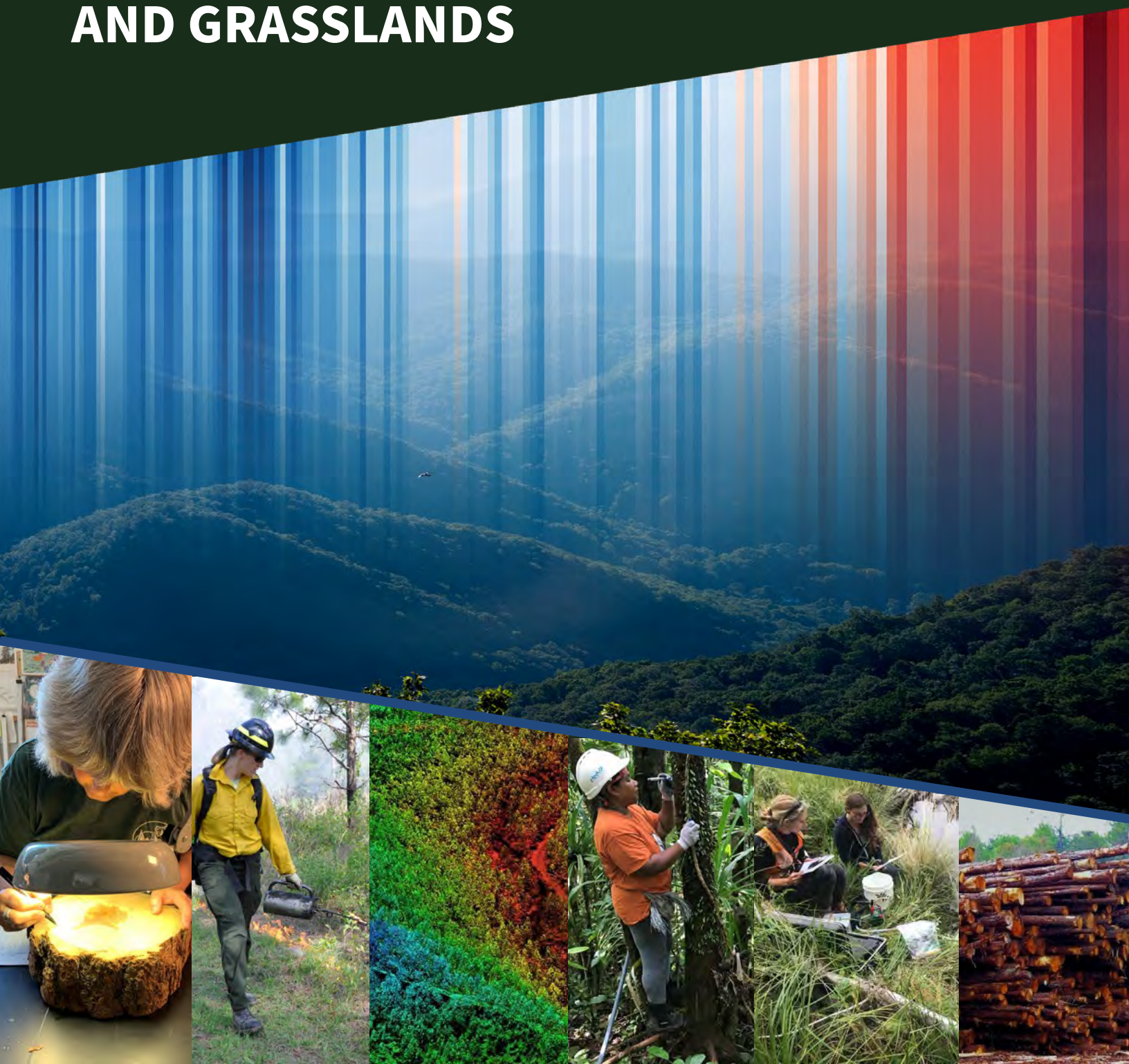
USDA Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Research & Development | FS-1175 | June 2021

RESEARCH IMPROVES CLIMATE-SMART MANAGEMENT OF AMERICA'S FORESTS AND GRASSLANDS



Main cover image: An overlay of red and blue stripes that represents the annual global temperature change from 1850–2019. More information is available on the Show Your Stripes website. Graphic courtesy of Professor Ed Hawkins, University of Reading.

Cover photos (from left to right): a researcher studies tree rings; a wildland firefighter lights a prescribed burn; satellite image of a forest; recording measurements in a tropical forest; taking biology samples in a creek; harvested timber is ready to use. USDA Forest Service photos.

This document was edited, compiled, and published with assistance from Jennifer Hayes and Lara Murray, Forest Service Research and Development; Kirsten Healey, freelance graphic designer; and Amanda Perry, Andrew McClean, and Joe Bruce, Forest Service Office of Communication.

Contents

Executive Summary

America's forests and grasslands are integral to global efforts to address current and future impacts of climate change. Healthy forest and grassland ecosystems are vital to the well-being and livelihoods of all Americans. These ecosystems provide drinking water for millions of people, influence the global carbon balance, supply food, support rural and urban jobs, provide places to recreate, and are home to diverse fish and wildlife populations. Climate change is already having substantial impacts on these systems, which are increasingly stressed by severe wildfires, invasive species, diseases, drought, and other climate-driven disturbances.

U.S. Department of Agriculture (USDA), Forest Service, Research and Development (R&D) helps the Department and the Nation move closer to achieving its climate and carbon goals. Specifically, Forest Service R&D contributes in the following areas:

Investing in Natural Climate Solutions on Working Lands. Carbon sequestration by forests is a vital mitigation tool. The most cost-effective way to boost carbon storage is to enhance reforestation efforts, which can increase carbon storage by as much as 20 percent. Forest Service research is the Nation's authoritative source on practices for increasing and tracking forest and grassland carbon sequestration.

Wildfire Decision Support. Climate change has altered fire regimes, increasing the frequency and severity of wildfire. Forest Service R&D is a world leader in wildfire research. Scientists have pioneered fire behavior and prediction technology, improved firefighter safety, developed novel spatial planning and risk management tools, and worked with communities to improve protections against catastrophic fire.

