Forest and Grasslands Carbon: Science to Support Principles for Carbon Stewardship in the Nation's Forests

A Science Statement of the National Association of Forest Service Retirees
Approved February 6, 2024

Purpose

To create a framework for:

- increasing public literacy about forest carbon,
- explaining current and emerging issues in forest carbon stewardship
- integrating forest carbon knowledge into public and private discussions about contemporary climate-related issues, mitigation options, and potential solutions, and
- exploring the science needed to refine and apply principles of carbon stewardship in managing forests and grasslands to promote resilience to effects of changing climatic patterns and associated disturbances.

Scope

The nation's forests and grasslands are the living intersections of major cycles and successional pathways, many of which are experiencing pronounced effects of a changing climate. The forest and grasslands carbon cycles (combined here as forest carbon) are some of the most important connective cycles to multiple ecosystem values including wildlife habitat and water quality, have important roles in climate change mitigation, and their own sensitivities to climate change effects. Forest carbon is the center of many contemporary conflicts and opportunities and overlaps with other public issues related to land uses, active management, protection, and sustainability of forests and grasslands.

This statement provides a science-based rationale for the USDA Forest Service—given its mission, program assets, history, and global reputation in science-based forest management—as well as other public agencies, non-governmental organizations, and private landowners to: (1) increase their domestic and global influence in the science, application, and innovation in carbon stewardship; and (2) advance the roles of forests and grasslands, forest products, and forest management in integrating climate adaptation and carbon stewardship as goals for success. This brings together mitigation, long-term carbon resilience, and ecosystem adaptation in the face of rapidly accelerating climate impacts. This integration better positions agencies, organizations, and landowners to deal with new realities in carbon cycle dynamics and disturbance patterns and creates climate-informed ecosystem management options for managers, policy makers, and citizens.

Why the Growing Interest in Forest Carbon?

Forest carbon stewardship has emerged as a new challenge in meeting the missions of the Forest Service, other public agencies, and private organizations. Forest carbon stewardship is now a component of many other issues, such as the longstanding issues of the role of active management in mature and old growth forests and the expansion in use of wood products in commercial and residential construction to gain environmental, social, and governance (ESG) benefits. Carbon stewardship is now an important socio-economic concern whose ramifications are affecting land management policies and decisions—nationally, regionally, locally—with implications for the reputation and credibility of public agencies and their ability to partner with non-governmental organizations and pursue their missions in a future shaped by changing climatic patterns.

Broadening and Deepening Public Literacy about Forest Carbon

Forest carbon stewardship is complex because the roles of carbon in ecosystems are complex. Therefore, the first step toward improving and expanding forest carbon stewardship is to increase public literacy about forest carbon—why it is important in forest ecosystems, what the major forces are that drive carbon sequestration, storage, and flows in carbon cycles, and how changing climatic patterns are affecting carbon cycles.

The state of knowledge about forest carbon management is solidly based on pioneering work by Forest Service scientists, their partners, and resource managers, many of whom are now members of NAFSR. That knowledge base is growing rapidly with unfolding implications for management decision making. Forest carbon science activity has grown from less than 100 publications per year in 1990 to over 6,000 annually in 2021 (D'Amato 2023).

NAFSR congratulates the Forest Service for producing an excellent synthesis of scientific information about options for managing carbon in forests and grasslands. Syntheses like this are an important contribution to public literacy by the Forest Service Research and Development mission area. With the proliferation of individual research studies by the agency and university scientists digging into the many aspects of forest carbon and climate change, periodically synthesizing the many recent research findings and making sense of them for forest managers, consultants, and others in a comprehensible way is a vital agency contribution to public literacy.

NAFSR's Perspectives on Forest Carbon Literacy

For the past five years, NAFSR has been an active member of the Forest Climate Working Group (FCWG). Through our participation with 31 like-minded organizations, we are helping to increase public literacy about forest carbon. The FCWG sponsors events focused on increasing knowledge and public awareness of the importance of forest carbon. The FCWG website also publicizes synopses of new scientific papers and journal articles by members and public agencies, such as the scientific synthesis hyperlinked above.

NAFSR applauds the contributions of several public literacy programs. The Forest Owner Carbon and Climate Education program is a cooperative of research and extension professionals at 13 land grant universities and three USDA climate hubs. The Forest Carbon and Climate Program at Michigan State University hosts the Forest and Climate Learning Exchange Series of monthly webinars. The Sustainable Forestry Initiative created a Forest Literacy Framework in partnership with Project Learning Tree to connect forest carbon with climate change and other natural resource issues. These resources—and others—for educators and natural resource professionals are helping to improve public literacy about forest carbon and climate change, especially among today's youth.

