Appendix 5

Forest Service Research & Development

The Forest Service, the lead federal agency for U.S. forestland, was established in 1905 to sustainably manage national forests and promote conservation across the land. It is part of the Department of Agriculture and has a permanent workforce of some 22,000 employees, whose numbers swell to 40,000 with temporary employees during the peak summer work season. Its annual budget is some $4 billion.

The agency has four mission areas and three other program areas:

- *National Forest System.* This mission area, the largest part of the agency, manages a system of 154 national forests and 20 national grasslands—193 million acres in all—across 43 states, the Virgin Islands, and Puerto Rico. These lands include specially

designated wilderness areas, wild and scenic rivers, national monuments, and other natural and cultural treasures.

- *State and Private Forestry.* This part of the agency provides services to help state, local, and tribal governments, forest industries, and private forest landowners improve forest conditions and wood utilization in both urban and rural areas. Its programs include suppression of wildfires and insect and disease outbreaks.
- *Research & Development.* The R&D mission area consists of a network of research units, laboratories, and experimental forests and rangelands. Some of the research is done by an in-house cadre of 500 researchers and 2,000 technical support staff. About 17 percent of its annual budget is used to fund cooperative research with university scientists, who work in partnership with agency researchers to solve complex problems. The research program is broad and covers all aspects of forestry, rangeland management, biological and physical sciences, socioeconomics, forest uses, and more.
- *Business Operations.* This mission area provides administrative support for all the agency's programs.
- *Other Forest Service programs.* The International Programs staff provides technical assistance to foreign governments to help them solve problems and expand their capacity to manage their own forests. It also help coordinate disaster relief programs, working with the U.S. Department of State and Agency for International Development. The Forest Service Law Enforcement Staff works with local law enforcement officials to provide protection to users of national forests. The Forest Service also operates some Job Corps Civilian Conservation Centers to educate and train America's youth.

Research & Development mission area

Forest Service R&D calls itself a mission-driven, problem-focused organization. With 500 full-time researchers, most having PhDs, plus about 200 postdoctoral fellows and term appointments and 1,800 technicians and support staff, it is the largest research organization in the country. Forest Service R&D scientists produce 2,000 publications annually, both peer-reviewed journal articles and departmental or agency publications.

The R&D mission area is led by the Deputy Chief for R&D, who has a small staff of national program leaders in Washington, D.C. There are six regional stations, each led by a station director, and 68 research laboratories (Figure 1). The national lab—the Forest Products Laboratory at Madison, Wisconsin—used to be a separate station but is now led by the director of the Northern Research Station, located in Newtown Square, Pennsylvania. Field research is conducted on 76 experimental forests and ranges. Some of the agency's experimental forests are paired with experimental sites on university property or other partners' lands.

