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6.0. Forest Service

U.S. Department of Agriculture (USDA), Forest Service Research and Development (R&D) is a world leader in forestry research. Integral to the mission of the Forest Service since the agency's inception in 1905, R&D studies the most pressing natural resource management issues of our day, generating science findings and tools that help sustain the health, diversity, and productivity of our national forests and grasslands—and ultimately enhance the rigor and impact of the entire agency.

6.1. Understanding

Technology transfer ("tech transfer") and science delivery at the USDA Forest Service R&D, with the goal to enhance the utility of scientific information, is defined as *pulling together and synthesizing information from a range of disciplines and delivering it in clear and accessible formats to fit user needs.* USDA Forest Service science is complex, but the need for research is simple. Land managers, forest managers, city planners, and policymakers need sound science on all aspects of the natural world and its complex connections with people to make decisions resulting in a healthy and sustainable future for present and future generations of Americans.

The culture of focusing on science delivery (and "tech transfer" as a subset of science delivery) is a bit dated. R&D has evolved as a science organization to pursue co-development of knowledge together with practitioners and decisionmakers. Science delivery and tech transfer describe a linear process where science is conducted, knowledge is gained by scientists, and then is provided to the end-users as a final step. In contrast, our scientists are bringing knowledge users, stakeholders, and decisionmakers into the science process from the very beginning, a process that includes feedback loops. In today's Forest Service, this co-development of knowledge has become central to the research process and helps to increase the relevance of the organization's science findings and tools. This valuable form of science production and application, of which Forest Service R&D is a pioneer, sets the agency apart from universities and other academic institutions. In short, R&D works hand-in-hand with managers to build knowledge together and design solutions.

6.2. Mission Statement

The overall mission of the Forest Service is to *sustain the health, diversity, and productivity of the nation's forests and grasslands to meet the needs of present and future generations*. Established in 1905, the Forest Service is an agency within the USDA that directly manages 193 million acres of public land in National Forests and Grasslands, and works with state forestry agencies and other partners to assist in managing 491 million acres of state and private forest lands. The ***Forest Service is the only land management agency in the USDA***. Gifford Pinchot, the first Chief of the Forest Service, summarized the mission of the Forest Service as *to provide the greatest amount of good for the greatest amount of people in the long run*. The Forest Service is composed of five areas: National Forest System (NFS), R&D, State and Private Forestry (S&PF), Business Operations, and Work Environment and Performance.

The R&D leadership's intent is for research to enhance the rigor and impact of the entire agency. Research provides a seamless connection between the needs of agency's land management mission areas and the latest science. R&D staff are engaged in ensuring the sustained and productive use of our nation's

forest and grasslands, enhancing customer service, and providing a learning core that ensures a positive and productive workplace.

As the world's leader in forestry research, the agency is poised to capitalize on scientific developments, science deliveries, and transfer technologies to help Forest Service scientists:

- gain recognition;
- deliver valued information and knowledge;
- protect intellectual property rights;
- develop research agreements to leverage academic, government and industry partnerships to improve the health and productivity of our nation's forests and grasslands;
- inform natural resource policy and land management decisions; and
- anticipate emerging natural resource issues.

R&D scientists are a key part of the nation's scientific expertise, which includes colleagues in other federal and state agencies, universities, industry, non-governmental organizations, and even citizens with interest in science. Citizen Science is defined by the Crowdsourcing and Citizen Science Act of 2017 (5 U.S. Code § 3724) as a form of open collaboration in which individuals or organizations participate voluntarily in the scientific process in various ways, including:

- enabling the formulation of research questions;
- creating and refining project design;
- conducting scientific experiments;
- collecting and analyzing data;
- interpreting the results of data;
- developing technologies and applications;
- making discoveries; and
- solving problems.

A fundamental expectation in the scientific community is that research findings are presented in scientifically credible forums, and that scientific publications resulting from research will undergo review by other scientists to ensure the scientific rigor of the work. Once the reviewed research is published as scientific or primary literature, the science-based information from those publications must be made available to the public. The Forest Service does this in several ways, including through a dedicated website, Treesearch, which contains all the published scientific research conducted by R&D scientists.

6.3. Nature and Structure of Research Program

R&D is committed to impactful science, effective delivery, and organizational synergy, with a nimble and intentional approach to our work.

Research Framework

Forest Service research produces three key deliverables: resource inventory and assessment, decision support, and innovations in practices and utilization.

Research Priority Areas

- Applied science to support shared stewardship and improve forest conditions.
- Forest inventory and trend analysis.
- Enhancements to the wildland fire system, including prediction, planning, decision support, impact assessment, and recovery.
- Wood product and market innovations.

Foundational Research Areas

- Forest and grassland health.
- Forest soils, air quality, and hydrology.
- Silviculture and ecology, including forest ecology and fish & wildlife ecology.

Today, research is conducted by more than 400 scientists and several hundred technical and support staff, located at 67 sites across the United States, working in a range of biological, physical, and social science fields to promote sustainable management of the nation's diverse forests and rangelands. Their research covers a lot of territory, with programs in all 50 states, U.S. territories, and commonwealths. This

structure provides sites for long-term research and management studies of major vegetation types found across the United States, as well as diverse research areas operated in collaboration with partners. The Forest Service R&D organization includes five research stations: Northern, Pacific Northwest, Pacific Southwest, Rocky Mountain, and Southern; the Forest Products Laboratory; the International Institute of Tropical Forestry in Puerto Rico; and R&D Headquarters in Washington, DC. Although not in the research area of the Forest Service, there are also two Technology and Development Centers operated by NFS, located in Missoula, Montana and San Dimas, California.

6.4. Role of the National R&D Office, Staff Directors, and National Program Leaders

The Washington Office of R&D serves the Forest Service and R&D-specific mission area, advancing and building support for the work of R&D and recognition of the public value that work creates. The national office focuses on strategic planning, policy development, oversight, and national coordination with other Forest Service mission areas as well as among the research stations. The Washington Office of R&D also provides coordination and oversight of the entire R&D budget, working closely with the agency's national budget office on budget formulation, presentation, allocation to research stations, and performance reporting. Forest Service research is overseen by the Deputy Chief for R&D, with the assistance of the Associate Chief for R&D, and four Director-led staff areas. An important aspect of these staff areas is the development and representation of national research programs. Examples of national program activities include: leveraging research and research funding from other federal agencies (typically in interagency working groups); coordinating with the R&D Deputy Chief's Office to report and promote R&D to Forest Service leadership and the Department, other agencies, and Congressional staff; fostering cross-station communication and collaboration among scientists; and developing working relationships with national-level non-profit organizations and professional and technical associations.

While National Program Leaders do not have budgetary or supervisory authority over Station programs and scientists, they coordinate national and Station elements of their research areas and, ideally, work with other NPLs and Station leadership and scientists to develop Station research priorities and programs that effectively address national issues as well as local and regional ones. In some cases, NPLs make recommendations regarding the use of Washington Office funds to coordinate research inputs among Station scientists and to support grant programs in accordance with specific Washington Office projects of national scope.

R&D Foundational Assets

Forest Service R&D maintains a vital network of 81 Experimental Forests and Ranges, 29 of which were established in the 1930s. Long-term records from some of these forests can provide unprecedented

insights into global climate change, watershed function, disturbance recovery, and many other areas. Major research themes include, developing systems for management and restoration of forests, range lands, and watersheds; investigating forest and stream ecosystems; characterizing plant and animal communities; and observing and interpreting long-term environmental change.

Forest Service R&D also includes the Forest Inventory and Analysis (FIA) Program, which is considered a secondary unit of the Federal Statistical System. The United States has a highly decentralized statistical system, spanning 125 agencies spread across the government, all of which are engaged, to some degree, in collecting data and producing statistics. The Office of Management and Budget's Statistical and Science Policy Office, headed by the U.S. Chief Statistician, coordinates the activities of the Federal Statistical System to ensure the efficiency and effectiveness of the system as well as the integrity, objectivity, impartiality, utility, and confidentiality of information collected for statistical purposes. The FIA program is legislated to provide the nation's forest census, which includes forest conditions, landowner characteristics, and timber products output data. These data are fundamental to the public and private sectors for policymaking and decisions about forest investments and are vital to researchers and scientists.

6.5. Current Technology Transfer Goals, Objectives, and Measures of Success (Metrics)

The Forest Service utilizes many means of technology transfer and science delivery that include, but are not limited to, marketing efforts at tradeshows; marketing in cooperation with universities; patents; webinars; workshops; partnerships; field visits; coordination and participation in conservation education and citizen science; public outreach; and most critically, publications.

Many metrics associated with these efforts are currently being tracked, and the Forest Service plans to track new metrics such as social media engagement, web visits, and citation indices. One major improvement to the technology transfer program in 2022 will be the addition of contract docketing program support. The program also is working to better support the Lab-To-Market technology transfer goals by working directly with funding recipients on intellectual property ownership and development by no longer working through iEdison. This change will improve the entire Forest Service IP partnership interaction.

The principal contact for technology transfer via intellectual property agreements, patents, and licensing within the Forest Service is the Technology Transfer Coordinator, who reports to the Washington Office and is located at the Washington Office-Baltimore Field Office. The Forest Service Patent Program receives and tracks all invention disclosures, providing guidance to scientists regarding all aspects of intellectual property protection. The Forest Service Patent Program is changing the emphasis from utility patent filing to provisional application filing, seeking a development partner, and/or extensive marketing prior to a decision to file the utility patent. Reducing the technology to practice under a Cooperative Research and Development Agreement (CRADA) greatly increases the opportunity for successful development. The goal of this program is to file provisional patent applications and involve the inventing scientist to help find a CRADA partner prior to filing a utility patent. This process includes working with the USDA Small Business Innovation Research (SBIR) program. The Patent Program conducts prior art searches and prepares all needed paperwork for the U.S. Patent and Trademark Office. The Patent

Program also oversees contract law firms that draft utility patent applications (applications are filed by USDA Office of General Counsel), and files and prosecutes applications in the Patent Office. Draft patent licenses are prepared by the Forest Service Patent Program and signed by the Agriculture Research Service Office of Technology Transfer. Forest Service commercial licenses are royalty-based only, with the valuation priority toward making the technology available for internal Forest Service management use along with industry support.

CRADAs and other technology transfer agreements for the Forest Service are handled by the Forest Service Grants and Agreements Specialists in conjunction with the Forest Service TTC, with patent marketing responsibilities falling to the Forest Service Patent Program. If a partner or a successful market plan (this could involve procurement for Forest Service use) cannot be developed, the technology will be published and placed in the public domain.

The Forest Service Patent Program's goal is the broadest dissemination of scientific outcomes, and the Patent Program desires to support, not encumber or delay, such dissemination.

R&D will also continue to build a scientific foundation for natural resource management and policymaking at multiple spatial scales in forest and rangeland ecosystems. Methods used include conducting leading-edge research, synthesizing existing research, and improving access to and highlighting field research to identify and prioritize critical management-driven needs. The data and research generated through this work are an important part of Forest Service technology transfer, and Forest Service R&D will continue to gather, analyze, provide, and report on data to improve management decisions. In addition to the FIA program mentioned above, the Forest Service also has "big data" residing in Star Metrics and VIVO, its fire weather modeling, its remote sensing and landscape analyses, and its tracking of weather and hydrology at the Experimental Forests and Ranges. The Forest Service will also continue to add data collection points to its internal data collections programs, Research Information Tracking System (RITS) and iWEB, to allow better reporting, distribution, and management decisions.

Publications, agreements, patents, partnerships, and data will continue to provide practical solutions to problems and issues by creating technologies, tools, methods, and information that serve the needs of internal customers with NFS and S&PF, as well as other federal agencies, universities, and international communities.

6.6. FOREST PRODUCTS LABORATORY

The Forest Products Laboratory, based in Madison, Wisconsin, promotes healthy forests and forest-based economies through the efficient, sustainable use of our wood resources. The long-term health of our Nation's forests depends on sound conservation practices, including utilization. Since 1910, the Forest Products Laboratory (FPL) has used science and technology to conserve and extend our Nation's forest resources. Many everyday products and processes have been improved through FPL research, such as building products (structural and composite), housing, paper, bridges, adhesives, packaging, recycling, biofuels, and wood preservatives, to name a few. Historically, FPL has contributed to great improvements in areas such as wood finishes, sawing and drying techniques, prefabricated housing, and lumber grading.

Forest Products Laboratory Research Priorities

1. **Advanced Structures**: New technologies referred to as mass timber provides the means to engineer taller wood buildings and enable much faster assembly of multi-story buildings.

2. **Nanotechnology:** Woody cell walls can be disassembled into fundamental nano-scale particles that have applications as varied as oil-well drilling fluids, barrier films, high-performance composites and improved cement.

3. **Forest Biorefinery/Woody Biomass Utilization**: Particle boards, wood pulp, cellulose nanomaterials and biorefinery are commonly produced from smaller-diameter wood and, in some cases, slash and other wood wastes. Increasing the market for smaller-diameter trees will increase value sufficiently to pay all logging and transportation costs and increase the rate at which overgrown forests can be treated.

4. **Advanced Composites**: New products, like wood-plastic composites, and potential products, like cellulose nanomaterial-reinforced composites, provide new lightweight materials for applications as varied as deck boards, lightweight vehicle parts, and lightweight armor.

Forest Products Laboratory 2021 Research Highlights

Moving toward understanding the mechanism of copper tolerance

Brown-rot basidiomycete decay fungi are the greatest threat to wood products in service because they can reduce the effectiveness of copper-containing wood preservatives. It is critical to study the mechanism of copper tolerance to prevent copper-treated wood deterioration by these fungi. The goal of this research was to better understand this mechanism in the copper-tolerant decay fungus *Fibroporia radiculosa*.

The decay of untreated and copper-treated wood, and the amount of copper removed from copper-treated wood, were evaluated for two copper-tolerant fungi and one copper-sensitive fungus. The two copper-tolerant fungi were able to cause higher decay and removed greater amounts of copper in copper-treated wood. Additionally, genes that could be contributing to copper-tolerance were evaluated during fungal decay of copper-treated wood. Two genes that respond to stressful environments, and two other genes that may be involved in moving copper inside the fungus, were studied.

All four genes decreased in the copper-tolerant fungi on copper-treated wood, while the copper movement genes increased in the copper-sensitive fungus on copper-treated wood. Results suggest that copper-tolerant fungi decay copper-treated wood using different genes than the copper-sensitive fungus. Future research is ongoing to clarify how copper-tolerant brown-rot fungi manage intracellular toxic copper environments.

The XyloPhone smartphone peripheral brings AI wood identification potential to your pocket

One rate-limiting factor in the fight against illegal logging is the lack of powerful, affordable, scalable wood identification tools for field screening. Computer-vision wood identification using smartphones fitted with customized imaging peripherals offers a potential solution, but to date such peripherals suffer from one or more weaknesses: low image quality, lack of lighting control, uncontrolled magnification, unknown distortion and spherical aberration, and/or no access to or publication of the system design.

To address cost, optical concerns, and open access to designs and parameters, Forest Service scientists developed the XyloPhone, a 3D-printed, research-quality macroscopic imaging attachment adaptable to virtually any smartphone. It provides a fixed focal distance, exclusion of ambient light, selection of visible light or UV illumination, and uses the lens from a commercially available loupe. The XyloPhone is powered by a rechargeable external battery, is fully open-sourced, and at a price point of less than 110 USD, is a highly affordable tool for the laboratory or the field. It can also serve as the foundational hardware for a scalable, field-deployable computer-vision wood identification system.

Forensic Identification of CITES Appendix I Cupressaceae

Two closely-related species of the cypress family, Fitzroya cupressoides and Pilgerodendron uviferum, are endemic to southern Chile and Argentina. Both are listed in Appendix I of the Convention on International Trade in Endangered Species of Fauna and Flora (CITES), which bans them from international trade without special permits. Despite these bans, the continued loss of these trees has been difficult to curtail. Combatting such illegal logging is important to protect biodiversity through sustainable harvesting, promote economic development, curtail international crime and its attendant money laundering, and eliminate market distortion that reduces the profitability of legally traded timber. In response, the United States and other countries have enacted laws that prohibit the import or trade of illegal timber. An important aspect for stopping this illegal trade is to have effective and rapid tools for identifying the species of suspected banned timber. A collaborative project between Chile and the USA was designed to determine the usefulness of chemical and wood anatomical characteristics to reliably separate these species. Wood anatomy alone cannot separate them, but mass spectrometry was able to unequivocally determine taxonomic source. The mass spectra results obtained from heartwood demonstrated that identification is feasible after a few seconds, using only a small sliver of wood.

Rethinking the role of water when preparing composites of micro-/nanocellulose and polymers

Cellulose micro-/nanomaterials (CNs) are an emerging class of materials with many potential applications, often in combination with polymers. Unfortunately, their preparation typically results in dilute, aqueous suspensions, and inefficient water removal prior to composite preparation has hindered commercialization. However, water may present opportunities for improving overall process efficiencies if its potential is better understood and if it is better managed throughout the various stages of CN and composite production.

Forest Service scientists and partners are seeking to better integrate water into composite preparation processes, leveraging water's ability to: 1) aid in CN dispersion; 2) act as a transport medium for metering and feeding of CNs; 3) plasticize polymers; and 4) facilitate fibrillation of pulps during composite preparation.

The perception that water has no value in polymer processing and must always be removed prior to composite preparation needs to be revisited. A more sophisticated understanding of water's role will become increasingly important as more bio-based materials are used in polymer composites.

Using synchrotron techniques to understand the role of metals in wood decay

Brown-rot fungi cause a type of wood decay that results in rapid strength loss of wood in the built environment. Research has shown that brown-rot fungi are responsible for 85% of the damage to wood structures caused by decay fungi. Understanding brown-rot decay mechanisms is important because brown-rot decay can cause rapid reductions in the strength of lignocellulosic polymers even with low amounts of mass loss. It is generally accepted that the first stage of brown-rot decay involves chelator-mediated Fenton catalytic degradation where metal ions are used to generate hydroxyl radicals that depolymerize wood. However, the oxidation states of these metal ions have not been characterized during the decay process.

Forest Service scientists and partners teamed up to use synchrotron-based X-ray Absorption Near Edge Spectroscopy (XANES) to characterize the metal oxidation states during wood decay.

Investigations of fungal wood decay mechanisms reveal novel enzymes

Wood extractives, solvent-soluble fractions of woody biomass, impede or exclude fungal colonization of the freshly harvested conifers. However, certain fungi have evolved unique systems to rapidly colonize softwood stumps and thereby prevent invasive growth of destructive pathogens. To clarify the mechanism(s) of this process, an international team of scientists examined the transcriptome, proteome, and metabolome of Phlebiopsis gigantea when grown on defined media containing loblolly pine sapwood extractives. An array of enzymes was implicated in the metabolism of softwood. Based on its extracellular location and characterization of the recombinant enzyme, a highly expressed and inducible lipase is likely responsible for lipophilic extractive degradation. Our results provide a framework for genetic improvements of root rot biocontrol agents, and the lipase has considerable potential in a wide range of industrial processes.

Characterizing mold susceptibility

The U.S. Department of Defense utilizes a diversity of wood materials and available wood species for construction of munitions wood packaging materials (WPMs). Concerns related to mold contamination in WPMs exposed to moisture during storage or transport has necessitated the evaluation of potential moldicides that could be used with the preservative treatment systems already in use. During preliminary tests, it became clear that evaluations of moldicidal additives would be difficult because of variation in mold susceptibility across all the different wood species and wood types that are allowed for WPM fabrication. A study was initiated to examine mold susceptibility of various wood species and types, with the goal of selecting representative materials that could be used in subsequent laboratory mold tests.

Acid hydrotropic fractionation (AHF) for sustainable biorefinery

Fractionation of lignocellulosic biomass is the prerequisite step for producing fibers/cellulose nanomaterials, sugar/biofuel, biochemicals, through the biorefinery concept. While alkaline chemical pulping has been commercialized for producing commercial wood fibers, efficient and sustainable utilization of low-grade lignocellulosic biomass requires low cost and sustainable fractionation process that remains a challenge. In this research, we are developing aqueous maleic acid hydrotropic fractionation (MAHF) to achieve efficient fractionation of lignocelluloses at atmospheric pressure. There are several advantages of maleic acid hydrotropic fractionation (MAHF): (1) maleic acid is a solid acid that can be easily recycled. Furthermore, it is an US FDA approved indirect food additive with negligible environmental impact. (2) Dissolved lignin can be easily separated through diluting the spent liquor to the minimal hydrotropic concentration with water. (3) Both the dissolved lignin are minimally condensed and carboxylated that facilitate valorization. Furthermore, the residual lignin is also carboxylated that improved enzymatic sugar production at low cellulase loadings, mechanical refining and fibrillation for fiber and cellulose nanomaterial production from the fractionated solids; (4) The dissolved xylose can be dehydrated into furfural by the maleic acid in the spent liquor without additional catalyst. These advantages were demonstrated in the publications that include an invited minireview on the subject featured on the cover of August issue of ChemSusChem.

Sustainable production of cellulose nanomaterials

Existing processes for producing cellulose nanomaterials (CNM) suffers from difficulties in chemical recovery or expensive mechanical energy cost using pure mechanical processing. In this research we focus on using dicarboxylic acids to produce carboxylated CNM (DCA-CNM), including CNCs with chiral nematic properties, DCA-CNFs with great dispersity, and cellulose nanowhiskers (DCA-CNWs) with similar morphology to CNCs. The less corrosiveness nature and great recyclability of solid dicarboxylic acids are substantial advantages over mineral acid hydrolysis for producing conventional sulfuric acid CNCs. The DCA-CNM also has higher thermal stability than sulfuric acid CNCs. We also found that DCA-CNF performed better in water-based oil drill fluids than commercial product. We also developed reaction kinetics for tailored production of a diverse of DCA-CNM with desired morphology. When using maleic acid, an acid hydrotrope, we can produce LCNM directly from raw biomass through MAHF process. Recent progress are reported in the listed publications including a perspective paper in Nature.

X-ray crystallographic protein structure determination of the novel bacterial xylobiohydrolase AcXbh30A

The novel bacterial xylobiohydrolase, derived from *Acetivibrio clariflavus*, AcXbh30A, has been shown to be highly specific in the hydrolysis of xylan to yield xylobiose. Xylobiose is a prebiotic dimeric sugar derived from lignocellulosic biomass and a major functional food ingredient. Inclusion of the enzyme xylobiohydrolase in multi-enzyme systems can be used to generate novel structured, branched xylooligosaccharides and xylobiose.

As part of continued research into the function of this enzyme, Forest Service scientists and partners have obtained protein crystal structure models of AcXbh30A using X-ray crystallography. The xylobiose bound structure reveals why this unique xylobiohydrolase shows better specificity then similar fungal-derived xylobiohydrolases. The xylobiose is complexed into a two-sugar sized binding slot and makes four specific hydrogen bond contacts.

Understanding the crystallinity and supramolecular structure of cellulose

Crystallinity and structure of aggregated cellulose are poorly understood, and the current methods used to measure these qualities have limitations. Therefore, further investigation was carried out in this study, using cotton microcrystalline cellulose (MCC) and ball-milled MCC. It was found that when these ball-milled samples were wet with water, most underwent conformational changes at the molecular level. Although formation of cellulose II (another type of cellulose whose crystal structure differs from that of cellulose I) was observed in longer duration than ball-milled samples, the changes primarily gave rise to increased contributions in spectral and diffraction regions typically associated with the contributions of crystalline cellulose I.

Moreover, when the wet samples were air-dried at 25°C, the newly formed cellulose I-like structures partly reverted to the previous form present in the initial dry state. These findings explained for previously studied X-ray diffraction and nuclear magnetic resonance observations, where the addition of water resulted in increased crystallinities of cellulose samples.

Characterizing nanocelluloses to comprehend their application potential

To optimize the applications of cellulose nanocrystals (CNCs), it is important to understand their supramolecular structures. In this research, using many techniques, structures of sulfuric-acid-produced CNCs were analyzed. CNCs were produced from poplar wood, bleached kraft pulp, cotton microcrystalline cellulose, bacterial cellulose, tunicin, and cladophora cellulose. The findings indicated that significant differences among the CNCs existed, and that they seem to arise largely from differences between the starting materials. This research helped in estimating the applications of the various types of CNCs.

Hitting the reset button on water vapor sorption in wood

The uptake, or sorption, of water vapor is a fundamental characteristic of wood. Moisture content affects most engineering properties of wood, including heat capacity, thermal conductivity, strength, stiffness, and dimensions. Furthermore, moisture is vital for wood degradation mechanisms such as fungal decay. The basic physical interaction of water vapor with wood at the molecular level has long been interpreted using theoretical models that were developed for other materials. Although these idealized systems are inconsistent with wood-water interactions and ignore important physical phenomena, the sorption models happen to provide acceptable empirical fits to the relationship between equilibrium moisture content and relative humidity. The models have also been widely used in the wood science literature to predict physical properties of wood.