Forest carbon education and literacy is also aligned with many of NAFSR's Principles, Beliefs, and Values:

- Wide array of uses.
- Actively managing landscapes
- Balancing considerations with best available science
- Protecting the public's interest and safety
- Addressing emerging national issues

- Partnering with others
- Maintaining a diverse and productive field organization

Several existing NAFSR position statements and white papers—fire, restoration, climate effects, reforestation, and others—also contribute to increasing public literacy about forest carbon stewardship by connecting forest management with carbon stewardship.

As literacy increases, dialogues about forest carbon's importance and stewardship options will need to spend less time developing a shared understanding among dialogue participants of what forest carbon is and why is it important, which will make more time available to exploring options and building consensus for action. Exploring options and building consensus for action is the critical part of implementing forest carbon stewardship on the ground.

Forest Carbon – Intersection of Emission Reduction and Climate Adaptation Challenges

NAFSR's recent (2/7/2023) climate change science and position statements described some implications of the changing climate on systems, cycles, and management challenges for the Forest Service mission. Stewardship of forest carbon involves creating outcomes for emissions that intensify climate effects as well as being affected by climate. Carbon stewardship implies maintaining long-term balances between managing emissions and effects to resources, including the capture and storage of carbon itself. Managing that balance requires continual expansion of the knowledge base that addresses the points made in NAFSR's science and position statements.

New Realities of Climate Effects and Forest Carbon

Forest carbon plays multiple roles in the ecological, physical, social, and economic systems affected by climate change. Carbon is more than a market commodity or a separate ecosystem service. Rather, it is a core component of the forest and grassland systems. The Forest Service has weaved carbon into its overall resilience and adaptive capacity focus as described in the 2022 USFS Climate Adaptation Plan and in publications such as GTR WO-95 Considering Forest and Grassland Carbon in Land Management. These and other reports have broadened our attention on forest carbon beyond emissions offsetting, markets, and carbon-centric framing toward carbon's roles in relationships among multiple resources and opened discussions about system dynamics, long-term resilience and equity in meeting the agency's overall sustainability mission. The NAFSR climate change statements outlined three major climate-driven trends that are reshaping forests and grasslands and their management that also have strong implications for forest carbon.

Trend 1—Changing disturbance patterns. The nation's forests have long been viewed, even taken for granted, as a reliable carbon sink and offset for other emissions. However, annual greenhouse gas (GHG) inventories confirm that the national sink may be weakening. The forest resources in nine states have become net emission sources. The recently released 2020 Resources Planning Act (RPA) Assessment projects that the national net sink is likely to level and may become a net source soon due to a combination of the increased number and intensities of disturbances, aging forests, net loss of forest land to urban development, and climate-driven shifts to other ecosystem types. Ironically, climate change itself is becoming a stronger factor in decreasing forest carbon sequestration. Even as public and private investments in nature-based solutions have risen, new carbon sequestration resulting from them may have to be counted as replacements for increasing losses in the strength of the forest carbon sequestration and storage.

Dealing with rapidly changing disturbance patterns has prompted resource managers to look beyond historical experience for answers. They are finding that policies and management guidelines that are anchored in historical disturbance regimes and management strategies may not be effective in dealing with new climate-driven disturbance processes. They recognize the need to better understand the effects of changing disturbance regimes and system transitions on the: (1) sequestration and storage of carbon; and (2) prospects of building carbon resilience. This calls for a more integrated and usable framework for working with the interplay between carbon and other resources in forest and grassland systems. This new knowledge will be needed to grow the capacity of public agencies to adapt to changes yet to be defined and reduce climate-driven risks to multiple resources.

Trend 2—Changes in ecological and social systems in response to rapid and extreme climate change effects. Many ecological and social systems are in transition. Ecosystem services are at the interface between natural and human systems. As Seidl and others found, a forest's resilience to changing climatic patterns and disturbances arising from those changes not only has ecological dimensions, it also has social dimensions. These transitions in ecological and social systems occur at multiple spatial and time scales across a range of forest conditions, landscapes, and ownerships. Some will result in novel systems and resilience linkages, with carbon cycle patterns or social dimensions for which little scientific information or management experience exists. The current state of knowledge may be inadequate about the resilience of forest carbon stocks and flows to management activities, disturbances, and their cascading effects on the qualities and quantities of ecosystem services sought by society. Uninformed attempts can be wasteful, misleading, or even destructive. What's needed are new, more adaptive, and agile models of partnerships among scientists, managers, and stakeholders that allow tracking, evaluating, and responding to changes in both ecological and social systems and their inter-related implications for resilience of forest carbon stocks, flows, and other values.