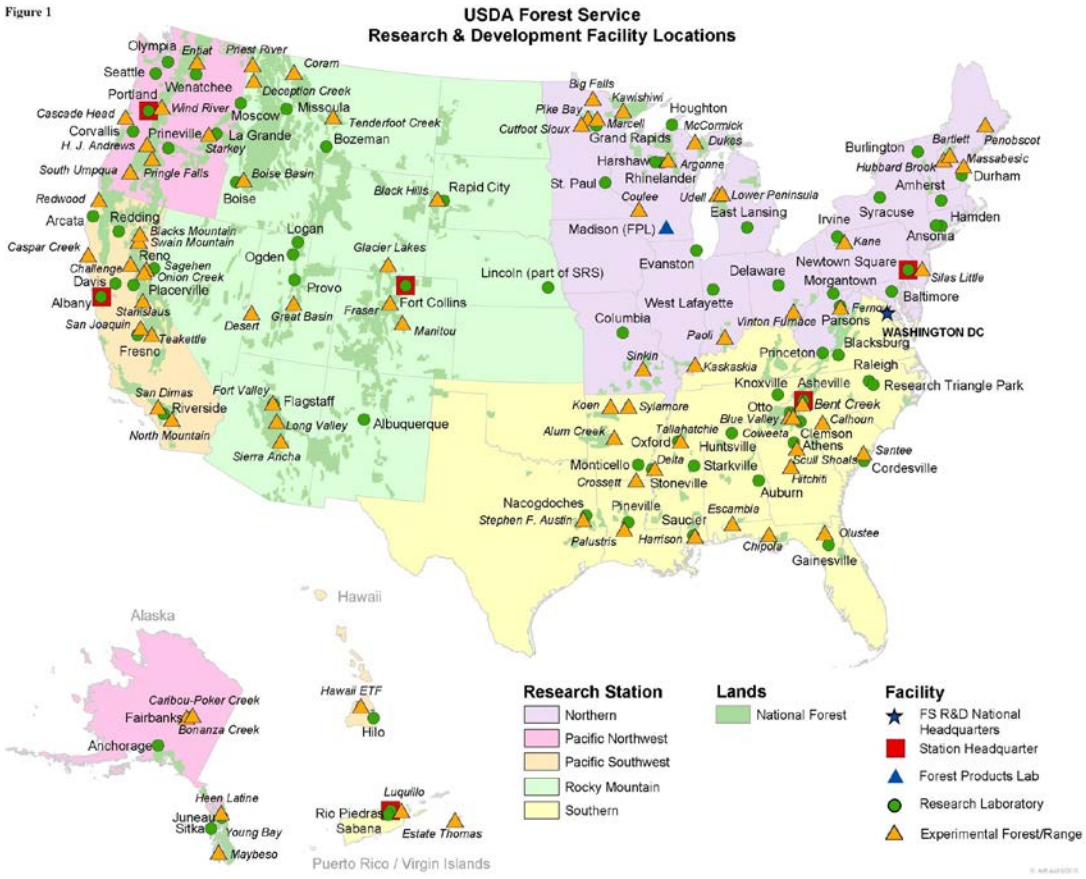

Figure 1. U.S. Forest Service research stations, laboratories, and experimental forests

The Forest Service R&D portfolio of research consists of research work units and research programs. Each one operates under a five-year or 10-year charter that assigns specific problems to study. Assignments may require basic research, applied research, or development activities; sometimes all three. Each unit has a senior scientist as a unit leader, and one or more scientists plus support staff (e.g., forest or laboratory technicians). Some research laboratories have a single research work unit; others have several. Units may draw scientists with required

expertise from other locations. Units may also determine whether to seek help from experts at universities, and if so, enter into cooperative agreements (a form of extramural research grant) that fund faculty members and graduate students who work with agency researchers towards problem solution. The fact that most of the agency's research laboratories are located on or near universities—55 campuses in total—promotes collaborationr.

Forest Service R&D uses a matrix-type organizational structure: one axis of the matrix is geographic location, the other is program area. The station directors are the leaders from a geographic perspective. For example, the Southern Research Station director is headquartered at Asheville, North Carolina, and is responsible for research in the 13 southern states. The director's main responsibility is to consult with stakeholders throughout the South and develop a diverse program of research to address the highest-priority southern problems. Meanwhile, staff directors in the Deputy Chief's Office in Washington, D.C., are responsible for research across the nation, by discipline or national problem area. For example, the national program leader for wood utilization and forest products research assesses the needs for research throughout the forest sector and works with the station directors to target the highest priorities across the country. Some national program leaders are responsible for a cross-cutting science area, such as climate change research; they work with leaders and scientists at all the stations to develop a coherent national program of work that addresses the highest priorities from a national perspective. Cross-cutting programs draw expertise from many units and disciplines. For example, research on climate change may draw researchers from silviculture and ecology research units, atmospheric sciences units, economics research units, and urban forestry units.

Every five to 10 years, station scientists and leaders work with national program leaders to assess stakeholders' science needs, consider regional needs in the context of national needs, and identify the specific problems to be assigned to a unit in the next five- or 10-year charter. Station and headquarters staff then present the proposed new charter to the station director and staff director for approval.

Research programs

Forest Service R&D budgets are presented to Congress clustered into seven strategic program areas. Figure 2 shows funding trends for these areas (with inventory and monitoring separated into two categories). Descriptions of the research topics follow.