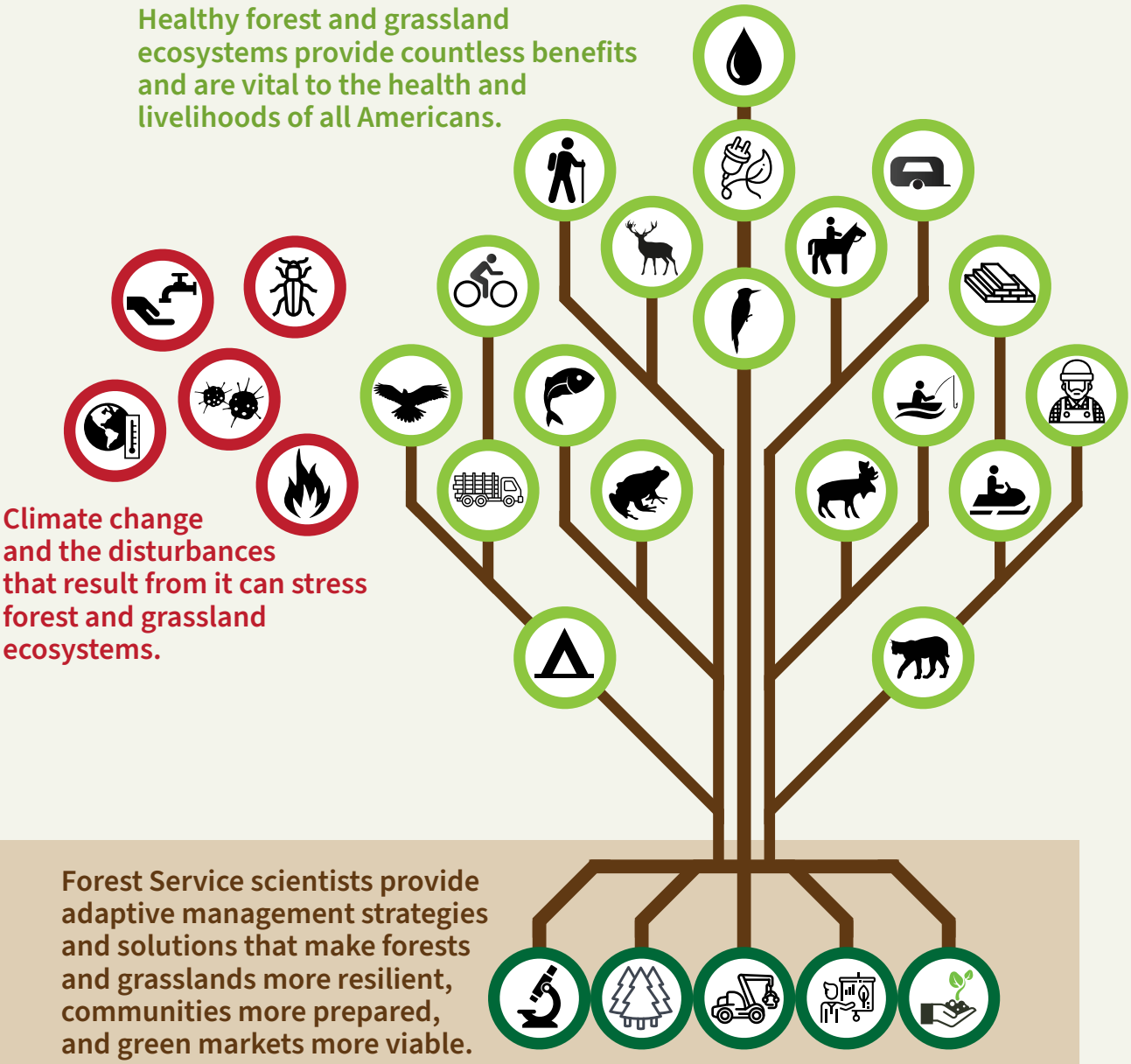
Managing for Forest and Grassland Resilience to Climate Change. As the climate changes, many forests and grasslands are expected to shift in composition. Forest Service research identifies the key attributes of resilient natural systems that can withstand and recover from climate-caused disturbances. From landscape-scale experiments like the Adaptive Silviculture for Climate Change Project, to forecasting drought and floods, to providing the scientific basis for fuels management and prescribed fires, Forest Service researchers are generating knowledge and solutions for managing and restoring climate-impacted landscapes.

Innovation in Science and Science Delivery. Over the last decade, Forest Service R&D assembled interdisciplinary teams to respond to the expected, accelerated, and unprecedented changes associated with climate change. As active leaders and participants in the USDA Climate Hubs, Forest Service researchers help create and deliver proactive, practical climate-informed knowledge and tools. Forest Service R&D wood products research delivers groundbreaking technologies and solutions for using forest-based products, such as cross-laminated timber, nanotechnology, biocomposites, biochar, and bioenergy.

Forest Service Climate and Carbon Research Provides Solutions

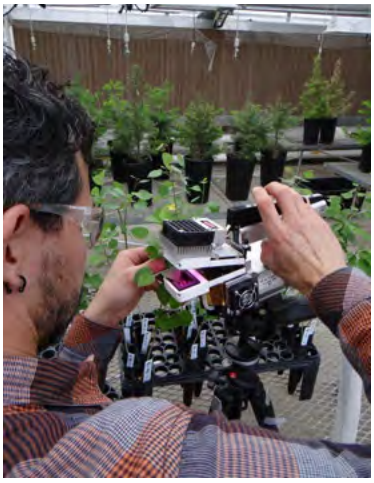
U.S. Department of Agriculture (USDA), Forest Service Research and Development (R&D) provides the scientific understanding needed to manage forests and grasslands across the country and around the world. Forest Service scientists are at the forefront of gaining new knowledge through basic science, as well having the responsibility to create and demonstrate practical applications of that knowledge. Agency scientists provide data and develop adaptive management and mitigation strategies that contribute to making forests and grasslands more resilient, communities more prepared, and green markets and initiatives more viable.

Forest Service R&D, along with our vast network of partners and collaborators, is actively committed to addressing the threat of climate change by providing research for the needs of today and the issues of tomorrow.