To test the validity of common sorption models, Forest Service scientists and partners first identified the most reliable literature data for water vapor sorption in wood over a wide range of temperatures. They then fit the models to the sorption data and evaluated physical properties predicted by the models against independently measured values. They found that none of the theoretical models accurately predicted any of the physical properties. They conclude that these models are not valid. To move wood science forward, new models are needed that correctly describe wood-water interactions.

Better enzyme cocktails for biorefineries

Fungi are experts at eating lignocellulosic biomass, i.e., wood. Biomass has three major biopolymers: cellulose, hemicellulose, and lignin. By producing a mixture of enzymes, they break these biopolymers into bite-sized pieces. For example, cellulases break cellulose down into simple sugars. Fungi adapt the quantity and type of enzymes for the biomass they are consuming.

For many years, there has been a desire to use fungal enzymes on an industrial scale. Forest Service scientists and partners aimed to turn woody biomass into simple sugars, so these sugars can be fermented into biofuels and other products. Typically, the enzyme supplier grows the fungus, isolates the enzymes, blends several types of enzymes, and ships them to the biorefinery. Enzyme cost is often the second highest operating cost, after biomass cost. In this study, Forest Service scientists and partners show that by letting fungus grow on the substrate, it produces an enzyme cocktail as good as a state-of-the-art commercial enzyme mixture. This opens the door to producing optimizedenzymes on-site at a biorefinery, which would reduce cost and improve efficiency.

Digging deeper into the science, this study also gives guidance to enzyme producers. The study combines complete biomass characterization, observations of fungal morphology, measurements of enzyme activity, and genomics. Fungus grew on softwood samples that were pretreated in three different ways: one pretreatment removed most of the lignin; one removed most of the hemicellulose; and one opened the structure, but largely did not change the composition. By acquiring data from several scientific disciplines on fungi grown on systematically varied substrates, it is possible to identify fiber characteristics that correlate with the expression of each class of enzymes. As expected, the greatest variation was observed for the hemicellulose-specific enzymes, xylanases and mannanases.

Estimating lumber properties with acoustic-based technologies

In this research article, Forest Service scientists and partners used fundamental mechanics in an idealized specimen to derive a mathematical model of acoustic wave behavior. Published information on the physical and mechanical properties of clear, defect-free wood are inputs in the model to examine acoustic wave behavior. Wave behavior is then examined experimentally in a series of wood specimens. Observed wave behavior in the clear wood specimens, in both time and frequency domains, closely resembles idealized wave behavior. The predictions from the model are used to improve estimation of the ultimate tension stress of wood specimens.

Southern Yellow Pine Properties across Five Decades

Climate change, forest management, genetics, processing, and other factors have been considered as reasons for the change in design values of southern yellow pine, which occurred in 2012. Whether the mechanical properties of this resource have changed over the past 50 years remains an open question. This research uses archival and modern data to detect possible resource changes in southern yellow pine density, flexural properties, compression properties, stiffness, and strength.

The use of ground-penetrating radar in the evaluation of wood structures

Moisture detection is of prime concern in wood products, and several researchers have labored to measure internal moisture using ground penetrating radar (GPR). While there have been several laboratory studies involving the use of GPR on wood, its use as an inspection tool on large wood structures has been limited. Knowledge gaps have been identified that need to be addressed to improve the efficacy of GPR as a reliable inspection tool of wood structure. Chief among these gaps is the ability to distinguish the type of internal feature from GPR output, and the ability to identify internal decay.

A convenient and inexpensive bioreactor for oxidation of wood sugars

There is great potential for the manufacture of high-value chemicals from wood sugars using a combination of chemical and biological catalysts. To demonstrate the utility of an inexpensive inflatable shipping pillow as a reactor for bio-catalysis, Forest Service scientists and partners oxidized glucose on a multi-gram scale using an enzyme derived from a wood-decay fungus that was expressed at high levels in a bacterium. Importantly, only a single charge of 100% oxygen is required for stoichiometric conversion of glucose using the shipping pillow bioreactor with a high surface area at the liquid-gas interphase and with gentle mechanical mixing for whole-cell catalysis. The reaction can be successfully repeated with recycled bacterial cells that are easily recovered by centrifugation. The resealable valve of the shipping pillow is a convenient port for transfer of both the reaction solution and molecular oxygen. In contrast to rigid-walled reactors, the sealed inflatable/collapsible pillows maintain constant pressure (1 atmosphere) of 100% oxygen even as the gas is consumed. This method is expected to have application with other oxygen-dependent enzymes.

Cradle-to-grave life-cycle assessment and techno-economic analysis of biochar produced from forest residues with various portable systems

Producing biochar from forest residues can help resolve environmental issues by improving soil quality, which can reduce the impacts of forest fires and climate change. However, transportation and storage of biomass to a centralized facility is often cost-prohibitive and a major hurdle for the economic feasibility of producing bio-based products, including biochar. This study evaluates the environmental impacts and economic feasibility of manufacturing biochar from forest residues with small-scale portable production systems such as Biochar Solutions Incorporated (BSI), Oregon Kiln (OK), and Air Curtain Burner (ACB).

The results illustrated that the global warming impact, as measured by carbon sequestration, of biochar production through BSI, OK, and ACB were 0.25 – 1.0, 0.55, and 0.61-tonne CO_2eq./tonne biochar applied to the field, respectively. One tonne of biochar, produced with the portable system at a near-forest site and applied to the field, reduced the global warming impact by 0.89 – 2.6 tonnes CO_2eq. Overall, the net global warming impact of biochar produced from forest residues can reduce environmental impacts (i.e., 1 – 10 times lower CO_2eq. emissions) compared with slash-pile burning. The MSP per tonne of biochar produced through BSI, OK, and ACB were $3,000;$5,000; $1,600; and $580, respectively, considering 100 working days per year. However, with improved BSI systems, when allowed to operate throughout the year, the MSP can be reduced to below $1000/tonne of biochar. Further, considering current government grants and subsidies (i.e., $12,600/ha for making biochar production from forest residues), the MSP of biochar can be reduced substantially (30 – 387%) depending on the type of portable system used.

The portable small-scale production systems could be environmentally beneficial and economically feasible options to make biochar from forest residues at competitive prices, given current government incentives in the United States, where excess forest biomass and forest residues left in the forest increase hazard to wildfire.

Mechanical performance of hybrid CLT panels made of low-value sugar maple and white spruce

Tall timber buildings have gained more and more attention in North America. Massive composite timbers such as cross-laminated timber (CLT) are essential for tall timber buildings that require use of locally available wood resources to reduce manufacturing costs and minimize environmental impacts. This opens a potential sustainable market for undervalued hardwoods dominating the Lake States and the northeastern United States. Current commercial CLT building products are almost exclusively made from softwood species, primarily spruce and fir. Although those softwood CLTs generally can meet code requirements, they have some deficiencies inherent from the material from which they are made. For example, the low rolling shear strength is due to low stiffness and strength properties of softwoods.

This study evaluates the mechanical performance of hybrid mixed species CLT panels made of low-value sugar maple and white spruce boards through a mechanical test and numerical simulations. Three-layer hybrid CLT panels with layup combinations of sugar maple-white spruce-sugar maple and white spruce-sugar maple-white spruce were prepared to evaluate the effects of layups on the performance of the CLT samples. The mechanical properties of hybrid CLT panels were evaluated with different layups and both melamine- and resorcinol-based adhesives. The influence of adhesive types was not significant. The mechanical properties of the hybrid CLT panels with sugar maple surface layers were improved significantly compared with those of the current standard layups.

The results of this study suggest that the hybrid CLT with low-value sugar maple and white spruce can provide better structural performance than standard CLT made with spruce-pine-fir. Enhancing the panel properties by using low-value sugar maple lumber in individual layers is feasible and effective.

Influence of temperature on termite gut microbiome

Temperature is a major factor influencing insect distribution because insects cannot regulate their own body temperature. Instead, their internal temperature fluctuates with external environmental conditions. To survive, insects must adapt both physiologically and behaviorally to contend with shifting climate conditions. Recent work has suggested that associations with symbiotic microorganisms may help foster tolerance to thermal stress.

Subterranean termites are widely distributed across the United States but are limited by harsh winter conditions along their northern range. While several researchers have examined certain physiological responses in termites to varying temperatures, little attention has been given to the impact of temperature on termite gut symbionts. Microbial symbionts in termites have been credited as drivers of species evolution in termites, so there is strong potential for these symbionts to impart some level of thermal tolerance plasticity. Forest Service scientists and partners examine the response of termite bacterial symbionts to temperature stress. Results showed distinct shifts in termite gut microbiota with temperature exposure that may be related to cold tolerance. This research advances understanding of the potential links between microbial symbionts and adaptability. This type of work is important for future predictions of termite dispersal and establishment, particularly in colder, temperate climates where termite risk is generally considered to be lower.

Mechanical performance of CLT panels made from salvaged beetle-killed white spruce

Dead standing trees resulting from insect outbreaks increase the hazard to wildfire and pose a safety hazard in recreation areas. Forests left in the wake of an insect outbreak represent a significant economic resource. Timber salvage from such areas could generate revenues for affected landowners to offset the cost of forestland restoration. Manufacturing cross-laminated timber (CLT) with non-destructive rated salvaged lumber could be a high value-added option for utilizing the salvaged lumber. The orthogonal layup of CLT can reduce the impact of mechanical property variance caused by local defects such as checks, knots, and decay by redistributing the loads into other directions.

This study evaluates the flexural and shear properties of CLT panels fabricated from salvaged dead standing white spruce resulting from recent eastern spruce budworm activity in Upper Peninsula, Michigan, through mechanical tests and computational analysis to determine whether the CLT panels can reach the standards required by the PRG 320 standard. The results suggest that CLT panels fabricated from salvaged white spruce can meet the baseline performance requirement of the PRG 320 standard and provide adequate stiffness and strength for uses as structural components, especially for components under bending with short spans. The finite element modeling of the CLT panels, according to the orthogonal constitutive law and progressive damage model, can be used to estimate the flexural and shear properties of CLT panels, based on the lamination E-rating results. A comprehensive qualification testing program is recommended to further validate the use of salvaged white spruce lumber in manufacturing CLT panels.

Cellulose nanomaterials from wood have the potential to improve the shelf-life of dry food in bio-based packaging

The potential of neat bio-based polyactic acid (PLA) and PLA/cellulose nanocrystal (CNC)-blown films in extending the shelf-life of crackers, a moisture-sensitive food product, was assessed. The shelf-life of the crackers, defined as the time required by the product to reach its critical moisture content (CMC) of eight percent, was determined experimentally from moisture content versus storage time plots at a constant temperature (25°C) and various conditions of relative humidity. Neither crackers within PLA nor PLA/CNC packages reached the CMC when stored below 50% relative humidity at 25°C, indicating that crackers packaged in both films were shelf-stable at these conditions. Above this relative humidity, the crackers inside both packages reached the CMC at different times; however, crackers in CNC-based packages had approximately 40% longer shelf-life than those in neat PLA packages.

Wildland fire may be more sensitive than we think

Wildland fires occupy the biosphere as both an ecological process essential for maintaining species diversity and a hazard to human lives, infrastructure, and activities. Our ability to anticipate fire behavior is key to maximizing ecological value of fire while simultaneously minimizing negative impacts. Predictive models are often called upon as tools to aid in forecasting potential outcomes. However, prediction of fire behavior is complicated by the fact that small changes in environmental conditions can have large impacts on wildfire outcomes. This is most evident in marginal burning conditions, like prescribed fire, where fine-scale details have been observed to drastically influence resulting fire behavior. FPL scientist Kara Yedinak, along with colleagues from Los Alamos National Laboratory have begun quantifying the sensitivities of wildfire behavior to small changes in atmospheric conditions using FIRETEC, a process-based, computational fluid dynamics model of fire-atmosphere interactions.

Repeat (ensemble) simulations are used to sample small changes in the turbulent wind field over evenly distributed grass. Characteristics of the turbulent atmosphere are probed to better understand mechanisms that may influence fire behavior. Overall spread is quantified using a variety of metrics to look for clustering and diverging behaviors. The results indicate a sensitivity to perturbations that show less predictability as the burning conditions grow more marginal.

Soft-story seismic isolation with elliptically profiled CLT

Curvilinear cuts to CLT panels and steel connections transform the wall system into a form of soft-story isolation that may buffer buildings from sustaining damage, even in major earthquakes.

Cross-Laminated Timber shear wall seismic force resisting system in U.S. codes

Cross-Laminated Timber (CLT) offers several advantages to the wood building market, such as the potential for mass production, prefabrication, construction speed, and sustainability as an environmentally friendly and renewable construction product. Good thermal insulation, acoustic performance, and fire ratings are some additional benefits of the system. Despite these advantages, the lack of a current design approach is one of the challenges inhibiting widespread adoption of CLT in North America. One area that required attention was the development of a CLT lateral shear wall system that can be used in seismic and high-wind regions of the United States. CLT shear wall-based Seismic Force Resisting Systems (SFRS) are not recognized in current U.S. design codes.

A five-year systematic research effort integrated a suite of CLT building archetypes, a new design methodology, both component and systems tests, nonlinear static and dynamic structural modeling, and incremental time history analyses and incorporated uncertainties. All phases of development resulted in both the structural design procedure and associated seismic design parameters that led to a code changes proposal at the Building Seismic Safety Council (BSSC), American Wood Council (AWC), and American Society of Civil Engineers (ASCE).

Performance of structural insulated panel walls under seismic loading

Structural insulated panels (SIPs) are strong and energy-efficient construction systems that use the strength of wood structural panels and the energy attributes of foam plastic insulation to provide cost-effective solutions for compliance with governing building codes. However, the acceptance of SIPs by many design professionals has been hindered by the lack of a systematic evaluation of their lateral load performance in wall applications.

This research established the test data needed to characterize the lateral load performance of SIP walls with full bearing on a sill plate and a cap plate (restrained) under cyclic loading. The program involved structural testing of 54 full-sized SIP walls of various configurations that bracketed a range of SIP wall configurations commonly used in the field. Single-wall configurations were evaluated with and without hold-downs.For broad acceptance of SIPs in high seismic regions, hysteric models are critical for nonlinear time history analysis. Data generated in this study was used to determine the 10 parameters for the modified Stewart models.

Based on experiments of SIP wall configurations with openings, it is justified for engineers to use the traditional Perforated Shear Wall approach to predict stiffness and strength of these wall arrangements. Finally, lateral load resistance of single-panel SIP walls with aspect ratios of 1:1, 2:1, and 3:1, and five-panel SIP walls without openings, satisfied the cyclic performance parameters of overstrength, drift, and ductility capacities, as defined in

ICC-ES acceptance criteria AC04 and ASTM D7989, which is equivalent to light-frame walls. This analysis has been presented and is currently under review by the ICC-ES staff for acceptance.

Determining char rates of exposed glulam columns to a three-hour standard fire

The fire resistance of a structural building member consists of its ability to survive a specified fire, in both exposure and duration, without loss of its loadbearing function. For exposed mass timber, the ability to endure a fire includes the development of a char layer that protects the unburned wood. The rate at which the char layer forms as the thermal wave moves deeper into the wood is known as the char rate. Char rates are then used to calculate the residual load-bearing cross section to appropriately size wood structural members. The current calculation method relies on an empirically derived char rate of 1.5 inches/hour, which was obtained from numerous standard fire tests and has only been verified for fire resistance ratings of two hours or less.

Currently, mass timber structural members are required to be protected with layers of non-combustible fire protection, such as gypsum board, to achieve a three-hour fire resistance rating required in high-rise buildings. However, over the past decade there has been a push toward greener buildings utilizing mass timber elements and a desire by designers to leave the wood exposed rather than covering it with non-combustible protection. To achieve this, the char rates of glue-laminated timber to use in the fire resistance calculations of up to three hours were needed.

Forest Service scientists and partners exposed nine glue-laminated columns to the standard fire for three hours in an intermediate-scale furnace. Three types of columns were tested in triplicate, all without non-combustible protection. The columns were highly instrumented with thermocouples to obtain the thermal profile during the exposure period. Both the temperature profiles and the final cross-sections used calculated a char rate for glulam at three hours. The fire test results provide a verified char rate needed to calculate the amount of outer sacrificial char layer to obtain a three-hour rating. This can be used to inform engineering analyses of exposed mass timber in high-rise mass timber structures, further increasing the adoption of mass timber in the United States.

United States Forest Products Annual Market Review and Prospects, 2015-2021

The U.S. began 2020 on firm economic footing, but by June, COVID-19's effects on world health, and U.S. and world economies, were becoming apparent. The FOMC revised their 2020 U.S. GDP forecast to minus 3.7 percent and the FRBP-SPF projected it at negative 5.2 percent. COVID-19's negative effects on employment were greater than those from the Great Recession.

U.S housing markets continued their steady, but gradual, recovery in 2019 and into 2020. In spite of COVID-19's devastating effects, new housing construction is a bright spot for the U.S. economy. In the first-half of 2020, total starts were 2.3 percent greater and single-family starts were minimally less (0.3 percent) than reported for the same period in 2019. New house sales in 2020's first-half were nearly 690,000 units and this was 2.8 percent more than the first-half of 2019. R&R's expenditure volume surprised most and improved more than 15 percent from 2019's first-half. The shelter-in-place or work-at-home orders resulted in a positive effect on the R&R subsector and may lead to changes in residential design and nonresidential construction.

The shelter- or work-at-home orders are a double-edged sword – consumer paper products recorded large purchase increases, while office paper products were the opposite. In 2019, several wood product categories production and consumption volumes were negligibly less than in 2018 – other categories reported moderate

declines. Softwood lumber production and consumption both increased year-over-year in 2019. Composite panel products; hardwood plywood; and furniture consumption also increased from 2017 to 2018. Wood pellet production and sales continue to increase. One factor for the increase is that several Euro nations have invested substantially in pellet facilities for the generation of electricity. Conversely, sawn hardwood production and consumption decreased for the second consecutive year; structural panel production and consumption was minimally less than 2018; paper and paperboard production remain in a decade long decline; pulpwood consumption decreased for the fifth year in a row; and furniture production declined from 2018 to 2019. Softwood lumber exports decreased in 2019, due to trade tensions, decreasing demand, and a surge in Central European exports.

6.7. Forest Service Decision-Support Tools and Data

A decision support tool (decision support system (DSS)) is a computer-based information system that supports business or organizational decision-making activities. Decision support tools serve the management, operations, and planning levels of an organization (usually mid and higher management) and help people make decisions about problems that may be rapidly changing and not easily specified in advance—i.e., unstructured and semi-structured decision problems. Decision support systems can be either fully computerized, human-powered, or a combination of both. All aspects of forest management, from log transportation and harvest scheduling to sustainability and ecosystem protection, have been addressed by modern decision support tools. In this context, the consideration of single or multiple management objectives related to the provision of goods and services with tradeoffs that need to be factored into decision making.

Although a number of Forest Service tools have been developed, IT modernization and cybersecurity needs require tools to be checked by the Chief Information Office to receive approval to be used on USDA-imaged computers. Major decision support tools include:

- LANDIS II Landscape Disturbance and Succession model - LANDIS is designed to model forest succession, disturbance (including fire, wind, harvesting, insects, global change), and seed dispersal across large (>1 million ha) landscapes. Hosted by partners; (https://www.landis-ii.org/)
- Invasive Plants in Southern Forests App - This app provides information on accurate identification of the 56 nonnative plants and groups that are currently invading the forests of the 13 Southern States. Recommendations for prevention and control of these species are provided. App hosted by partners; https://apps.bugwood.org/apps/southern-forests/
- i-Tree – i-Tree is a state-of-the-art, peer-reviewed software suite from the USDA Forest Service that provides urban and rural forestry analysis and benefits assessment tools. The i-Tree tools can help strengthen forest management and advocacy efforts by quantifying forest structure and the environmental benefits that trees provide. Since the initial release of the i-Tree Tools in August 2006, thousands of communities, non-profit organizations, consultants, volunteers and students around the world have used i-Tree to report on individual trees, parcels, neighborhoods, cities, and even entire states. By understanding the local ecosystem services that trees provide, i-Tree users can link forest management activities with environmental quality and community livability. Whether your interest is a single tree or an entire forest, i-Tree provides data that you can use to demonstrate value and set priorities for more effective decision-making. Hosted by partners; https://www.itreetools.org/

• EMDS - The system provides decision support for landscape-level analyses through logic and decision engines integrated with the ArcGIS geographic information system. The NetWeaver logic engine evaluates landscape data against a formal logic specification designed in the NetWeaver Developer system, to derive logic-based interpretations of ecosystem conditions. The decision engine evaluates NetWeaver outcomes, and data related to the feasibility and efficacy of land management actions, against a decision model for prioritizing landscape features built with its development system, Criterium DecisionPlus (CDP). CDP models implement the analytical hierarchy process, the simple multi-attribute rating technique, or a combination of the two methods. The system has been used in a high variety of applications. (https://www.fs.usda.gov/pnw/tools/ecosystem-management-decision-support-emds-system)

• FireFamilyPlus (FF+) - is a software package used to calculate fuel moistures and indices from the US National Fire Danger Rating System (NFDRS) using hourly or daily fire weather observations primarily from Remote Automated Weather Stations (RAWS). NFDRS use is mandated for fire preparedness and response decisions by all Federal and most State agencies and is operationally run with USFS FAM Weather Information Management System (WIMS). (https://www.firelab.org/project/firefamilyplus)

• Forest Vegetation Simulator (FVS) - Forest Vegetation Simulator (FVS) is a family of forest growth simulation models. https://www.fs.fed.us/fvs/

• The Hot-Dry-Windy Index improves fire weather forecasting - A new tool helps fire managers anticipate when wildfires could become erratic or dangerous. Hosted by partners; https://www.hdwindex.org/

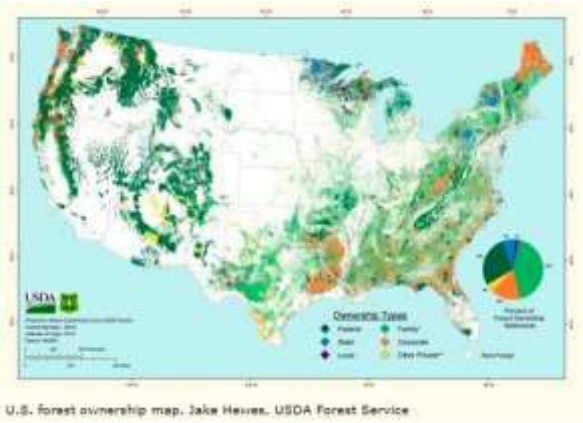
Data – Forest Service Research Data Archive (FSRDA)

The FSRDA was created in 2010 to publish and preserve digital scientific data collected from studies funded by Forest Service R&D and the interagency Aldo Leopold Wilderness Research Institute. In 2012, its scope expanded to the interagency Joint Fire Science Program (JFSP). To date, ~25% of FSRDA publications are from JFSP-funded studies. In 2019, a pilot project was initiated to provide publishing support for USDA APHIS' National Wildlife Research Center. FSRDA actively works with the network of Forest Service Experimental Forests, Ranges, and Watersheds to publish and preserve the highly valuable data from their long-term studies. This work frequently involves converting paper-based historical data into modern digital formats and assembling metadata on the data from study notes, interim reports, and scientific articles.

FSRDA released 118 new data publications in FY2021. Data publication downloads increased 32% relative to FY 2020. This is the tenth consecutive year of substantive increases in the customer base. Interest in western wildfires was reflected in strong interest in FSRDA data publications describing wildfire occurrence, wildfire hazard potential, and wildfire risk to communities. This interest appeared as downloads and use of these publications on third party websites that presented value-added content.

FSRDA staff help to coordinate the availability of Forest Service R&D-created datasets to NFS users via the Forest Service Enterprise Data Warehouse. Based on user data, publications are being used by the private sector for determining insurance premiums (fire occurrence dataset), by higher education as part of data science training, and by various state and local governments (e.g., the State of New Mexico's web site presents fire data from one of the FSRDA publications).

6.8. Who Owns the Forest?


U.S. forest ownership map. Jake Heaves. USDA Forest Service

Contrary to popular belief, nearly two-thirds of forests in the conterminous United States are privately – not publicly – owned. The distribution of ownership is 43 percent family, 28 percent federal, 16 percent corporate, 7 percent state, and 4 percent other private land (which includes Native American tribal ownerships). By showing the distribution of forest ownership, the *Forest Ownership Map of the Conterminous United States,* developed by the Northern Research Station Forest Inventory and Analysis program, promotes the development of policies that support the conservation and wise management of public and private forests.

More than half the forest land in the United States is owned and managed by some 11 million private forest owners. These working forests benefit us all. Private forest lands:

- supply nearly 30 percent of the water we drink as well as provide clean air, fish and wildlife habitat, and significant recreation opportunities;
- provide over 90 percent of our domestically produced forest products, including the timber needed to build homes and fuel wood for heating them;
- support 2.4 million jobs primarily in rural communities; and
- contribute to our nation's energy security, housing, and infrastructure.

6.9 State & Private Forestry

Encompassing two thirds of America's forests, state- and privately-owned lands provide public benefits such as clean air, clean water, wildlife habitat, outdoor recreation, and most of the nation's wood supply. These forests face many threats, including wildland fire, invasive species, pests and disease, and the permanent loss of working forest land to non-forest uses. S&PF helps ensure that forest landowners have the best technical, educational, and financial assistance available to achieve their unique objectives and to keep forests working for all of us. Below are just a few examples of S&PF technology transfer projects.