Trend 3—Policy, management, and accountability challenges. Balancing goals for carbon storage capacity, sequestration rates, wildland fire, forest health and other ecological and socio-economic conditions involves a new and more complex set of tradeoffs and synergies. Maintaining these balances demands: (1) more agile processes for refining policy and management strategies and integrating new science findings; and (2) more specific definitions of carbon stewardship as an element of forest sustainability that can be translated into management guidelines at appropriate scales and integrated into agency accountability measures. Risk-based thinking and the wise use of science-based tools to confront multiple, interactive risks may become necessary skills for agency leaders and specialists. These skills would have to be accompanied by more effective and transparent communication of risks and management processes to help stakeholders understand the consequences of managing disturbances. New levels of climate/carbon/forest system literacy and innovative problem-solving partnerships at scales akin to the spatial and temporal scales of emerging disturbance patterns, system changes, and resource implications will help accelerate mitigation and adaptation thereby increasing resilience.

Science in Support of Forest Carbon Stewardship and Mission Accountability

Accountability for Carbon Stewardship

Federal direction[1] and recent legislation[2] call on all agencies to strengthen their accountability for incorporating carbon management into decisions and program design. This will require commitment to implement strategies based on actionable principles for carbon stewardship and to translate these principles into baselines, performance measures, and goals that are consistent with the science base. They would also be incorporated into strategic guidance for regional ecosystem conditions adjusted to meet the vulnerabilities of carbon and other resources and cost-effectiveness of alternative management actions. These principles would be fleshed out and given strong weight in agency programming and budgeting.

In building on its history of success in resource management, the Forest Service can become an even more prominent national and global influence in science-based carbon stewardship. The agency is already a leader in defining and modeling carbon stewardship and in demonstrating the role of forest and range ecosystems in climate change mitigation and adaptation. The agency's recognized progress in forecasting national carbon

[1] Executive Order 14008: Tackling the Climate Crisis at Home and Abroad. Executive Order 14072: Strengthening the Nation's Forests, Communities, and Local Economies. USDA Secretary's Memo 1077-004: Climate Resilience and Carbon Stewardship of America's National Forests and Grasslands.

[2] Infrastructure Investment and Jobs Act of 2021 (Public Law 117-58)(IIJA). IIJA is also known as the Bipartisan Infrastructure Law (BIL). Inflation Reduction Act of 2022 (Public Law 117-169)(IRA).

resources; establishing baselines for carbon stocks and stock change on National Forests and other lands; and integrating forest carbon into land management planning has given it standing for collaboration with other agencies and global partners. Given the importance of the nation's forests and grasslands in global carbon cycles and national goals for both mitigation and adaptation, all mission areas of the agency could strengthen and make more visible their contributions to policy dialogues at national, state, and local levels. A key to strong leadership is aligning programs with forest carbon implications across the agency. Doing so will enhance the agency's carbon credibility.

Science for Accountability

The agency can grow its accountability from a strong carbon, ecosystem, and social science base and design new systems for integrating carbon stewardship with resource objectives on public and private lands. Partnerships to advance this base could involve scientists, managers, and citizen stakeholders to translate and disseminate science findings, carbon inventories, and methods for optimizing carbon and multi-value resilience. Emerging and long-standing social science knowledge and the lessons of collaborative landscape-scale coalitions in restoration and fire/fuels management can also be used to guide the adoption of climate-informed practices.

The most complete picture of carbon cycles, including important belowground processes and possible future conditions can be best drawn from long-term science investments that show how coupled natural/human systems determine when, where, and how carbon is sequestered, emitted, and transferred. As climate and other influences alter these systems, research can lead to agency adaptation responses, pointing out changes and how they occur and offering options for dealing with them.

Monitoring and diagnosing forest carbon cycles as they intersect with water, vegetation, social, economic, and other cycles require a workforce and an investment strategy that looks beyond forest stand delineations, ownership boundaries, and local projects or plans. As the fate of local forest resources are being influenced by shifts in global phenomena and large-scale transitions in biological and social systems, managing forest carbon demands closer attention to global-scale changes in ecosystems, societies, and economies, along with reevaluations of historic cycles and familiar disturbance regimes.