Investing in Natural Climate Solutions on Working Lands

Above: Tree rings tell the story of a tree's history, helping to reveal how resilient different species and forests are to disturbances. **Below:** Plant genetics and nursery research improve the success of reforestation efforts. USDA Forest Service photos.



Carbon Sequestration

Carbon sequestration by forests and grasslands is a vital mitigation tool. Long-term research demonstrates how important healthy forests are to this goal, and also demonstrates that different management practices can affect sequestration rates. While U.S. forests overall are a net carbon sink, some forests transition to carbon sources due to pests, drought, and wildfire. With an extensive carbon research and monitoring portfolio, Forest Service R&D is revealing how forests, grasslands, wetlands, farms and cities sequester carbon in plants, soils, wood-based products, and even snow.

Carbon sequestration is one of the highest value services provided by forests. Recent research found that over the next 35 years, the value of carbon stored in U.S. forests (private and public) will be worth more than $100 billion. The two most cost-effective ways to boost carbon sequestration in U.S. forests are to invest in the reforestation of public lands in the West and offer incentives to rural landowners for climate-smart practices. Such activities could result in as much as 20 percent more carbon stored in some landscapes. Our research shows emerging carbon markets can provide new income streams for farmers, ranchers, and forest owners. The introduction of such incentive payments could have substantial impacts on future land use patterns. Research also indicates carbon emissions due to land use change from forest to non-forest can be significant, and that soils play a significant role in carbon storage.

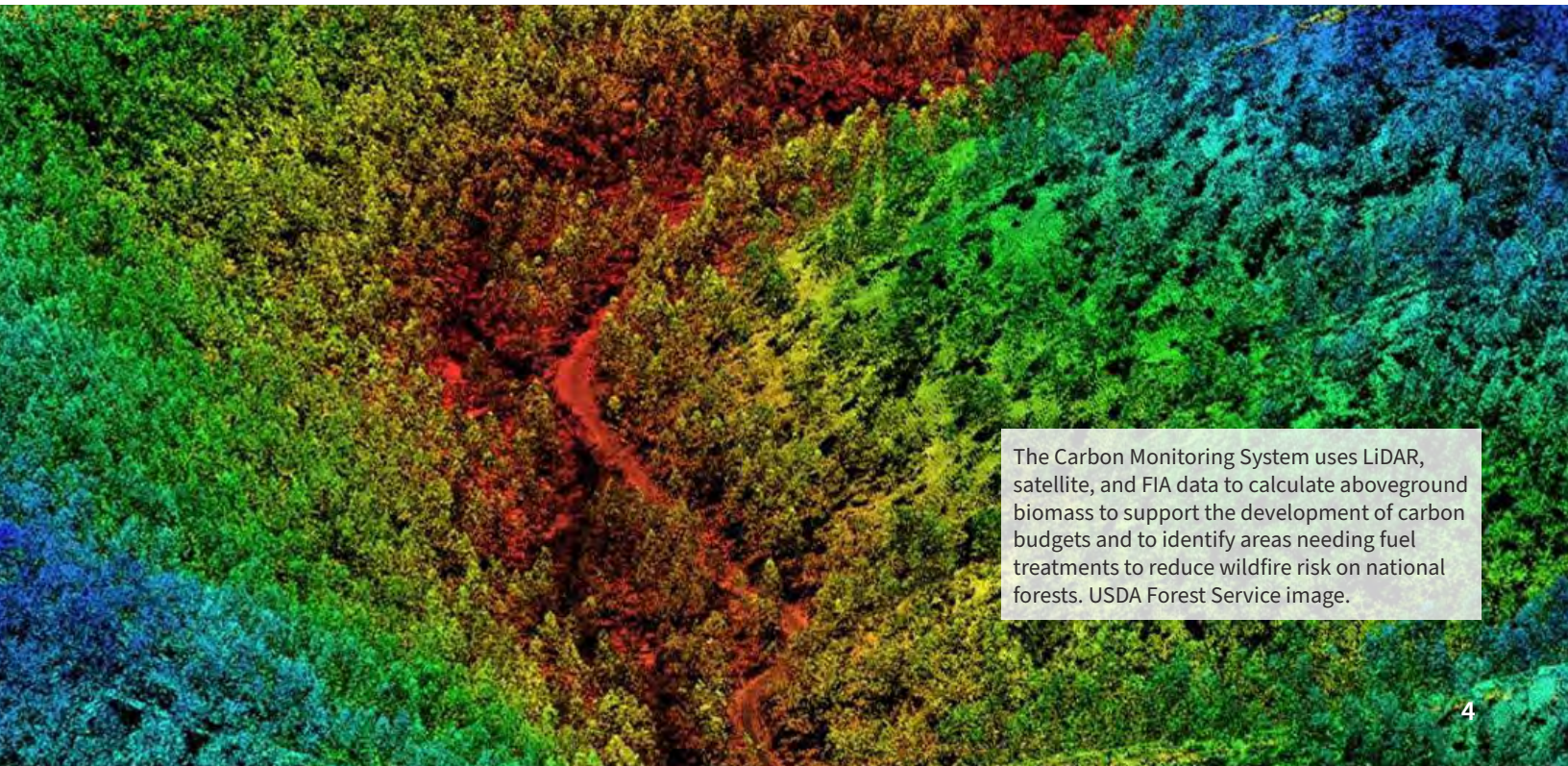
This research establishes the foundation for application and tool development. These science products support carbon markets, conservation finance, climate-smart and fire-wise land management practices, and other proactive climate solutions.

Monitoring data from the Forest Inventory and Analysis makes it possible for landowners to incorporate carbon as a management objective, and to evaluate their success. USDA Forest Service photo.

Monitoring and Analysis of Carbon on U.S. Lands

Forest and grassland carbon monitoring is critical to meeting the information needs of land managers and policymakers. Monitoring is also critical for demonstrating the effectiveness of policies and incentives.