Tribal Relations

The Tribal Connections Viewer is a new geographic information systems tool available to Forest Service staff, tribes, and others that provides a visual, interactive map that shows where and how lands managed by the Forest Service connect or overlap with current tribal trust lands. Nearly 4,000 miles of shared boundaries between tribal lands and Forest Service-administered/owned land are identified. Tribes and the Forest Service can now engage in shared land management activities across administrative boundaries and at larger landscape scales than was previously possible. This online resource helps to promote sound management of protected areas through conservation efforts, capacity-building activities, and education initiatives. The accuracy of the tool is being continuously refined through input provided by users from tribal nations, who will note where corrections should be made, in comparison with their own local data.

The Tribal Connections Viewer improves data-based decision making on incidents and in resource management for both tribes and the agency; encourages meaningful consultation and collaboration with tribal partners; shares

technology and knowledge across boundaries and borders; honors treaty rights and the federal trust responsibility; and identifies opportunities for new and expanded partnerships between tribes and the Forest Service; or collaboration on conservation projects and programs. The Tribal Connections Viewer uses the most current data available from the U.S. Census Bureau, Forest Service, Smithsonian Institution, and other sources to provide current and historical details, such as historic treaties, for each location on the map. Housing this information in one, easily available online resource will improve the efficiency of Forest Service-tribal coordination, collaboration, and consultation.

Wildland Fire

Wildfire season is now year-round and, regardless of where they start, wildfires impact thousands of communities at the wildland-urban interface. Helping communities in fire-prone areas prepare for wildfire reduces impact on those communities, has the potential to reduce suppression needs, and helps protect civilian and firefighter lives. Addressing the impacts of wildfire on communities is an all-lands-all-hands effort. Some examples are:
Community Fire Adaptation – Federal, state, and local governments partner with non-profits, fire departments, and other stakeholders to reduce wildfire risk locally through mitigation best practices. The Forest Service has developed best practices to enable effective, efficient, and sustainable mitigation efforts locally. Those best practices are based on the best-available science, supported by experience on the ground, and shared with communities and partners nationwide.

Wildland-Urban Interface Research – Work to reduce community wildfire risk by the Forest Service and its partners is based on science and verified by experience. Partners like the JFSP, the Insurance Institute for Business and Home Safety, the various Forest Service Research Stations, and Forest Service fire scientists form the foundation of best practices. As an example, the Forest Service, states, and partners have long thought messaging through public service advertising, literature distribution, and social media was the route to mitigation actions on the ground. Research supported by experience has shown that this is not the case. Messaging may help people become aware of their wildfire risk, but it is not a key factor in spurring them to take action to reduce risk. That takes one-on-one, face-to-face engagement at the local level and building trusted relationships. Sharing that information in an effort to change the approach to community wildfire mitigation is key to accomplishing risk reduction on the ground.

The Community Mitigation Assistance Team (CMAT) concept was piloted in 2015 and is now a standing resource for communities impacted by wildfire. The teams use the teachable moment of smoke in the air, high fire activity, or high fire risk to work collaboratively with community leaders to share best mitigation practices, help form local mitigation partnerships or coalitions, and plan effective and efficient mitigation programs that can live on in the community long after a wildfire or the deployment of the CMAT. The CMAT has worked with communities and helped mitigation coalitions in association with the Bridger-Teton National Forest, Rogue River-Siskiyou National Forest, Pisgah National Forest, Pike and San Isabel National Forests, and the Okanogan-Wenatchee National Forest. The CMAT has also developed a stand-alone Community Mitigation Academy best mitigation practices course that is available to states or regions at no cost, to share the most effective ways to reduce community wildfire risk and to build a local cadre to accomplish on-the-ground mitigation.

Working with Partners – Internal and external partners are key to getting work done in communities and to sharing the latest effective methods to accomplish risk reduction. An important long-term partner has been the National Association of State Foresters. In addition, the Forest Service continues to increase technology transfer through important partnerships with career and volunteer fire departments nationwide. Work with the National

Volunteer Fire Council helps share best practices for assessing homes and communities for wildfire risk and ways to share that information with residents:

The FAC Learning Network – out of which grew a collaborative effort with the Forest Service, The Nature Conservancy, and The Watershed Center. The FAC Learning Network's mission is to connect and support people and communities who are striving to live more safely with wildfire. The Network is a catalyst for spreading best practices and innovations in fire adaptation concepts nationwide. The purpose of the FAC Learning Network is to exchange information, collaborate to enhance the practice of fire adaptation, and work together and at multiple scales to help communities before, during and after wildfires.

The Fire Adapted Communities Coalition was formed in 2009 and still functions primarily as a technology transfer, information sharing effort among partners (and their individual audiences) engaged in community wildfire mitigation efforts. Coalition partners share their successes and the work they are doing to help communities reduce risk, and work to collaborate for efficiency and innovation across programs. Coalition members use webinars (recorded for later access), social media, videos, face-to-face learning sessions (also recorded), and workshops to share best practices. Fire Adapted Communities Coalition members are the Forest Service, the National Association of State Foresters, the National Volunteer Fire Council, The Nature Conservancy, The Watershed Center, the Insurance Institute for Business and Home Safety, the National Fire Protection Association, FEMA, U.S. Fire Administration, Department of the Interior bureaus, and the International Association of Fire Chiefs.

Forest Health Protection

The Forest Health Protection (FHP) Program works through partnerships across all lands, providing forest insect, disease, and invasive plant survey and monitoring information, and technical and financial assistance to prevent, suppress, and control outbreaks threatening millions of forested acres across the nation. Within FHP, the Forest Health Monitoring program is designed to determine the status, changes, and trends in indicators of forest condition on an annual basis, providing data to guide land managers in maintaining, enhancing, and restoring healthy forest conditions. FHP conducts aerial surveys and uses remote sensing to assist federal and state partners and the public, and to guide forest management actions to improve forest health. The FHP program also uses data from ground plots and surveys, and other biotic and abiotic data sources, and develops analytical approaches to address forest health issues that affect the sustainability of forest ecosystems. These efforts make scientific data available to land managers and states to reduce the risk and impact of damage caused by insects and diseases.

FHP recently completed a 2018 update of the National Insect and Disease Risk Map (NIDRM) and has facilitated transfer of these digital data to states in support of the 2020 State Forest Action Plan updates. The NIDRM provides a nationwide strategic assessment of the risk of tree mortality caused by insects and diseases. Values at risk in the NIDRM represent the expectation that, without remediation, 25 percent or more of the standing live tree basal area will die over a 15-year (2013 to 2027) time frame due to insects and diseases. The 2018 update depicts areas where recent significant tree mortality events have occurred, removing these areas from at risk conditions. Since 2012, upon completion of the last NIDRM, major tree mortality events from forest pest outbreaks, fire, and broad-scale forest harvesting operations have reduced or, in some cases, eliminated risk. A major tree mortality event was defined as one or more of the following:

- areas depicted as forest cover loss in the University of Maryland Global Forest Change dataset;
- three or more years of mortality mapped in aerial detection surveys; or

- in the eastern United States only, three or more consecutive years of defoliation mapped by aerial detection surveys.

The 2018 update does not account for increases in risk due to recent tree growth and increased density, which can render additional trees susceptible and vulnerable to new forest pest attacks.

NIDRM provides the following in support of State Forest Action Plans:

- A spatially explicit dataset of areas at risk for experiencing 25% or more tree mortality from insects and diseases through 2027.
- A critical portion of the timetable of forest health, by linking historical aerial detection survey data to future projections of mortality events associated with forest pests.
- A baseline for monitoring the current and potential extent of new and existing forest insect and disease threats.
- Early identification of areas with potential for new forest health threats to help prioritize management activities and increase the affordability and effectiveness of control strategies.
- Improved communication and awareness of forest health threats.

Urban & Community Forestry

The Forest Service is a proud partner in restoring and sustaining America's community forests. The Urban & Community Forestry (UCF) Program supports forest health for all our nation's forests, creates jobs, contributes to vibrant regional wood economies, enhances community resilience, and preserves the unique sense of place in cities and towns of all sizes. By working with state partners to deliver information, tools and financial resources, the UCF Program supports fact-based and data-driven best practices in communities – maintaining, restoring, and improving the more than 140 million acres of community forest land across the United States. Learn more about how the UCF program supports a thriving America. The Forest Service has a long history – well over three decades – of delivering urban forestry research, technology, and information to partners, stakeholders, and customers. In FY 2019, the UCF Program provided technical or financial assistance to more than 7,755 communities across the United States. Sharing Forest Service knowledge and tools is essential to improving the management and long-term sustainability of urban ecosystems. Partners and customers, including 63 state and territory forestry agencies, more than 35 national partners, more than 150 community tree groups, private industry, academic institutions, and municipalities, are asking the Forest Service to continue providing much-needed science and technology delivery services. This demand is increasing as the audience and customer base expands to new user groups such as public works, planning, sustainability, and public health and safety professionals. The demand is also evolving as we aim to be more effective in reaching a diverse audience in communities of all sizes, and as information sharing becomes more essential. To best serve customers, the Forest Service formed the UCF Technology and Science Delivery Team in 2014. This team is made up of S&PF UCF Program Managers and Forest Service R&D personnel from around the country. The group's focus is on ensuring Forest Service urban forestry staffs are strategic, skillful, creative, and nimble in our science delivery efforts. The team employs a contemporary technology transfer approach to reach diverse audiences, and to coordinate across deputy areas, regions and stations to ensure that we are sharing information that is timely, relevant, and easy to access, understand, and use.

Priorities, tasks, resource allocation, partnerships, program direction, performance measures, and accountability at all levels of the UCF Program align with the seven goals outlined in the collaboratively developed Ten-Year Urban Forestry Action Plan (2016-2026):

1. Planning
2. Human Health
3. Diversity, Equity and Leadership
4. Environmental Health
5. Management
6. Funding
7. Education and Awareness

Important new UCF-supported resarch includes:

Trees Cool Cities and Save Human Lives

Heat-related deaths are a major concern as more frequent and severe heat waves threaten U.S. cities. Forest Service scientists worked with external partners to develop a tool that calculates how much tree cover can help. The team estimates 3,800 fewer deaths in New York City with a 10% increase in tree cover! This tool will be essential for urban planners in efforts to mitigate climate change and promote environmental justice and equity. This work also builds on a previous study that found tree canopy cover could mitigate premature heat-related deaths in Philadelphia.

Wood Innovations in Building

Wood may be one of the world's oldest building materials, but it is also now one of the most advanced, and the Forest Service is playing a critical role in providing assistance to state, tribal, local, and private entities on how to incorporate wood as a green building material. By building stronger markets for innovative new wood products, the Forest Service is supporting sustainable forest management, helping to reduce greenhouse gas emissions, and putting rural America at the forefront of an emerging industry. One key avenue for providing technical assistance around the use of wood in building is through a partnership with WoodWorks.

WoodWorks, an initiative of the Wood Products Council, provides free, one-on-one technical support to architects and engineers on wood building design. Through partnerships with the Forest Service, major North American wood associations, and other organizations, WoodWorks promotes the construction of wood buildings. WoodWorks provides technical expertise on a wide range of building types, including schools, mid-rise/multi-family, commercial, corporate, franchise, retail, public, institutional, and more. The $2 million contributed by the Forest Service in 2017 leveraged an additional $4.5 million from the wood industry and the Canadian government, allowing significantly greater impact than could have been achieved independently. WoodWorks hosts yearly conferences across the country and provides workshops and training opportunities on a range of topics to expose architects and engineers to wood design. WoodWorks has directly or indirectly influenced the use of wood in over 500 buildings.

Owner Assistance

The Forest Service cooperates with researchers and partners to understand landowner behavior and develop technical assistance programs that meet the interests and management needs of America's non-industrial private

forest landowners. Through investments in the National Woodland Owners Survey, the Reforestation Nurseries and Genetic Resources program (RNGR), National Seed Lab, and the National Agroforestry Center, S&PF advances technology transfer. RNGR, a unique and innovative collaboration across Deputy Areas, provides science-based technical expertise to 1,400 native plant nurseries. RNGR helps plant professionals respond to ever-increasing demand for high-quality, ecologically appropriate plant materials to address climate change, invasive species and pests, habitat loss, and post-wildfire restoration. In addition, RNGR employs contemporary technical transfer approaches to reach diverse audiences including federal, state, private, tribal, and international professionals through webinars, the Native Plant Propagation Protocol database, *Tree Planters' Notes* (international applied journal focused on plant production and establishment), and a website with over 70,000 downloads annually of articles pertaining to reforestation, restoration, and native plant production.

The Forest Legacy, Community Forests and Open Space, Landscape Scale Restoration, and Forest Stewardship Programs ensure information sharing on forest management and conservation is timely, relevant, and easy to access and use for partners, including federal, state and local agencies, tribes, non-profit organizations, and university extension programs. The Forest Legacy program has online implementation tools and is developing a resource library for states and other partners. The Forest Legacy Program also supports the Land Trust Alliance's Learning Center that provides critical permanent forest land conservation information through online resources, webinars, and courses to over 900 land trust organization members.

In FY2019, the Forest Stewardship Program, through state forestry agencies, provided technical assistance to over 602,000 private forest landowners. Through a partnership with the Forest Service, Yale University's Tools for Engaging Landowners Effectively (TELE) helps federal, state and local agencies, university extension, and non-profit organization staff to address complex conservation challenges using targeted marketing tools and techniques. Hosting more than 50 workshops in 39 states and Guam, TELE has trained more than 1,500 people representing over 500 organizations and leading to 15,000 landowners taking management actions on more than 730,000 forested acres. In FY2019, TELE developed online tools for natural resource professionals to foster peer-to-peer learning and streamline implementation of the TELE approach. Tools include marketing tips, lessons learned, a facilitator's guide, and a landowner engagement guide – a complete resource to designing landowner programs and communications.

Conservation Education

Forest Service Conservation Education helps people of all ages understand and appreciate our country's natural resources and learn how to conserve those resources for future generations. Through structured educational experiences and activities targeted to varying age groups and populations, conservation education enables people to realize how natural resources and ecosystems affect each other and how resources can be used wisely. Through conservation education, people develop the critical thinking skills they need to understand the complexities of ecological problems. Conservation Education also encourages people to act on their own to conserve natural resources and use them in a responsible manner by making informed decisions. Forest Service Conservation Education is part of the advisory board of the Conservation Education Works project, developed by the North American Association for Environmental Education and Stanford University, which is designed to demonstrate the impact and value of environmental education by substantiating powerful anecdotes from across the professional field with empirical evidence. The project is conducting comprehensive literature reviews that demonstrate the impact of environmental education on key environmental and social outcomes and is translating findings into communication tools to benefit researchers, educators and land users..

For more than a decade, Conservation Education has partnered with Prince William Network to bring nature learning to classrooms through technology, including webcasts and webinars, and hosting online education materials. Under the FSNatureLIVE banner are numerous "LIVE" projects, each arranged around a theme and housed in a dedicated website, complete with broadcast links, associated curriculum, and classroom grant opportunities. Recent projects include FreshWaterLIVE, WetlandsLIVE, and GrasslandsLIVE.

The Latino Legacy Youth Leadership in Nature Challenge and Green Ambassador Model is an outdoor leadership training program that hosts approximately 20-25 diverse youth per session. The program serves first- and second-generation students of diverse ethnic backgrounds. This week-long connection with nature and natural resource career opportunities has provided visits and one-on-one networking with major Hispanic-serving institutions, state universities, agricultural colleges, and governmental agencies.

The Natural Inquirer publications focus on STEM education, targeting 5th-8th grade students. Hardcopy and digital publications are available to students and educators. These publications educate students about research generated by the Forest Service, engage youth in STEM education, and inspire youth to pursue science-driven careers. Scientist cards present information on specific Forest Service scientists from many different backgrounds, and many of the cards, which inspire young conservation leaders in the pursuit of natural resource related careers, are translated into Spanish.

Partnering with the National Environmental Education Foundation, the Forest Service reaches underserved children and their families through health care providers with prescriptions to recreate in parks and forests near their homes with an emphasis on underserved areas of the country. Over 880 health care providers have been trained about the health benefits of nature and have written over 1,000 prescriptions for outdoor activity. They have also created digital applications for outdoor activity to help motivate technology-bound children to get outside.

7.0 Water

National Forests are the most important source of water in the United States. The annual value of water flowing from Forest Service lands has been estimated at $7.2 billion. More than 60 million Americans – including residents of cities such as Atlanta, GA; Denver, CO; and Portland, OR – rely on drinking water that originates on National Forests. In a sense, the Forest Service is the nation's largest water company.

Forests provide people with clean, reliable drinking water. But these waters are at risk due to the needs of growing human populations, continued conversion of forests to other land uses, and anticipated changes in climate conditions. Given such threats, it is important to understand how much drinking water originates in forests, which populations and communities are served, and how best to regulate water quality through proper watershed management. Recent important technical transfer examples include:

- A 2014 report published by the Southern Research Station showed that clean water begins in National Forests for over 19 million people in the South – roughly equivalent to the population of Florida. The report provides information at a level not previously available on the amount of surface drinking water provided by National Forest lands to communities in the South. This information can help support partnerships among state, federal, and non-governmental organizations that work to conserve the forest cover that provides the region's clean, dependable water supplies.

How Forests Provide Clean Water

Small headwater streams determine the water quality of the larger rivers, lakes, and reservoirs that they flow into. Researchers used data from Hubbard Brook Experimental Forest to study the pathways water takes from the time it lands as rain until it reaches a headwater. By tracing water isotopes, they found that the median time it takes rainwater to reach a stream ranges from 50 days during wet periods to 190 days during dry periods. The team took it one step further and measured changes in the concentrations of dissolved substances that naturally occur in water, such as calcium, and are often what make water hard or soft. They found that not only does the amount of time water spends flowing through forest soils determine how much a forest filters the water removing dissolved substances, thereby impacting water quality. Research like this could potentially help land managers target specific areas of a forest that provide the most filtration services for restoration or conservation to improve a forest's water filtering capabilities.

Best Management Practices Improve Water Quality and Save Money

Whether developing camp sites for visitors or restoring stream habitats, work on National Forests often involves disturbing the ground, which creates opportunities for sedimentation and other negative water quality impacts. Best management practices are techniques that help control and reduce water pollution and protect aquatic ecosystems.

Forest Service scientists pioneered the first national program to strengthen implementation and monitoring of best management practices used to protect water quality from the diverse range of ground disturbing and management activities that occur on national forest system lands. The national best management practices monitoring program provides consistency for evaluating implementation and effectiveness across all National Forest System units, which, in turn, allows the Forest Service, for the first time ever, to report national performance results to regulatory agencies, states, tribes, other stakeholders, and the public. The consistency of the monitoring program is expected to result in improved water quality and millions of dollars of savings through simplified and streamlined monitoring approaches that contribute to the success of both local and national adaptive management strategies.

7.1. Fire & Fuels Technology Updates Fire and Aviation

The results of Forest Service fire research help society address the ongoing challenges of living with wildland fire. The results of Forest Service fire research come in many forms, from user-friendly software and data, to real-time support-trained analysts on active wildfires, to educational materials for school children.

Research Highlights

Smoke forecasting systems: Even low-intensity prescribed fires can have adverse effects on air quality and human health. Smoke modeling tools integrate meteorological data, cutting edge smoke science, and fire behavior predictions to help fire managers schedule essential prescribed burns to minimize these health impacts.

Decision support for treating wildland fuels: Forest Service research provides methods to answer questions such as:

- Which communities are most at risk to fire?

- What fuel treatments will be most effective at reducing the risk of severe fire?
- How can forests be restored to a healthier condition where fire plays a positive role?
- How and where should scarce funds be best invested to reduce the negative consequences of fire?

Fire and fuels research provides the scientific foundations to a *National Cohesive Wildland Fire Management Strategy*, a cross-jurisdictional strategy to restore resilient landscapes, create fire-adapted communities, and respond to wildfire.

Smoke Updates

AirNow is used by air resource advisors to model and create public smoke forecasts, compliant with S.47 Dingle Act of 2019.

Monitoring 4.1 is another tool used to analyze the trends in particulate matter produced during wildfire events that assists in forecasting impact areas and advising precautions to public health.

Risk Assessment & Vegetation Mapping Tools

LANDFIRE includes updated layers and development of an analysis tool.

Fire Sciences Laboratory (list) https://www.fs.fed.us/research/wildland-fire/

7.2. Science Delivery by the R&D Washington Office and Field Research Stations

R&D's Washington Office provides leadership, conducts strategic planning, and ensures scientific integrity. Washington Office R&D program staff also develop national research policy priorities and directions and communicate them to resource planners and land managers within the agency, as well as to other government agency employees, academics, personnel from nonprofit organizations and industry, and the public.

Inventory, Monitoring, and Assessment Research

Through data collection, analysis and research, Inventory, Monitoring, and Assessment (IMAR) produces the authoritative information to inform strategic-level decision making related to forest management and conservation, forest policy and forest investments. IMAR also provides the expertise in enhancing earth observation methodologies ranging from global to local scales. IMAR products are key for assessing forest sustainability and provide a basis for analysis and research at multiple scales. The information is used by a broad spectrum of interests and communities, including forest owners; county, State, Federal, and Tribal leaders; non-governmental interest groups; investors; and private firms.

IMAR work focuses in four areas: (1) Forest Inventory and Analysis Program (FIA); (2) Resources Planning Act (RPA) Assessment; (3) Sustainability Assessment: and (4) Remote Sensing and Geospatial Analysis Research. In partnership with Forest Service International Programs, IMAR also provides leadership and coordination for international monitoring and assessment activities to the United Nations Food and Agriculture Organization's (FAO) Global Forest Resource Assessment, the FAO North American Forestry Commission, the United Nations (UN) Economic Commission for Europe Committee on Forests and the Forest Industry, the UN Forum on Forest, the Canadian Forest Service, and various U.S. agencies for international development activities.

Forest Inventory and Analysis Program

Since 1930, the Forest Inventory and Analysis (FIA) program has been building the largest continuous dataset on forest resources in the world. Through consistent inventory processes, FIA data are widely used to address local and regional issues related to trends in forest extent, health, and productivity; land cover and land use change; the changing demographics of private forest landowners; and industrial and non-industrial uses of timber. Forest inventories have expanded their primary supporting role in decision making from forest products and economic development in the last century to a wider range of ecosystem services today, including carbon, water, recreation, wildlife habitat, biodiversity, and human health. Hundreds of public and private entities – from state forest agencies to academic institutions to timber management companies – rely on FIA to generate authoritative protocols and data, conduct applicable research, and operate businesses.

Despite the unprecedented difficult circumstances caused by the COVID-19 pandemic, hazardous conditions and poor air quality induced by a devastating wildfire season, and staff shortages due to hiring limitations, the FIA program conducted inventory activity in all 50 States, including Interior Alaska, and U.S. islands. Field plots have been collected on approximately 91 percent of the U.S. forestlands, with the remaining 9 percent in parts of interior Alaska yet to be surveyed and only accessible by air. Although plot-based field surveys provide information concerning existing forest conditions, additional surveys such as the timber product output (TPO) provide information on commercial product generation and the National Woodland Owner Survey (NWOS) on the characteristics and management objectives of the Nation's private woodland owners.

Resources Planning Act Assessment

Leads the Resources Planning Act (RPA) Assessment, conducting research on the current status and trends and projected futures of forest and rangeland renewable resources. The RPA Assessment is mandated by the Forest and Rangeland Renewable Resources Planning Act of 1974, covering resources on all ownerships. The Assessment examines how the interaction of socioeconomic and biophysical drivers affects the productivity of forest and rangeland ecosystems and their ability to meet increasing demands for goods and services, including analyses of forests, rangelands, forest products, wildlife and fish, biodiversity, water, outdoor recreation, carbon, land use, and urban forests. The 2020 RPA Assessment is currently anticipated to be released by the end of 2022.

Sustainability Assessment

The Sustainability Assessment program conducts research on criteria and indicators of forest sustainability (54 indicators in total). It uses existing sources to compile data to populate specific indictors at a national aggregate level, and it uses these to provide a comprehensive picture of forest conditions in the United States as they relate to the ecological, social, and economic dimensions of sustainability. Forest sustainability is directly tied to the Forest Service's core mission. Understanding whether forests are sustainable at the national level is important because such understanding is needed to guide national policy formulation, it can take a long time to improve forest conditions, and trade of wood products domestically and internationally increasingly expects sourcing from sustainable forests.

The United States is updating its National Report on Sustainable Forests, last compiled in 2010. The report uses a criteria and indicators framework (The Montréal Process Criteria and Indicators) for describing forest conditions and their associated values, characterizing the essential components of sustainable forest management. These internationally agreed-upon criteria and indicators were developed collaboratively with other Montreal Process member countries as a shared response to the pressing need for sustainable forest management.

