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Supporting National Forest System Planning with Forest Inventory and Analysis Data

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Abstract

In 2012, the US Forest Service promulgated new regulations for land-management planning that emphasize the importance of scientifically credible assessment and monitoring strategies for adaptive forest planning and the maintenance or restoration of ecological integrity. However, in an era of declining budgets, the implementation of robust assessment and monitoring strategies represents a significant challenge for fulfilling the intent of the new planning rule. In this article, we explore opportunities for using data and products produced by the USDA Forest Service's Forest Inventory and Analysis (FIA) Program to support the implementation of the 2012 Planning Rule. FIA maintains a nationally consistent statistical sample of field plots that covers most national forests with hundreds of plots. We suggest that leveraging FIA data and products can generate efficiencies for assessment, planning, and monitoring requirements detailed in the 2012 Planning Rule, and help fulfill the adaptive intent of the new planning rule. However, strong national leadership and investment in regional-level analytical capacity, FIA liaisons, and decision-support tools are essential for systematically realizing the benefits of FIA data for forest planning across the National Forest System.

Keywords: assessment, broader scale, decisionmaking, ecological integrity, monitoring, natural range of variability, planning

Recent years have seen a significant shift in goals and paradigms for natural-resource management. Holistic, multiscalar concepts such as ecological integrity are increasingly used to guide adaptive ecosystem management (Reza and Abdullah 2011, Wurtzebach and Schultz 2016, Carter et al. 2019). In the context of forest planning and management, large-scale forest inventories represent a potential source of information for ecological integrity assessment and monitoring. Indeed, as the adoption and implementation of large-scale forest inventories have expanded globally, so have their role in biodiversity monitoring, and climate-change mitigation and adaptation (Maniatis and Mollicone 2010, Corona 2016). Recent scholarship emphasizes the importance of integrating forest inventory and monitoring data with remote-sensing data, modeling tools, and classification typologies for adaptive planning and decisionmaking at multiple

Management and Policy Implications

Our analysis highlights several ways in which Forest Inventory and Analysis (FIA) data and products can be used to comply with regulatory requirements and support National Forest-planning processes under the US Forest Service's 2012 Planning Rule. FIA fulfills planning rule criteria for the best available scientific information and can be used to address assessment, planning and monitoring requirements associated with ecological integrity, at-risk species, ecological drivers and stressors, carbon stocks, and sustainable timber production. Leveraging FIA data in modeling applications and implementing temporal and spatial intensifications of FIA data collection represent "value-added" strategies that can create efficiencies for forest planning and National Environmental Policy Act of 1969 analysis. Using FIA for assessment, plan development, and forest and broader-scale monitoring represents a mechanism for fulfilling the adaptive intent of the 2012 Planning Rule. However, effective application of FIA in forest-planning processes requires investment in analytical capacity, particularly at regional levels of the agency. Investment in capacity is essential for coordinating data acquisition and interpretation, translating FIA attributes to regional vegetation classification standards, developing modeling and decision-support tools, and providing technical support to forest staff.

Box 1. Important definitions associated with the 2012 Planning Rule for reference.

Ecological integrity is a concept that is increasingly being used to structure ecological assessment, monitoring, and conservation planning in public land-management agencies (Wurtzebach and Schultz 2016). Within the 2012 Planning Rule, ecological integrity is defined as: "the quality or condition of an ecosystem when its dominant ecological characteristics (for example, composition, structure, function, connectivity, and species composition and diversity) occur within the natural range of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human influence."

Best available scientific information is a term often applied in land management, and the planning rule provides the definition "the responsible official shall determine what information is the most accurate, reliable, and relevant to the issues being considered." There remain concerns about what constitutes the best available scientific information, from peer-reviewed literature to gray literature, and including expert knowledge and experience. See Esch et al. (2018) for details.

Natural range of variability is a term used to describe, in general, the possible state conditions that existed prior to European settlement of the US (Swetnam et al. 1999). As a variability concept, it embraces the notion that multiple states, or places in a successional sere, are possible for any given ecosystem. Although the utility of natural range of variability has been recently questioned, it remains a very useful concept to guide planning and management. Until it is clearly demonstrated that the processes driving natural systems have changed enough to ignore the past, using natural range of variability will remain an important component of establishing ecological integrity associated with the planning rule (see Timberlake et al. 2018 for implementation).

scales (Corona 2016, White and Cornett 2017, Hutto and Belote 2013). However, there are often significant challenges for leveraging large datasets and operationalizing ecological integrity assessments in practice, particularly for multiple-use management agencies (Wurtzebach and Schultz 2016, Carter et al. 2019).