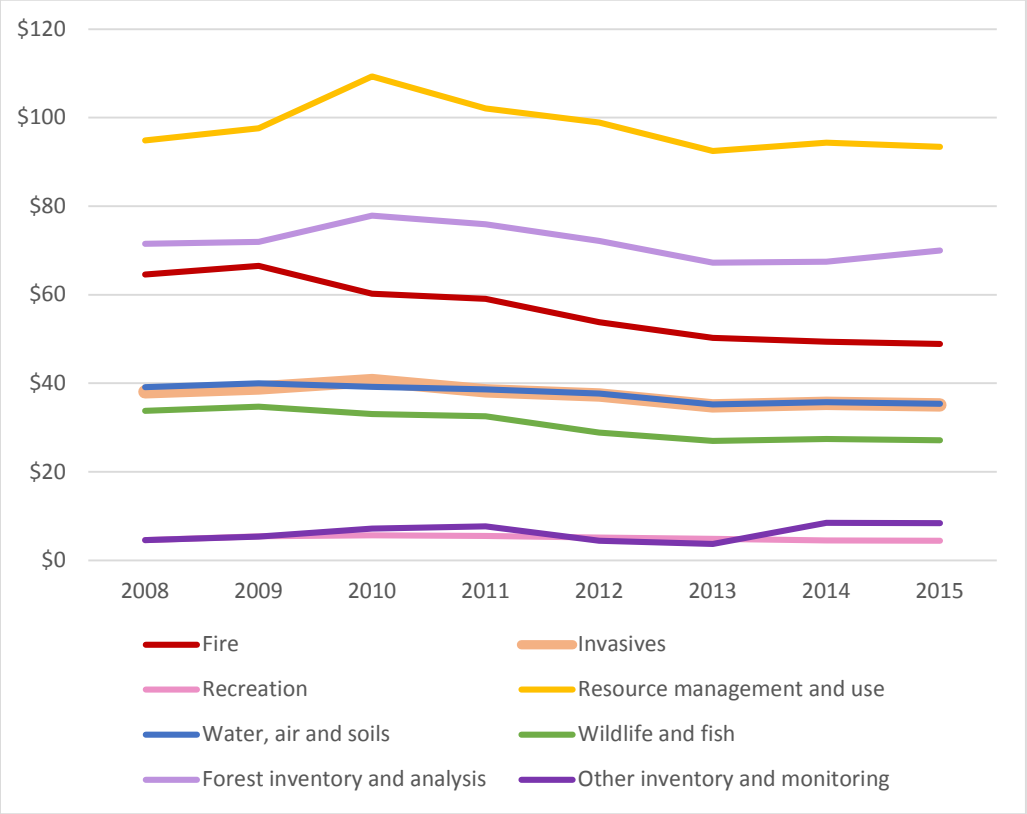

Figure 2. R&D funding for strategic program areas, 2008–2015 (million 2015 dollars)

Note: The Fire funding line includes appropriations for fire research and allocations from the National Fire Plan and Joint Fire Sciences Program. Forest Inventory and Analysis (FIA) is separated from Other Inventory and Monitoring. The FIA funding line includes appropriations to State and Private Forestry for FIA, which were then transferred to the FIA program to help support state agency employees in collecting FIA data.

Fire

To better equip managers to deal with wildland fires, fire scientists develop and provide knowledge and tools that help reduce the damage of fire while enhancing the benefits of fire and fire management for society and the environment. The research focuses on fundamental fire processes, interactions of fire with ecosystems and the environment, social and economic aspects

of fire, integrated management strategies and disturbance interactions, and application of fire research to management problems. Fire scientists also help develop new and better tools to fight fires, working with technology development centers outside R&D; one example is improving firefighting apparatus and fire shelters to protect firefighters during burn-overs.

Invasive Species

Invasive species have damaged United States ecosystems and cost millions of dollars to prevent, detect, and control. This program provides scientific information, tools, and methods for regulators, managers, and the public to address invasive species. Researchers work with local and international scientists, land managers, concerned citizens, and other partners to reduce, minimize, or eliminate the introduction, establishment, and spread of invasive species. The Animal and Plant Health Inspection Service and the Foreign Agriculture Service are two major clients within USDA for this research; the Transportation Security Administration's Customs arm is another. Current priorities include invasive species biology, ecology, interactions, and effects; forecasting and prioritizing invasive species for detection and treatment; and managing invasive species and altered ecosystems.

Recreation

Forest Service R&D has a small recreation research program that focuses on recreation experiences and satisfaction; recreation supply, demand, and use; and tools to measure and manage recreation capacity and performance.