Remote sensing and geospatial analysis research

IMAR staff provides advocacy of field researchers' work in remote sensing and geospatial analysis research broadly at multiple spatial scales in boreal, temperate, and tropical forest ecosystems. Research scientists serve on NASA's Landsat Science Team, coordinate the biomass estimation function of NASA's GEDI (Global Ecosystem Dynamics Investigation) mission, and serve on Carbon Monitoring System Biomass and Uncertainties Working Groups, and have been instrumental in the NASA Arctic-Boreal Vulnerability Experiment (ABoVE) programs. This area also serves as the Federal Geographic Data Committee co-lead for the land use – land cover (LULC) theme in annual reporting in response to the Geospatial Data Act (GDA) of 2018. Under the LULC Theme, thirteen National Geospatial Data Assets (NGDA) are officially recognized, of which the Forest Inventory and Analysis Database is recognized as an NGDA. Other NGDAs include Landfire, National Land Cover Dataset (NLCD), NLCD-Tree Canopy Cover, and USDA NASS's Cropland Data Layer.

Some of the research is focused on increasing the Forest Inventory and Analysis program's National Forest Inventory efficiencies and meeting broader user needs. Using remote sensing, National Forest Inventory precision targets can be resolved at a smaller landscape scale, typically resulting in better forest inventory estimates and translating into cost savings. Currently, free and public satellite data, such as from the USGS-NASA Landsat constellation, and data from the National Agriculture Imagery Program (NAIP), are used to complement FIA activities. Airborne and satellite Light Detection and Ranging (LiDAR) are remote sensing technologies that are increasing FIA's data collection efficiencies in remote or inaccessible areas. LiDAR and stereo digital imagery offer great potential but require higher skillsets and greater storage and computational needs.

Recent achievements by IMAR staff and FIA units located at the research stations

Some of efforts to transfer the technological and research findings to the scientific community and public include:

- *Published a cost-effective field measurement protocol to support lidar-assisted carbon monitoring programs* – FIA produced a prototype of a "measurable, reportable, verifiable" (MRV) design for cost-effective carbon monitoring using a limited number of FIA field plots integrated with lidar sampling and disturbance information derived from Landsat time series data. The report documents field measurement protocols that are consistent with those of the FIA Program and can be used in combination with remote sensing data sources to estimate and model forest carbon and biomass at multiple spatial scales.
- *Developed a tutorial in model-assisted estimation with application to forest inventory* – National forest inventories in the U.S. combine ground plot data with remotely-sensed information to improve precision in estimates of forest parameters. Because of the increased availability of remotely-sensed data with improved spatial, temporal, and thematic grains, there is a need to equip the forest inventory community with a more diverse and applicable set of statistical estimators. This tutorial provides the steps on how to construct and assess the relative performance of seven estimators using forest inventory data. Related publications can be found in *Forests* 2020.
- *Published report on defining, analyzing, and understanding the U.S. Land Base* – an effort to assess the changes in U.S. forestland area depending on what definitions, methods and datasets are used to measure.
- *Released the latest results from the FIA National Woodland Owner Survey through a new dashboard* – The new data shed light on who owns America's forests, why they own land, what they have done with it in the past, and what they plan to do with it in the future. This information can be used in designing programs and policies that help family forest owners obtain the information and assistance they need to help conserve forests for current and future generations.
- *Delivered urban FIA data through updated application, My City's Trees* – A major update to this web application improved the functionality to explore exiting and new data for inventoried cities.
-

- *Published report to provide a compilation and analysis of all conversion factors for roundwood and residue used by FIA in each regional Timber Product Output (TPO) program* – For the first time, conversion factors used to convert mill-reported volumes to various units of measurement in TPO data processing were made available to researchers and the general public. Access to these conversion factors will allow TPO data users to understand how reported volumes are determined.
- *Making forest inventory data ready to use through FS management tool, the Forest Vegetation Simulator* – The Forest Vegetation Simulator (FVS) is used by scientists and managers to project forest conditions into the future under a wide range of different management scenarios at scales ranging from single stands to entire States. FIA made forest inventory data available in FVS-ready format for users to have access to a consistent and accurately translated inventory dataset. The data are now being used for numerous applications, such as national forest planning, education, scientific analysis, and management of small private forest ownerships.
- *Intensified forest inventories across the Pacific Coast to inform climate analysis and policies, as well as managing forest carbon resources* – The greater intensity of plot measurements will improve forest and carbon estimation accuracy and improve estimates of carbon pool dynamics for wildfire, insects, and drought effects. As States consider carbon policy options to combat effects of a changing climate, the FIA program can help by providing unbiased estimates of current forest carbon stocks and flux.
- *Released the first inventory of the Tanana Valley in Interior Alaska* – Inventory data from the first fully-completed unit of the Interior Alaska, the Tanana Valley unit, became available online. The remote location of the 33.7-million-acre inventory unit made field data collection cost-prohibited. FIA partnered with local communities and the State of Alaska, as well as leveraging high-tech innovations developed by NASA to pilot a new way of monitoring remote areas and reduce costs.
- *Published research on estimating land use and land cover change by augmenting field inventory data with remote sensing observations* – Research findings revealed the temporal patterns and thematic transitions associated with forest cover loss by augmenting traditional forest inventory data with remotely sensed observations, photo and satellite imagery. The article also includes recommendations on how to harmonize ground and remote sensing observations through a defined enhanced plot interpretation process.
- *Supplied 324 spatial data requests and almost 1.4 million online data requests and responded to almost 1,500 consultations, investing 16,735 hours of staff time* – Through online applications, the Spatial Data Service Team, and subject matter experts, FIA addresses the growing informational needs related to forest conditions, forestland ownership, and timber product generation.
- *Provided technical assistance to customers* – FIA National Inventory and Monitoring Applications Center (NIMAC) provides technical assistance on planning, conducting, processing, and analyzing forest inventories to FIA's broad range of customers, including NFS, other Federal agencies, State governments, and other countries.
- *Sought input from partners and supporters through meaningful national and regional engagements* – FIA held 4 user-group meetings and 10 management meetings to ensure that the program is providing the highest quality service and meeting its planned objectives according to the goals stated in the FIA strategic plan and on-going commitments made to our partners. Of the total meetings, eight were national in scope and six were regional.
- *Published reports to support development of the upcoming 2020 RPA Assessment* – These reports examine the changing composition of the U.S. land base and establish plausible scenarios for future U.S. socioeconomic growth and climate change. This information sets the stage for resource analyses in the RPA Assessment.
- *Developed data guides and catalogs to help land managers use information from the RPA Assessment to support planning and decision making* – In particular, the RPA-LMP Data Catalogue will assist addressing the requirements of the 2012 Planning Rule by connecting the Planning Rule assessment topic areas and directives with relevant datasets, tools, reports, maps, and other information from the RPA Assessment.

- *Provided US forest sector carbon projections* in support of the United States of America in responding to the United Nations Framework Convention on Climate Change, including development of the Nationally Determined Contribution, the Fourth Biennial Report, and the Long-Term Strategy.
- *Co-sponsored an international conference of the International Boreal Forest Research Association* held (virtually) in Fairbanks Alaska, August 16-20, 2021 (proceedings in preparation).
- *Published national-scale forest sustainability indicator reports* on (1) the productive capacity of forest resources; (2) forest ecosystem and harvested wood products carbon balances; and (3) selected socioeconomic indicators describing payments for ecosystem services, socioeconomic conditions in forest communities, and forest based recreation activity – The published reports are produced on a rolling basis. The 2021 publications updated 11 of the 54 indicators internationally agreed to by the Montreal Process, an international effort assessing sustainable forest management and providing a framework for describing the value and condition of participant nations' forests. (See https://www.fs.fed.us/research/sustain/criteria-indicators/).
- *Classifying forest type in the national forest inventory context* -- Developed a methodology that uses a combination of airborne hyperspectral and lidar data to map forest inventory and analysis (FIA) program defined forest type between sparsely sampled FIA plot data collected in interior Alaska. The random forest classification algorithm with hyperspectral vegetation indices and lidar-derived topography and canopy height metrics had the highest accuracy
- *Landsat forest height signal saturation reduced using new GEDI LiDAR asset on Google Earth Engine* -- While Landsat has proven to be effective for monitoring many elements of forest condition and change, the platform is limited in measuring forest structure, which determines several key ecosystem functions. Results suggest Landsat-based maps of components such as height may substantially benefit from local calibration with dense, global sample of LiDAR observations collected by NASA's Global Ecosystem Dynamics Investigation (GEDI).

Forest Inventory and Analysis continued leading implementation of policy change on agreements and published a record number of publications

Since FY2020, the FIA program adopted changes to ensure that confidential information annually collected through the program's surveys on field plots, landowner characteristics, and timber product output from mills, was protected to the full extent of existing laws when entering into agreements with third parties. Revising the traditional entry into formal partnerships also ensured FIA acknowledgement and recognition of all products and derivatives built from FIA data and produced by third parties. In addition, to best protect FIA assets, this policy change demonstrated to our partners and clients the extent of their investments in products produced in partnership with other institutions.

To protect 325,000 plot locations across 50 states and U.S. islands, landowners' personally identifiable information, non-public corporate data, and unpublished information, FIA adopted the use of Material Transfer Agreements (MTAs) and Cooperative Research and Development Agreement (CRADA) as the exclusive agreement types to sign when transferring FIA confidential data to a third party. FIA also adopted the use of the Memorandum of Agreement (MoA), in cases where it was necessary to hold parties legally accountable for the established commitments and terms agreements. In 2021, FIA entered into the following new agreements: 35 MTAs, 18 joint venture agreements, 11 interagency agreements, 1 international joint venture agreement, and 1 participant agreement (table 1).

.Table 1. Number of new FIA agreements entered with partners, 2019-2021

	2019	2020	2021
Material transfer agreement	0	30	35
Cooperative research and development agreement	0	1	0
Memorandum of agreement	0	3	0
Memorandum of understanding	23	5	0
Interagency agreement	7	5	11
Memorandum of cooperation	0	0	0
Cooperative agreement	0	2	0
Joint venture agreement	28	18	18
International joint venture agreement	0	1	1
Participating agreement	2	2	1
Total	**60**	**67**	**66**

The FIA program published 239 publications, a 17 percent increase from last year, including 107 core publications (reports specific to a complete survey unit, complete State, national forest, or national reports), and 101 journal articles. Of the published core publications, 7 were 5-year State reports, analyzing inventory data collected in previous years for the States of New Hampshire, New York, Vermont, Mississippi, Texas, California and Coastal Alaska; and 3 inventory reports for the U.S. Virgin Islands, American Samoa, and Guam. Published research articles included the following areas of work: forest carbon and biomass, land use and land cover change, small area estimation of forest inventory, urban inventory, interior Alaska inventory, ecosystem health estimations, forest products and utilization, forest ownership, geospatial analysis and products, and statistical data processing, analysis, and delivery. The number of FIA publications per analyst and researcher averaged 2.8 for the entire program.

Urban Sustainable Research

In dense urban centers, a city's treescapes (or lack thereof) have a big impact on the quality of life. A unique government and academic partnership use Lidar and GIS technology to help communities map, assess, and monitor their urban tree canopy. https://www.gisforscience.com/chapter11/

Baltimore Field Station

FS report on the financial and technical analysis for Baltimore City's Wood Sort Yard (funded by S&PF urban and community forestry) resulted this fall in an internal Baltimore City Innovation Grant for ~$900k and will lead to 8 new jobs.

https://www.fs.usda.gov/inside-fs/delivering-mission/deliver/baltimore-urban-wood-project-seeks-transform-waste-wood

http://baltimorewoodproject.org/pdf/FreshCut_BaltimoreUrbanWood_v3_2019.05.14.pdf

http://baltimorewoodproject.org/

Sustainable Forest Management Research

Sustainable Forest Management Research builds a solid scientific foundation for natural resource management and policymaking at multiple spatial scales in forest and rangeland ecosystems in the U.S. and globally. Methods used include conducting leading-edge research, synthesizing existing research, and improving access to and highlighting field research. The program:

- Investigates natural disturbances, stressors, and threats caused by insects, diseases, and invasive species; fire; weather (hurricanes, ice storms, droughts); and physical phenomena (avalanches, landslides, volcanoes) that impact forests and grasslands.
- Studies human-caused disturbances, stressors, and threats related to fragmentation of forests and rangelands and changing weather patterns (temperature and precipitation), atmospheric deposition, air quality, and soil health.
- Researches sustainable production of forest and range-land resources.
- Manages systems, practices, and policy options for restoring forests, rangelands, and agroforestry systems.
- Researches and manages landscape ecology issues at national, regional, and local levels.
- Researches meteorology and the effects of climate variability on living organisms.
- Conducts vulnerability and risk assessments.
- Conserves biological diversity using methods such as genetics, gene conservation, and species conservation.
- Develops reforestation and revegetation methods and materials.
- Manages experimental forests and ranges, research natural areas, and demonstration areas.

Recent achievements news, products, links & activities

- Campaign: Trees for Community Recovery
- Federal Registry Notice: Identifying barriers to advancing racial justice and equity and support for underserved communities at USDA
- Project Learning Tree – A guide to teaching and learning about forests
- Associated Press – Young adults' relocations are reshaping political geography
- WV Public Broadcasting – Research reveals clean air makes stronger forests
- USDA Forest Service – New web resource: The need for field-based tree monitoring
- ESRI – Urban parks play a key role in curbing inequity and climate impacts
- USDA Forest Service funds 15 Landscape Scale Restoration projects in Northeast, Midwest
- National Public Radio – What the cherry blossom bloom can tell us about climate change
- Smart Cities Dive – Pittsburgh applies equity lens amid push to plant 100K trees
- American Forests – Seeing the city for the trees

New and Recent Research

- Dye, Alex W.; Kim, John B.; McEvoy, Andrew; Fang, Fang; Riley, Karin L. 2021. Evaluating rural Pacific Northwest towns for wildfire evacuation vulnerability. Natural Hazards.
- McDonald, Robert I.; Biswas, Tanushree; Sachar, Cedilla; Housman, Ian; Boucher, Timothy M.; Balk, Deborah; Nowak, David; Spotswood, Erica; Stanley, Charlotte K.; Leyk, Stefan. 2021. The tree cover and

temperature disparity in US urbanized areas: Quantifying the association with income across 5,723 communities. PLOS ONE.

- Sinha, Paramita; Coville, Robert C.; Hirabayashi, Satoshi; Lim, Brian; Endreny, Theodore A.; Nowak, David J. 2021. Modeling lives saved from extreme heat by urban tree cover. Ecological Modelling.
- Campbell, Lindsay K.; Svendsen, Erika; Johnson, Michelle; Landau, Laura. 2021. Activating urban environments as social infrastructure through civic stewardship, Urban Geography.
- McDaniel, Josh; White, Eric M.; Derrien, Monika; Blahna, Dale. 2021. Using social media as data to better understand recreation on public lands. Science Findings 238.
- Flower, Charles E.; Pinchot, Cornelia C.; Knight, Kathleen S.; Woeste, Keith; Slavicek, James M. 2020. Back from the brink: Forest Service efforts to create Dutch Elm Disease tolerant trees for use in urban and rural restoration. In: Nelson, C. Dana; Koch, Jennifer L.; Sniezko, Richard A., eds. Proceedings—Tree Resistance to Insects and Diseases: Putting Promise into Practice. Gen. Tech. Rep. SRS–252.
- Anderson, Sarah M.; Heath, Linda S.; Emery, Marla R.; Hicke, Jeffrey A.; Littell, Jeremy S.; Lucier, Alan; Masek, Jeffrey G.; Peterson, David L.; Pouyat, Richard; Potter, Kevin M.; Robertson, Guy; Sperry, Jinelle. 2021. Developing a set of indicators to identify, monitor, and track impacts and change in forests of the United States. *Climatic Change.*
- Locke, D.H., Hall, B., Grove, J.M. *et al.* 2021. Residential housing segregation and urban tree canopy in 37 US Cities. *npj Urban Sustainability*.
- Pataki Diane E.; Alberti M.; Cadenasso M.L. *et al.* 2021. The Benefits and Limits of Urban Tree Planting for Environmental and Human Health. *Frontiers in Ecology and Evolution.*

Knowledge Management and Communications

The Knowledge Management and Communications (KMC) staff's mission is to disseminate results of the agency's research to varied audiences and provide the information technology needed to disseminate those results. Audiences include the scientific community, landowners and resource managers, academics, policymakers, the public, and students. KMC is responsible for leadership, development, oversight, and delivery of communications; performance accountability; science applications; science education; data quality; peer review; tech transfer and licensing activities; and information management for Forest Service (FS) Research & Development (R&D). KMC also defines, develops, and maintains the national information architecture and content of databases essential to managing the strategic information flow and messaging about FS research. Specifically, KMC:

- Plays a leadership role in the Forestry Research Advisory Council (FRAC) Federal Advisory Committee. The FRAC meets annually to present recommendations to the Secretary on the Forest Service R&D program and consists of up to 20 members appointed by the Secretary of Agriculture from federal, state, university, industry, and nongovernmental organizations.
- Provides information technology resources for communicating research, including the R&D website, which provides public access to more than 50,000 scholarly publications authored by R&D scientists and collaborators.
- Maintains databases of research and archives information.
- Develops and disseminates science applications.
- Manages R&D data quality, peer review, and performance accountability.
- Manages R&D patents, licensing, and technology transfer.

- Manages the Forest Service History Program.
- Produces the Natural Inquirer, a free science education journal for students.
- Manages R&D's science delivery and communications program, which produces products and services that target varied audiences, including the scientific community, landowners and resource managers, policymakers, the public, and other stakeholder groups. This work involves overseeing the strategic planning and production of web and hard copy communications products, new outreach products, communications promoting the rollout of major R&D initiatives, and the translation of technical information into plain language.
- Records Management- The planning, controlling, directing, organizing, training, promoting, and other managerial activities involved with respect to records creation, records maintenance and use, and records disposition in order to achieve adequate and proper documentation of the policies and transactions of the Federal government and effective and economical management of Agency operations. The program lead for KMC is required to create and manage information that documents our work, safeguard information that needs to be protected, and keep or dispose of Federal records according to an approved records schedule -- A records schedule is a document that tells you how long to keep specific types of records and what should happen to those Federal records when you no longer need them. 36 CFR 1220.14

Recent achievements

R&D WO Newsletter: Produced 12 monthly newsletter issues on time. Recruited 1,100 new subscribers in 2021, including leaders in the Forest Service and partner organizations and Congressional staffers. There are nearly 11,000 subscribers from the Forest Service, other federal agencies, state or local governments, non-profits, universities, and the public. Many of these subscribers forward the newsletter to others, so its reach is likely well beyond 11,000. Infographics featured in the newsletter are multi-purpose and among the Office of Communication's most popular social media features.

Rollouts of Reports: Wrote communication plan for agroforestry report and helped execute plan, which helped agroforestry report score in top 5 percent of all research outputs rated by Altmetric. Wrote first draft of communication plan for Non-Forest Timber Products. Helped coordinate rollout of PNW Forest Plan Science Synthesis.

Research Highlights: 118 highlights originating from the Research Stations were reviewed, edited, and will be made available on the web.

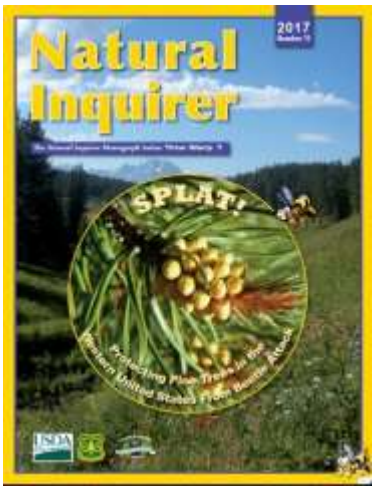
Other High Impact Products: Produced four new glossy factsheets: 1) Postfire Stabilization and Recovery; 2) Wood Innovations for a Sustainable Future, 3) Forest Carbon Estimation and Monitoring, and 4) Forest Carbon Status and Trends (All factsheets are in production). Also produced 2021 R&D At-a-Glance brochure, and "A Sample of Recent Research Accomplishments: Science and Innovation for a New Century of Conservation*."* Informally called "Greatest Hits". Large sections of this document were incorporated into a Charles Riley Memorial Foundation document that describes the importance of R&D.

Altmetrics: Expanded the coverage to track mentions of research outputs as offered on five station websites. Produced 45 weekly reports of "most mentioned" R&D research outputs. Reports were

originally used to brief R&D Deputy Chief for weekly meetings with the Chief but were modified to assist public affairs officers in what marketing approach led to improved visibility of Forest Service research results.

Facebook and Inside the Forest Service: Provided postings for these outlets on a regular basis.

Web Modernization: Reached agreement on the design, taxonomy and content types that will, together, define the information architecture and appearance of a common web infrastructure. The new solution will consolidate ten of R&D's websites into a modern searchable solution offering hundreds of thousands of pages of rigorous, science-based content all under a common department brand.



The *Natural Inquirer* program creates and distributes re-usable science journals and materials written for K-12 students. In FY 2021, approximately 94,201 of these products were distributed to classrooms, homeschools, and individuals across the country. It is notable that the COVID19 pandemic affected our work during FY 21. All work is done with our non-profit partner, the Cradle of Forestry in America Interpretive Association (DBA FIND Outdoors), and the University of Georgia. https://naturalinquirer.org

Important FY21 program accomplishments

*Note: The COVID-19 pandemic had a major impact on our distribution and event participation this FY.

By the Numbers

- 36,203 journals, booklets, and activity guides distributed
- 52,998 scientist and engineer cards distributed
- 86,914 unique visitors to *Natural Inquirer* website (Dec 2020 & Jan 2021 did not have data due to a glitch in the website)
- 30,000 Woodsy Owl 50th birthday cards (5,000 through *Natural Inquirer* and the balance through the National Symbols Cache)
- 100 Science Hours (available on *Natural Inquirer* website & social media only) Science Hours highlight a *Natural Inquirer* article and activity that a student can do in about an hour. It is one of distance learning outreach products. https://www.naturalinquirer.org/Science-Hour-v-249.html
- 620 Forest Service volunteer hours to help create products from FS retiree (equivalent paygrade GS-14)
- **Grand total:** 94,201 of these products were distributed to classrooms, homeschools, visitor points of contact, and individuals across the country in FY21

Products Published

- Cream of the Crop *Natural Inquirer* monograph
- Knock on Wood *Natural Inquirer* monograph
- Woodsy Owl 50th Birthday Scientist Card

- Meet Dr. Jovan *Natural Inquirer* Reader (with Woodsy Owl)
- Distance Learning Modules (Smokey Bear, Capitol Christmas Tree, Climate Change) (available on *Natural Inquirer* website & social media only) https://www.naturalinquirer.org/Module-page-v-312.html
- Research FINDings

Social Media

- Instagram- (began building Instagram presence this year, reaching new people, between 500-700 views a month)
- Twitter- maintaining our Twitter presence with 2,064 followers
- Facebook- increased our followers from 1,726 to 1,787
- Pinterest- 304 followers, 53 pins, 184 monthly views, and 9,877 impressions

In Production

- Pacific Islands *Natural Inquirer*
- To Harvest or Not to Harvest *Natural Inquirer* monograph
- The Bee Frequency *Natural Inquirer* monograph

Upcoming Products

- Woodsy Owl "Lend a Hand, Care for the Land" journal
- Moon Trees monograph

FY21 Partnerships

- Forest Service Conservation Education
- Forest Service National Symbols program (Woodsy Owl)
- Forest Service International Institute of Tropical Forestry
- Forest Service Pacific Southwest Research Station
- NASA for the Moon Trees project*
- 4-H

*The Moon Trees project is a joint project between the Forest Service and NASA that celebrates the 50th anniversary of the original Moon Trees that were brought to space and returned to Earth by Stuart Roosa. Roosa was a smokejumper for the Forest Service, who later became an astronaut. In celebration of the 50th anniversary of the Moon Trees and NASA's return to the moon with the Artemis mission, a new batch of tree seeds will be sent to the moon and returned to Earth for distribution at a variety of educational and public spaces. There will be ongoing educational outreach and Moon Tree data gathered from this project.

National Agroforestry Center

Established in the 1990 Farm Bill, the National Agroforestry Center advances the health, diversity, and productivity of working lands, waters, and communities through agroforestry. The Center provides science-based information for integrating trees and agriculture on farms, forests, and ranchlands across

the United States, to improve water quality, enhance crop and livestock production, create wildlife habitat, and sequester carbon. Located in Lincoln, Nebraska, the Center works with a national network of more than 4,000 natural resource and agriculture professionals who, in turn, provide technical assistance to farmers and landowners.

