastrophic wildfires on habitat extent, quality, and connectivity for the endangered Mexican spotted owl and the critically endangered Mount Graham red squirrel.

- Reconstruct historical forest insect outbreak regimes and the dynamics of endemic populations, with particular focus on western spruce budworm and mountain pine beetle.

- Predict future distributions of key root diseases across forests of the western U.S.

2024-2029:

- Determine the ecological functions of key pathogenic microbial populations in forest ecosystems, particularly as they are associated with forest health, resilience, carbon sequestration, and genetic interactions between populations and host trees.

- Expand our knowledge about poorly understood hardwood, riparian, and woodland species, including oaks, birches, cottonwoods, and pinyon pines.

- Synthesize the state of knowledge about the role that fungal symbionts play in bark beetle population ecology.

Advance our predictive capabilities about forests and woodlands dynamics in a period of increasing climate variability to promote sustainable, resilient and productive natural ecosystems. (Research Focus Area 2).

Forest and woodland dynamics are driven by known, relatively stable, and predictable factors such as soils, topography and long-term climate, but also by more dynamic, infrequent, and episodic factors, such as disturbance events and climate/weather extremes. Early models of forest dynamics focused on soil and topography as the key drivers of species composition, successional pathways, and productivity, with the assumption that average climate-related factors were sufficiently known and predictable. This latter assumption is no longer true and increasing climate variability has made predicting climate and related disturbance events more difficult, uncertain, and urgent. For example, in the mountain West, documented widespread warming and drying reduce the snowpack’s ability to function as a water reservoir during longer fire seasons resulting in a higher risk of catastrophic fires. Warming and drying also result in lower soil water availability, increasing tree water-stress and vulnerability to root diseases, bark beetles, and defoliating insects. Warmer winters have also altered insect population dynamics, which has facilitated widespread tree mortality associated with native and exotic insect outbreaks. Finally, as ecosystems become warmer and dryer, pathogens and

insects have spread to higher elevations and are impacting tree species previously tolerant or unavailable to them.

To address these issues, FWE develops conceptual and mathematical models to describe, explain, and predict forest and woodland dynamics. These methods provide critical tools to assess and project the potential consequences of future changes in ecological conditions, disturbance regimes, and management actions. Such information is critical for management decision-making in a dynamic and changing world. These models are based on information developed from original research and knowledge syntheses and are used to understand, define, quantify, visualize, or simulate disturbance, regeneration, growth, mortality, biodiversity, and plant community organization (and disorganization).

The temporal and spatial scales of these models vary considerably and include individual tree-, stand-, gap-, landscape-, and subcontinental-scale models that simulate the influences of climate, wildfires, prescribed burns, insect outbreaks, and their interactions on decadal and centuries-long forest dynamics.

Deliverables and Dues Dates

2019-2023

- Provide scientifically based guidance to land managers and policy makers on how plants and soils could respond to novel climates and disturbance regimes. This work includes generating estimates of plant and soil carbon and water availability and making predictions about the mortality, regeneration, productivity, decomposition, and invasive potential of native and nonnative bark beetle and nonnative pathogens.

- Improve understanding of the links between climate drivers and insect outbreaks, fire, floods, and other disturbance agents. This research will use tree-ring analysis, remote sensing, and long-term measurements to inform forest planners of the historical range of interactions between climate and disturbance and to predict disturbance behavior in future forests. New data management, statistical approaches, and improved analytical tools provide heightened accessibility and insight to the actions and interactions of disturbance in forest and woodland ecosystems.

- Produce 3-D maps from field and LIDAR point cloud data to provide managers with information about spatial relationships on landscapes and input to models. For example, 3-D maps of natural, heterogeneous fuel beds are used in physics-based fire models so that fire and smoke managers can better estimate emissions.

- Implement improved soil heating models for use with the Forest Service's First Order Fire Effects Model to provide managers with more physically realistic simulations of the effects of soil heating during prescribed burns and wildfires.

2024-2029

- Improve crown fire models used by fire managers with information about crown development, branch spacing, and tree spacing parameters that affect crown fire initiation.

- Improve spatially explicit dynamic landscape disturbance/succession models to enhance the ability to understand and predict effects of changing climate, management, and disturbance regimes on vegetation composition and structure.

- Develop new observation-based, multiscale approaches to predict tree species distributions and ranges at landscape to continental scales.