Resource Management and Use

Resource Management and Use is R&D's largest program in terms of funding. It includes research on forest products and wood utilization forest economics, urban forestry, agroforestry, forest management and operations, and landscape science. No funding breakdowns by these subcategories are available. Thus, it's not possible to understand which components have seen the largest decline in funding over the past five years. However, the constant dollar decline of

$10.5 million (from $103.9 million in 2010 to $93.4 million in 2015) is believed to have hit forest products research the hardest.[1]

This program seeks to understand values and markets for ecosystem goods and services. It supports traditional and emerging forest products that contribute to the U.S. economy and the American quality of life, encourages rural development through local business growth and job creation, helps communities plan sustainable and desirable urban spaces, and provides management and operations advice for forest landowners to maintain their forest base.

Water, Air, and Soils

Forests absorb a great deal of rainfall, slowing runoff and mitigating flash floods during heavy rains. Land management activities and the pattern of activities across small to very large watersheds influence water quality and quantity. Researchers in this program focus on determining how basic water, air, and soil processes operate and how they interact to help maintain water and air quality and safe stream flows in wild, managed, urban, and rural forest and rangeland watersheds. Their studies on erosion from forest roads have led to tools for analyzing the effects of current or potential future roads on forested watersheds.

This program also is responsible for long-term, multiple-scale research on interactions among vegetation, soils, and the atmosphere and how the effects of these interactions on water quality and quantity in different kinds of watersheds—from wildland to urban. Much of this work is conducted in collaboration with university partners and substantial funding by two National Science Foundation program networks—the Long-Term Ecological Research (LTER) network and the National Ecological Observatory Network (NEON). The six LTER network sites on Forest Service land are regarded as the "crown jewels" of the agency's experimental forests. NEON is still in its initial development phase.

The air research has focused on understanding how smoke from wildfires and prescribed burns affect air quality and human health. Some climate change science has also been a component of this program.

[1] Based on private conversations with research project leaders and assistant station directors.

Wildlife and Fish

This program provides land managers and decision makers with knowledge and tools to help protect, enhance, and restore fish and wildlife habitats and minimize the effects of disturbances, such as fire, pest outbreaks, urbanization, and climate change. Forest Service R&D focuses on wildlife and fish habitats; research on the animals themselves is the purview of the U.S. Fish and Wildlife Service in the Department of the Interior. Because these areas overlap, the two organizations often collaborate.

The fish program regards climate change as a critical long-term threat to fish populations and aquatic habitat resilience. Increasing stream temperatures, altered stream flows, and changing patterns of disturbance affect the ability of aquatic habitats to support fish populations. Researchers in this program are conducting long-term studies on the complex interactions between fish habitat quality, natural disturbances, and human activities. The FS has one of the largest and most valuable stream temperature monitoring networks built form landscape-scale stream temperature monitoring. The monitoring program covers cold-water fisheries habitat at high elevation—locations where climate change effects are seen early and most intensely. The monitoring data are being used to construct improved models of stream temperatures and determine how impending human activities and changes in weather patterns are likely to affect fish.

Wildlife research focuses on ungulates (deer, moose, elk), bats, and birds, but includes many others. In the East, white-tailed deer have been a dominant force shaping forests over the past 70 years, causing shifts in patterns of plant composition and abundance throughout many temperate forests. As an example of the impact of this research, the Pennsylvania Game Commission changed from managing doe populations at the county level (political jurisdiction) to an ecological zone framework, which has proven more effective in reducing high deer densities. In the West, land managers are concerned with the potential effects of timber management, livestock grazing, road use, recreation, and hunting regulations, as well as the constraints associated with these activities, on mule deer and elk. In the Starkey Project, researchers are evaluating deer, elk, and cattle responses to intensively managed forests in a controlled research setting—the largest research enclosure ever built to study ungulates,

measuring 40 square miles enclosed by 27 miles of fencing. The habitat research results have informed the elk management plans of state and tribal governments.

Within the past decade, a rare fungus has begun colonizing caves used as hibernacula by bats, obliterating many colonies. Forest Service researchers are among the national leaders in white nose syndrome research, studying both how bats are being infected and how to reduce bat mortality rates. They are also estimating how the reduction in bat populations has increased insect damage to farm crops and forests, with a resulting increase in pesticide applications by farmers. This work has quantified the ecological value of bats to farmers.