Understanding changing forest carbon cycles will demand coordinated scientific vigilance among multiple disciplines. The Forest Service's Research and Development mission area and International Programs Staff need to continue being active and influential in the global scientific and policy communities. They should nurture partnerships among managers, scientists, and stakeholders in many forest and grassland systems—here and abroad. The aims of fostering learning environments where managers, scientists, and stakeholders jointly gain experience and understanding by experimenting together include enhancing trust and capacity to detect, identify, and evaluate emerging changes and implications at early stages when mitigation and adaptation are simpler and less expensive.

Forest Carbon Stewardship Principles

In 2013, the Forest Service Executive Leadership Team (ELT) adopted five principles for forest carbon stewardship. They have been shared with different sets of stakeholders several times—receiving accolades. The five principles flow from the premise that land management and use of forest products can be designed to sequester and store carbon while meeting other objectives. They are a guide for integrating carbon into national and regional policies and programs, thus making carbon stewardship a core part of sustainable forest management and climate change response.

The five principles form a framework to help inform decision-makers and citizens about agency views on forest management approaches to climate mitigation and to guide agency engagement in international, national, regional, state, and local climate discussions and partnerships. The principles assert that sustainable uses of wood can help reduce carbon emissions in the forest sector over the long-term.

The carbon stewardship principles also offer a framework for setting investment priorities both inside and outside the agency for research and development; for integrating science-based climate adaptation and mitigation goals into land management planning, decisions, and major initiatives; and as the basis for developing partnerships with like-minded organizations. Already, they have helped some national forests and agency programs integrate carbon stewardship in land management and climate adaptation planning and better communicate the roles of the agency in responding to a changing climate.

The carbon stewardship principles have been featured in Considering Forest and Grassland Carbon in Land Management, GTR-WO-95 and are displayed on the Carbon page of the Forest Service website along with portals to agency programs and actions that illustrate some of the principles. Carbon stewardship and resilience are core concepts in the agency's new Climate Adaptation Plan which was developed to implement Executive Order 14008 on Tackling Climate Crisis at Home and Abroad, EO 14072: Strengthening the Nation's Forests, Communities, and Local Economies, and the USDA Secretary's Memo on Climate Resilience and Carbon Stewardship of America's National Forests and Grasslands (1077-004). Carbon-related actions in Forest Service Regions are being documented and reported through the FS Climate Action Tracker reporting tool which highlights actions consistent with these principles.

The principles are:

1. **Emphasize ecosystem function and resilience. (Function First).** Carbon sequestration capacity depends on sustaining and enhancing ecosystem function to maintain resilient forests adapted to the changing climate and other conditions.

2. **Recognize carbon sequestration as one of many ecosystem services. (One of Many Services).** Carbon sequestration is one of many benefits provided by forests, grasslands, and forest products, now and in the future. Carbon sequestration should be considered in context with other ecosystem services.

3. **Support diversity of approaches in managing carbon, reflecting differences in ownership goals, policies, ecology, geography, socioeconomic concerns, and others**. **(Diverse Approaches)**. Recognize that decisions about carbon in America's forests are influenced by ownership goals, policy, ecology, geography, socioeconomic concerns, and other factors that vary widely. The FS supports a variety of approaches to payments and exchange for carbon sequestration to provide choices that are compatible with the objectives of different owners.

4. **Consider system dynamics and scale in decision making. (Scale and Timeframe).** Evaluate carbon sequestration and cycling at landscape scales over long time frames. Explicitly consider uncertainties and assumptions in evaluating carbon sequestration consequences of forest and grassland management options.

5. **Use the best information and methods to make decisions about carbon management. (Decision Quality).** Base forest management and policy decisions on the best available science-based knowledge and information about system response and carbon cycling in forests, grasslands, and wood products. Use this information wisely by dealing directly with uncertainties, risks, opportunities, and tradeoffs through sound and transparent risk management practices. FS units should strive to develop and adopt uniform and consistent methodology in carbon estimation, climate forecasting, and other elements of decision making to compare alternatives and reliably detect changes in forest conditions. Where practical, the FS

will consider the full life cycle impacts of management decisions in influencing atmospheric GHG concentrations.

An overarching 6th principle was to strive for program integration and balance – making carbon stewardship part of the overall program of sustainable forest management and climate change response.