Forest Service R&D's Forest Inventory and Analysis (FIA) program is the primary source for information on U.S. forest carbon stocks and trends. For over 30 years, FIA program definitions, protocols, expertise, and data have been used to estimate carbon in trees, down deadwood, and soil. Working with the U.S. Environmental Protection Agency, FIA provides annual data on greenhouse gas emissions and removals from forest land, woodlands, harvested wood products, urban trees, and related land use change. This information is used in National Greenhouse Gas Inventory reporting to the United Nations Framework Convention on Climate Change and for forest sustainability reporting for the Montreal Process. FIA is the Nation's forest census. The FIA program, with the help of States and other partners, conducts nationwide surveys on forests, forest landowners, and timber output. Surveys in places like interior Alaska are conducted with partners, including the National Aeronautics and Space Administration (NASA), integrating ground data with Light Detection and Ranging (LiDAR), and hyperspectral and thermal image observations. Data from over 100,000 field-sampled research plots, combined with remotely sensed data, provide the most robust set of forest carbon information available in the United States.



The Carbon Monitoring System uses LiDAR, satellite, and FIA data to calculate aboveground biomass to support the development of carbon budgets and to identify areas needing fuel treatments to reduce wildfire risk on national forests. USDA Forest Service image.

The Resources Planning Act (RPA) Assessment Program provides regularly updated information on natural resource production and use trends in U.S. forests and rangelands across all ownership types. RPA identifies drivers of change and projects the conditions of these renewable resources 50 years into the future, in part based on FIA data. In response to legislation, Forest Service researchers project the amount of carbon in forests and harvested wood products, and examine the benefits from substituting less energy-intensive materials for more energy-intensive materials using life-cycle assessments. RPA includes analyses of forests, rangelands, urban forests, forest products, carbon, wildlife and fish, biodiversity, outdoor recreation, wilderness, water, and the effects of socioeconomic factors and climate change on these resources. Projections are available for a variety of climate change and economic scenarios. RPA assessment models are used to inform reporting required under the United Nations Framework Convention on Climate Change.

Forest Service R&D works with agencies from across the U.S. Government to improve research and the collection and analysis of data on carbon on U.S. lands. Forest Service R&D partnered with NASA to develop a Carbon Monitoring System, which tests the ability of satellites to estimate carbon on a variety of U.S. landscapes. Scientists are mapping carbon in woody biomass, as well as identifying areas for fuel treatments to reduce fire and carbon loss risk in the West. The Forest Service was also a key contributor to the U.S. Global Change Research Program's Second State of the Carbon Cycle Report.

Experiments conducted on the Forest Service R&D network of over 80 experimental forests, ranges, and watersheds provide baseline data, in some cases dating back over 100 years, contributing to our understanding of climate change and carbon on the landscape. For example, the Tropical Responses to Altered Climate Experiment at the Luquillo Experimental Forest in Puerto Rico looks at the effects of climate change on tropical forests, particularly the effects on carbon and nutrient cycling and the impacts of hurricane disturbance. The national AmeriFlux network is another long-term research partnership that has helped advance our understanding of carbon and water cycles in different forest ecosystems. Coproduction science initiatives, such as the Carbon Dynamics for Land and Watershed Managers, develop easy-to-use tools and policy-relevant products for understanding carbon flux and carbon accounting.

Forest Service scientists have partnered with the U.S. Department of Energy on the Spruce and Peatland Responses Under Changing Environments (SPRUCE) Program to demonstrate the potential for peatlands, a powerful carbon sink, to convert to a carbon source under warming conditions at sites like the Marcell Experimental Forest. USDA Forest Service photo.

Urban trees sequester carbon, create energy savings, help reduce pollution, and enhance the quality of life in cities. USDA Forest Service photo.

Climate-Smart Land Management Practices and Conservation Programs

Forest Service R&D offers climate-smart land management solutions based on over a century of data. Forest Service researchers work with partners to develop climate vulnerability and adaptation assessments and tools (e.g., Intermountain Adaptation Partnership reports, Northern Region Adaptation Partnership reports, FIRECLIME tool). In addition, publications like Effects of Climatic Variability and Change on Forest Ecosystems: A Comprehensive Science Synthesis for the U.S. Forest Sector and Climate Change in United States Forests, and the Climate Change Response Framework provide risk-based approaches for those weighing climate-smart management options and issues.

Additionally, Forest Service research findings promote agroforestry—the use of trees on agricultural lands—which have a range of tangible benefits to farmers and ranchers. Scientists estimated the cost-effectiveness of specific USDA conservation programs that provide incentives for cropland owners to plant trees. They found that in the Southeastern United States, an average Conservation Reserve Program rent rate of $71.21 per acre would cause more than 100,000 acres of cropland to become newly enrolled in afforestation efforts. This could serve to absorb 2.1 million tons of carbon per year.

Forest Service R&D is also actively engaged in urban areas. Recent research on urban trees proves that properly placed shade trees reduce electricity use and, therefore, reduce carbon emissions from electricity generation. Scientists across the Urban Field Station Network investigate urban tree health, climate-smart restoration of natural areas, and the role of civic environmental stewardship in readiness, response, and recovery. These efforts provide new approaches for understanding the role of trees in reducing climate vulnerability and economic instability in urban areas, and also enhance the resilience and sustainability of communities.

Silvopasture systems, an agroforestry technique, manage for both trees and livestock grazing. These systems provide short- and long-term income sources, improved forage nutrition, offer shade for livestock in the summer, and result in shorter forest rotations. USDA Forest Service photo.

The Baltimore Wood Project, a partnership between the Forest Service, Humanim, Room and Board, and the City of Baltimore, reclaims valuable timber from thousands of abandoned rowhomes. This project creates employment opportunities, a pathway to reviving blighted neighborhoods, reduces landfill waste, and retains carbon stored in building timbers. USDA Forest Service photo.

Climate Change and Environmental Justice

Through research, partnerships, and community engagement, Forest Service scientists are working to help eliminate environmental disparities and improve quality of life for low-income and disadvantaged residents throughout the United States. Agency research addresses inequities, such as disproportionately lower tree canopy cover, reduced access to green space, and increased exposure to heat in minority and lower-income communities. In addition, our scientists are assessing the vulnerability of these same groups to smoke from prescribed burns, wildfire risk, and other potential threats.