Ten to 20 years ago, much of the wildlife and fish research program was aimed at threatened or endangered species, such as the northern spotted owl and Canada lynx. Some of that work continues, but in recent years the program has achieved more balance between species-specific studies and landscape-level research of value to land managers and landowners more interested in multispecies assemblages.

Inventory and Monitoring

Inventory and Monitoring is R&D's second-largest program, after Resource Management and Use. Its principal component is the Forest Inventory and Analysis (FIA) program, the nation's forest census. Begun in 1927, FIA has continually collected and reported on current forest conditions, evaluated recent trends, and projected forest conditions 10 to 50 years into the future. FIA data enable the agency and external stakeholders to consider whether current forest management practices are sustainable in the long run and to assess whether current policies will allow future generations of Americans to enjoy and benefit from forests.

Fifteen years ago, the FIA program changed from a periodic survey to an annual survey. Under the former approach, field data collection proceeded state by state. For example, FIA field crews would go to Maine and, over two or three field seasons, measure the 6,000 field plots, then move on to New Hampshire and Vermont; they would return to Maine in 12 to 15 years. As changes in forest conditions started to occur more rapidly, waiting years for a new inventory became unacceptable to state agencies and investors. Under the standard annualized system, a fixed percentage of the plots in every state are measured every year: 14 percent of a state's plots

annually (i.e., it takes seven years to measure all plots in a state) east of the Great Plains and 10 percent of the plots (a 10-year remeasurement cycle) west of the Great Plains. If states contribute funding or in-kind support (e.g., assigning state employees to help collect the field data), the survey intensities rise to 20 percent of the plots each year (a five-year remeasurement cycle) in the East and a five- to seven-year cycle in the West. Nearly every eastern state provides funding or in-kind assistance, and many in the West also do.

FIA's three-phase, integrated sampling design relies on a tessellated[2] hexagonal grid:

1. *Analysis of remotely sensed data.* In phase 1 of the inventory process, FIA surveys more than 3 million grid points across the country, each representing 250 hectares (about 600 acres). Sensors are primarily the 30-meter thematic mapper sensor on LANDSAT and the 200-meter MODIS sensor on the TERRA and AQUA satellites.[3] This image analysis determines whether the point is forested and some other features, such as distance to the nearest building and nearest road. Comparison with prior images reveals whether land cover and proximity of development have changed. The pixel spectra from this first phase of the analysis can be combined with known cover, cover density, and other features to impute a great deal of detail to all the other pixels in the image. In essence, one can create accurate wall-to-wall maps at 30m or 200m resolution through modeling.
2. *Field crew visits to a subsample of plots.* In phase 2, FIA crews collect data on an average 28,000 to 32,000 plots each year. Some of these plots meet the definition of *forest* (10 percent minimum tree cover); those that do not are classified as nonforest. These classifications are done in the office, based on geospatial analyses of satellite and aircraft imagery. FIA crews visit each forest plot and gather some 300 pieces of information. A subsample of the plots classified as nonforest are also visited to confirm that the classification was correct. All the data roll into FIA's national database, which now covers more than 3 million trees, some of which have been covered in multiple field visits over the past 70 years.

[2] In a tessellated pattern, an entire surface is covered by an identical shape, without any gaps (cf. a mosaic floor consisting of hexagonal tiles). This sampling framework avoids the problem with grids based on latitude and longitude: because lines of longitude converge toward the North Pole, grids don't represent equal land areas as one proceeds south to north.
[3] A 30-by-30-meter pixel is just slightly larger than a baseball diamond's infield (bases are 90 feet apart). A 200-by-200-meter pixel is slightly larger than six football fields, including end zones.

3. *Quality assurance and quality control review of a subsample of plots inventoried in phase 2.* Experienced field crew supervisors visit 3 to 5 percent of the plots surveyed by field crews to confirm the accuracy of the information.