Science Priorities to Support the Forest Carbon Stewardship Principles

Following are science advancement areas that support investments and implementation of carbon-related goals of the Infrastructure Investment and Jobs Act of 2021 and the Inflation Reduction Act of 2022. Each of these areas are presented below under one of the carbon stewardship principles because it represents the most needed improvements in science-based knowledge and tools to support that principle. These areas do not represent a full sweep of science work needed to achieve excellence under any or all principles.

Principle 1: Emphasize Ecosystem Function and Resilience. (Function First)

Priority: Understanding the whole forest carbon cycle – especially belowground carbon. Managers and policy makers need to be able to address the complexities of the carbon cycle as it intersects with ecological and socio-economic cycles that influence the forest and grasslands sectors, including forest management and resource uses. Partial views of the carbon cycle can lead to simplistic interventions that fail to produce desired results or create problems elsewhere in the cycles.

When it comes to sustainability reporting in annual corporate reports, an increasing number of commercial forest owners want to report on the status and trends in belowground carbon through environmental, social and corporate governance (ESG) metrics—the intersections of ecological and socio-economic interests. Especially for landowners seeking to achieve zero net emission goals, tracking belowground carbon stocks are emerging as an important metric. For example, a firm that manages on 40-to-45-year rotations may have two prior rotations worth of dead roots still belowground decaying while a current rotation is growing and want to take credit in ESG reporting for that residual biomass carbon.

Science priorities: Understanding and measuring belowground carbon needs serious attention. Carbon stocks in forest ecosystems can be divided into five storage pools[3]. Stock changes (flows or fluxes) are reported either as carbon coming into a pool or leaving a pool (e.g., death of a tree results in loss of carbon from both the aboveground and belowground carbon pools and an increase in carbon in the dead wood pool). Creation of belowground forest carbon depends on many factors, including growth rates of aboveground biomass, the rooting morphology of different species (e.g., shallow-rooted versus tap-rooted) and site conditions (e.g., species composition and stocking density, site quality, rainfall, etc.).

This set of belowground carbon pools represents more than half of the nation's forest ecosystem carbon stocks and is exposed to high losses through transitions to non-forest systems, forest clearing, and land-use change. Knowledge about the belowground carbon is progressing more slowly than our advances in understanding of the aboveground components. It is subject to different risks than carbon stored above ground and is important in

[3] *Aboveground biomass* is all living biomass above the soil—overstory and understory components. *Belowground biomass* is all living biomass in coarse living roots greater than 2 mm in diameter. *Dead wood* is all non-living woody biomass, either lying on the ground, still standing, or in the soil. *Litter* is all duff, humus, and vine wood debris above the mineral soil. *Soil organic carbon* includes all organic material in both organic (e.g., peat and muck) and mineral soils to a depth of 1 meter, excluding coarse living roots. A sixth pool often accounted for is *Harvested wood* products. This pool includes products currently in use as well as discarded wood products stored in solid waste disposal sites. See Chapters 1 and 4 in the 2006 guidelines from the Intergovernmental Panel on Climate Change for more details.

complex ecosystem functions such as regeneration and in interactions with water, nitrogen, micronutrients, erosion, and other biophysical processes.

Forest and grassland soils can become massive sources of carbon and other GHG emissions because of extreme disturbances or improper management. Many of the best management practices (BMPs) designed for stormwater, sediment, and nutrient management only partially protect carbon storage and may need to be modified to provide protection for longer-term storage and outyear sequestration.

Much more needs to be known about belowground carbon, its dynamics, its roles in forest ecosystem function, and its exposure to climate and human disturbance impacts. Measures and estimates of belowground carbon need to be improved, including its vulnerability to fire, extreme precipitation, management and harvesting actions, vegetation changes, and other factors.

Principle 2: Recognize Carbon Sequestration as One of Many Services. (One of Many Services).

Priority: Linking carbon stocks and flows with changes in multiple ecosystem services. Understanding tradeoffs and synergies in balancing carbon and other goals depends on a strong and expanding science base. Understanding forest carbon at multiple scales and having access to accurate carbon cycle estimates and forecasts are vital for decision making. Science investments can provide new perspectives, deeper knowledge and foresight needed to support diligence across all ownerships in making decisions about forest carbon. It can help public and private land managers better understand carbon on their own lands and its interactions with their other ownership goals.

The challenges of introducing carbon stewardship into an already crowded mix of objectives and public expectations can be daunting. Management interventions ranging from active vegetation management to "hands-off" protection alter forest carbon cycles in different ways and often favor one or more co-benefits or core values over others. For example, forest density reduction for fire, insect, and disease management and watershed protection may conflict with preferences to maintain high densities of aboveground forest carbon stocks and/or carbon densities proportionately higher in large trees.