- Develop new landscape-scale habitat suitability models (used by managers to plan vegetation treatments) using relationships between habitat characteristics and the presence or absence of threatened and endangered species and other species of interest.

Discover and develop knowledge of soil and plant carbon and water dynamics to changes in vegetation, disturbance regimes and management strategies (Research Focus Area 3).

FWE advises land managers about the impacts that disturbance can have on ecosystem carbon and water balance. In healthy forests, these two critical functions are strongly coupled in a way that maximizes carbon uptake (photosynthesis minus respiration) while minimizing water loss (soil evaporation plus plant transpiration). But when disturbance decouples and desynchronizes the carbon and water cycles, forest resiliency, productivity, and associated ecosystem goods and services (EGS) decline. Unfortunately, current societal demands on EGS are increasing just as extreme climate change-driven disturbances (extensive insect outbreaks, exacerbated root disease problems, severe fires, longer droughts and heavier precipitation, wind, and avalanche events) are intensifying. Thus, the increasing risk of extreme disturbance makes managing complex forest and woodland landscapes more challenging and critical than in the past. Optimal management of these ecosystems and their goods and services requires knowledge of the climate in which they are embedded, their carbon and water cycle dynamics in the context of both historical and current disturbance regimes, and the influences of different management practices. FWE scientists seek solutions to these issues using a multifaceted approach that includes (a) impact of disturbances on soil and plant carbon and water dynamics; (b) atmosphere-ecosystem exchange fluxes of energy, carbon dioxide, and water vapor; (c) physical and biological stressors and agents of change of ecosystem carbon and water cycles; and (d) long-term studies to improve assessment of ecosystem carbon and water dynamics.

3(a). Impacts of disturbance on plant and soil carbon and water dynamics.

Healthy soil is vital to all ecosystems, making it a significant component of FWE's carbon and water research portfolio. Within this focal area, FWE researchers examine the mechanistic links between soil health and its carbon and water budgets in relation to disturbance, restoration, and harvest practices.

3(b). Atmosphere-ecosystem exchange fluxes.

An ecosystem flux is the rate of flow of energy (heat, radiation, etc.) or mass (water vapor, CO2, etc.) between an ecosystem and its surroundings, such as the atmosphere, subsurface, or streams. The networks reporting fluxes nationally (AmeriFlux) and globally (FluxNet) for over 20 years are continuing to provide flux-based data that reveals how subtle, long-term

shifts in climate can affect forest productivity and ecosystem energy, water, and carbon usage on a variety of spatial (stands to landscapes) and temporal (daily to decadal) scales. Incorporating this knowledge into ecosystem-level models is critical to understanding, anticipating, and responding to potential changes in ecosystem water and carbon cycles and EGS.

3(c). Agents of change in ecosystem carbon and water cycles.

Forested ecosystems throughout western North America are experiencing changes in the amount, duration, frequency, and timing of precipitation, as well as shifts in temperature regimes resulting in warmer nights, earlier snow melt, and warmer, drier summers. FWE researchers continue to investigate how these physical agents of change interact at multiple spatial and temporal scales to both cause and respond to changes in forest structure and function. FWE also develops scientific knowledge regarding the adaptive capacity of forest species to novel stressors and how they affect species trajectories.

3(d). Long-term studies of ecosystem carbon and water dynamics.

FWE is continuing its program of long-term monitoring and data acquisition to assess how historical disturbances in forests have influenced local hydrology, vegetation productivity, soil quality, and nutrient availability. We will also maintain and continue to monitor a network of ponderosa pine study sites to investigate the forest health implications of ponderosa pine reproduction phenology. We continue to collect data to assess long-term ecosystem change on experimental forests in Idaho (Priest River, Boise Basin, and Deception Creek), Montana (Coram), South Dakota (Black Hills), Colorado (Manitou), Wyoming (Glacier Lakes) and Arizona (Fort Valley), as well as Research Natural Areas and other sites suited to long-term monitoring. These long-term sites also assess ecological function to help inform responses to restoration. At present, the length of these long-term experimental forest data sets varies between 30 and 100 years depending on the specific site.

Deliverables and Due Dates

2019-2023

- Document and quantify changes in carbon and water budgets in a small watershed resulting from forest succession over the past century.
- Document temperate, tropical, and agro-forest soil health changes associated with soil forest disturbance and loss of carbon.
- Extend ongoing research on endemic microbes that act as natural biocontrol agents against phytopathogens, with the goal of developing management practices that favor beneficial microbes that suppress disease.
- Quantify the biological and physical factors regulating soil and vegetation response to interacting bark beetle and fire disturbances.