Forest Service scientists have assessed the impact of climate change on resources important to Native American Tribes, such as huckleberries and bitterbrush. In a national assessment, researchers and partners provided a comprehensive synthesis of nontimber forest products, including the impacts that a changing climate will have on the resources and on peoples' livelihoods. A Tribal Climate Adaptation Menu was created to help incorporate indigenous and traditional knowledge, culture, language, and history into the climate adaptation planning process. This resource is being used to help Tribal natural resource professionals develop climate adaptation plans and help nontribal organizations communicate with Tribal communities. Researchers have also worked with Indigenous and First Nation people in the Arctic through the Silalirijiit collaborative to link traditional ecological knowledge with technology-based climate modeling.

Researchers work with Indigenous and First Nation people in the Arctic through the Silalirijiit collaborative to link traditional ecological knowledge with technology-based climate modeling. USDA Forest Service photo.

Scientists also study the environmental justice implications of managing hazardous forest fuels on Federal lands, filling a long-standing research gap in quantitative environmental justice research on dispersed rural populations. Our network of urban field stations has made major contributions to the field of environmental justice research, revealing both spatial patterns of environmental inequality and the social and institutional processes for creating those patterns. This research looked at different types of amenities and lack of amenities, such as parks, trees, toxic releases, flood, urban heat islands, and the impact of COVID-19.

Forest Service agroforestry outreach specialists work with partners to assist minority farmers, ranchers, and forest owners. A team from the 1862 and 1890 Land-Grant Universities collaborated with the National Agroforestry Center to prepare Profitable Farms and Woodlands, a practical guide to assist underserved and limited resource small farmers and woodland owners to adopt best management technologies in agroforestry.

Forest Service R&D research has shown that the presence and health of forests in cities is key to the resilience of communities and ecosystems, and a critical component of public health, environmental justice, and a healthy childhood experience.

A tree-lined park in Portland, OR. USDA Forest Service photo.

Wildfire Decision Support

Wildland firefighters can use the real-time Wildfire Safety Evaluator, a web app designed by Forest Service scientists in partnership with Technosylva, to calculate safety zones and prevent burn injuries.

Climate change has altered fire regimes, increasing the frequency and severity of wildfire. As a world leader in wildfire research, Forest Service R&D has pioneered work on fire behavior and spread, prescribed fire, fire ecology, post-fire emergency stabilization and rehabilitation, and the long-term restoration of forests and grasslands. Forest Service researchers are leading the way on how to better use and manage fire on the landscape.

For more than 60 years, Forest Service R&D has worked at the forefront of wildland fire science. Researchers focus on improving firefighter safety, building better fire behavior models, understanding and predicting risk, developing novel tools (e.g., spatial fire planning around firesheds), and working in the wildland-urban interface to help protect communities from catastrophic fire. Firefighters and fire managers use this work daily to manage risk, improve decision making, and enhance safety measures.

To improve the safety of communities and firefighters, our scientists have developed tools like Wildfire Risk to Communities and WildfireSAFE and have improved safety zone and escape route information. Weather plays a significant role in wildfire size, spread, and potential danger for firefighters. Forest Service R&D scientists teamed up to develop the Hot-Dry-Windy Index, a new fire-weather

Firefighters and fires managers use Forest Service fire research daily. USDA Forest Service photo.

Research on fire spread and behavior at the Missoula Fire Sciences Laboratory provides a foundation for models used to predict and manage fire. USDA Forest Service photo.

prediction tool based on the key atmospheric variables that affect wildland fire. Forest Service scientists have also been able to link a variety of independent models of fire information, fuel loading, fire consumption, fire emissions, and smoke dispersion through BlueSky, a single online system for providing smoke monitoring and forecasting. Forest Service R&D researchers have also updated the Wildland Fire Decision Support System and created tools like WindNinja to help managers better predict fire behavior.

Through significant long-term research, both in the lab and in the field, scientists have made novel discoveries on how fires spread. This information is paving the way for the next generation of fire models. Scientists developed potential operational delineations, which better evaluate risk and improve fire management across different land ownership types. These tools support shared stewardship initiatives with States (e.g., working with New Mexico on the State's Forest Action Plan by providing scenario planning analysis support). This type of knowledge allows managers to evaluate trade-offs and run comparative scenarios to focus investing funds in locations with the highest likelihood of fire prevention and suppression success.

Forest Service researchers studying the wildland-urban interface (WUI) found that the WUI is the fastest growing land use type in the conterminous United States, expanding from 30.8 million homes in 1990 to 43.4 million in 2010 (a 41-percent increase). The expanding WUI poses challenges for wildfire management, creating more structures at risk to wildfire in environments where firefighting is often difficult. Forest Service R&D scientists will make available a national assessment on changing conditions in the WUI in 2021. They are working closely with communities in the WUI to understand the communities' perceptions of risk, and what works best for getting the communities to act on their own lands. They are also working to understand evacuation decisions and other social aspects of fire. Forest Service researchers work closely with practitioners on the ground to create more fire-adapted communities through projects like WiRē (Wildfire Research), a partnership that integrates local social science into wildfire education and mitigation programs.

Licensed image from Adobe Stock.

Managing for Forest and Grassland Resilience to Climate Change

Unprecedented tree mortality due to drought in California impacts both public and private lands. U.S. Department of the Interior photo by Nathan Stephenson, U.S. Geological Survey.

Forest Service partners identify, tag, map, and measure trees within a permanent forest dynamics plot in Ngardok Nature Reserve, Palau, to understand ecosystem changes over time. USDA Forest Service photo.

As the climate changes, many forests and grasslands are expected to shift in composition due to temperature changes and water availability. Forest Service research helps create resilient forest, grassland, and aquatic systems that can better withstand and recover from climate-caused disturbances. Forest Service researchers study the impact of drought, changing weather patterns, hurricane effects, and other climate-influenced landscape disturbances on forest structure, plants, water, wildlife, soils, carbon, recreation, fuels, and more.

Forest Service R&D scientists are working with land managers to co-produce information and guidance in the wake of disturbances such as hurricanes and fires. Research is critical for understanding species survival rates, soil stabilization techniques, seed provenances, and expected vegetation shifts in these new climates, so that managers can continue to effectively restore forests into the future. Forest Service researchers provide regular consultations on burned-area rehabilitation and work with managers to identify species that are climate-hardy to improve restoration success.