These considerations are particularly relevant for forest planning and management in the United States. In 2012, the USDA Forest Service (USFS) released new regulations for national forest planning under the authority of the National Forest Management Act of 1976 (NFMA). The 2012 Planning Rule (commonly known as "the planning rule") identifies the maintenance and restoration of ecological integrity as an overarching goal for forest planning and management, and elevates the importance of multiscale assessment and monitoring for adaptive planning and decisionmaking (36 CFR 219.1). However, key challenges for the National Forest System (NFS) remain. NFS staff often lack relevant and scientifically credible information for planning at appropriate scales, have difficulty navigating and interpreting reams of data, and struggle to implement monitoring programs that can inform decisionmaking processes (Deluca et al. 2010, Archie et al. 2014, Peters et al. 2018). Budgetary constraints, risk aversion, and pressure to meet performance measures (i.e., "targets" such as acres treated) reduce incentives for NFS staff to invest in ecological monitoring and information management. Institutional pressure for scientists to generate publishable research reduces their incentives to engage in management-relevant monitoring (Biber 2011, Wurtzebach et al. 2019).

In this article, we highlight applications of data from the USFS Forest Inventory and Analysis (FIA) program that can support forest planning processes required by the 2012 Planning Rule and the National Environmental Policy Act of 1969 (NEPA). Given its robust and spatially balanced "all lands" sampling grid, extensive plot-level data, timely remeasurement cycles, ability to quantify uncertainty, and dedicated funding from Congress, the FIA program represents the agency's best available scientific information (BASI) for many forest-planning topics, and an important resource for meeting the adaptive intent of the planning rule. However, FIA data are relatively underused by forest planners in the NFS; recent research highlights a lack of understanding around the utility, relevance, and accessibility of FIA data for forest-planning processes among many regional and forest-level NFS employees (Wurtzebach et al. 2019).

In the following sections, we first discuss substantive requirements and directives associated with the planning rule, drawing attention to specific assessment, planning, and monitoring processes that can be supported by data from FIA. We then discuss existing applications and future opportunities for using FIA for forest-planning processes in the Interior Western United States (Interior West), before highlighting important benefits and institutional considerations for using FIA to fulfill the adaptive intent of the planning rule. Given the increasing adoption and expanded role of large-scale forest inventories, our findings may also be of relevance to practitioners around the globe.

Forest Planning under the 2012 Planning Rule

NFMA provides a three-tiered framework for federal forest management. National regulations and directives (the highest tier) guide the development of forest plans (the second tier), which in turn govern site-specific planning and management implementation (the lowest tier). The new planning rule differs in a few key ways from previous regulations for land-management planning. Specifically, it identifies the maintenance and restoration of ecological integrity (EI) as a primary goal for land-management planning, and it elevates the importance of monitoring and evaluation (see Box 1; Schultz et al. 2013, Wurtzebach and Schultz 2016). The planning rule framework involves a three-step cycle of assessment, planning, and monitoring in a continuous feedback loop. Assessments are used to identify the need for change and support the development of plan components that guide future project activity. Plan components include desired conditions, management objectives for achieving desired conditions, standards and guidelines that regulate management implementation, and suitability designations that zone different forest areas for specific management activities and uses (36 CFR § 219.3). Monitoring information is used to evaluate the implementation of plan components and inform subsequent assessment processes over time (36 CFR § 219.1). This planning framework is designed to "inform integrated resource management and allow the Forest Service to adapt to changing conditions, including climate change, and improve management based on new information and monitoring" (36 CFR § 219.5 [a]). In developing forest plans under the planning rule, the responsible official must also comply with the procedural requirements of NEPA as part of the environmental impact assessment process that runs concurrently with plan development (36 CFR 219.7).

Assessment Requirements

During the assessment phase, forest staff (i.e., the responsible official and staff on national forests or administratively combined national forests) are required to evaluate existing and readily available information associated with 15 topic areas, and develop an assessment report for the public and the responsible official (Table 1) (36 CFR § 219). Topics 1–4 are associated with EI and represent a significant focus of assessments completed by forests undertaking plan revision under the new planning rule (Ryan et al. 2018). For topic 1, terrestrial ecosystems, aquatic ecosystems, and watersheds, planners are directed to identify ecosystems for planning direction and select an appropriate scale for assessment that allows planners to evaluate the interrelation of ecosystems within the plan area and across the broader landscape. Assessing the EI of ecosystems requires the identification of "key ecosystem characteristics." Key ecosystem characteristics are dominant attributes of composition, structure, function, and connectivity that are associated with the long-term resilience and integrity of ecosystems (USDA Forest Service 2015a). The natural range of variation (NRV, Box 1), or a suitable alternative, is important for insight into the temporal and spatial dynamics of key ecosystem characteristics. The assessment of drivers and stressors (Table 1, topic 3) is also essential for assessing the relative integrity of forest ecosystems; drivers and stressors

Table 1. Required assessment topics in the 2012 Planning Rule.