- Quantify how different disturbance agents affect forest structure and the rates and amounts of snow sublimation at three contrasting forested sites within the Rocky Mountain region of northern Colorado and southern Wyoming.

- Characterize white pine blister rust disease resistance phenotypes in five-needle pine species and their implications for management to sustain population viability in the presence of the pathogen in a changing climate.

- Synthesize the ecological and economic benefits related to water/snow dynamics that indirectly result from large natural bark beetle eruptive events or smaller managed events using these insects.

- Determine how long-term changes in precipitation (water and snow amounts, duration, timing, and frequency) and daily and seasonal temperatures (warmer nights, earlier snow melt, drier and warmer summers) affect vegetation and disturbance dynamics (e.g., successional pathways, invasives, fire regimes, insect outbreaks, etc.).

- Quantify long-term relationships between historical climate change and observed environmental responses (e.g., stream flow dynamics; stream water quality).

2024-2029

- Evaluate how increasing soil carbon from soil amendments can alter forest health to enhance resistance and resilience to insect or disease outbreaks.

- Develop and validate models of reproduction phenology and productivity of ponderosa pine throughout the western United States.

Continuing throughout 2019-2029

- Determine the adaptive capacity of western larch and associated species in the northern Rocky Mountains to climate change by synthesizing existing research on regeneration, survival, and mortality factors, develop new hypotheses about how and where climate change will affect those factors, and test them to provide the basis to manage for the persistence of these species in the United States.

- Develop guidelines to aid ponderosa pine regeneration by synthesizing available knowledge of ponderosa pine regeneration and long-term, west-wide observations of ponderosa pine catkins, conelets, cones, pollen, seedfall, and germination success.

Develop, assess, and provide scientific knowledge of vegetation treatments to restore and promote the resiliency and productivity of complex landscapes under changing environmental conditions and conflicting societal priorities (Research Focus Area 4).

FWE develops effective applied management methods, systems, and strategies to maintain productive, resilient ecosystems and to address present and future management needs with science-management partnerships. Unlike the early 1990s when timber production dominated forest management decision-making and silviculture in the western U.S., today's social and economic priorities for forest management, such as mitigating risk of catastrophic wildfire, restoring fire-adapted ecosystems, creating resilient landscapes, conserving old

growth, and producing forest products, wildlife habitat, recreation opportunities, and water resources, are evolving and often conflict with one another. Furthermore, management strategies are now needed for ecosystems such as pinyon-juniper and lodgepole pine that were not previously managed for timber production. It has also become increasingly difficult to develop effective solutions to complex resource management challenges because of dynamic environmental conditions and changing disturbance regimes, driven in part by changing climate and human activities. FWE researchers embrace a model of co-creation in which we partner directly with managers to jointly develop research priorities and projects, appropriate to current conditions, and to ensure that the research results are directly relevant and applicable to present-day, real-world management needs. As active participants in this work, land managers can readily use this knowledge to inform planning and management decisions in concert with applicable laws (e.g., National Forest Management Act, Endangered Species Act, National Environmental Policy Act), policies, regulations (e.g., Forest Service 2012 Planning Rule), and specific management goals and objectives.

Uniquely supporting and enhancing our science-management partnerships are the FS network of Experimental Forests (EFs) and Research Natural Areas (RNAs). EFs and RNAs provide the capacity to conduct landscape-scale and long-term studies of the effects of environmental factors, disturbance agents, and management strategies on forest composition, structure, and change. As such they serve as reference areas, provide location-based long-term study areas, and provide a foundation for assessing and informing a wide range of management decisions. Such conditions are critical to understanding complex interactions between ecological and management processes at various spatial and temporal scales. Success in this focus area has real, pragmatic, on-the-ground consequences and is critical to achieving optimal solutions to multi-faceted and complex management objectives.

Deliverables and Due Dates

2019-2023

- Update the existing century-long body of ecological knowledge concerning ponderosa pine forests and mixed-conifer forests. This research guides the development and adaptation of management approaches to address contemporary and evolving issues by focusing on fuel hazard treatments, wildfire relationships, insect and disease interactions, heterogeneous forest structures, seedling regeneration and establishment, timber production, wildlife habitat, species adaptation to climate change, and forest restoration.