Work at the Center includes research and/or outreach on the five agroforestry systems most utilized in the United States:

Windbreaks and shelterbelts, to shelter crops, people, animals, buildings, and soil from wind, snow, dust, and odors;

Riparian forest buffers that filter farm runoff, reduce soil erosion, and diversify income sources;

Silvopasture, to increase the efficiency of grazing, pasture and forest land uses, and to diversify incomes;

Alley cropping to incorporate annual or perennial crops into the management of trees, thus augmenting landowner income before trees are mature enough to harvest and/or produce fruit, berries, or nuts; and

Forest farming, or multi-story cropping, to produce food, herbal, botanical, or decorative crops under the protection of a managed forest canopy**.**

Efforts in FY 2020 included expanding outreach and information transfer through support for partner organizations to develop regionally-specific educational materials on agroforestry practices. Topics funded this year include forest farming in Appalachia, agroforestry in the Midwest, and silvopasture in California. The Center also funded projects to develop outreach materials related to urban agroforestry in Texas, Hawaii, and Washington D.C. In addition, new publications have been produced on land access for agroforestry, soil health, and other agroforestry topics. Research advances have included publishing and presenting research from a systematic review on pollinators in agroforestry systems, continued development of inventorying trees outside forests (TOFs) using high-resolution land cover images, and setting the stage for future agroforestry assessments through a national survey of agroforestry adopters.

Northern Research Station

The Northern Research Station provides the science land managers, city planners, and policy makers need to improve the condition of the Nation's forests and grasslands. In a region extending from Maine to Minnesota and from Missouri to Maryland, Northern Research Station science aims to understand all the elements of forests and related landscapes. The Northern Research Station is one of seven Forest Service research units conducting research within all 50 states as well as in U.S. territories and commonwealths.

Northern Research Station scientists reach these audiences in a variety of ways, including:

- Participation in and contribution to hundreds of consultations with national forest and state forest managers and other partners in efforts to improve access to and use of Station science.
- Publishing in peer-reviewed journals and Station technical reports; providing access to over 15,000 publications authored or co-authored by current or former Northern Research Station scientists.
- Robust science communications and science delivery platforms that host regular webinar series, trainings, digital science briefs, and science roundups.
- Data visualization and digital storytelling through innovative platforms, include Tableau and StoryMaps.

- The Northern Research Station's Forest Inventory and Analysis group is responsible for inventory and monitoring in 24 states. The Forest Inventory Data Mart and other tools deliver extensive data, providing stakeholders in State agencies, private industry, and other Federal agencies alternatives for generating tables and maps.

- The Station manages 22 of the 81 experimental forests that are part of the FS Experimental Forest Network; most of these long-term research sites lie within national forests. The ability to conduct scientific research in-house, to apply research findings on National Forest System lands, and to transfer these findings to others for use on all the Nation's forest land sets the Forest Service apart as a natural resource agency.

Specific Science Delivery Projects Include:

Rooted in Research

Rooted in Research is the Station's new science delivery platform. Focused on synthesizing science to natural resource managers and policy advisors, Rooted in Research supports the integration and use of best available science in natural resource planning and management across the Station footprint. This platform highlights emerging research topics relevant to land managers with the intention of promoting strong science-manager integration by making current research more available to busy resource managers. Rooted in Research is a multichannel platform, distributed via Constant Contact, and includes:

1. **Rooted in Research bimonthly publication**
   This digital publication focuses on the management implications of new science findings for natural resource managers through providing technical scientific information to our stakeholder base.
2. **Rooted in Research Webinar Series**
   Launched in February 2021, the Rooted in Research Webinar Series discusses research with a direct land management application. All webinars are interactive and targeted toward a land manager audience. Webinars follow a format of 30-minute presentation/30-minute Q&A and discussion.
3. **Rooted in Research Science Roundup**
   Based on input from land managers, Rooted in Research Science Roundup is designed to provide a quick look at emerging, locally relevant research around high priority themes, such as climate change, water, and fire.

Fueling Collaboration

Fueling Collaboration is a virtual panel discussion series developed by the Northern Research Station, Southern Research Station, and members of the Joint Fire Science Program's Exchange Networks in the East. This panel discussion series brings researchers and managers together to learn about and discuss emerging topics in fire science research, with a focus on practical management considerations. The goals of this panel discussion series are to communicate Forest Service Northern and Southern Research Station fire science, build new and lasting science –manager connections, and elevate the profile of fire science in the East. Topics include Fire and Timber Management, Fire and Climate Change, Fire and the Wildland Urban Interface in the East, and Fire and the Carbon Cycle.

SCIENCEx

SCIENCEx is a new cross-station webinar series focused on bringing together scientists and land management experts from across R&D to explore the latest science and best practices for addressing natural resource challenges across the country. On a quarterly basis, SCIENCEx is organized as week-long webinar 'blitzes' around salient topics, allowing for deep-dives into subtopics or dynamics within specific geographies. From November 2020 – November 2021, SCIENCEx has showcased a diversity of R&D science and enjoyed excellent engagement. Nearly 5,500 people have attended 20 webinars that have featured 60 R&D scientists. Continuing educations credits (CECs) have been arranged by webinar organizers and help managers meet these CEC need. Each webinar features scientists from across R&D. Webinars average 200-250 attendees each day.

Fernow Experimental Forest Key to Delisting of an Endangered Plant

Running buffalo clover was listed as an endangered species in 1987; it was identified on the Fernow Experimental Forest (Fernow) in 1993. Then Project Leader Clay Smith responded quickly and worked with the U.S. Fish and Wildlife Service to protect the plants and allow for long-term silvicultural research to continue. Those actions became an unplanned experiment in the ecology of running buffalo clover when more plants were discovered on new skid trails built to avoid the other plants. Publications by Northern Research Station (NRS) scientists in 2002 and 2013 described the habitat of running buffalo clover on the Fernow and documented the importance of disturbance in maintaining populations. Staff and volunteers have monitored running buffalo clover populations since 1994, and a recent analysis of 20 years of data lends support for the published findings showing the association between sustained periodic disturbance and running buffalo clover abundance. Some sites on the Fernow with no management or no recent harvest activity were found to have negative trends of running buffalo clover over time. USDA Forest Service monitoring of running buffalo clover on the Fernow has been shared with partners and this work directly contributed to the decision to delist the species. Through the years, NRS scientists have also been members of the recovery team and helped in development of management plans for the species.

How Does Forest Canopy Management Really Affect Wildfire Behavior?

Forest managers use tools such as mechanical thinning of stands and prescribed fires to reduce fuel loads and the likelihood of future severe wildfires in fire-prone ecosystems. However, the reduction of midstory and understory vegetation does not drive fire behavior in isolation. A Northern Research Station scientist partnered with scientists from the University of California Irvine, the Southern Research Station, Tall Timbers Research Station, and Los Alamos National Laboratory in a study using the FIRETEC fire-behavior model to investigate how the factors of mid-canopy fuel loading, fuel moisture, and wind interact to ultimately affect how fires spread through a forest stand containing longleaf pines, common persimmon, and turkey oak. The study showed that the desired outcome of lower fire intensities via the application of fuel-load reduction strategies is highly sensitive to fine-scale changes in local wind conditions and fuel moisture. In dry conditions, too much thinning can introduce more windy and turbulent conditions, which can increase fire intensity. But doing no thinning can also lead to an increase in fire intensity when fuels are dry. When fuels are moist and windy conditions are present, reduced mid-canopy fuel loads via thinning can also increase fire spread rates. This study and other fire-behavior modeling studies provide valuable information to forest managers that can guide them as they develop fuel reduction strategies to mitigate wildfire risk.

Rise and Fall of Black Cherry Tied to a Forest of Unintended Consequences

In the heart of black cherry's native range, including a region that bills itself as the "Black Cherry Capital of the World," the tree's regeneration, growth, and survival have been declining for over a decade. Regionally, black cherry is a foundational species providing excellent wildlife habitat and serving as the backbone of a high value timber economy. A team of scientists from the Northern Research Service and University of Missouri synthesized long-term experimental records in the region in addition to Forest Inventory and Analyses data to examine the leading hypotheses for the tree's waxing and waning fortunes. They concluded that fluctuating black

cherry dynamics are the unintended consequence of actions and policies often unrelated to land management activities. High deer populations and elevated nitrogen deposition favored black cherry over other tree species during much of the 20th century. Presently, however, decreases in nitrogen following the Clean Air Act Amendments, increased pathogen effects, and a warmer and wetter climate negatively affect the species. The researchers conclude that observed changes in black cherry dynamics may herald impending changes to forest health, local economies, and forest ownership patterns as other tree species respond to changing environmental conditions and biotic stressors over the coming century.

With Help from Two States, Two National Forests, and Scientists, a Songbird is Making Itself a New Home in Missouri

Exploitative logging and the loss of most of the shortleaf pine woodlands in the Missouri Ozarks led to the extirpation of the brown-headed nuthatch in Missouri more than a century ago. Decades of pine woodland restoration by the Mark Twain National Forest and other agencies over the past several decades, which included using prescribed fire and thinning, created more than 150,000 acres of habitat suitable for the reintroduction of brown-headed nuthatch. A team that included the Northern Research Station, Mark Twain and Ouachita National Forests, Missouri Department of Conservation, University of Missouri, Tall Timbers Research Station, and other partners began reintroducing the bird in 2020. In August, 56 birds were captured on the Ouachita National Forest in Arkansas and released in restored pine woodlands on the Mark Twain National Forest in Missouri. Forty-six birds were released in August 2020, and monitoring revealed that most of the birds survived and four successful nests were documented. With the reintroduction of birds in 2021, the team exceeded the initial goal of reintroducing 100 brown-headed nuthatches by exactly two birds. While generally considered restoration, this project is also a test of a climate adaptation strategy because this ecosystem and species may need to move north with climate change.

Speeding Up Science: Modeling Used to Anticipate Outcome of Climate Adaption Treatments in Minnesota's Pine Forests

The Cutfoot Experimental Forest in Minnesota is home to one of the nation's largest climate adaptation experiments—the Red Pine Adaptive Silviculture for Climate Change (ASCC) experiment established by Northern Research Station scientists in 2014. The Red Pine ASCC is evaluating adaptation approaches for iconic northern pine forests that range from doing nothing (control), to thinning pines to fewer trees per acre to increase soil moisture availability (resistance), to combinations of harvesting and planting of native future-adapted tree species (resilience), or novel species (transition). The ability to say anything definitive about long-term outcomes of these treatments is limited by the newness of the project. This is where computer modeling comes in. Northern Research Station researchers have used the Forest Vegetation Simulator (FVS), a computer model used by most National Forests, to evaluate long-term responses to the ASCC treatments. The results point to the transition treatment showing the lowest end-of-century mortality, increasing tree productivity compared with the other treatments, and greatest tree diversity. This work provides an important context for silviculture aimed at climate change by offering insight into potential long-term outcomes of near-term treatments.

In a Region Valued for Water, Habitat and Lumber, Hydro-Ecological Modeling is Informing Management Decisions

Soil moisture is a critical driver of hydrological and ecological processes including stream flow, forest productivity, nutrient cycling, and wildland fire behavior and effects. It also influences ecosystem structure and tree species distribution across regional and local scales. Hence, land managers need high quality information about soil moisture distribution both spatially and through time to inform their decisions. Researchers from the Northern Research Station are working with the Canaan Valley Institute to implement the Regional Hydro-Ecological Simulation System (RHESSys) to better understand how spatial and temporal variability in soil moisture and water stress influences several ecosystem processes in midwestern and eastern US forests. At the Fernow Experimental Forest in WV, researchers are modeling how forest succession and changing climate interact to alter water yields in the central Appalachians which provide drinking water for millions of people. A second effort involves assessing historic and potential future habitat suitability for oak savannas and woodlands across a gradient stretching from Oklahoma to the Appalachians. Savannas and woodlands provide critical

wildlife habitat and raw materials for local industry. Hydro-ecological modeling efforts will help managers determine where and when to focus prescribed fire, silvicultural, and restoration treatments to maintain the critical services that savannas and woodlands provide.

Managing Forests for Soil Carbon: Protecting an Invisible Resource

In the Lake States, soils hold well over half of all forest carbon. Until now, researchers have not known how management affects the size of this resource—the largest single pool of forest carbon—at the landscape scales where many management decisions are made. Thanks to an analysis of existing data from a range of sources, Northern Research Station scientists and their partners can now offer forest managers the information they need to incorporate soil carbon into planning, assessments, and operations for a region that covers 6 percent of the land area but holds almost 10 percent of the forest soil carbon in the United States. The team established that soil properties such as texture mean the difference between significant gains and significant losses of carbon when forests are harvested. Researchers also revealed how past management, such as Civilian Conservation Corps reforestation, continues to support soil carbon sequestration and highlighted the contribution of reforested minelands in sequestering soil carbon. To make their results usable, the team published a map of forest harvesting impacts on soil carbon that is now in use on three National Forests across the region, and a menu of place-based options to protect against losses or enhance potential gains in soil carbon.

With Reboot, Climate Change Atlas Updates Habitat Modeling and Introduces Tree Migration Projections

The Climate Change Atlas is the most popular Northern Research Station online tool, with an estimated 860,000 visitors annually. The Atlas delivers information about current and potential future habitat suitability in the Eastern United States; version 4 includes a new feature that allows users to quantify the likelihood of tree migration potentials. The Tree Atlas, a component of the Climate Change Atlas, has been expanded to provide current information for 148 eastern United States tree species and future projections for 125 of the species; these changes are based on new models published in 2019. Maps and statistics are provided for individual species, while regional summary tables aggregate species information for national forests, national parks, watersheds, ecological regions, states, and 1-degree grids. Four tutorial videos help users understand the information and products, and guide navigation of the Atlas. The newer models use projections from three general circulation models under two greenhouse gas emission scenarios to provide the upper and lower bounds of plausible conditions. Other improvements include a hybrid grid of 10×10 and 20×20 km cells, which increases the model information based on the density of forest inventory samples, newer Forest Inventory and Analysis data, and 45 updated environmental predictors. Users can now explore current and future habitat suitability and tree migration potentials to assist in management planning of forest resources.

New Management Guide Translates Research Results for Family Forest Owners

Since 1950, scientists with the USDA Forest Service, Northern Research Station have been studying more than a dozen approaches to forest management on the Penobscot Experimental Forest in Maine. The findings highlight advantages and disadvantages of different approaches to harvesting, including changes in wildlife habitat, carbon storage, aesthetics, and wood production. To bridge the divide between scientists and the public, the Northern Research Station scientists partnered with the University of Maine, Maine Audubon, and New England Forestry Foundation to publish a guide that translates research results into easy-to-understand language. The new guide "Managing your Woodland – Forestry Research Translated for Landowners" uses historical and contemporary images from the Penobscot Experimental Forest and elsewhere, descriptive text, and infographics to explain forests, forest management, and the short- and long-term outcomes of different approaches to harvesting. With this information, family forest owners can make more informed decisions about their woodlots and better achieve the outcomes they want now and in the future.

Pacific Northwest Research Station

The Pacific Northwest (PNW) Research Station develops and delivers knowledge and innovative technology to improve the health and use of the Nation's forests and rangelands—both public and private. Since 1925, the PNW Research Station has been dedicated to understanding forests and rangelands. We believe that resilient forests are a promise to generations to come—a promise to replenish the air we breathe and the water we drink and use to grow food. Forest trees store carbon from the roots to the tops. Trees supply wood for homes, biomass for fuel, and fiber for paper. From remote mountains to bustling cities, forests provide habitat for fish and wildlife. Wherever they grow, forests are places of beauty, renewal, and solace.

Land managers understand more than ever just how important forests are to people from every walk of life. The PNW Research Station is in the unique position to offer scientific knowledge—built on decades of research—that can be used now to assure future generations enjoy the same benefits from forests that we do today. As part of Research & Development, the station has access to national forests and an experimental forest system that hold the keys to new understanding of forests and rangelands.

The PNW Research Station has strong partnerships with universities, national forests, state agencies, nonprofits, private industry, and other federal agencies. With these partners, we address key questions associated with managing forests, wildlife and fish habitat, recreation, climate change, human health and well-being, and more. We have the honor of bringing science to the table as people make often-difficult choices about managing land.

The PNW Research Station is a leader in the scientific study of natural resources. We generate and communicate impartial knowledge to help people understand and make informed choices about natural resource management and sustainability.

Research in Progress

West-Side Fire Research Initiative

The PNW Research Station launched the West-Side Fire Research Initiative in 2019 to produce information relevant to fire-related management on landscapes west of the Cascade Range in Oregon and Washington. Wildfires on the west side of the Cascades are becoming more frequent and more intense, with increasing risk to the extensive wildland-urban interface in the area. Scientists, fire managers, and other stakeholders are working to coproduce the science needed to keep people safe and the forests resilient. The group identified 3 priority areas for research: 1) historical and future fire regimes, 2) fire- and carbon-oriented management, and 3) postfire management. The West-Side Fire Research Initiative will produce actionable science and tools that help managers and responders plan for changing fire regimes on the west side of the Cascades.

The first publication stemming from the initiative, *Hazards of risk: Identifying plausible community wildfire disasters in low-frequency fire regimes*, was published in 2021. Findings from this study were shared via a station-hosted webinar attended by county and state emergency responders and fire managers in October.

Carbon Dynamics Research for Land and Watershed Managers

In 2019, the PNW Research Station launched a carbon research initiative to enhance policy-relevant understanding of carbon flux and carbon accounting, and to fill knowledge gaps about forest carbon dynamics. Forest carbon accounting is notoriously complicated, and uncertainty over the state of science hinders forest management.

The research initiative is addressing unresolved questions of policymakers and other partners. Working groups consisting of researchers, policymakers, and natural resource managers have convened around three questions:

- How do we identify and improve the most appropriate carbon models of the forest sector and all lands?
- What is the state of the current knowledge for green carbon in Pacific States?
- What are the carbon fluxes and social implications of different forest management strategies?

This initiative will deliver tools and information to policymakers and other partners that will help answer questions about forest carbon and how it interacts with other forest management objectives and practices.

PNW Science Delivery

BlueSky Framework: Upgrade to v4.3

The BlueSky framework, developed by scientists within the PNW Research Station, is used across the country to support air quality forecasting during wildfires and to plan prescribed burns. BlueSky links independent models of fire information, fuel loading, fire consumption, fire emissions, and smoke dispersion. In FY 2021, scientists updated several modules and added ones. They also added routines to ingest Canadian fire data and factor into daily smoke predictions. BlueSky output supports the Interagency Wildland Fire Air Quality Response Program and the air resource advisors deployed to wildfire incident management teams. Many regional and state agencies also use the daily BlueSky smoke predictions to forecast smoke and protect the public.

Evaluating Rural Pacific Northwest Communities for Wildfire Evacuation Vulnerability

Scientists with the PNW Research Station and their partners evaluated the evacuation vulnerability of nearly 700 rural communities in Oregon and Washington. Some of the most vulnerable communities were located along the western Cascade and Coast Ranges due to poor road networks. The findings have been integrated into the Risk Management Assistance Dashboard website used by Forest Service Fire and Aviation Management. County and state emergency responders and fire managers attended a webinar about the study hosted by the station in July 2021.

Air Quality Conditions Now Available to the Public Through AirNow.Gov Map and Mobile App

Wildfire smoke is the predominant cause of major air quality events in the United States that affect millions of Americans each year, causing significant negative health effects. Scientists with the PNW Research Station, other

colleagues in Forest Service, and the Environmental Protection Agency made current air quality information available directly to the public through the AirNow.gov website and mobile app. Millions of people have visited the AirNow.gov website since its release, and it was highlighted by the White House as an important source of information for the public on air quality and smoke conditions.

Genetic Database Enables "Forest Forensics" for Investigating Bigleaf Maple Theft

Bigleaf maple (*Acer macrophyllum* Pursh) is among the most common targets of timber theft in western North America. Scientists with the PNW Research Station led development of a range-wide bigleaf maple genetic database to aid law enforcement investigations. It was used to successfully prosecute a theft of bigleaf maple from the Olympic National Forest. The genetic markers identified thru this research are also being used by the hardwood industry in the Pacific Northwest to manage clonal inventories in breeding populations and to evaluate marker associations with wood grain variation.

Communities Empowered by Collaborative Urban Air Quality Biomonitoring Project

Scientists with the PNW Research Station worked with community leaders and others to investigate the distribution of heavy metals in air pollution in two Seattle neighborhoods adjacent to industrial areas. Moss collected from street trees revealed small-scale distribution and variability of metals in particulate matter. Concentrations of six toxic metals of interest were significantly higher in these neighborhoods compared to similar regional studies.

These findings are helping community leaders, regulators, and others strategically focus on improving conditions in the Georgetown and South Park neighborhoods within Seattle's Duwamish Valley. In response, community leaders requested follow-up air quality monitoring by regulatory agencies. These findings also informed recommendations for tree planting and "green" infrastructure that are now being funded through the city of Seattle.

Updates to Westside Elk Modeling Tools and Datasets

Newly revised tools enable users to project nutrition and habitat use for elk across 11 million hectares of western Oregon and Washington. Wildlife biologists and forest planners can also use the tools to evaluate the likely effects of management alternatives on elk habitat. A dual set of instructions provides guidance to those working within the Forest Service spatial analysis environment and for anyone using the models in a desktop application. The PNW Research Station hosted two virtual workshops in November 2021 for biologists and database managers. Feedback from attendees was used to finalize the user handbook.

PhenoMap: A Rangeland Management Tool

This web-based tool provides a method for closely monitoring rangeland vegetation as drought conditions develop and subside during the growing season. PhenoMap uses satellite imagery to provide near-real-time information about plant life cycle events over large areas. It also allows comparison of current grass development to the historic annual greenness pattern. Range managers can use this information to make in-season adjustment to grazing practices.

Webinar Series on Drought in the Northwestern United States and Alaska

To increase preparedness for future drought conditions and support climate-informed decisions, the Northwest Climate Hub, housed within the PNW Research Station, and partners convened a bi-monthly webinar series and regular drought status updates for Alaska, Idaho, Oregon, and Washington. These efforts have reached thousands of people and provide critical information to support drought-related management decisions from the local to federal level.

Identifying Environmental Conditions that Trigger Coho Salmon to Migrate and Spawn

Researchers found that patterns of river discharge and temperature appear to trigger upstream migration by coho salmon, whereas spawning appears to be triggered primarily by thermal conditions. The Oregon Department of Fish and Wildlife is using these findings as it develops a hydrologic model for the state. These findings will inform interpretation of patterns of river discharge and temperature during spawning, as well as the thermal effect of stream restoration actions.

Updated Web-Based Tools Help Natural Resource Managers Find Seed Sources Adapted to Future Climate

The Seedlot Selection Tool and Climate-Smart Restoration Tool have been updated to allow managers to input seed inventories and prioritize seedlots for a planting site based on the best match between the historical climate of the seedlots and the projected near- and long-term climates of the planting site. The new versions of these tools also allow users to input data from their own trials or published genetic studies to help find adapted seed sources.

Geneticists with the Forest Service's Pacific Northwest Region are using the Seedlot Selection Tool to design test plantations to study seedlot adaption and to evaluate how well their seed orchards will meet the needs for reforestation in a future climate. Geneticists in the inland West are using the Climate-Smart Restoration Tool to identify seed needed for postfire restoration and to help to ensure that the seed sources needed for future climates are conserved.

Enhanced Global Databases Facilitate Tracking of Deadly Amphibian Diseases

An international coalition of researchers, including scientists with the PNW Research Station, is working to minimize the spread of deadly amphibian diseases around the world through tracking, reporting, and development of biosecurity measures. In 2021, the coalition updated the global ranavirus reporting system and the amphibian chytrid fungus online database, to include new web platforms for data archival with improved user capabilities. These publicly accessible online amphibian disease databases are used by scientists and managers worldwide to conduct research and address threats to many species of wildlife.

PACIFIC SOUTHWEST RESEARCH STATION

The Pacific Southwest (PSW) Research Station represents FS R&D in the states of California and Hawaii and the U.S.-affiliated Pacific Islands. The region has the lowest, driest desert in the country, the highest elevations within the 48 contiguous States, and the wettest tropical forests. It is home to an abundant diversity of native plants and animals and nearly half of the Nation's threatened and endangered species. PSW scientists are engaged in research across a network of 14 experimental watersheds, ranges and forests and eight research facilities. PSW scientists conduct a broad array of natural resources research to achieve our mission to "develop and communicate science needed to sustain forest ecosystems and their benefits to society." Research is organized into five research units: conservation of biodiversity, ecosystem function and health, fire and fuels, urban ecosystems and social dynamics, as well as Pacific Islands forestry. For more information, visit www.fs.fed.us/psw.