Decision makers need carbon information about different time frames, scales, likelihoods of disturbance and severity, and carbon carrying capacities as they work with stakeholders to understand different objectives and provide transparency and accuracy in deliberations. These judgments and choices require the best science available, fed by a robust long-term science program to guide adaptations through the life of projects and rebalance carbon and other co-benefit strategies to unforeseen changes and complications. They also need information and how carbon patterns correlate with outcomes for different co-benefits. Better understanding of carbon and co-benefit relationships can help frame carbon stewardship into measures of long-term resilience of the forest and grassland infrastructure and balancing goals to meet the needs of present and future generations.

Science-based information about carbon and other ecosystem service values can illuminate tradeoffs and synergies to improve decision making. It can reveal different long-term pathways for carbon stewardship in different regions and sites, and better define measures of resilience to changing risk patterns and future use demands. For example, although ambitious decarbonization goals may call for increasing both the rate of sequestration and the amount of carbon stored in forest ecosystem and wood products pools, these goals may not be compatible with co-benefits production or risk management goals. Wrestling with these difficult tradeoffs benefits from having the possible assessments of carbon/co-benefit relationships.

Science priorities: New knowledge is needed in the following areas.

- Understanding how forest carbon in different forms (pools and flows) is linked with different ecosystem service values, such as wildlife habitat quality and clean air and water.

- Assessments of relationships between carbon cycles and other resource cycles (e.g., water, nutrients, successional pathways), including those involving new and invasive species introduced through changing disturbance patterns and human activities.
- Developing measures of forest carbon conditions and trends as indicators of overall ecosystem change and resilience that can be integrated with other measures of ecosystem health and functional condition.
- Understanding joint carbon cycle and co-benefit implications of ecosystem state changes. Examples are climate-driven shifts from forest to grasslands, land-use changes such as forest clearing or recolonization of abandoned cropland by pioneer tree species, and the creation of novel vegetation communities.
- Cross-walking forecasts of climate change vulnerabilities with projected changes in forest and grasslands carbon cycle changes and net emissions. This can translate into meaningful measures of forest carbon resilience and rates of post-disturbance recovery.

Principle 3: Support Diversity of Approaches in Managing Carbon, Reflecting Differences in Ownership, Goals, Policies, Ecology, Geography, Socioeconomic Concerns, and Others. (Diverse Approaches)

Priority: Science to support participation and accountability in carbon stewardship. As concerns and calls for climate action grow, public and private sector organizations have been asked to take ambitious actions to: (1) reduce their total GHG emission footprint in operations, facilities, public use, and ecosystem management; and (2) disclose and manage climate-related risks to agency mission accomplishment. Public agencies have emphasized internal mandates and guidance; private concerns have focused on incentives and market-based approaches to encourage investment in decarbonization and adaptation investment. Public/private partnerships attempt to align public and private sector players through cost-sharing incentive payments, tax incentives, technical assistance and other mechanisms are being implemented through the IRA and IIJA (BIL) funding packages and the USDA Climate-Smart Agriculture and Forestry Strategy.

There is strong public interest in supporting efficient markets for forest carbon and products sequestration and long-term carbon resilience. Federal and state agencies are providing opportunities for these public/private partnerships to reduce their cost burden and manage the uncertainties and complexities of carbon stewardship for a diverse range of forest ownerships.

Mechanisms for advancing carbon stewardship goals and actions operate through existing programs and authorities that have been adjusted to incorporate carbon stewardship and encourage public/private investments in meeting goals.

The sustainability mission of the Forest Service implies that social values of carbon be included in program design and implementation, even in programs that service private ownerships. Roles vary from integrating carbon into National Forest System management, sharing technical options with international partners, supporting the sustainable development and equitable access to carbon market options for private forest owners, and others. Advancing carbon goals on National Forest System lands has become more complex as resource managers try to "optimize" multiple values and service flows rather than "maximize" any one or more of these values.

Federal guidance and promotion for carbon stewardship. On January 9, 2023, the Council on Environmental Quality (CEQ) issued guidance to assist agencies in analyzing greenhouse gas and climate change effects of proposed actions under the National Environmental Policy Act (NEPA). Federal agencies have been encouraged to use the Social Cost of GHG Emission (SC-GHG) that estimates the social values of carbon emissions avoided or carbon sequestered. The measure allows managers and stakeholders to consider net carbon emissions as a cost of managing multiple resource systems.