- Update knowledge on quaking aspen, placing it in the broader context of other aspen landscapes in the U.S. FWE research will also strengthen the knowledge on sudden aspen decline, insect interactions, and develop silvicultural systems for reducing animal damage (e.g., elk) and encouraging regeneration.

- Design new or modify existing silvicultural systems that are adaptive to climate change, altered disturbance regimes, and evolving priorities. This research will determine what timber volumes can be sustainably produced in even- and uneven-aged forests while simultaneously providing a variety of ecosystem services and will also address previously unmanaged systems. Information gained will be used to modify decision support tools such as the Forest Vegetation Simulator (FVS), and to inform wildlife habitat, planning and

management activities and policy for a variety of species including Canada lynx, (and snowshoe hare), northern goshawk, fisher, marten, red-cockaded woodpecker, spotted owl, elk, and other managed, sensitive and threatened wildlife species.

- Characterize the effects of long-term salvage harvesting in areas impacted by forest insect outbreaks, particularly bark beetles.

- Determine how different land management strategies alter soil biodiversity and soil-born tree pathogens and strengthen our knowledge of the impacts that known diseases (e.g. Armillaria root disease) and non-native pathogens (e.g., white pine blister rust) have on forest ecosystems.

- Develop measurement and restoration strategies aimed at increasing the heterogeneity of soil resources and conditions to ensure continued ecosystem sustainability.

- Continue work on the genetic basis of tree improvement and pioneering studies of landscape genomics to understand the adaptive capacity and variability of both natural and genetically improved tree populations across the interior West, with particular focus on white pine blister rust resistance. FWE will also show how improved trees perform in providing products and other ecosystems services and will develop molecular tools and models to discover the reliability and effectiveness of promoting genetic blister rust resistance for five needle pines.

- Forest assessment: Develop tools that use satellite imagery and LIDAR technologies for quantifying, describing, and characterizing disturbances and their severity, forest biomass, fuel treatment effectiveness, and tree characteristics across varying temporal and spatial scales.

2024-2029

- Continue decadal stand- to landscape-scale silviculture and vegetation management experiments and assess the effectiveness of existing, modified, and new vegetation management approaches in forests and woodlands. Resulting syntheses and publications will assess how well various management approaches improve or sustain forest resilience to changing climatic conditions.

- Genetics: Complete a 75-year review of white pine blister rust knowledge and several syntheses addressing conservation and restoration strategies for high-elevation five-needle pines in a changing climate.

- Synthesize the state of knowledge on the major western bark beetle species in coniferous forests with respect to informing policy and management of Rocky Mountain forests in a changing climate.

- Develop knowledge on how to integrate native insect activity (e.g., western spruce budworm, tussock moth, etc.) into management strategies for altering forest structure.

11. Technology Transfer

FWE research involves our stakeholders throughout the research process; in many cases stakeholders are collaborators. As a result, technology transfer is a continuous activity including many informal and formal interactions. Results are often distributed in multiple formats to reach diverse audiences. To ensure scientific rigor and credibility, research results are documented through peer-reviewed publications in scientific journals. Other publication outlets ensure that research results and recommendations are readily available to today's managers, the general public, and interest groups, as well as future readers. Other technology transfer efforts include presentations, field trips and tours, workshops, symposia, brochures, general technical reports, informational and educational websites, media releases, and synthesis documents. Publications, decision support tools, models, and other useful information will be made available on the RMRS website.

12. Partnerships and List of Cooperators

Addressing research questions in today's work requires integration, teamwork, and collaboration within and among management and research organizations. Researchers in the FWE program work extensively with scientists in other agencies, academic institutions, public organizations, and with land and resource managers throughout the Station's territory, as well as nationally and internationally. The following is a partial list of partners and cooperators.

Universities

Arizona State University

Auburn University

Boise State University

Colorado State University

Iowa State University

Michigan Technological University

New Mexico Highlands University

Northern Arizona University

Oklahoma State University

Oregon State University

Salish-Kootenai College

University of Alaska, Fairbanks

University of Arizona

University of California—Davis

University of Colorado

University of Florida

University of Guam

University of Idaho

University of Kentucky

University of Missouri

University of Montana

University of New Mexico

University of Northern Colorado

University of Washington

University of Wisconsin

University of Wyoming

Utah State University

Washington State University

Western Colorado University

Federal

Agricultural Research Service

Argonne National Lab

Arizona National Guard

Army Garrisons at Ft. Jackson, SC and Ft Stewart, GA

Bureau of Indian Affairs

Bureau of Land Management

Department of Defense

Department of Energy

Eglin Air Force Base, FL

Forest Service, Cooperative Forestry and Forest Health Protection

Forest Service, Forest Health Protection and Forest Health Management

Forest Service, Forest Management Service Center

Forest Service, Regions 1, 2, 3, 4, 5, 6, and 10 (including Ranger Districts)