PSW Science Delivery

Identifying the wide diversity of stewardship organizations working on the Los Angeles River Watershed

The Los Angeles River Stewardship Mapping and Assessment project surveyed and mapped groups conducting stewardship work in the LA River Watershed. Results show a diverse group of stewardship groups engaging in social-ecological based stewardship, with a strong focus on place-based work, and the involvement of non-traditional groups such as colleges and universities. This information can be used to facilitate the NEPA process, promote collaboration among stakeholder groups, and identify partners and sites needing stewardship work. Urban ecosystems are under increasing stress from an array of social-ecological challenges including climate change, land-use change, pollution, population growth, biodiversity declines, and social inequalities. Place-based stewardship is gaining increased recognition as a solution for achieving maintaining and/or restoring urban ecosystem health. Although they are usually not the primary landowners, stewardship groups take an increasingly greater responsibility for a wide range of land use types including street and riparian corridors, watersheds, vacant lots, and public parks. The Stewardship Mapping and Assessment Project (STEW-MAP) is a national research program developed by the US Forest Service that has been implemented at numerous locations in the United States and internationally. In 2019, researchers from PSW and the Los Angeles Urban Center partnered with Loyola Marymount University's Center for Urban Resilience to identify and map the different groups working stewardship-related activities in the Los Angeles River Watershed, including portions of the Angeles National Forest. In addition to research publications, the project will produce online interactive maps and tools that can support stewardship activities such as informing the NEPA scoping process; and identifying key stakeholders and potential partners. We found a diverse range of groups involved in stewardship of the watershed. Although the majority were non-profits, there were also government agencies, higher education institutions, for profit groups, and public private partnerships working across 41 types of sites. Notably, some of the groups worked at off-site locations, such as an indoor office or laboratory. Furthermore, in addition to the expected focus on environmental

issues, many of the organizations were involved with more social issues such as social justice, community improvement, education, and health. The presence of non-traditional stewardship groups has important

implications for cities and Wildland -Urban interface land managers. Conventional views on what is environmental stewardship, and which types of groups undertake this work are often not inclusive, and risk excluding key partners. Instead, practitioners and researchers would do well embrace the concept of social-ecological stewardship and adopt a broader view of where the stewardship work can take place.

All Fish, All the Time": A Good General Objective for Fish Passage Projects?

In the effort to sustain animal populations of special concern on National Forest lands, the appealing notion of "habitat connectivity" has led to many efforts to increase it, often at considerable expense. In this study, Forest Service researchers used a novel individual-based, spatially explicit modeling framework to test the influence of different levels of habitat connectivity on the population dynamics of highly valued salmonid fishes. The results indicate partial connectivity of sub-populations within stream networks can yield the same benefits for population abundance as complete connectivity; this finding can lead to more efficient prioritization and design of habitat restoration projects.

Stream networks on National Forests contain many human-built barriers to movement by highly valued salmonid fishes. Many prioritization schemes for barrier removal use the assumption that allowing movement of, "all fish, all the time," is the most desirable restoration goal, but creating this level of connectivity can be expensive, and in some settings can conflict with other resource management goals. Better understanding of the degree of "passability" needed to sustain robust sub-populations upstream of barriers could increase the efficiency of restoration efforts. We used spatially explicit, individual-based modeling of stream salmonids to explore the population-level consequences of various levels of upstream passability by adult fish only. In 30-year simulations, allowing resident adult salmonids (such as Cutthroat Trout) to move over barriers during only the highest 4% of streamflows yielded the same distribution and abundance of fish as allowing all fish unrestricted movement. In simulations of production from single years of spawning in a stream reach fully accessible to adult anadromous salmonids (such as Chinook Salmon), variation in the number of barriers to upstream movement by young salmon had no effect on the production of large outmigrants. Passage objectives less ambitious than, "all the fish, all the time," may often suffice to maintain populations.

Guidance for forest restoration following California megafires

2020 and 2021 have surpassed records for uncharacteristically large and severe wildfires in California and much of the West, and land managers are struggling to keep up with the need for postfire restoration efforts. To help address this challenge, Forest Service scientists and managers released a postfire restoration framework for California forest, chaparral, and sagebrush-steppe ecosystems and delivered findings to land managers and members of the public who have been impacted by giant wildfires in the past year.

A team of scientists from Forest Service research and management and other colleagues released a framework to guide post-fire restoration on national forests in California. The report highlights guiding principles, current tools for assessing postfire conditions, and case studies of applications of the framework to forests in the Sierra Nevada, chaparral in southern California, and sagebrush-steppe ecosystems in eastern California. Contributing scientists presented on their research to the Western Klamath Restoration Partnership, where tribes and other communities were devastated by the Slater fire in 2020, and national forest managers, Congressional staff, and stakeholders concerned about recovery from the enormous August Wildfire of 2020. Members of the team are working both to apply the framework to these recent megafires and to provide additional science guidance to address the growing challenge they represent.

The California Tree Mortality Network: Revealing the drivers and consequences of tree morality in the Central and Southern Sierra Nevada

Much of California experienced drought in 2012-2015. While consecutive years of drought are not uncommon in California, this drought was the most severe in 1,200 years in parts of the Sierra Nevada and likely foreshadows future impacts of drought under climate change. Working with managers and research partners, the California

Tree Mortality Network provides data on the causes and consequences of tree mortality following drought. This information is used to develop and prioritize management responses aimed at increasing forest and community resilience.
The California Tree Mortality Network consists of 180 monitoring plots installed in three elevation bands on the El Dorado, Stanislaus, Sierra, and Sequoia National Forests. Each plot is surveyed annually to record changes in forest conditions following an extreme drought (2012-2015) and bark beetle outbreak (2014-2017). Observations from these plots reveal how levels of tree death have impacted forest structure and composition, fuel loads, fire risk and behavior, pollinator communities and invasive plants. Other efforts leverage these data to predict how carbon sequestration and storage trajectories have changed in the Sierra Nevada; to model and compare silvicultural alternatives for improving forest recovery; and to better understand relationships between water storage and drought stress in seasonally dry forests. Working with managers, these data are used to develop and prioritize application of treatments to restore these forests and to increase resilience for future disturbances.

Working towards national wildfire prevention for the Republic of Palau

In FY21, PSW scientists partnered with Palau's Network for Wildfire Prevention to host a quarterly wildfire webinar series for Palau focused on wildfire prevention, fire suppression, fuels mitigation, and restoration of wildfire impacted areas. This series has resulted in the development of a NWP Dry Season Response Plan to identify needs, strategies, and stakeholder partners for fire education and outreach to prevent wildfires that will be integrated into the development of a National Wildfire Protection Plan.
Through collaboration with the USDA-FS, the Ebiil Society has worked with partners across the Republic of Palau to establish the Network for Wildfire Prevention (NWP) comprised of members from across Palau's national government, state level governments, and protected area network to address wildfire issues and work towards the development of a National Wildfire Protection Plan (NWPP). In FY21, PSW scientists partnered with the NWP to host a quarterly wildfire webinar series for Palau focused on wildfire prevention, fire suppression, fuels mitigation, and restoration of wildfire impacted areas. This series has resulted in the development of a NWP Dry Season Response Plan to identify needs, strategies, and stakeholder partners for fire education and outreach to prevent wildfires that will be integrated into the NWPP. Webinars have also addressed wildfire suppression topics as well as incorporate a wildfire response drill and an on-site after-action review of Palau's largest recorded wildfire that occurred in April 2020. A need identified through webinar discussions was a way to assess fire risk to inform a fire danger warning system, public messaging, and risk mitigation activities. In response, partners from NOAA and Guam Department of Agriculture participated in a webinar on Guam's Fire Danger Warning System that can be adapted for Palau through collaboration of the NWP, NOAA, and Palau National Weather Office. The webinar series will continue through FY21 and PSW scientists will continue to provide technical assistance to support the NWP in its development of a draft NWPP for Palau.

Removing barriers to pile burning

A low-cost collaborative study has helped reduce fuel treatment costs and provided scientific information resulting in a local air board permitting the burning of plastic-covered debris piles.
A collaborative study between the national forests in southern California, PSW Research Station and the University of California-Riverside helped determine that burning silvicultural debris piles covered by polyethylene plastic did not change the smoke emissions. In 2016 it was estimated that the results of this study saved the FS and state agencies over $100,000 annually in labor costs. Recently, the results were used by the Klamath National Forest resulting in an air quality rule change by the Siskiyou Air District to permit the use and burning of polyethylene covered slash piles.

Collaborative Use of Post-Fire Restoration Framework on the Creek Fire

The science-based, holistic, landscape scale postfire restoration framework from PSW-GTR-270 was applied to the 2020 Creek Fire in the southern Sierra Nevada. A categorized restoration priorities map was developed based on fire severity, fuels, natural regeneration potential, and drought risk, with special attention given to fishers and wildland-urban interface (WUI).
The Creek Fire (Sierra NF) was the largest single-fire (noncomplex) fire in 2020 and was the fifth largest in California's modern history at 379,895 acres, with almost half of it burning at high severity. Researchers from PSW and R5 ecology group formed a team to help tackle this massive scale restoration need following PSW-GTR-270's Postfire Restoration Framework to look at the larger landscape and help prioritize actions and areas. The team identified restoration objectives: restore forest resilience; maintain and promote Pacific fisher habitat and population corridors; reduce risk of future catastrophic wildfire, particularly around communities; and sustain future yellow pine mixed conifer forests in the near and long-term. Forested areas where the fire improved conditions (low severity burn) were highlighted as areas to maintain and promote desired conditions. Areas where factors (such as high fuel loads and lack of natural seedling regeneration) threatened the sustainability as a forested area were considered for reforestation and fuels reductions if future climate conditions were faciliatory (low drought stress). Special consideration was given to fisher, an old forest specialist, since a large amount of its habitat and key population linkages burned. Areas of remaining good habitat were identified to be improved/maintained. Prioritization for reforestation, with a focus on black oak, was given to identified areas of degraded fisher habitat and drainages to allow for connectivity. This analysis was provided to the Sierra National Forest to aid them in prioritizing their restoration plans along with the help of local specialists and ground-truthing of this analysis.

Creating a new legacy: working together to save large trees

Following a century of fire exclusion, the forests in the Caples Creek watershed are at a high risk of wildfire and a prescribed fire was implemented to reduce fuel loads. In addition to supplying water to over 110,00 people, having never been logged the watershed contains a high density of old forest trees. To reduce the risk of mortality to these trees during the burning operations, over 50 volunteers worked to reduce fuels around 200 trees in the Caple Creek Watershed. By comparing data collected pre and post fire across the 20,236-acre watershed, researchers at the Pacific Southwest Research Station in collaboration with the Cal Academy of Sciences and the Region 5 Ecology Program found that these community efforts not only helped protect large trees from fire mortality but helped to reduce future fire hazard.
To protect the many values at risk to wildfire, the Caples Creek Watershed Ecological Restoration Project sought to reduce hazardous fuels and restore watershed health in the drainage using prescribed fire. In preparation for the burn, over 50 volunteers worked to reduce fuels around 200 trees across 100 acres to protect remnant old growth forest and large, legacy trees from incidental fire mortality. By comparing data collected pre and post fire across the 20,236-acre watershed, researchers at the Pacific Southwest Research Station in collaboration with the Cal Academy of Sciences and the Region 5 Ecology Program found that these community efforts not only helped protect large trees from fire mortality but helped to reduce future fire hazard throughout the watershed.

Rocky Mountain Research Station

Rocky Mountain Research Station scientists work in a range of biological, physical and social science fields to promote sustainable management of the Nation's diverse forests and rangelands. The Station develops and delivers scientific knowledge and innovative technologies with a focus on informing policy and land-management decisions. Our researchers work in collaboration with a range of partners, including other agencies, academia, nonprofit groups and industry. The Rocky Mountain Research Station serves the Forest Service as well as other federal and state agencies, international organizations, Tribes, academia, non-profit groups and the public. Our Science Programs include: Air, Water and Aquatic Environments; the Aldo Leopold Wilderness Research Institute; Fire, Fuel and Smoke; Forest and Woodland Ecosystems;

Maintaining Resilient Dryland Ecosystems ; Human Dimensions; Inventory and Monitoring; Science Application and Communication and Wildlife and Terrestrial Ecosystems.

The Rocky Mountain Research Station maintains 14 research laboratories throughout a 12-state territory encompassing the Great Basin, Southwest, Rocky Mountains, and parts of the Great Plains. RMRS administers and conducts ecological research on 14 experimental forests, ranges and watersheds over the long-term. Some of this research dates back over a century and offers invaluable insight into how forests change over time, particularly as we face a changing climate and new disturbance regimes. We also oversee activities on several hundred research natural areas, a network of ecosystems set aside to conserve biological diversity.

Station-Wide Science Delivery and Technology Transfer

The Rocky Mountain Research Station public-facing website uses a modern Drupal-based platform which has provided a template for modernization for Research and Development. This year our website had over 1 million pageviews. The Rocky Mountain Research Station is actively engaged in the R&D web modernization effort which will greatly improve efficiency of IT resources, unify R&D and allow R&D web content to align with USDA web requirements.

The Rocky Mountain Research Station *Science You Can Use* (SYCU) publications continue to be highly regarded and sought after by land managers, congressional staff and other scientists. This year we continued to expand our reach and impact. SYCU is directly distributed to a mailing list of over 16,000. We produced a total of 25 SYCU publications in FY21 – 7 *SYCU Bulletins* and 16 *SYCU (in 5 minutes).* We also took advantage of a continued high number of teleworking land managers with our SYCU webinar series in the spring of 2021. These 15 short, interactive land manager-focused webinars enjoyed excellent participation hosting nearly 2,300 attendees and resulted in 48,539 webinar pageviews plus a 201% increase in pageviews from pre-webinar associated webpage visits.

Introducing Charboss: New Mobile Biochar Production Machine Results from Forest Service & Industry Patent

The USDA Forest Service is driving the development of technology for making biochar, a carbon rich soil amendment that can help restore degraded soil. Air curtain burners, also called air curtain incinerators or fire boxes, designed principally as a pollution control device for open burning. The Rocky Mountain Research Station is partnering with industry and land managers to develop new curtain burners that turn piles of unmerchantable wood waste into biochar. RMRS soil scientist Debbie Page-Dumroese and others are working with Air Burner Inc. under a Cooperative Research and Development Agreement to innovate ways to create useful biochar from new were air

The CharBoss team demonstrated how the equipment can be used to combat Gorse, reducing invasive species to create a product that can aid in restoration and enhance forest resilience and tree seedling quality (USDA FS photo).

woody biomass. The team was recently awarded a patent for their mobile biochar production system designed for their air curtain burner. The new system is called the CharBoss. The CharBoss has the capability to separate charcoal from the burning biomass using a mobile through-put method, or conveyor belt, that expels the biochar from the burner and subsequently quenches it.

The CharBoss has fewer size and moisture content limitations than existing mobile biochar production machines, and it can consume material from most burn piles with minimal to no preparation. The new technology immediately quenches the coals to reduce the risk of fire and reduce waiting time for cooling before application or transport to another site. The team's current machine burns at a rate of 1 to 2 tons per hour. Recent Rocky Mountain Research Station research shows how biochar can enhance forest resilience and tree seedling quality. One goal of the CharBoss development is to recover or offset costs of land treatments to reduce non-merchantable vegetation by producing a product that has value for augmenting and restoring degraded soils. On October 5, 2020, the CharBoss team held a field demonstration in Oregon to show off how the equipment can be used to combat the invasive woody shrub gorse; thereby reducing the biomass into a product that can aid in restoration. The mobile CharBoss system provides a landscape management opportunity and offers a value-added product for vegetation management activity that previously had none. This new mobile biochar technology provides forest managers with opportunities not only to remove unwanted biomass, but to benefit from the biochar created in the process.

PODs User Community Escalates Multiagency Engagement in Pre-fire Planning

Wildfire is becoming more frequent and intense across the country, and fire planning and management professionals are increasingly strained. Forest Service scientists develop tools and processes that can be used across boundaries to prepare for and respond to wildfire, such as Potential Operational Delineations (PODs) and several of the analytics hosted by the Risk Management Assistance (RMA) Dashboard. However, these tools require greater capacity and interagency coordination to provide the most benefit to communities facing wildfire. To generate solutions, the Rocky Mountain Research Station Wildfire Risk Management Science (WRMS) team convened the PODs User Community, a community of practice to build innovation, collaboration, and capacity around spatial planning. The Infrastructure Investment and Jobs Act identified PODs as a critical tool for wildfire management, supporting its application and increasing the need for interagency collaboration with a $100 million investment to expand delivery and training for PODs planning.

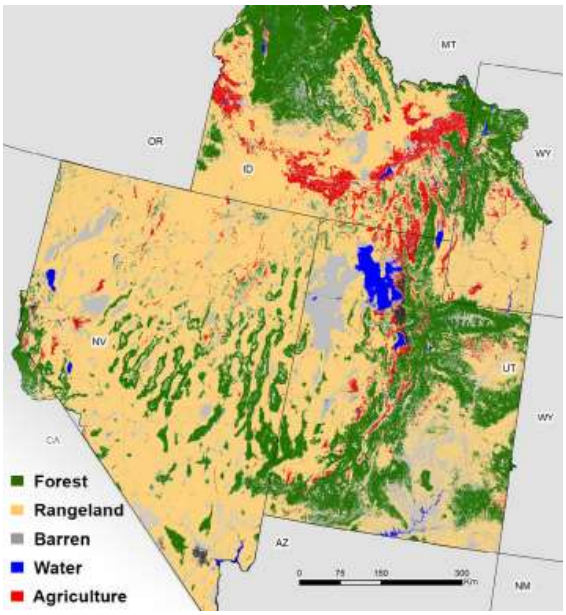
The RMRS hosted the PODs: Collaborative Fire Planning Workshop on February 24-25, 2021. The workshop included case studies from the field, showcased how PODs have been adapted for a range of applications, and identified implementation barriers and opportunities to improve this collaborative fire planning method. Over 450 fuel planners, line officers, management planners, scientists, and consultants participated in the event. Recordings of each session of the workshop are available on the PODs website.

The workshop also kicked off the PODs User Community, a group for PODs users, from experts to beginners. The User Community will continue to grow and adapt with PODs, as members of the group share their unique experiences with PODs on their local landscapes. The WRMS team at RMRS continues to advance PODs science, integrating feedback from the workshop as well as members of the User Community.

During the third virtual PODs User Community workshop November 3 – 5, 2021, over 150 participants including fuel managers, planners, and resource specialists had honest conversations about spatial fire planning opportunities and challenges. These user community meetings focus on PODs not as a stand-alone tool, but as a framework providing a natural springboard for developing risk-informed approaches to address emerging wildland fire management challenges.

New Approach for Estimating Rangeland Carbon Stocks Helps Managers Plan Climate Change Mitigation Strategies

Methods for estimating how much carbon is stored in rangelands have been lacking—until now. Using existing models and soil data sets, RMRS research ecologist Matt Reeves and a team of RMRS scientists and managers in the Intermountain Region developed a way to quickly assess rangeland carbon. And the great news—the process can be applied at local or larger scales. The technique involves assessing above ground carbon stocks in shrubs and below ground in soil organic carbon, which varies by plant community type. Standing carbon can be calculated either from plot level inventories or from spatial data describing shrub cover, height and species. The outputs help managers decide which types of management are most suited to maintaining or increasing carbon levels above and below ground and can be used to estimate where and how quickly ecosystems may change with a changing climate. The data are also useful for forest planning. This new approach was shared widely with managers as a Science You Can Use (in 5 minutes) publication.



Map showing areas of rangeland (tan color) in the Intermountain Region. Map by Matt Reeves.

FireWorks Curriculum Sparks Learning About Wildland Fire

The FireWorks curriculum, developed at the Rocky Mountain Research Station, has brought the science of wildland fire to life in classrooms across the western United States for more than two decades. Children living in the wildland-urban interface often grow up with the reality of wildland fire right in their backyards. Many students, however, rarely have an opportunity to learn about fire behavior, ecology or preparedness. FireWorks provides teachers and students with interactive lesson plans and trunks of materials that help students understand the physical science of fire, the important role that fire plays in many ecosystems, and how human activities can influence fire. The program features engaging, hands-on activities, like the popular "Matchstick Forest," which lets students see firsthand how factors like slope and fuel density affect fire spread. Curricula are available for grades K-12 and are updated to include the latest science and educational standards. The program is widely used by teachers and fire educators across the West – in the Missoula area alone, the program reaches more than 1,400 students and 300 adults each year.

RMRS ecologist Ilana Abrahamson uses a FireWorks activity to teach students about how trees grow and how thick bark can help them survive surface fires. USDA Forest Service photo.

Simple, Fast, and Cheap: A New Photoload Sequence Building Technique for Fuel Load Estimates

Fast and efficient fuel loading are vital estimates for fire prone ecosystems and for accurately predicting fire behavior effects. Fuel loads using photoload sequences are estimated by a set of comparing the fuels on a landscape to side- or downward-looking photos of photo simulated fuel beds with defined amounts of fuels. To create these sets in the past, researchers built simulated fuel beds by selecting, weighing, arranging, and photographing all materials and sequences in the lab. This process was time consuming and needed to be replicated for any new ecosystem. To improve accuracy and efficiency, Rocky Mountain Research Station scientists have developed a new method for creating photo sequences in the field. Using this new procedure, land managers will be able to more quickly create locally relevant photoload sequences to assess the fuel loads for their area.

The researchers measure the fuels and then collect them for drying and weighing in the lab. USDA Forest Service photo by Ian Grob.

The photoload technique provides a quick and accurate means of estimating the volume of wildland fuels on the landscape including 1-hour, 10-hour, 100-hour and 1,000-hour downed dead woody, shrub and herbaceous fuels. This is done by visually comparing conditions in the field with a set of photographed sequences. It has been implemented in multiple inventory and fuel monitoring projects worldwide. A new land manager-focused comprehensive handbook from RMRS details this new procedure for creating a set of photoload sequences in the field with minimal effort by photographing local fuel beds in situ. This new approach was shared widely with managers as a Science You Can Use (in 5 minutes).

One-stop Shop for 27 Years of Mappable Information About U.S. Wildfires

As fire seasons become longer, the amount of land burned has become greater. Climate change and other factors have meant more wildfires occurring outside of historic fire seasons in different parts of the country and more extreme fire behavior. In order to improve our ability to predict, manage, and recover from fire, having data about how fire has behaved in the past is important. Rocky Mountain Research Station research ecologist, Karen Short recently updated the Fire Program Analysis Fire-Occurrence Database. This database catalogues all wildfires reported in the U.S. from 1992-2018, representing a total of 165 million acres burned during the 27-year period. These data have served as critical inputs for many notable products, including a national wildfire hazard map and associated Wildfire Risk to Communities analyses. They are ready for use by fire managers, planners, decision makers and others inside and outside the agency.

Two-Part Salvage Science Summit

During a two-part series on forest salvage, panels of experts and practitioners were brought together to discuss the operations, technology, and ecology behind post-fire salvage science. The Salvage Science Summit Series, in May and December 2021, was a collaborative effort between Rocky Mountain Research Station, Southern Rockies Fire Science Network, Northern Rockies Fire Science Network, and the Northwest Fire Science Consortium. The Summit featured scientists (including numerous Rocky Mountain Research Station researchers) and land management experts from across the country to provide guidance in post-fire salvage operations. As a discussion-based event, all presentations were previously recorded and available for participants to view ahead of time. Each day, presenters shared an overview of their recorded presentation followed by discussion and Q&A session. This webinar was open to all audiences.

Forest Management Science Highlighted at Western Governors Association Workshop

Scientists from the Rocky Mountain Research Station participated in the Western Governors' Association workshop on Working Lands, Working Communities held in Denver, Colorado, October 7-8, 2021. Rocky Mountain Research Station research forester Nate Anderson served as a panelist on the *Forest Management Infrastructure Roundtable*, where he delivered a short presentation on opportunities, barriers and infrastructure for forest biomass and bioproducts. This science was developed with his Rocky Mountain Research Station colleagues Debbie Page-Dumroese, Dan McCollum, and Jeff Morisette. The panel explored infrastructure needs for effective forest management and economic development tied to forest restoration and the bioeconomy. Specifically, Anderson discussed synergies between forest restoration, transportation infrastructure, investments in bioeconomy enterprise, and

RMRS Research Forester Nate Anderson at the WGA Workshop (Courtesy photo by Ellen Jaskol).

workforce development. Watch this discussion and others from the workshop online. Moving forward, the Western Governors' Association is hosting webinars, work sessions, and podcasts to further examine these subjects. For over 100 years, Forest Service science has sparked innovations in forest products. Today, Forest Service science provides new uses and technologies for wood products and advanced bioproducts, such as biochar, cross-laminated timber, mass timber buildings and more. These products, and associated processes and innovations, strengthen economies, and provide environmental benefits.

Management Practices for Limiting Soil Disturbance During Harvest Operation

Timber harvesting can negatively impact soil health required for sustained forest production. Limiting the degree, extent, and distribution of soil disturbance during harvest operations will help continue the production of ecosystem services and goods from national forests. To help achieve this goal, RMRS research soil scientist Debbie Page-Dumroese and colleagues authored a report (RMRS-GTR-421) titled "Soil Sustainability and Harvest Operation: A Review." This new resource highlights the science on long-term soil recovery after timber harvests and reviews types of impacts, effects of different harvest operation methods, and recovery times. A Science You Can Use (in 5 minutes) shared this new report with land managers.

A New Road Map for Forest Service Science and Management Partnering

Bringing bright minds together from across Deputy Areas into a unique partnership built around an adaptive learning framework is what the Science Partner Program is all about. This effort has been designed and piloted by the Rocky Mountain Research Station and Intermountain Region (R4). By matching up research scientists with managers, this Science Partner Program has built positive relationships and networks between Research and Development and the National Forest System while working on specific, timely questions like: Can we downscale climate change maps to the National Forest level? How can we increase the accuracy and efficiency of Boreal Toad monitoring? And how might we improve our rangeland monitoring that leverage the best data available?

An example of one of the larger science partner program efforts, the Bridger-Teton National Forest and Rocky Mountain Research Station Scientists are collaborating in advance of Forest Plan Revision to get ahead of science-based needs that will inform the forest's process (USDA Forest Service photo by Nehalem Clark).