Guides for integrating carbon in private forest management have been encouraged in part by carbon pricing and market systems. Carbon-offset market accounting frameworks and success measures have helped to provide criteria such as carbon additionality, permanence, and avoidance of indirect emissions elsewhere (leakage) to assure transparency, and integrity in contracting and trading. These criteria help assure that the benefits of well-functioning carbon can accrue across the range of forest ownerships and accumulate to meet national mitigation targets.

USDA has recently reissued a federal strategy to advance GHG emissions measurement and monitoring for the agriculture and forest sectors and new technical guidelines for quantifying greenhouse gas emissions sequestration. Forest Service scientists and managers led the writing teams for the forest sector chapters in each of these new guidance resources.

Several proposals have arisen about the potential participation of the National Forest System in voluntary carbon-offset markets or other financial partnerships. The possibilities of generating income through monetizing carbon storage and sequestration on National Forest lands have generated much discussion. However, without a clear and science-informed concept of carbon stewardship, the agency runs a risk of creating a new multiple use, a revenue source, and commitments to maintaining forest conditions that could conflict with other public values. Proposals such as these should be guided by a clear and cohesive foundation in carbon stewardship.

Science priorities: Science-based knowledge and tools are bedrock support for offering different approaches to carbon stewardship. Decisions about market participation, tradeoffs among objectives, standards for accountability and equity, and other aspects of implementing stewardship depend on science-based estimates and carbon outcomes of disturbance and management at multiple scales. The effectiveness of accountability measures depends on the quality of the underlying science – including social science - about how management actions influence new emissions and how the pricing mechanisms or incentives stimulate human carbon stewardship commitments. The better the science base, the more effective the market price or internal pricing instruments can become in signaling incentives for improving and scaling up levels of practice.

Science is contributing to a deeper understanding of the compatibility of carbon goals with landowner objectives and their responses to different policy instruments and payment systems and the effectiveness of different management alternatives in blending carbon and other benefits. Forest Service R&D, FIA's National Woodland Owner Survey, and the Family Forest Research Center are advancing knowledge about private owners participation in carbon markets and their adoption of stewardship practices. This stream of inquiry will help government incentives and market initiatives to better assess their design and performance and adjust their strategies.

Principle 4: Consider system dynamics and scale in decision making. (Scale and Timeframe).

Priority: Improving the evaluation of forest carbon cycles at multiple scales. Forest carbon cycles operate at multiple spatial and temporal scales. Disturbance agents also interact and influence carbon cycles at these scales so managers must call on science insights from multiple spatial views to guide judgments of forest management alternatives and consequences. Implementing programs and evaluating outcomes at scales that are too small to detect true differences or degrees of alignment with larger goals can be misleading and result in scattered efforts without strategic direction or cohesion. New science needs to help sharpen awareness of drivers, patterns, and institutional efforts that operate at multiple scales—larger to evaluate management effects on carbon cycling across landscapes and three to five decades, and smaller to estimate stand-level responses to management practices and relevance to landowner choices over shorter times.

Science priorities. More science is needed to help managers design, implement, and evaluate programs and practices at large spatial scales and longer planning periods. Two important knowledge gaps are: (1) how to configure multiple projects to build long-term resilience to multiple disturbances; and (2) how to frame ecological and economic portfolios that use diversification, risk spreading, redundancy, and other risk management strategies to manage compound risks. At larger scales, net carbon emissions can be tracked more accurately, and management practices can be deployed and located more effectively on landscapes to address expected behavior of disturbance agents.

The top priorities for new scientific data and insights are:

- Plausible future disturbance scenarios and potential management impacts at multiple scales;
- Time frames and expected responses to management and/or disturbance events;
- Estimates of limitations and likelihoods of error in estimating or attempting to manage emissions at project-level (partial) scales;
- Knowledge of how forest disturbance patterns (including harvesting and management) influence larger scale dynamics;
- Interactions among drivers of carbon flows, including transfers among carbon pools across different spatial and temporal scales; and
- Linkages between forest ecosystems and different forest carbon pools, including product use, urbanization of forests, and the adoption of agroforestry systems.

Principle 5: Use the best information and analysis methods. (Decision Quality).