Forest Service, Research Stations

Forest Service, State and Private Forestry

Los Alamos National Laboratory

National Aeronautics Space Administration

National Oceanographic and Atmospheric Administration

National Park Service (Glacier, Rocky Mountain, Great Sand Dunes, Yellowstone, Grand Canyon)

National Weather Service

Natural Resource Conservation Service

National Center for Atmospheric Research

National Ecological Observatory Network

U.S. Fish and Wildlife Service

U.S. Geological Survey

USDA, AAS, National Center for Genetic Resources Preservation

Corporations

Air Burner, Inc

Bennett Lumber Products, Princeton, ID Boise Corporation, Boise, ID

DroneSeed, Seattle, WA

Northwest Management, Inc., Moscow, ID

Stimson Lumber

Tribes

Confederated Tribes of the Colville Reservation

Confederated Salish & Kootenai Tribes of the Flathead Reservation, Forestry Department

Navajo Nation

Spokane Tribe

White Mountain Apache Tribe

Confederated Tribes and Bands of the Yakama Nation

State

Colorado State Forest Service

Idaho Fish and Game

Idaho Department of Lands

Idaho Geological Survey

Montana Fish, Wildlife, and Parks

Nevada Division of Forestry

Oregon Department of Forestry

Utah Division of Forestry, Fire, and State Lands

Washington State Department of Natural Resources

Montana Department of Natural Resources and Conservation

Cooperatives, Partnerships, and NGOs

Coalition for the Upper South Platte

The Wilderness Society

Colorado Forest Restoration Institute

Ecological Restoration Institute

Front Range Fuels Treatment Partnership

Inland Empire Tree Improvement Cooperative

Inland Northwest Growth and Yield Cooperative

The Lands Council (Spokane, WA)

Intermountain Forest Tree Nutrition Cooperative

Mountain Studies Institute

National Wildlife Federation

New Mexico Forest and Watershed Restoration Institute

New Mexico Wildlife Federation

Priest Community Forest Connection (Priest River, Idaho)

The Nature Conservancy

U.S. Biochar Initiative

Western Aspen Alliance

Whitebark Pine Ecosystem Foundation

International

British Columbia Ministry of Forests, Lands, and Natural Resource Operations

Beijing Forestry University, China

Natural Resources Canada

Chinese Academy of Forestry

Colegio de Postgraduados, Texcoco, Mexico

Czechoslovakia University of Life Sciences, Agrobiology, Food, and Natural Resources

Czechoslovakia Forest and Game Management Research Institute

Forestry and Forest Products Research Institute, Japan

Inner Mongolia University (China)

INRA Ecologie des Forêts Méditerrané, France

International Society of Tropical Foresters

Kazakh Research Institute of Plant Protection and Quarantine

Korea Forest Research Institute

Korea Forest Service

lnstituto Nacional de lnvestigaciones Forestales y Pecuarias, Mexico

Polytechnic University of Madrid, Spain

Nanjing Forestry University, China

National University of Mongolia

Northeast Forestry University, China

Norwegian Institute of Bioeconomy Research, Norway

Seoul National University, Korea

Swansea University, Wales, UK

Swiss Federal Institute for Forest, Snow and Lands (WSL)

Unidad de Micologia, Instituto de Ecologia A.G., Xalapa,Veracruz, Mexico

Universidad de Guanajuato, Irapuato, Mexico

University of Agriculture in Krakow (Poland)

University of Alberta

University of British Columbia

University of Oxford (UK)

University of Sao Paulo (Brazil)

University of the Basque Country (Spain)

Consultants

Landeco Consulting, Inc.

Rocky Mountain Tree-Ring Research, Inc.

Local Government

Boulder and Jefferson County, Colorado

City of Fort Collins, Colorado

13. Environmental Considerations

Proposed research activities in this science area are limited in context and intensity and are not expected to have a significant effect on the quality of the human environment. The environmental effects of specific actions will be considered during the development of study plans, at which time the existence of extraordinary circumstances related to the proposed action, and categorical exclusion will be documented as a part of the study plan as described in FSH 1909.15 Chapter 30. Where environmental concerns exist regarding particular studies, these may be evaluated within individual study plans, or by preparation of an environmental assessment or environmental impact statement prepared with and reviewed by the cooperating Ranger District or National Forest Staffs. For research having the potential to affect a plant or animal species that is federally listed as endangered or threatened or proposed for such listing, the unit will consult with the U.S. Fish and Wildlife Service as per Section 7 of the Endangered Species Act of 1973, as amended.