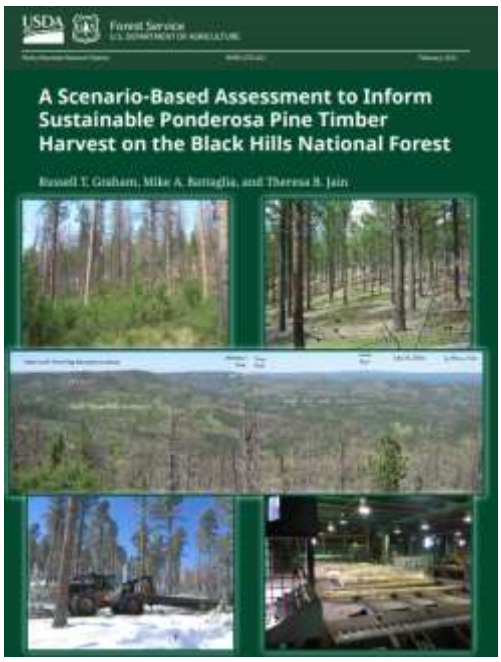
The newly published Intermountain Region-Rocky Mountain Research Station Science Partner Program: A Road Map to Connecting Forest Service Science and Management (RMRS-RN-89) and companion Story Map provide a blueprint for how a structured partner program can yield new approaches. The Road Map highlights key components for success while also sharing lessons learned, challenges the program faced, and future opportunities. A section of the Road Map is dedicated to how this model of pairing science and management can be applied to forest planning. The Science Partner Program is co-led by Nehalem Clark (Rocky Mountain Research Station) and Natalie Little (R4), and the program teams include representatives from boththe Rocky Mountain Research Station and R4. The program concept was conceived in 2016. This Road Map seeks to share inspiration for this type of co-production model with other land managers and scientists interested in knowing more about or creating these kinds of cross-agency connections. The science partner group members were instrumental in creation of the document, providing snapshots of what the 15 groups have set out to accomplish and lending valuable insights about what has been learned.

New Research Shows California Spotted Owls Benefit from Forest Restoration

Forest restoration treatments can reduce future fire severity and benefit populations of California spotted owls, even with temporary disruptions within owl habitats in the Sierra Nevada, California. This finding is showcased in "Forest restoration limits megafires and supports species conservation under climate change," a new research publication released in *Frontiers in Ecology and the Environment*. The research team also included collaborators from the USFS Pacific Southwest Research Station, USFS Region 5, University of Wisconsin-Madison, and University of California-Merced. The scientists developed a fire simulation model that predicted future severe fire across the Sierra Nevada through mid-century. The predicted amount of severe fire then changed as a function of simulated fuels reduction and forest restoration treatments. The fire model was then linked to a Sierra Nevada-wide population model of California spotted owls, which also responded to potential direct effects of treatments on owl habitat.

New Report Informs Sustainable Forest Management on the Black Hills National Forest

Rocky Mountain Research Station scientists published the general technical report, *A Scenario-Based Assessment to Inform Sustainable Ponderosa Pine Timber Harvest on the Black Hills National Forest*. The report, based on forest census data, provides context, rationale and evaluation of harvest level scenarios across a range of mortality and growth rates in the Black Hills. This report offers scientific information that can inform discussions concerning future harvest levels on the Black Hills National Forest. A primary finding is that the current volume of standing live sawtimber does not support a sustainable timber program at recent rates of harvest, under a wide range of scenarios considering growth and mortality rates. This report along with other best available scientific information can support forest managers, Tribes, stakeholders and the public in working together in future forest planning efforts on the Black Hills National Forest.



To ensure the highest quality data and scientific standards, a comprehensive review process was used. Scientists, technical and blind peer reviews, and an open public comment period produced over 350 comments. In response to reviewer comments, the final report contains ten times the original number of possible future scenarios covering a wide range of mortality, growth, and harvest rates. General technical reports, such as this one, are scientific documents, not policy or decision documents. This report, the associated Forest Inventory and Analysis data, and a large body of science related to the Black Hills are available for land managers to consider. USDA Forest Service Rocky Mountain Research Station also hosted a science-focused webinar to share the outcomes of the report on April 7, 2021.

Cutting Edge Research on Decision Support Systems for Wildland Fire

After several years of intense fires across the west, scientists have been working to develop new methods to support decision making. USDA Forest Service Rocky Mountain Research Station research foresters Dave Calkin and Matt Thompson assembled and authored cutting edge research as invited editors in a new special issue of the journal *Forests*. This issue compiles the latest science behind emerging decision support systems that help managers deal with the uncertainty of wildfire throughout the management cycle of planning, deciding, executing, monitoring and learning. Managing wildland fire is inherently complex. Successful strategies require innovative partnerships

between the research and management communities to create models that inform real-time decisions. Researchers from the USDA Forest Service Pacific Northwest Research Station contributed a publication to this special issue, "Hazards of Risk: Identifying Plausible Community Wildfire Disasters in Low-Frequency Fire Regimes." The authors hosted a webinar about the findings of this research on October 27, 2021.

Microscale Wind Modeling: WindNinja for Fire Management

WindNinja, a tool developed by Rocky Mountain Research Station scientists, delivers high-resolution wind predictions within seconds for emergency fire responders making on-the-ground decisions. The program computes spatially varying wind fields to help predict winds at small scales in complex terrain. These predictions are extremely important in fire-prone landscapes where local changes in the near-surface wind are not predicted well by either operational weather models or expert judgment but are extremely important for accurate fire behavior predictions.

WindNinja is a model that simulates high-resolution winds in mountainous terrain and is designed specifically for use in operational wildland fire applications (USDA image).

WindNinja performs microscale wind modeling and is typically run on domain sizes up to 50 kilometers by 50 kilometers at horizontal resolutions around 100 meters. This microscale wind modeling is used for a variety of tasks in wildland fire management, including planning, reconstructing past events, and exploring what-if scenarios. It is embedded within a number of operational systems routinely used by U.S. Interagency Wildland Fire response teams, including the Wildland Fire Decision Support System and FlamMap, and is also regularly used as a standalone model by both fire managers and on-the-ground firefighters in the United States and abroad. WindNinja can be run in three different modes depending on the application and available inputs. The first mode is a forecast, where WindNinja uses coarser resolution mesoscale weather model data from the U.S. NWS to forecast wind at future times. The second mode uses one or more surface wind measurements to build a wind field for the area. The

third mode uses a user-specified average surface wind speed and direction. This new tool was shared widely with land managers via a Science You Can Use (in 5 minutes).

Investigating Community Perspectives and Fuels Treatments in The Arctic

Rocky Mountain Research Station scientist Patty Champ will help co-produce a framework for research on fuels treatments in four communities in the Arctic through a new National Science Foundation grant. *The National Science Foundation's Navigating the New Arctic* program is funding a team of eleven researchers to assess fuel treatments as a strategy to reduce wildfire risk in Alaska and western Canada through the collaborative Socio-ecological considerations for sustainAble Fuel treatments to Reduce wildfire Risk project (SAFRR). This project is receiving funds as part of the larger $2.3 million NSF grant. The project team includes researchers from the University of Alaska Anchorage, Northern Arizona University (NAU), the University of Colorado (UC), Tanana Chiefs Conference (TCC), and Rocky Mountain Research Station economist and Wildfire Research, WiRē, team member Patty Champ. *Navigating the New Arctic* projects address the convergence of scientific challenges in the rapidly changing Arctic.

Wildfires occur naturally in boreal forests, but they have become increasingly dangerous as the climate warms. The area of boreal forest burned each year in Alaska and western Canada has doubled since the 1990s, and the region has experienced some of the most deadly and costly wildfire events in the last decade. Effective fuel treatments such as thinning and prescribed burns require significant planning, implementation costs, and maintenance; and they may face resistance from nearby residents. The SAFRR project team will work with many stakeholder groups, including public land and wildfire practitioners; Indigenous organizations; and, communities (Kenai Peninsula, Interior Alaska, Anchorage, Whitehorse, and Yukon Territory), to co-produce an integrated assessment of fuel treatments. The team will study how vegetation responds to different treatments. They will also analyze treatment costs, the acceptability to residents of different types of treatments in boreal forests, and how land managers can use fuel treatments to reduce wildfire risk.

Beetle Outbreaks in Subalpine Forests and What They Mean for Snowmelt

It is hard to overstate the importance of snowmelt as a source of fresh water in parts of the Rocky Mountain West, and great attention is paid to ecosystem water cycles in this region. Some of the snow that falls in the mountains goes directly from crystalline snow to water vapor, bypassing the liquid water phase. This phenomenon—sublimation—accounts for the loss of a large portion of the snowfall

during the winter months in the Rocky Mountains. Snow intercepted by tree branches sublimates the fastest, often disappearing within a few days of a snowfall. Starting in the mid-2000s, a spruce beetle outbreak caused widespread damage to an Engelmann spruce subalpine fir forest in the Snowy Range Mountains of southeastern Wyoming. By 2010, the outbreak killed 75 to 85 percent of mature Engelmann spruce trees in some areas. The loss of the needles following the outbreak meant that less snow was being retained in the canopy and was instead falling through the tree branches and onto the ground. Snow on the ground has less surface area, which slows sublimation, while the loss of canopy increases the amount of wind and sunlight reaching the ground, speeding up the sublimation of the snowpack. Recently published work by Rocky Mountain Research Station Electronics Engineer John Frank and colleagues teases apart how the loss of spruce canopy affects the sublimation rates for snow both in the canopy and on the ground in these ecosystems. And these findings have important implications to snow interception and retention for forest and water managers. These findings were shared widely with the RMRS land manager mailing list as a Science You Can Use (in 5 minutes).

Engelmann spruce trees killed by spruce beetle (right) in Wyoming's Snowy Range have far fewer needles to catch snow, compared to the living subalpine fir on the left. Less snow in the canopy leads to lower sublimation rates and more water being retained in the forest. Photo credit: John Frank, USDA Forest

Tree-level Map of U.S. Forests Developed by RMRS Scientists

Scientists from the Rocky Mountain Research Station have created TreeMap, a first-of-its-kind tree-level map of the forests of the United States. Forest Service scientists developed TreeMap to understand the risks wildfire poses to carbon stored in forests. Current wildfire simulation models addressed the fire component of their question, but to tackle the carbon side, they needed information on U.S. forests at the individual tree level. That dataset did not yet exist at a national scale, and with over 2.8 billion pixels of imagery to populate, creating it was a daunting task. In a research paper published in *Nature Scientific Data,* the scientists, Karin Riley, Mark Finney, and Isaac Grenfell describe their innovative approach. TreeMap paired two databases: The Forest Inventory and Analysis database and LANDFIRE. FIA contains tree-level information from thousands of plots across

the United States, but the plots don't provide wall-to-wall coverage. LANDFIRE provides a 30x30 meter grid of geospatial information like vegetation type and disturbance history for the entire United States but lacks information at the tree level. Through an artificial intelligence technique, the scientists essentially matched each pixel of the LANDFIRE database with a forest inventory plot that best represented that area. For any 30x30-meter pixel, a TreeMap user can download tree-level information and produce maps of those attributes, like tree density, heights, and species.

Beyond understanding fire risk to carbon, TreeMap has broad applications for land managers. It is already being used to inventory wildlife habitat, map forest types, and evaluate how proposed management actions may affect carbon stocks and local hydrology. Several of Riley's colleagues have been applying the dataset to improve firefighter safety by providing snag hazard maps for active fire incidents. Snags (standing dead trees) are one of the most common causes of firefighter casualties. Incident-specific maps are created and shared through the Risk Management Assistance Dashboard, giving incident response teams a quick picture of what conditions to expect on the ground, identifying hazardous areas, and ultimately improving firefighter safety. With TreeMap in hand, the Rocky Mountain Research Station team can now return to the broader question of how wildfire affects forest carbon, including expected emissions and how much carbon fires leave behind. Eventually, they hope to evaluate these impacts into the future, as changing climate and fire regimes reshape forests.

New Updates to the Wildfire Risk to Communities Website

Marking the one year anniversary of the Wildfire Risk to Communities website, the USDA Forest Service - with strong science input from Rocky Mountain Research Station Spatial Fire Analyst, Greg Dillon and our partners, Headwaters Economics and Pyrologix - have updated the website with new features. New features include the ability to interact with wildfire risk data for your community, county, and state. New "expanded areas" show your risk in populated areas outside official community boundaries. The update also facilitates comparing your community's risk to other communities in the county, state or nation. Prior to the update, community comparisons were limited to your state. The website is free and easy-to-use with interactive maps, charts, and resources to help communities understand, explore and reduce wildfire risk. The website

uses the best available science to identify risk and provide resources for communities to manage and mitigate risk. The resources at wildfirerisk.org give our community a deeper understanding of our Wildfire Risk to Communities is designed to help community leaders understand how risk varies across a state, region, or country and prioritize actions to mitigate risk. As a national project, Wildfire Risk to Communities is best for comparing risk among, rather than within communities, and it is not designed for considering risk at the local, neighborhood or individual home scale. Wildfire Risk to Communities is the Forest Service's response to direction in the 2018 Consolidated Appropriations Act (H.R. 1625, Section 210). In the legislation, Congress directed the Forest Service to produce a nationwide map that could inform communities about wildfire risk, help them understand their risk profile, and guide them toward steps to reduce their risk.

New Phenomap Tool Provides Range Managers with Real-Time Forage Conditions

Timing is everything, especially when it comes to the complex ecological interactions between plants and the environment. For range managers concerned with maintaining the integrity and productivity of rangelands, it is critical to monitor the seasonal conditions of grasses and other vegetation on which cattle graze. PhenoMap is a new Web-based tool that managers can use to assess the production and location of high-quality forage. PhenoMap uses satellite imagery to serve up near-real-time maps of what is happening on rangelands over large scales. For instance, what is happening with western wheatgrass green-up or buffalo grass senescence can be detected via desktop. Phenomap allows range managers and producers to see what is happening across their areas of interest and perhaps make shifts in grazing with changing conditions. PhenoMap was jointly developed by researchers at the Forest Service's Western Wildland Environmental Threat Assessment Center, Pacific Northwest Research Station (PNW) and Rocky Mountain Research Station. PhenoMap was also featured in the new Rocky Mountain Research Station science delivery product: Connected Science. This new special series highlights important collaborations that deliver relevant, applied science about natural resources to people who make and influence decisions about managing land and natural resources.

Climate Change, Wildfire and Mexican Spotted Owls: Delivering the Most Recent and Best Science to Managers

Rocky Mountain Research Station scientists are working to understand how the changing climate and fire are affecting Mexican spotted owls, a threatened species found primarily in the Southwestern US and Mexico. Across their range, a 13-fold increase in the area burned is expected by the 2080s which could translate to large-scale habitat loss. As nesting environments become warmer and drier in future climates with predicted higher temperatures, owl nestlings may experience greater water stress. This means the owls could ultimately be pushed beyond physiological thresholds for survival. Rocky Mountain Research Station scientists and collaborators evaluated the annual climate cycle in the Sacramento Mountains of New Mexico. These climate change effects are likely to be apparent first in lower and warmer habitats occupied by Mexican spotted owls, therefore the research team recommend that

managers monitor the occupancy and reproduction in such areas to provide an early warning system for climate change effects.

The RMRS team has also launched the 'Living Map' of Mexican spotted owl habitat, which includes annual maps of owl nesting habitat from 1985 to now. This map provides a living, updatable tool allowing managers to track changes in amount and distribution of owl habitat over time, and to better understand the effects of disturbance events such as wildfires on amount and distribution of that habitat. This knowledge will aid in integrating habitat needs of Mexican spotted owls with efforts to restore forest structure and more natural fire regimes throughout the southwest, which is one of the major challenges facing managers in this region.

Global Technology Transfer and RMRS Entomological Expertise: Forest Service Scientist Identifies Important New Endemic Fly Species on Monserrat

Smaller than a house fly, both adults and larvae in the fly family Dolichopodidae (known as long-legged flies) are predators that play important roles in the ecosystems in which they occur. They feed on other small invertebrates and may play important roles in controlling mosquitoes, bark beetles and more agricultural pests. Yet even though there are than 7,500 species of Dolichopodidae await worldwide, many undescribed species still discovery. Rocky Mountain Research Station research entomologist and world expert on Diptera, Justin Runyon has recently identified 63 species, including eleven new species of Dolichopodidae on Monserrat. These new species are described and illustrated in 'The Dolichopodidae (Diptera) of Montserrat, West Indies.' The new paper provides keys to the genera and species of Montserrat, summarizes their distribution, and provides additional new island records for many species.

RMRS Research Entomologist Justin Runyon has identified eleven new species of flies in the family Dolichopoididae on Monserrat. Photo by Catherine Wensink (UK Overseas Territories Conservation Forum).

These records and new discoveries are critical to understanding the diversity and distribution of long-legged fly species, information essential to manage and protect biodiversity. Six of the long-legged fly species are endemic to Montserrat and protecting their habitats can ensure conservation of these unique species. Protection of areas currently inhabited by these endemic species is among the highest priority conservation recommendations. Runyon also identified threats to the fly fauna on Monserrat, both natural and human.

Can Ponderosa Pine Bounce Back After High-Severity Fire?

Ponderosa pine forests were historically shaped by frequent, low- to mixed-severity fires. Land managers and scientists are concerned that recent high-severity fires, which have left expansive treeless patches in their wake, may prevent ponderosa pine from successfully regenerating in much of its former area. If ponderosa pine does not reclaim these sites, these areas will become grasslands, shrublands, or other forest types, such as aspen or Gamble oak. Rocky Mountain Research Station scientists and their colleagues examined the spatial patterns of ponderosa pine regeneration following fire, as well as the influence of environmental factors, such as distance to seed source, elevation, and other vegetation, on ponderosa regeneration success. They focused on large, high severity patches in Arizona, Colorado, and South Dakota wildfires. Their results – shared widely in a recent Science You Can Use Bulletin – show that ponderosa pine generally regenerated in groups or clumps, rather than in a relatively homogenous pattern, and the amount of ponderosa pine regeneration declined sharply with distance to seed source. The researchers also found that ponderosa pine regenerated more abundantly in higher-elevation sites where climate tends to be cooler and wetter. Other vegetation generally did not negatively influence ponderosa regeneration, and in many cases, had a positive effect on regeneration success, probably by mitigating harsh site conditions. Downed logs also appeared to ameliorate harsh site conditions, to the benefit of regeneration.

Overall, these results suggest that ponderosa pine may recover in high-severity patches that are close to surviving seed sources, but in large patches far from surviving trees, ponderosa pine recovery may be compromised, especially where growing conditions are harsh. These results can help managers better anticipate recovery within high-severity patches, and in turn, better determine whether tree planting treatments are needed to maintain ponderosa pine forests in the future as well as where and how to conduct them.

Understanding and Managing Pinyon and Juniper Woodlands in a Changing Climate

Across the western United States, pinyon and juniper woodlands are undergoing significant changes that are of concern to land managers and the communities who depend on them. In some areas, the woodlands are expanding, resulting in increased fuel loads, risk of more severe fires, and loss of high value habitat for species such as greater sage grouse. In other areas, these woodlands are contracting due to human development, more severe droughts, and larger wildfires. Rocky Mountain Research Station scientists and their partners synthesized over 1,000 research and management papers on pinyon and juniper woodlands in order to help land managers, researchers, and the interested public understand and address these concerns. The resulting publication, The Ecology, History, Ecohydrology, and Management of Pinyon and Juniper Woodlands in the Great Basin and Northern Colorado Plateau of the Western United States (RMRS-GTR-403), is designed to help managers quickly reference the current state of knowledge of these semiarid woodland ecosystems, prioritize areas where conservation and restoration efforts will have the greatest benefits, and identify appropriate management actions. The synthesis covers the ecology, history, and hydrology of these semiarid woodland ecosystems as well as

the history of and responses to restoration and other management treatments. This reference was shared widely with land managers as a Science You Can Use Bulletin.

Real-Time Forecasting of Wildfire Ignitions Across the United States

Dr. Ned Nikolov and his team at the Rocky Mountain Research Station Rocky Mountain Center for Fire-Weather Intelligence (RMC) has developed (in cooperation with Colorado State University) a unique new forecasting tool for quantifying the *chance* of wildfire start (ignitions) up to 10 days in advance on a uniform 20-km resolution grid across the Conterminous USA. The new application became operational in the summer of 2021 and is accessible through the RMC website. It produces probability forecasts for ignitions due to either lightning-caused, human-caused, or all-cause wildfires. At the core of the application is a comprehensive statistical model derived from a large amount of gridded 3-D meteorological data fields from NOAA's NARR database spanning the period 1992 – 2016, high-resolution vegetation cover and fuel maps, and Karen Short's updated Fire-Occurrence Database. An essential part of the ignition probability model is a module that forecasts *cloud-to-ground lightning* at 20-km resolution across the USA derived from observed lightning and meteorological data over a period of 24 years. Real-time lightning forecasts are also operationally available at the RMC website.

Testing of Low-Cost Smoke Sensors

Smoke Sensor Testing at the Missoula Fire Lab

Wildland fires produce significant air pollution and real-time measurements of these pollutants are critical for mitigating the human health impacts of smoke. With climate change increasing the severity of the western U.S. wildfire season, there is an urgent need for new air pollution measurement technologies to reduce coverage gaps in existing air monitoring networks. The Environmental Protection (EPA) has partnered with Rocky Mountain Research Station (RMRS) Physical Scientist Shawn Urbanski in a multi-year effort to advance the development of new air measurement technologies for real-time smoke monitoring and to evaluate the performance of existing instrumentation in smoke impacted environments. In the initial project phase, several federal agencies partnered with the RMRS/EPA team for the 2018 Wildland Fire Sensor Challenge which focused on low-cost, easily deployable sensors capable of measuring $PM_{2.5}$, CO, and CO_2. During the Sensor Challenge, prototype systems were evaluated in testing at the RMRS Missoula Fire Sciences Laboratory combustion facility. Several

prototype sensors were identified for further development. In later project phases the second-generation low-cost sensors, some capable of measuring several air pollutants present in smoke, were evaluated by the RMRS/EPA research team in laboratory testing and multi-year field testing at the Mobile Ambient Smoke Investigation Capability (MASIC) site located on the Missoula Fire Sciences Laboratory campus. This project will ensure these low-cost smoke sensors provide accurate pollutant measurements and are suitable for use in the high pollutant concentrations observed during wildland fire events. This new class of sensors will provide the ability to rapidly deploy an on-demand network that will guide smoke mitigation efforts, improve smoke forecasts, provide data for the validation and improvement of smoke emission and dispersion models, and support smoke exposure research.

The Great Basin Five-Needle Pine Proactive Strategy Engagement: A Collaborative and Science-based Approach

Great Basin bristlecone pine, limber pine, and whitebark pine protect watersheds, play important ecological functions, are symbols of perseverance and longevity, and are valued by the public. These high-elevation five-needle pines of the Great Basin face direct and indirect effects of climate warming and the threat of the continued spread of *Cronartium ribicola*, the non-native fungus that causes the lethal disease white pine blister rust (WPBR). The Great Basin ecosystems are unique, and the scope of the threats requires landscape-scale solutions. The primary objective of this ongoing project, led by RMRS researcher Anna Schoettle along with other scientists and managers, is to coordinate a cross-boundary partnership of managers, researchers, and professionals to identify critical information gaps and outline priorities for building a strong science foundation that can assist in timely decision making for managing and conserving the high elevation five-needle pines for resilience to WPBR in a changing climate.

Group photograph of the participants of the workshop in July 2021 (USDA Forest Service photo).

We brought together representatives from the USDA Forest Service (R&D, NFS, FHP), USDI Park Service, USDI Bureau of Land Management, USDI Fish and Wildlife Service, academia, and State, Tribe, and non-governmental organizations for a field workshop in July 2021 in eastern Nevada to share knowledge and build a collaborative High-5 group in the Great Basin (Figure 1). This project was supported in-part by the USDA FS R4-Rocky Mountain Research Station BeSMART Program intended

to spur Intermountain Region (R4) management – FS research partnerships to bring innovative approaches to management challenges.

Carbon Monitoring System

The U.S. Forest Service is working to concurrently mitigate and adapt to climate change when managing the nation's forests and rangelands, which have varying capacity to absorb carbon. Knowing the distribution of aboveground forest and woodland biomass across the landscape is crucial to inform management decisions. Accurately mapping aboveground biomass with confidence requires multiple sources of information, most notably forest inventory plot data, satellite imagery, and Light Detection and Ranging (LiDAR) remote sensing data. Tree measurements in field sample plots provide the biomass estimates needed on the ground. Satellite imagery captures variation in forest cover across space and through time. LiDAR is highly sensitive to variation in 3-dimensional forest structure that relates closely to the distribution of biomass across the landscape and serves to bridge the scale gap between field plots and satellite imagery.