Priority: Understanding the interplay of management actions and climate-influenced disturbance processes. Climate change is reshaping disturbance interactions—gradual warming, extreme heat, drought, wildfire, insects, disease, extreme precipitation, and other agents—into new interactive regimes and stress complexes[4] that alter carbon cycle dynamics. Compounded disturbance regimes are now emerging from individual hazard patterns and interacting with harvesting and management practices—or their absence—to interrupt or divert successional pathways and reduce carbon sequestration and carrying capacity.

As managers pursue new management strategies to cope with these changes, they confront the new costs, benefits, risks, tradeoffs, and complexities of integrating carbon stewardship into forest management. Managers cannot rely on experience alone or simplistic prescriptions to maintain resilience. Investments in more strategic prevention and restoration strategies have been supported through recent federal legislation (IIJA, IRA). But this investment stream must be informed by assertive ongoing efforts to understand how disturbance processes reconfigure and interact over time.

For example, wildfire is a primary driver of forest carbon emissions in the West and the object of a 10-year loss reduction initiative. This strategy positions thinning, prescribed fire and managed wildfire as mechanisms for restoring and maintaining native vegetation and stabilizing long-term carbon sequestration. Fire has powerful potential as a single agent to emit carbon and cause short-term reductions in carbon sequestration but in combination with multiple stressors, it becomes part of a stronger set of increasingly correlated forces. This initiative highlights the need for a new and more multidimensional strategy to manage forest density and composition as well as human behavior to lower composite risks and improve resilience. The coupling of climate-driven agents makes the multiple resource resilience challenge more formidable but also offers hope that these risks can be managed jointly through multi-scale, longer-term silvicultural strategies.

Science priorities: As disturbance processes become more closely coupled, the interplay between managed and unmanaged disturbances creates confusing—perhaps constraining—factors in meeting management goals. The effectiveness of traditional single-hazard management compared with alternative silvicultural strategies for multiple compound risks is being studied and could yield helpful guidance for building resilience. Innovative

[4] Stress complexes are combinations of biotic and abiotic stresses. Examples are how prolonged droughts interacted with insect populations to cause extensive dieback of pinyon-juniper forests in the southwestern U.S. and how fire exclusion and high stand densities (biotic effects of stand management) along with air pollution (an abiotic effect on forests) have affected mixed-conifer forests of the Sierra Nevada.

designs and experiments for management systems that use diversity, redundance, rebalancing, reserves, and other risk management concepts, as well as new science gained from large-scale experiments, need to be encouraged.

Forecasts of forest carbon conditions such as found in the 2020 RPA Assessment are important is guiding national and regional deliberations about carbon policy and setting priorities for large-scale intervention. However, these model-based forecasting efforts should be more transparent about assumptions and methods and designed to be interpreted more openly by multiple audiences. Here is an example of where increased public literacy about forests, management options, and climate change effects is essential for effective communication and dialogue. These forecasting efforts can become powerful learning tools to prompt discussion and broaden knowledge about underlying processes, disturbance interactions, and other elements for forest and grasslands carbon cycles. They also could offer new avenues for identifying unknowns and science needs as a broader group of stakeholders are attracted into these formative deliberations and investment choices.

One central effort that should be supported is the planned improvement and innovation pathway outlined under the 2014 Forest Inventory and Analysis (FIA) program's strategic plan with its expanding application of remote sensing and other advanced technologies. Improvements underway and planned are outlined on the Forest Service FIA Carbon Monitoring web page. In addition to improved inventories and forecasts at multiple scales, partnerships between carbon inventory and science are being focused on carbon, silviculture, forest products, and urban forestry knowledge that will help develop and test silvicultural and sustainable products approaches. It will also advance data collection to support forest products carbon pools and product innovation based on state-of-science life cycle analysis (LCA). All these efforts will build a more solid basis for maintaining carbon stocks, flows, and joint resilience for carbon and its co-benefits.

NAFSR Policy Position on Forest Carbon

NAFSR has prepared a position statement titled, **Forest Carbon Stewardship Principles for Our Nation's Forests**, accessed through the NAFSR website. The key elements of the position statement are:

- NASFR supports the USDA Forest Service in developing a strong leadership role in defining the concept of forest carbon stewardship for all lands

- NAFSR believes that a clear and compelling set of forest carbon stewardship principles is needed to better frame policy dialogues and guide carbon considerations in forest and grassland management strategies and programs.

- NAFSR is encouraged that the USDA Forest Service has developed and adopted a set of forest carbon stewardship principles.

- NAFSR supports creation of new scientific knowledge and tools to quantify carbon sequestration, stocks, flows, and emissions.