The field data are cleaned and verified, then run through estimation routines. For example, tree diameter is directly measured in the field with a diameter tape, and tree height is estimated with a laser measuring device. The diameter, height, and species information is then run through a volume estimation algorithm to derive tree volume (which cannot be directly measured in the field). The goal is to have all the data cleaning, verification, and estimation work completed within six months after the conclusion of annual field data collection. For example, if the 2016 fieldwork in Pennsylvania was finished by November 15, 2016, then the target is to complete the estimations and update the national database by May 15, 2017.

Analysts in the regional FIA headquarters (St. Paul for the Northeast; Knoxville for the South; Ogden, Utah, for the Interior West; and Portland, Oregon, for the Pacific Coast states and Hawaii) produce short annual reports for state foresters and interested stakeholders (e.g., forest industry analysts) and longer, more detailed state reports once every five years.

Another component of the FIA program is the National Woodland Owners Survey, which tracks land management activities and landownership objectives via a mail survey to a subsample of the nation's 13 million private forest landowners. The information is summarized periodically by FIA's Family Forest Research Center on the campus of the University of Massachusetts, in Amherst. This information helps state foresters plan their forest landowner assistance programs.

FIA also tracks timber products output, using both telephone and mail surveys to all types of primary wood processors to determine their wood demands (quality, volumes, species) and supply sources. This information is useful in characterizing industry wood consumption patterns and double-checking the timber harvest estimates made from FIA plot visits. For example, after Hurricanes Katrina and Rita in 2005, these data helped connect mills with landowners who wanted to sell salvage wood. In fact, one of the outputs of the FIA program of great value to southern state foresters is a model that can predict—from wind speed data issued by NASA—the likelihood, magnitude, and probable locations of potential forest damage when a hurricane is within 72 hours of making landfall. Immediately after the hurricane moves through, the initial

estimates are updated based on satellite and/or airplane imagery so that within 48 hours of the storm, state governors can use the information to support their requests for federal disaster assistance funding.

Within Inventory and Monitoring, a small amount of funding ($4 million to $5 million per year) targets other topics, such as developing new monitoring techniques (e.g., remote sensing applications) and periodic national resource assessments.

Since 2000, the FIA program has produced annual business reports that detail spending, amounts appropriated or contributed by partners, specific accomplishments for the funds available in the prior year, and specific commitments for the coming fiscal year. As detailed as corporate annual reports, these documents have helped explain and validate the program's activities to Congress and stakeholders.

The centralized leadership and management of FIA—the program has a staff director in Washington, D.C., and a national program leader—have proved effective. FIA has earned strong, vocal support from the FIA National Users Group, whose members include leading analysts and decisionmakers from state agencies, forest industry, and nongovernmental organizations. The support has developed through annual national and regional meetings where the program leaders listen to stakeholders' needs and respond to program critiques. The FIA National Users Group members benefit from having a single, credible, consistent forest inventory program whose estimates for a particular forest attribute in one location are directly comparable with estimates all across the country. This comparability is particularly important for mill operators. Further, the FIA program's openness and transparency about its funding have built trust and goodwill over the years as stakeholders sought to secure additional funds to expand from periodic to annualized inventories.

Funding and staffing trends

The Forest Service R&D funding levels (see Figure 2) suggest that the research capacity of the Forest Service has been funded at a relatively constant level since 2008. But this relatively stable funding level has hidden erosion of program capacity, from two perspectives.

First, economic studies indicate that the annual inflation rate in the cost of research has been roughly 50 percent higher—year by year—than the Consumer Price Index (CPI).[4] Chaining these differences between the annual CPI and the annual Biomedical Research & Development Price Index (Bureau of Economic Analysis, Department of Commerce) results in a 21 percent decline in purchasing power for research, compared with the CPI, for 2001 to 2014. This cost erosion affects scientific and laboratory equipment, which has become more expensive even as the replacement interval of the equipment has been halved, from six to eight years to three or four years, because of accelerating technical improvements and demands for state-of-the-art equipment.

Second, the number of researchers has declined over time because the costs of laboratory equipment, facilities, and services have grown, leaving less available for salaries. The Forest Service R&D mission area has seen a halving in the number of researchers over the past 30 years (Table 1). The major reduction—from 985 researchers to 607 (–38 percent)—occurred during the administrations of Presidents Reagan (1981–1989) and George H. W. Bush (1989–1993), but since 2005, there has been a further 16 percent reduction.