Restoration and resilience look different, depending on where you are. In areas like Puerto Rico, scientists have documented high resilience of wildlife populations, plant communities, and biogeochemical cycles to episodic weather-driven disturbances. On the other hand, in California, an estimated 129 million trees have died since 2010 on national forests due to conditions caused by climate change, unprecedented drought, bark beetle infestation, and high tree densities. Forest Service scientists have been helping land managers and the public understand and recover from the massive tree die-off by creating a tree mortality predictor map and identifying tree species and seed sources that are optimal for reforestation under changing climatic conditions.

As part of the Adaptive Silviculture for Climate Change Project, Forest Service researchers are leading on-the-ground, collaborative research with forest managers to test and demonstrate climate adaptation measures for forests.

Assessing Potential Climate Change Pressures Across the Conterminous United States: Mapping Plant Hardiness Zones, Heat Zones, Growing Degree Days, and Cumulative Drought Severity Throughout This Century is a valuable resource for restoration planners, offering a visual display of forest restoration in relation to water availability. In Hawaii and Palau, scientists developed decision support tools to identify emerging climate threats and to determine the best ways to protect and restore landscapes in the face of extreme climate events.

Effects of Drought on Forests and Rangelands in the United States: A Comprehensive Science Synthesis and Effects of Drought on Forests and Rangelands in the United States: Translating Science Into Management Responses provide the scientific foundation and best practices for managing drought on national forests. In the Southeast, research showed that forested lands provide drinking water to 65 million people in 13 States and drought incidences are expected to increase. In the West, most drinking water comes from public lands. Understanding the role of healthy forests in providing clean water will be critical as more drought and other climate-caused disturbance events continue to occur.

Fuels Management and Prescribed Burns

Fuels management is a key aspect of forest restoration. Forest Service R&D quantitative tools have provided the scientific basis for fuels management and fire risk reduction across millions of acres of forests and grasslands. Much of our understanding of fuel treatments as an effective restoration tool is based on Forest Service research on fire and fuel interactions. Forest Service researchers have evaluated fuel management methods (e.g., chipping, pile burning, new products) to understand which are the most efficient, economically feasible, and least impactive for various sites. Additionally, social scientists have been working with homeowners to understand perspectives on fuels management and to improve approaches to working with communities.

Prescribed fire has long been acknowledged as a critical solution to the wildfire challenge. Forest Service R&D is committed to supporting the agency in overcoming barriers to increase the pace and scale of prescribed fire use. In many places, fire is ecologically necessary. Scientists are working with managers across the country to develop

Researchers use drones and other technology to measure smoke outputs and wildfire intensity in the Fire and Smoke Model Evaluation Experiment (FASMEE) project. USDA Forest Service photo.

Scientists test different pile sizes to understand the impacts to soils resulting from burning material from fuels treatments. USDA Forest Service photo.

decision support tools to inform the best places to deploy prescribed fire and how to use fire to achieve restoration goals. For example, researchers published A Comprehensive Guide to Fuel Management Practices for Dry Mixed Conifer Forests in the Northwestern United States; have developed new techniques to describe, sample, and scale fuels and fuel loading; and have created models like FUEL3-D to provide place-based, fine-scale details on fuels. High-resolution infrared thermography, LiDAR, and photogrammetry are leading to new insights and new modeling tools, such as QUIC-Fire.

Prescribed fire results in fewer carbon emissions than wildfire in many forest types, and has been shown to have lesser impacts to native biodiversity than wildfires. In the tropics, prescribed fire experiments have led to new insights on the interactions of fire and tropical dry grasslands and forests. In the Florida cypress swamps, prescribed fire has been identified as critically important for preventing extreme wildfires during drought.

Minimizing the smoke exposure to communities from prescribed burns is a priority, as smoke can impact human health and safety. Forest Service researchers are working to understand how smoke from wildfires and prescribed fires differ. Furthermore, researchers from across the Forest Service are collaborating on the Fire and Smoke Model Evaluation Experiment (FASMEE). This collaboration with NASA, the U.S. Department of the Interior, the U.S. Department of Commerce, the National Oceanic and Atmospheric Administration, the U.S. Department of Defense, universities, and other institutions is providing new insights into the connections between fire behavior and smoke.

Combining prescribed fire with tree thinning helps restore oak woodlands and savannas. USDA Forest Service photo.

Improving Watershed Health

The Forest Service manages important water sources across the United States. About 50 percent of the surface water in the continental United States comes from forested lands, and lands managed by the Forest Service supply one-fifth of the water nationally. The needs of a growing human population, continued conversion of forests to other land uses, and anticipated changes in climate conditions are putting water supplies and quality at risk. Forest Service R&D conducts research on watershed vulnerability to a changing climate and associated disturbances (e.g., fire, drought, insect infestations). Forest Service R&D science and tools support managers responsible for meeting instream flow requirements for hydropower management, recreation, and water quality requirements. Additionally, Forest Service R&D water research supports the conservation of aquatic resources, habitats, fish, and wildlife.

Data show that spring water peak flows are shifting earlier in the year across much of the West. Snow is important for water and carbon storage in many areas of the West. Shifts in winter precipitation from snow toward rain has implications for flood risk and the need for additional water storage. Extreme weather also creates flood risks in the Eastern United States. Forest Service researchers have mapped where dangerous floods may occur in places like western North Carolina and are using artificial intelligence to model flood-prevention restoration techniques that mimic natural influences. For example, scientists have modeled meadows with beaver activity and found that these meadows store more carbon, capture more sediment, and hold

The snow-water equivalent, or the amount of water that snow holds, is measured by scientists to help predict how much runoff will be available in warm months, for avalanche safety, and for forecasting drought. USDA Forest Service photo.

Researchers measure mangrove roots and trunks, as well as the elevation of the forest floor, to help track changes in sea level. USDA Forest Service photo.

Water sampling is used to understand the quality of water and to collect environmental deoxyribonucleic acid (DNA), which can be used to identify fish and other animals that use streams and rivers, helping inform conservation efforts. USDA Forest Service photos.

more water for longer periods, which helps mitigate flood risks associated with extreme storm events.