14. FWE STAFFING (RGEG scientists) and FUNDING (Staffing through FY25)

Location	Name	GS Series	Title	Discipline	Focus Area 1 Ecological and physical processes and their interactions	Focus Area 2 Predictive capabilities about dynamics	Focus Area 3 Soil and plant carbon and water dynamics	Focus Area 4 Vegetation treatments for resiliency and productivity of complex landscapes
Flagstaff AZ	Hill, Alison (or vice)	401	Supervisory Biologist	Biology	0.25	0.25	0.25	0.25
Fort Collins CO	Battaglia, Michael	460	Res Forester	Forestry	0.5	0.2	0	0.3
Logan UT	Bentz, Barbara	414	Res Entomologist	Entomology	0.6	0.3	0	0.1
Missoula MT	Crotteau, Justin	460	Res Forester	Forestry	0.35	0.2	0.05	0.4
Flagstaff AZ	Cushman, Samuel	408	Res Landscape Ecologist	Ecology	0.35	0.4	0.1	0.15
Fort Collins CO	Fornwalt, Paula	499	Res Ecologist	Ecology	0.5	0.25	0	0.25
Flagstaff, AZ	Vacant (NEW) **	408	Res Landscape Ecologist	Ecology	0.35	0.4	0.1	0.15
Fort Collins, CO	Vacant [NEW]**	460	Res Forester	Forestry	0.5	0.2	0	0.3
Moscow ID	VACANT (vice Graham)**	460	Res Forester	Forestry	0.35	0.25	0.10	0.3
Moscow ID	Hudak, Andy	460	Res Forester	Ecology	0.3	0.3	0.25	0.15
Moscow ID	Jain, Terrie	460	Res Forester	Forestry	0.3	0.1	0.1	0.5
Moscow ID	Reinhardt, Jason	460	Res Forester	Forestry	0.3	0.1	0.1	0.5
Moscow ID	Klopfenstein, Ned	434	Res Plant Pathologist	Plant Pathology	0.3	0.3	0.1	0.3
Tucson AZ	Lynch, Ann	414	Res Entomologist	Entomology	0.85	0.15	0	0
Flagstaff AZ	VACANT (vice Lynch) *	414	Res Entomologist	Entomology	0.85	0.15	0	0
Fort Collins CO	Massman Jr, William J	1340	Res Meteorologist	Meteorology	0.1	0.45	0.45	0
Fort Collins CO	Mercado, Javier	414	Res Entomologist	Entomology	0.5	0.15	0.1	0.25
Flagstaff AZ	Moser, Warren	460	Res Forester	Forestry	0.2	0.2	0.1	0.5
Fort Collins CO	Negron, Jose	414	Res Entomologist	Entomology	0.75	0.25	0	0
Moscow ID	Page Dumroese, Deborah	470	Res Soil Sci	Soils	0.1	0.1	0.5	0.3
Moscow ID	VACANT (vice Page Dumroese) *	470	Res Soil Sci	Soils	0.1	0.1	0.5	0.3
Fort Collins CO	Schoettle, Anna	435	Res Plant Ecophysiologist	Physiol/ Ecology	0.3	0.25	0.25	0.2
Flagstaff AZ	Sieg, Carolyn	408	Res Ecologist	Ecology	0.25	0.25	0.25	0.25
Moscow ID	vacant (NEW) **	440/ 435	Res Geneticist/ Pathology	Genetics	0.75	0.15	0	0.1
Flagstaff AZ /MCW	vacant (NEW) **	430/43 4	Res Mycologist	Mycology	0.5	0.25	0.15	0.1
Moscow ID	Patrick Bennett	434	Res Plant Pathologist	Plant Pathology	0.5	0.1	0.2	0.2
			Total SY's		9.75	5.55	3.15	5.55

Footnote: * positions are NOT counted in totals as they replace existing employees; ** positions are counted in totals as these positions are new or there is no existing employee				
Annual Funding (including Station Overhead) by Focus Area ($million)	3.8	2.2	1.2	2.3