(1)	Terrestrial ecosystems, aquatic ecosystems, and watersheds;
(2)	Air, soil, and water resources and quality;
(3)	System drivers, including dominant ecological processes, disturbance regimes, and stressors, such as natural succession, wildland fire, invasive species, and climate change; and the ability of terrestrial and aquatic ecosystems on the plan area to adapt to change;
(4)	Baseline assessment of carbon stocks;
(5)	Threatened, endangered, proposed and candidate species, and potential species of conservation concern present in the plan area;
(6)	Social, cultural, and economic conditions;
(7)	Benefits people obtain from the National Forest System planning area (ecosystem services);
(8)	Multiple uses and their contributions to local, regional, and national economies;
(9)	Recreation settings, opportunities and access, and scenic character;
(10)	Renewable and nonrenewable energy and mineral resources;
(11)	Infrastructure, such as recreational facilities and transportation and utility corridors;
(12)	Areas of tribal importance;
(13)	Cultural and historical resources and uses;
(14)	Land status and ownership, use, and access patterns; and
(15)	Existing designated areas located in the plan area including wilderness and wild and scenic rivers and potential need and opportunity for additional designated areas. (36 CFR 219.6[b]).

may also be categorized as "key characteristics" (USDA Forest Service 2015a). The planning rule also requires the responsible official to evaluate the status and trends of carbon stocks, which can be considered a functional characteristic of ecosystem integrity. In addition to identifying key ecosystem characteristics associated with EI, forests are also required to identify key characteristics of ecological conditions needed to conserve and protect at-risk species. Once these characteristics are all identified, the responsible official is directed to evaluate: (a) the current condition and trend of key characteristics in comparison with the NRV or a suitable alternative; (b) the future trend of key characteristics given the predicted effects of climate change and other stressors; and (c) the predicted future trend given the maintenance of existing plan components (USDA Forest Service 2015a).

Information related to assessment topics 1–3 is also important for addressing assessment topics associated with social and economic sustainability and multiple use (topics 5–15). In evaluating the existing and potential contribution of natural resources for social and economic sustainability, planners are directed to evaluate available information on the current condition of rangelands and forests in the plan area and broader landscape, the potential impact of stressors on the sustainability of resource use, and the effects of range management and timber harvesting on EI (i.e., key characteristics). The final outcome of the assessment phase is a report that documents and integrates information associated with the 15 topic areas. The report also summarizes how the BASI informs the assessment; provides a clear base of information identifying the need for change; identifies information needs, key assumptions, and uncertainties; and identifies how the assessment can inform the development of the monitoring program (USDA Forest Service 2015a).

Planning Requirements

During the planning phase, information from the assessment is used to identify the need for change on the landscape, develop plan components, and support the analysis of plan alternatives as required by NEPA. Under the planning rule, plans must address several goals: maintain or restore sustainability and ecosystem integrity; protect at-risk species; promote sustainable multiple use; and support sustainable timber harvesting as required by NFMA (CFR 36 § 219.8–219.11). Additionally, forests must identify priority watersheds for restoration (CFR 36 § 219.7 [f][1][i]). Information associated with assessment topics 1–3 and 5 is fundamental for the development of plan components that maintain or restore ecosystem integrity and diversity (CFR 36 § 219.8 [a] and CFR § 219.9 [a]), and the ecological conditions needed to support at-risk species (36 CFR § 219.9[b]). Information associated with assessment topics 4 and 6–15 are likewise used to support the development of plan components associated with sustainable multiple uses (CFR 36 § 219.8, 219.10) and timber harvesting (36 CFR § 219.11). When developing plan components that address these requirements, planners are instructed to consider the interrelation between ecological conditions in the plan area and the broader landscape, the influence of system drivers and stressors, interactions between pattern and process at multiple scales, and the capability of the plan area to adapt to change and sustainably provide for multiple uses and ecosystem services (USDA Forest Service 2015b).