Forest Service researchers have developed predictive models using long-term research to forecast changes in water availability from National Forest System lands. This research has implications for agriculture, industry, and municipal drinking water supplies. Research on stream temperatures provides critical restoration information as it relates to aquatic wildlife and fish, as well as changing flows.

Forest Service scientists also study water quality responses to various disturbances, the frequency and intensity of which will increase in a changing climate. Wildfires have a significant effect on hydrology, and the long-term effects of severe wildfire in forested watersheds present management challenges for maintaining water quality, protecting water infrastructure, and watershed restoration. For example, after the extreme fire season of 2016, researchers compared hydrology in burned and unburned watersheds in the southern Appalachian Mountains and found decreased water quality and up to 39 percent increases in flows of water from burned watersheds. Another disturbance that impacts water quality is sea level rise, which causes saltwater to be pushed into rivers and groundwater, where it causes soil salinization. Soil salinization can kill coastal forests, degrade groundwater quality, and cause crop yields to decline. Forest Service scientists are working closely with partners to develop mitigation strategies for this issue.

Innovation in Science and Science Delivery

Over the last decade, Forest Service R&D has assembled cross-program, interdisciplinary research teams to respond to the expected, accelerated, and unprecedented changes associated with climate change. This collaborative approach provides science leadership under rapidly changing conditions. In addition to responding to the questions of today, Forest Service R&D is thinking ahead to provide solutions to future challenges.

Forest Service research stations have experience generating critically needed research while working within the realities of resource management and National Forest System decision frameworks. Forest Service R&D involvement in national networks allows for comparisons of various adaptive management and mitigation approaches and opportunities for hypothesis-driven research for continual learning.

Working closely with collaborators from other Federal agencies, Tribes, States, universities, and nonprofits, Forest Service R&D leverages expertise from various disciplines to bring cutting-edge thinking, tools, and technology to address issues associated with managing the nations forests and grasslands in changing climatic conditions. Additionally, Forest Service R&D is committed to mentoring and employing students and professionals from diverse backgrounds. Each year, Forest Service R&D recruits budding scientists and natural resource professionals through Historically Black Colleges and Universities; Minorities in Agriculture, Natural Resources and Related Sciences; the American Indian Science and Engineering Society; and the Hispanic Association of Colleges and University internship and hiring programs, ensuring that the next generation of scientists reflects the diversity of the public we serve.

Climate Hubs

USDA Climate Hubs are a source for practical, proactive thinking about climate change. Forest Service R&D scientists serve as leads, partners, and collaborators within these hubs. Working with partners, the hubs assess regional forest, rangeland, and agricultural vulnerabilities in a changing climate and develop decision support tools to track and respond to climate impacts (e.g., Adaptation Workbook, Seedlot Selection Tool). The hubs convene, educate, and support their stakeholders through in-person events, virtual platforms, and publications. Curricula developed by the hubs help a range of learners (e.g., USDA staff, land managers, K-12 students) identify climate risks

Hurricanes can have serious impacts on forest health, killing trees and creating conditions for insects or diseases to further damage the trees that remain. USDA Forest Service photo.

and adaptation options. Hub collaborators have provided technical assistance to 36 other countries and engaged in education and outreach with Native American producers, Tribal and Intertribal Timber Councils, and the U.S. Department of the Interior, Bureau of Indian Affairs. Members of the hubs work closely with States to consult on State Forest Action Plans and land-based carbon sequestration strategies to meet U.S. Climate Alliance commitments.

The hubs have provided essential information for disaster and extreme event preparedness and recovery. The USDA Climate Hubs were key partners in implementing disaster preparedness or post-disaster assessments for Hurricanes Dorian, Harvey, Irma, and Maria; wildfires in the Southwest and California; and drought in the Northern Plains. The tools they have developed, like a recent series of hurricane preparation and recovery guides, showcase the opportunities and challenges associated with climate-smart land management.

Promote Markets for Wood Products

Groundbreaking Forest Service research in the areas of biotechnology and nanotechnology have the potential to significantly enhance wood-use efficiency, create new markets for wood, and improve forest health. Scientists working on fiber and composite research have formulated efficient processes for converting wood to value-added chemicals and fibers, developed economically viable uses for underutilized wood resources, and improved methods for recovering and reusing forest products such as waste paper and construction debris. Forest Service researchers are collaborating with academic and industrial researchers to develop lightweight automobile parts using cellulose nanomaterials that lower exhaust emission from cars, which benefits users while also contributing to sustainability.

Carbon can be stored in wood for long time periods, benefiting both the environment and end users. Life-cycle analysis of carbon capture and storage in wood products is an area of research focus. Scientists assess how much carbon is stored and how many greenhouse gas emissions are avoided over the life cycle of the wood products, and compare that to other, more energy-intensive products to understand the substitution benefits. Forest Service researchers develop the technical foundation for a variety of wood products, such as cross-laminated timber used in building structures and other eco-friendly consumer products.

Researchers have shown the relationship between sound forest management practices and the production of renewable, sustainable, low-carbon harvested wood products. This information is widely

Scientists are studying the capacity for Southern forests to support a burgeoning bioenergy industry and benefit forest-dependent communities across the region. USDA Forest Service photo.

used in forest planning to ascertain the potential financial return for industrial partners as they strike a climate balance in implementing forest management practices. Forest Service R&D is actively addressing the challenge of finding markets for hazardous fuels, low-value timber, and wood residues from forest restoration projects. For example, scientists developed and patented a new technology using excess biomass to create biochar, which can be spread on the landscape as a soil enhancer and stabilizer, and is also a valuable agricultural and horticultural soil amendment product. Forest Service scientists have identified different tree species suitable as bioenergy sources and are breaking new ground in the scientific understanding of how genes control wood biomass, drought tolerance, and tree architecture with an eye toward increasing our ability to enhance carbon sequestration and climate-adapted forests.

Researchers coordinate with other organizations to leverage the newest knowledge to make advances in this area. Forest Service R&D participates in the Federal Life-Cycle Analysis Commons, a group that provides open access to Government products and data sets. These efforts contribute toward the development of eco-labels, green public procurement initiatives, and green-building certification. Additionally, Forest Service researchers partner with the Consortium for Research on Renewable Industrial Materials to develop performance measures related to the environmental performance and cost-effectiveness of alternative forest management and forest carbon strategies.