Table 1. Forest Service R&D scientist cadre, 1985–2015

Top 12 job series	1985	1995	2005	2010	2015	Percentage change	
						1985–2015	2005–2015
Forester	350	138	146	112	104	–70%	–29%
Entomologist	70	38	33	25	27	–61%	–18%
Forest products technologist	63	25	21	13	18	–71%	–14%
Plant pathologist	50	35	23	15	13	–74%	–43%
Wildlife biologist	42	44	34	30	25	–40%	–26%
Chemist	41	21	17	10	10	–76%	–41%
General engineer	32	29	18	14	14	–56%	–22%

[4] Studies of the cost inflation of research have focused primarily on research funded by the National Science Foundation and the National Institutes of Health. The studies showed that the cost of doing research outpaced the CPI. The limited information on environmental research suggests that its costs, too, have outpaced the CPI (https://officeofbudget.od.nih.gov/gbipriceindexes.html).

Geneticist	31	19	21	13	14	–55%	–33%
Biologist	30	14	22	12	19	–37%	–14%
Mathematical statistician	30	14	12	11	10	–67%	–17%
Ecologist	9	46	93	89	114	+1,167%	+23%
Plant physiologist	26	34	31	21	19	–27%	–39%
All other job series	211	150	126	117	116	–45%	–8%
Total	985	607	597	482	503	–49%	–16%
Percentage in top 12	78.6%	75.3%	78.9%	75.7%	76.9%		

The types of researchers employed have also changed, reflecting programmatic shifts inside the agency. The table shows a large reduction in scientists classified as foresters and a sharp increase in forest ecologists. This is largely an artifact of agency personnel procedures: in the late 1980s many forester positions were reclassified as forest ecologist positions, more comparable to other "ologists" (e.g., hydrologist, wildlife biologist, entomologist, pathologist). The other reductions are real reductions in capacity.

The reductions in forest products technologists (–71 percent), chemists (–76 percent), and general engineers (–56 percent) signify a loss of research capacity especially important to innovation in the forest products sector. Another notable reduction in research capacity occurred in the two areas critical to forest health—entomology (–61 percent) and plant pathology (–74 percent). The challenge to forest health and forest products research capacity was highlighted in a National Research Council (2002) report:

> Numerous gaps in knowledge related to various specific scientific aspects of forestry have been identified, but there is general agreement among forest researchers that basic biologic knowledge is limited and that our understanding of *forest health,* systems, and management and *wood science* is deficient. (p. 4, emphasis added)

The data since 2005 show that declines in forest health and forest products research capacity continued: plant pathologists, –43 percent; entomologists, –18 percent; chemists, –41 percent; general engineers, –22 percent; and forest products technologists, –14 percent.

Forest products research is roughly 8 to 10 percent of the Forest Service R&D portfolio—some $23 million to $28 million annually (the agency cannot say precisely how much). The bulk of this funding goes to the Forest Products Laboratory in Madison, the only federal laboratory dedicated to forest products research. Most manufactured wood products of commercial value to modern construction—oriented-strand board, laminated veneer lumber, cross-laminated veneer, glulam, parallam, and others—were developed from research conducted by Forest Products Lab scientists. Several other Forest Service research stations also conduct forest products research of regional interest. For example, the Southern Research Station has focused on utilization of southern pines and hardwoods, the Pacific Northwest Research Station studies wood utilization research in Alaska, the Northern Research Station conducts Appalachian hardwood research, and the Rocky Mountain Research Station works on utilization of biomass-derived products.

Forest products research is the program area that has seen the largest loss of researchers since 1985: forest products technologists, –71 percent; chemists, –76 percent; and general engineers, –56 percent. In total, the forest products program went from 136 scientists in 1985 to 42 in 2015, a loss of 94 researchers, accounting for 20 percent of the overall reduction in the agency's research cadre.

These reductions have eroded the capacity of Forest Service R&D programs. The departure of many researchers with 30 to 45 years of experience is a serious drain in expertise affecting not only for the Research and Development mission area, but also the stakeholders that relied on their research findings to empower investments in the management and utilization of forests . Further, because research priorities are shifting, new hires may not be assigned to the same problem as the scientists who departed, making it challenging for the agency to continue important lines of research.

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