Research Forester Andy Hudak and Geographer Ben Bright worked with multiple stakeholders across federal and state agencies, tribes, universities, and industry to develop a Carbon Monitoring System that leverages the respective strengths of forest inventory plot measurements, satellite imagery, LiDAR, aerial photography, topographic, and climate data to estimate forest and woodland biomass. The integrated maps of forest and woodland biomass (2000-2016) are available for the Northwest US, and ongoing work will expand the maps to the entire western US (1984-2020). Furthermore, the integrated maps are a valuable resource in support of managers working to meet objectives of the 2012 Forest Service Planning Rule and the Forest Service's Shared Stewardship Initiatives.

Southern Research Station

Technology Transfer and Science Applications

The Southern Research Station (SRS) includes research work units across 13 southern states and employs around 300 people, including close to 100 research scientists. SRS research advances many areas of forestry science: the use of prescribed fire; hardwood and softwood silviculture, harvesting, and utilization; protection of drinking water supplies and water quality; sustainable management of wildlife habitat; and the control of insects, diseases, and invasive plants. SRS partners with the Southern Region of the National Forest System to conduct research on a network of 19 experimental forests and one partner-managed demonstration forest.

Throughout FY21, SRS focused on research and technology that would foster productive, sustainable use of public and private lands. SRS shared these innovations with partners and stakeholders, including:

- 458 scientific publications
- 251 presentations, workshops, booklets, maps, and other science delivery activities
- 64 articles in the online science magazine, CompassLive
- 2 quarterly issues of Research Plots, a newly-launched newsletter featuring SRS science products
- 30+ webinars and online courses, including the SRS-hosted Science in Practice series and multiple contributions to the national R&D SCIENCEx series
- 14 datasets in the Research Data Archive
- 260+ posts to more than 6,300 followers on Twitter
- 30+ posts to more than 14,000 followers on Facebook

Some highlights of these outreach, science communication, science delivery, and technology transfer efforts are listed below.

Processing forest inventory data at 182 million pixels per second

Although the FIA program monitors more than 350,000 plots across the U.S. and measure hundreds of variables, it can't measure everything. There is incredible variation in land use and forested systems that occurs in between each of the plot observations. At the same time, remotely sensed imagery alone can't match the richness of data captured by FIA. To address these challenges and gaps, FIA created the Big Data Mapping and Analytics Platform, or BIGMAP. The ultimate result of the BIGMAP project is a spatially enabled FIA database, the public database of record for the U.S. that contains more than 20 million tree records. BIGMAP tuned to leverage the parallelization and mass storage required for raster processing at scale that fuses thousands of Landsat scenes with hundreds of thousands of plots. BIGMAP can process tens of trillions of pixels in the cloud to create first-of-its-kind data products, data delivery portals, and education and outreach materials for power users and new users alike. BIGMAP tackles complex, multi-dimensional raster analysis problems to support planning and decision-making with a seamless workflow from data generation to discovery, consumption, and application. BIGMAP is a cooperative effort between FIA, Forest Service national Geospatial Services, and ESRI.BIGMAP is a great example of successful collaboration with both internal and external partners. With BIGMAP, the USDA Forest Service joins the such as NASA and NOAA in its ability to process large data and produce broad-scale mapped products on a reliable, regularly updated basis. Learn more through this Story Map: https://arcg.is/1mzXj.

Handbook for 30-year-old bottomland oak stands

A Forest Service handbook outlines the methods – and supporting science – for managing bottomland hardwood stands to produce high-quality sawtimber, improve wildlife habitat through acorn production, or an integrated approach for both timber and wildlife. Researchers produced this synthesis specifically for the seven-state Lower Mississippi Alluvial Valley, with input from forest landowner and manager members of the Southern Hardwood Forest Research Group. A million acres of hardwoods were planted across this area since the 1980s, and many have reached the stage when silvicultural activity might be useful. The handbook targets even-aged stands, 15 to 40 years old, whether purely oak or mixed species. Most of the timber production prescriptions in the handbook were modified from practices developed for natural stands, with the expectation that oak-dominated planted stands will respond similarly. The prescriptions for wildlife habitat and for integrated management for both timber and wildlife were developed specifically for this handbook. Explore the silviculture handbook: https://www.srs.fs.usda.gov/pubs/62945.

Fast, field-based diagnosis of laurel wilt disease

A team of researchers developed a molecular, diagnostic test for laurel wilt disease. The researchers developed and tested the new method, a loop-mediated isothermal amplification assay, in the lab. They extracted fungal DNA from tissues of possibly infected wood samples and tested for the presence of the fungus. Pleased with the accurate results, the team carried the study to the field. Samples were collected from trees showing visual symptoms characteristic of the disease: wilting leaves and dark-streaked sapwood. Using samples of infected sapwood and portable equipment, the researchers were able to conduct DNA extractions and analyses on site. In under an hour, the LAMP method accurately detected laurel wilt disease in sassafras and redbay. In the past, lab confirmation of diagnostic tests could take upwards of a week. A broad scale, effective treatment for laurel wilt disease does not exist yet. Rapid detection and tree removal remain the best way to minimize its impacts. Learn more about the diagnostic approach: https://www.srs.fs.usda.gov/pubs/62506.

Soil salinization, a salty problem for coastal forest management

Soil salinization threatens the productivity of coastal forests in parts of the southeastern U.S. Sea-level rise causes saltwater intrusion and soil salinization, which can kill plants that are not able to tolerate the salt. Elevated salinity levels also cause increases in salt-tolerant invasive species, and marsh migration. In addition, vegetation stressed by salinization is more susceptible to mortality by events such as droughts, hurricanes, and fires. The USDA Southeast Climate Hub developed a manual to help coastal landowners and technical service providers identify potential salinity issues on their forestland, mitigate impacts, adapt management practices, and, when possible, keep their land economically productive. *Identification, Mitigation, and Adaptation to Salinization on Working Lands in the U.S. Southeast* addresses critical knowledge gaps identified during a soil salinization workshop with subject matter experts in the region. The manual can help extension agents, landowners, USDA Natural Resources Conservation Service field staff, and private consultants determine the stage and severity of soil salinization on forest land. It also provides guidance on early harvest, conversion to conservation easement, and alternative, salt-tolerant crop considerations when forestry operations are no longer economically viable. Find the manual here: https://www.srs.fs.usda.gov/pubs/61766.

Controlling the spread of Callery pear

The most common cultivar of the invasive Callery pear is the Bradford pear. In the last two decades, this near-ubiquitous landscaping tree has been identified as a serious invasive pest. When the tree borders roads and fields, its dense growth and sharp thorns threaten equipment and livestock. Callery pear can also grow in the understory of pine plantations, where it can impede some forest management practices. A Forest Service publication examines herbicide treatments to control the spread of Callery pear. The research team compared the efficacy of different herbicide treatments at two sites in Georgia and South Carolina. They

tested four common formulations: glyphosate, hexazinone, imazapyr, and triclopyr. Using handheld sprayers, the team applied the four herbicides, along with one combination of two, on the basal bark and leaves of Callery pear trees and to the soil around the base of the trees. The researchers compared the trees treated at each site and included a control group that was not treated. The study showed that the foliar and basal bark treatments were both effective at controlling Callery pear. Additional study is needed to evaluate soil applications, because rainfall at the sites may not have been sufficient. This research adds to land management control options and supports further development of integrated pest management practices for this invasive species. Read the article on herbicide treatments: https://www.srs.fs.fed.us/pubs/61988.

Updated guide to forest management and bats

Because more than half of the forest land in the U.S. is privately owned, forest landowners play an important role in the stewardship of our wildlife resources. *Forest Management and Bats* was first published by Bat Conservation International in 2006 and recently updated with data about white-nose syndrome. Written for landowners and land managers across North America, the guide provides information on various practices used to manage forests and how these practices affect bats. It includes sections on roosting, foraging, and water sources. Learn more about how active forest management can not only improve forest health and productivity but also improve habitat for this beneficial group of forest mammals: **https://www.srs.fs.usda.gov/pubs/61910**.

The status of northern long-eared bats in the Ouachita National Forest

The northern long-eared bat (*Myotis septentrionalis*) was recently classified as federally threatened by the U.S. Fish and Wildlife Service due to a dramatic decline in their numbers. Many bat species native to the eastern U.S. have experienced significant mortality because of white-nose syndrome, a disease cause by a fungus found in cold caves where bats hibernate during winter. SRS researchers and managers on the Ouachita National Forest began a new study to determine the extent of the species decline across the forest. A decade ago, the northern long-eared bat was abundant in the area. The team will determine the species' status through extensive trapping efforts. White-nose syndrome was first detected in the U.S. in 2006. The fungus has spread across the country and killed millions of bats. Learn more about SRS research on bats: **https://www.srs.fs.usda.gov/compass/?orderby=date&s=bat**.

Co-producing prescribed fire science with the National Forest System

For the past 20 years, managers on the William B. Bankhead National Forest, Alabama have been co-producing science with the Southern Research Station and other partners. The project has led to a multitude of technology transfer opportunities, such as:

- Fire management experts at national forests are using results and data from the study to develop prescribed fire protocols. Study results are used in university classrooms and by The Nature Conservancy.
- More than 70 students from Alabama A&M University, Tennessee State University, University of Alabama, and Auburn University have trained on the site. Student research has resulted in more than 100 presentations and 50 publications.
- The study is part of professional training opportunities offered through the Southern Group of State Foresters and the National Advanced Silviculture Program.
- Results have been shared at 30 scientific meetings, including the International Fire Ecology and Management Congress and two Fire in Eastern Oak Forests Conferences.

The team is tracking ecosystem response to forest management activities, including tree thinning and prescribed fires. The long-term study is showing how prescribed fire and thinning can keep forests healthy and at lower risk to catastrophic wildfire, insect and disease epidemics, and other threats. Learn more: https://www.srs.fs.usda.gov/pubs/62086.

Prescribed fire science: Why we need it now more than ever

Wildland fire is a keystone ecological and social process, but some areas have too much fire and others not enough. Prescribed fire is an essential but underutilized tool for mitigating wildfire risk and maintaining ecosystem health. Prescribed fires can span the same continuum of fire behavior and effects as wildfires, the only difference being the source and intent of the ignition. Because the choices on how, when, and where to ignite a fire are nearly unlimited, the practice requires a robust and mechanistic understanding of the complex interactions among ignition patterns, atmospheric dynamics, fire behavior, and subsequent smoke production and ecological effects. The Prescribed Fire Science Consortium joins scientists across disciplines with managers for a unified research approach aimed at understanding and improving prescribed fire as an ecological process and a management tool. Its members posit that the science required for guiding and improving prescribed fire is sufficiently unique to justify a separate approach – and that this will provide significant benefits to wildfire management as well. Learn more about the new Consortium: **https://www.srs.fs.usda.gov/pubs/59779**.

Long-term pine progeny tests lead to new insights

Decades ago, shortleaf pine (*Pinus echinata*) and loblolly pine (*Pinus taeda)* were planted in national forests across the USDA Forest Service Southern Region. The original purpose was progeny testing, but as decades passed, the studies were largely abandoned. However, many of the stands remained and kept growing. SRS researchers recently evaluated some of the surviving trees to see how genetics and environment affected three important traits: tree survival, height, and diameter at breast height (DBH). Shortleaf pine survival was not affected by differences between genetic families, as the team found. However, DBH and tree height were affected by genetics – both genetic families and the source of the seeds. Loblolly pine is usually evaluated after only a few years and performance among each genetic family is assumed to be relatively fixed over time. However, the study shows that this is not always the case. Depending solely on early height performance to select loblolly pine families for long-term (>50 year) volume or biomass yields may not be the best approach. The finding is important because choosing loblolly pine families that are not the best may limit the potential of carbon storage decades later. Learn more about the shortleaf progeny tests: https://www.srs.fs.fed.us/pubs/62718 and the loblolly progeny tests: https://srs.fs.usda.gov/pubs/62931.

Mechanical fuel reduction costs

Mitigating wildfire risk is a land management priority across the U.S. Reducing fuel loads through mechanical treatments can control understory and midstory vegetation and prevent fuel ladders that can spread fire from ground vegetation up into the canopy crown. SRS researchers summarized costs, benefits, and limitations for common mechanical fuel treatments. Plans for burning or spreading logging slash must be factored in with harvest treatments. Income from the harvest can offset some of the costs. If woody biomass markets are available, baling and bundling can be used to compress small trees and shrubs into residue logs. Without a market, this material would contribute to fuel loading. Whole tree chipping can also generate biomass or biofuel materials. The researchers tested the use of mulchers to produce firelines, because their use could decrease labor costs. They found wheeled mulchers to be cost competitive with bulldozers on gentle terrain, and their results suggest that mulchers may be useful for fire suppression in the wildland urban interface. Read more about the costs of these treatments: https://www.srs.fs.usda.gov/pubs/58338.

Get Black Outside events connect people of color with the outdoors

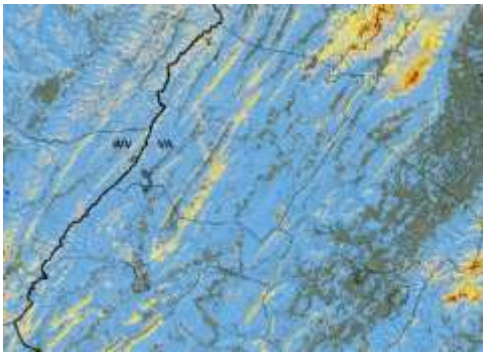
Data collected from 2019 surveys by the National Park Service, USDA Forest Service, and U.S. Fish and Wildlife Service found that 88 to 95 percent of all visitors to public lands are white. The national non-profit collaborative Get Black Outside is partnering with the Forest Service to change that statistic. Forest Service joined the National Association of Black Scuba Divers, See You at the Top, and the Tennessee Aquatic Project in hosting the first snorkel-and-camp Get Black Outside event in June 2021. More than 120 Black youth, youth leaders, and families participated in the event, some of them new to

visiting national forest recreation areas. They snorkeled, camped, hiked, and talked openly about cultural histories represented by recreation areas on the Cherokee, George Washington and Jefferson, Monongahela, and Ocala National Forests. The experience opened their eyes to the biodiversity that can be found in waters like Virginia's Passage Creek and how everyone can protect the water quality of their local watersheds. An SRS research fisheries biologist and member of the National Association of Black Scuba Divers helped bring new partners to the event. Another SRS scientist, along with the NatureWatch program, coordinated the national freshwater snorkeling educational programs and support staff across the National Forest System with snorkel programs to engage visitors in a fun way to learn about water. Bringing together partners whose missions focus on serving Black communities can help increase awareness of the abundant recreation opportunities national forests have to offer. Learn more about the events: https://getblackoutside.org/.

SCIENCEx webinar series connects research and the nation's forest and grassland managers

A team of scientists and science delivery specialists initiated a national, cross-station webinar series called SCIENCEx to share research results, tools, and applications on current issues relevant to land managers. The target audience includes federal, state, county, local, and tribal land managers, along with NGOs and other natural resource professionals from the public and private sectors. SCIENCEx furthers the agency's mission by demonstrating a "one U.S. Forest Service" collaboration, communicating and increasing accessibility to its science, and enhancing connections between deputy areas. Recent webinar themes included invasive species, climate change, and post-disturbance restoration, while upcoming topics include soils, silviculture and carbon, and forest planning. Participants can receive continuing education credits from Society of American Foresters or The Wildlife Society. SCIENCEx was born out of a Fire x Fauna webinar series in November 2020. More than 2,000 people attended the week's programs, including biologists and forest managers from the National Forest System. Learn more about SCIENCEx: https://www.fs.fed.us/research/sciencex-webinars/.

Satellite-based mapping tools reveal forest disturbances with extraordinary clarity



Innovative remote sensing tools developed by USDA Forest Service scientists now capture forest disturbances better than ever, just as severe weather and defoliations become big news. Recent mapping successes in the eastern US include a nine-state *Lymantria* moth outbreak and extreme weather. These monitoring efforts help support traditional forest disturbance mapping which has become more difficult due to Covid-19 restrictions.

The science team collaborated with Forest Service partners to improve the way that state and federal agencies monitor hurricane impacts in the Southeast using both *ForWarn* and *HiForm* maps of change. In spring 2021, the team mapped extreme freeze events in Missouri and Arkansas better than these poorly understood disturbances have ever been mapped—such spring freezes may become more frequent in the future with climate change. Coordinated use of *ForWarn* and *HiForm* proved itself again with a massive *Lymantria* moth outbreak that erupted in nine states and Canada. Observations from the field confirmed the accuracy of the technology for mapping these outbreaks, with implications for how such defoliations are routinely mapped moving

forward. Find out more: https://forestthreats.org/products/posters/phenological-implications-of-sequential-2020-spring-freezes-for-deciduous-forests-of-the-interior-east-usa.

Data and tools that link upstream forests and their management to downstream water supplies

Land and water resource managers need information that quantifies importance and value of forests for maintaining clean and abundant water supplies for source water protection and to maintain forests on the landscape. To meet these needs, USDA Forest Service scientists convened a special session at an American Water Resources Association conference that assembled researchers from several government agencies in the US and Canada to share their work linking forests to water in a changing environment. The session included nine presentations of studies ranging from empirical analysis of streamflow response to forest disturbance to national scale modeling efforts linking water originating on forest lands to downstream communities. Presentations included research efforts and tool development from the Forest Service, the U.S. Environmental Protection Agency, and Natural Resources Canada. The session was well attended and lively virtual discussion of potential collaboration ensued well after the session ended. The work presented and collaboration opportunities discussed in this session will "prime the pump" for continued understanding of the importance of forests for water supplies. Find out more about the special session: **https://www.awra.org/Members/Events_and_Education/Events/2021_Summer_Conference_Program/2021_Summer_Conference_Online_PAG.aspx**.

Santee Experimental Forest research forum

In April, scientists and experts gathered virtually to talk about research on the Santee Experimental Forest. The Santee was founded in 1937, one year after the Francis Marion National Forest was established north of Charleston, South Carolina. Fifteen presenters shared research updates, across of range of topics, including:

- Forest composition effects on pollinator communities
- Longleaf pine restoration effects on carbon and water balances at the watershed scale
- Extreme precipitation and culvert capacity
- Prescribed fire and drinking water quality
- Artificial intelligence-based flood detection and monitoring systems
- The role of microbes and termites in decomposing dead wood
- Tidal freshwater hydrology and its interactions with vegetation, carbon cycling, greenhouse gases, and water quality

The Santee is the only experimental forest with a tidal footprint. Understanding coastal processes within urbanizing landscapes that are threatened by climate change and development is important. Learn more about the Santee Experimental Forest.

Technology and Development Centers (Missoula and San Dimas)

History

Originally tasked with repurposing surplus military equipment to aid in fighting wildfires, the National Technology and Development Program (NTDP) started life as equipment development centers located in Missoula, MT and San Dimas, CA. These equipment development centers were responsible for many of the life- and cost-saving advances common to today's firefighters: standardized hoses, pumps, couplings, rappelling and parachuting equipment, and the essential fire shelter, credited with saving more than 300 lives on the fire line.

The center's scope eventually expanded beyond wildfire, and the centers were combined into one organization: the National Technology and Development Program. Today, the program works on projects touching on forest management, recreation, engineering, occupational safety and health and more.

The National Technology and Development Program now categorizes its work within three areas: application of innovative science and technology, knowledge synthesis, and specifications and standards.

The Mission of the National Technology and Development Program is to provide Forest Service employees and partners with practical, science-based solutions to resource management challenges by developing and managing specifications and standards, synthesizing and sharing knowledge, and applying innovative science and technology.

To support the Technology and Development Program's mission, the Program has a cadre of personnel with far-reaching skills. Engineers, technicians, foresters, biologists, draftsmen, writers, and publishers all work as project team members to support the problem-solving goals of the program.

The Program serves as a resource to three of the four deputy chief areas in the Forest Service: National Forest System, Business Operations, and State and Private Forestry.

The program partners with the fourth deputy chief area, Research and Development, as well as academia, private industry, and other governmental agencies to achieve its mission. The Program's team approach to creative problem solving has resulted in some unique and innovative solutions. Some of those solutions include:

- The Sweet Smelling Toilet
- Redesigned Fire Shelter
- Water-Based Tree Marking Paint

- Improved Helicopter Rappel Rope and Descender
- Electronic Forms for National Visitor Use Monitoring
- Machine Vision System for Forest Management (Patent & CRADA)
- Augmented and Virtual Reality Based Training
- Fueling Systems for Small Engines (CRADA)

International Institute of Tropical Forestry

The International Institute of Tropical Forestry (Institute) is housed in San Juan, Puerto Rico where it serves people from Puerto Rico, the U.S. Virgin Islands, the Caribbean, and central and south America. The Institute has an international mission as well as Research & Development and State and Private Forestry missions. It has been a unit of the Forest Service since 1939 and it specializes in tropical forestry, a specialty for which it is globally known given the level of excellence and continuity of its programs. As an example, the Institute pioneered tropical forestry in this hemisphere and developed the field at a time when there was no professional tropical forestry being practices in the region. Today, the programs of the Institute support the Forest Service mission in the only tropical forest in the National Forest System, the El Yunque National Forest. This forest is also an experimental forest in its entirety (unique in the agency) and is the most-studied tropical forest in the hemisphere. The results of the research program of the Institute are broadly transferred to a diverse network of collaborators including non-governmental organization, municipal and state governments, landowners, land management

practitioners, international organizations, and other scientists, to name a few. Through electronic media, the Institute now reaches millions of people.

Recent outcomes of Institute programs include:

Comprehensive understanding of the effects of hurricanes on tropical forests, including uncovering invisible effects through microbial action that may prove key to processing enormous quantities of debris produced by hurricanes and other extreme events.

Established the first experiment dealing with the response of tropical forests to increases in air temperature. Experiments on the effects of droughts and fire on tropical forests are also underway and yielding information relevant to forest conservation.

How do cities think? How can cities be made more adaptive and resilient to extreme events? These questions are being addressed through networks of tropical and temperate cities. Research shows that tropical cities are different from temperate cities in terms of their green infrastructure and social-ecological responses to extreme events.

The Institute transfers the results of its research to collaborating communities and landowners through programs that include tree cities, forest stewardship management plans, urban councils, land acquisition for conservation purposes, and new eco-tourism enterprises; all are programs that provide jobs and economic development to people.

The Institute also has a conservation education program that reaches underrepresented populations from kindergarten to post-doctoral levels.

7.3. Metric Tables.

TABLE 1. Collaborative Relationships for Research and Development.

*ND-no data available.

Forest Service (FS)	FY2017	FY2018	FY2019	FY2020	FY2021
Total number active CRADAs[2]	74	22	58	102	205
Number newly executed CRADAs	34	9	36	50	40
All other Non-CRADA/MTA Agreements	ND	ND	ND	2,872	2,413

1. Starting in FY 2019 the Forest Service will count all agreements under the authority of 15 U.S.C. 3710a as CRADAs

TABLE 2. Invention Disclosure and Patenting

*ND-no data available.

Forest Service (FS)	FY2017	FY2018	FY2019	FY2020	FY2021
Total number new invention disclosures[1]	20	10	9	12	13
University co-owned	7	1	2	5	6
Total number patent applications filed[2]	11	7	7	10	12
University co-owned	6	0	1	5	6

Total number patents issued	5	5	3	4	4
University co-owned	4	4	0	0	1

1. Inventions arising at the federal lab.

2. Includes U.S. patent applications, foreign patent applications filed on cases for which no U.S. application was filed, divisional applications, continuation-in-part applications, and provisional applications.

TABLE 3. Profile of Active Licenses
*ND-no data available.

Forest Service (FS)	FY2017	FY2018	FY2019	FY2020	FY2021
Total number active licenses	19	9	11	13	7
Executed to small businesses1	2	1	0	ND	ND
Executed to startup businesses2	1	1	0	ND	ND
Executed to universities	16	1	0	ND	3
Invention licenses3	19	9	11	13	7
Executed to small businesses	2	1	0	ND	ND
Executed to startup businesses	1	1	0	ND	ND
Executed to universities	16	1	0	ND	ND

ND = In progress but not signed

ABLE 4. Characteristics of Income Bearing Licenses

Forest Service (FS)	FY2017	FY2018	FY2019	FY2020	FY2021		
Total number of income bearing licenses	19	9	11	13	7		
Exclusive	18	9	11	13	7		
Non-exclusive	1	0	0	0	0		

1. Invention licenses refer to licenses resulting from a patent.
2. Other IP licenses included biological materials licenses and plant variety protection licenses.

Income from Licensing

*ND-no data available.

Forest Service (FS)	FY2017	FY2018	FY2019	FY2020	FY2021
Total income all active licenses	$2,634	$3,122	$800	ND	ND
Invention licenses	$2,634	$0	$800	ND	ND

ND = Funds not received in 2020

FY19 FS Accomplishment Metrics in support of the REE Action Plan

Fiscal Year: 2020		
Products (Software/Web & Multimedia), Peer Reviewed and Non-Peer Reviewed Publications		
Outcomes	***Product Type***	***Total Entries***
Publications	Formally Refereed	1289
Publications	Informally Refereed	528
Publications	Non-Refereed	87
Publications	All types	1904
Publications Articles	In Journals	1241
Publications Articles	Not in Journals	663
Science Delivery	Activities	1079
Science Delivery	Products	222