Forest Service scientists, in partnership with Air Burners, Inc., have received a conditional patent to develop a mobile biochar fire box, which turns piles of unmerchantable wood waste into biochar on the spot. USDA Forest Service photo.

Summary

Forest Service R&D develops practical applications of emerging and existing knowledge to inform forest management. Scientific understanding of land management activities helps clarify options, opportunities, and tradeoffs land managers face. The Forest Service research legacy is indisputable, long-lasting, and invaluable to the American public. Forest Service research on climate and carbon improves the Nation's forests and grasslands so they can continue to provide a wide range of benefits to the country and the world.

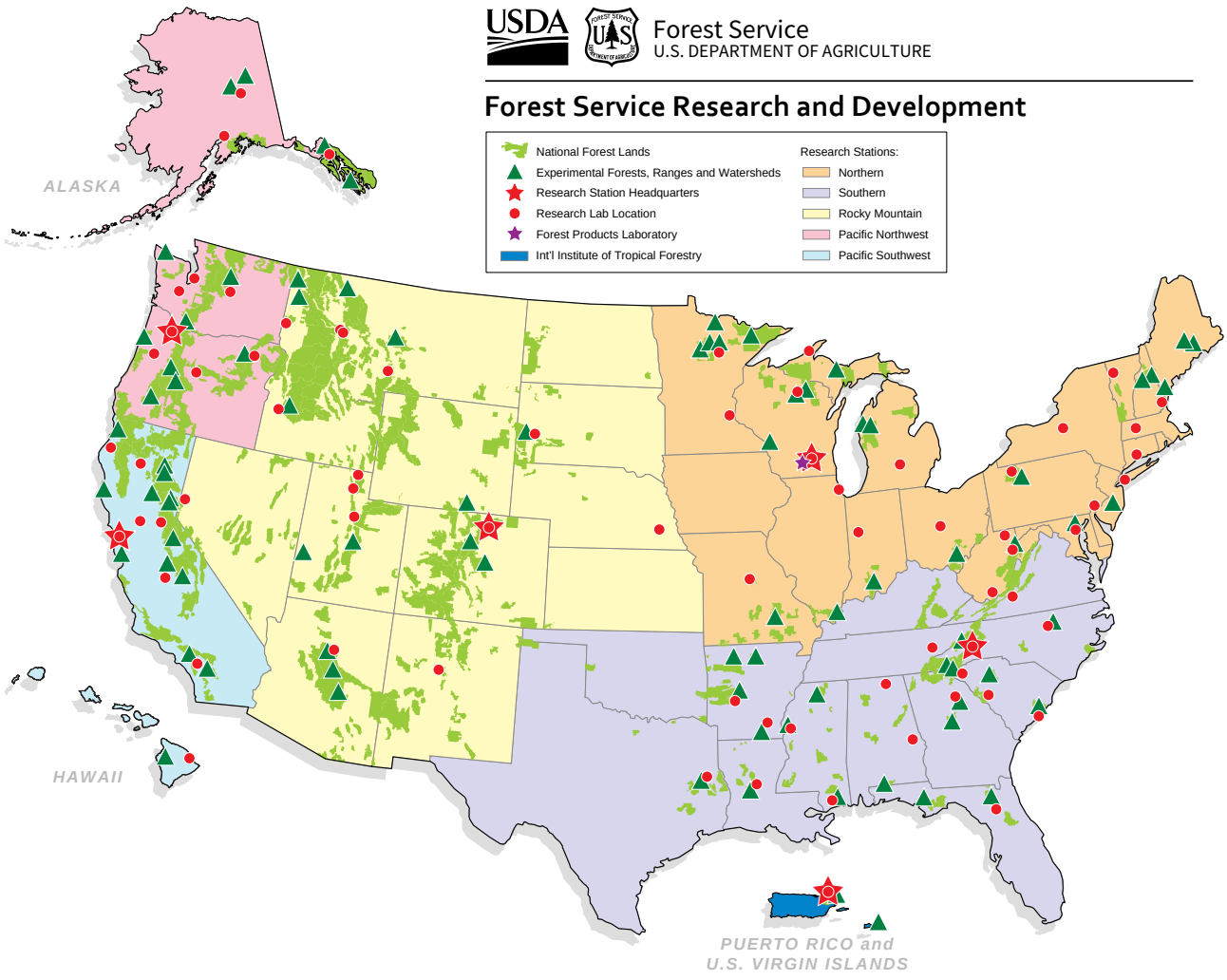
Forest Service R&D, along with a network of partners and collaborators, is committed to addressing the threat of climate change by providing research for the needs of today and the issues of tomorrow. A balanced and continued investment in Forest Service research—its people, infrastructure, and programs—will enhance the delivery of knowledge and services needed to meet the climate change challenges we face.

By investing in the expansion of existing science, as well as new innovations, Forest Service R&D and all of Forest Service research can help the USDA and the Nation move closer to achieving their climate and carbon goals.

About Forest Service Research and Development

Forest Service Research and Development works at the forefront of science to improve the health and use of our Nation's forests and grasslands. Research has been part of the Forest Service mission since the agency's inception in 1905. Forest Service Research and Development enhances the rigor and impact of the whole agency, connecting the needs of the organization and the latest science. The researchers work independently and in close collaboration with partners, including other agencies, academia, nonprofit groups, and industry. The information and technology produced through basic and applied science programs is available to the public for its benefit and use.

Scientists work across a range of biological, physical, and social science fields on projects that reflect the diverse needs of all 50 states, U.S. territories, and commonwealths. Forest Service R&D employees are located in five geographically based research stations (Pacific Southwest, Pacific Northwest, Rocky Mountain, Southern, and Northern), the Forest Products Laboratory, the International Institute for Tropical Forestry, and the national headquarters in Washington, DC.



Previous page photo: Sunset from the top of Squaw Peak Road on the Uinta-Wasatch-Cache National Forest, east of Provo, UT. USDA Forest Service photo by Nate Lowe.