Monitoring Requirements

Within the 2012 planning framework, monitoring is intended "to inform the management of resources on the plan area, including by testing relevant assumptions, tracking relevant changes, and measuring management effectiveness and progress toward achieving or maintaining the plan's desired conditions or objectives" (36 CFR § 219.12 [a][2]). There are two complementary tiers of monitoring in the planning rule: forest-plan monitoring and "broader-scale" monitoring. At the lower tier, forests are required to develop forest-plan monitoring programs that include monitoring questions and indicators that address eight required categories associated with EI, at-risk species, watershed conditions, and multiple use (Table 2). The development of the forest-plan monitoring strategy should be built on and informed by existing strategies, data, and information needs identified during the assessment phase, and the development of forest-plan components. The development of the forest-plan monitoring program should also "be coordinated with the Regional Forester, Forest Service State and Private Forestry, and Forest Service Research and Development" (36 CFR § 219.12). At the higher tier of monitoring under the planning rule, each of the nine Forest Service Regions is also required to develop "broader-scale monitoring" strategies "for plan monitoring questions that can best be answered at a geographic scale broader than a single plan area." Broader-scale monitoring is intended to generate efficiencies and complement forest-plan monitoring strategies (36 CFR § 219.12 [b]). Broader-scale monitoring approaches may include: the use of existing broader-scale monitoring information collected by National or regional NFS offices or USFS Research Stations; the development of new regionally coordinated monitoring strategies; the aggregation of data collected by forest staff that are analyzed in a unique way; or the analysis and communication of existing monitoring information collected by partner organizations (Wurtzebach et al. 2019).

To facilitate adaptive decisionmaking, a forest-plan monitoring evaluation report is to be produced and made available to the public every 2 years (36 CFR § 219.12 [d]). It "must indicate whether or not a change to the plan, management activities, or the monitoring program, or a new assessment, may be warranted based on the new information… [and] must be used to inform adaptive management of the plan area" (36 CFR § 219.12 [d][2]). The Forest Supervisor must document "how the BASI was used to inform planning, the plan components, and other plan content, including the plan monitoring program" (36 CFR §219.13 [a][4]). Planning rule monitoring requirements apply to all regions and forests, including forests not undertaking plan revision. In 2016, forests were required to transition their monitoring plans to ensure they comply with the new requirements, and all USFS Regions are required to develop broader-scale monitoring strategies "as soon as practicable" (36 CFR § 219.12 [c][2]).

Table 2. Eight monitoring requirements found in the 2012 Planning Rule.

(i) The status of select watershed conditions;
(ii) The status of select ecological conditions including key characteristics of terrestrial and aquatic ecosystems;
(iii) The status of focal species to assess the ecological conditions required under § 219.9;
(iv) The status of a select set of the ecological conditions required under § 219.9 to contribute to the recovery of federally listed threatened and endangered species, conserve proposed and candidate species, and maintain a viable population of each species of conservation concern;
(v) The status of visitor use, visitor satisfaction, and progress toward meeting recreation objectives;
(vi) Measurable changes on the plan area related to climate change and other stressors that may be affecting the plan area;
(vii) Progress toward meeting the desired conditions and objectives in the plan, including for providing multiple use opportunities;
(viii) The effects of each management system to determine that they do not substantially and permanently impair the productivity of the land (16 U.S.C. 1604[g][3][C]).

FIA Program

The USDA Forest Service Forest Inventory and Analysis (FIA) program represents an important source of data and science for land-management planning and decisionmaking. FIA operates across all forested lands of the United States and US Territories, and uses an annualized, repeated sampling system that is designed to make estimates of forested land status and trends across a wide range of scales. FIA plots are randomly located on a semisystematic random sampling grid. They are unbiased geographically, with a density of approximately one plot per 2,428 ha, and are measured in a nationally consistent way (Bechtold and Patterson 2005). FIA forest-plot data are remeasured on a 10-year cycle in the western United States, and on a 7-year or 5-year cycle in the eastern and southern United States (McRoberts et al. 2005). FIA data applications are used to generate estimates of measured attributes in tabular form (i.e., empirical estimates and modeled predictions of attributes in tables and spreadsheets) or integrated with modeling and classification strategies to generate spatial products. The versatility of FIA data to be used in a broad range of analyses has been shown in this journal (Shaw et al. 2017), and the range of applications is ever-increasing (Tinkham et al. 2018).

Using FIA Data to Support Planning Rule Implementation

FIA data can be used in a variety of ways to fulfill regulatory requirements associated with the new planning rule and NEPA. Here we provide examples of both existing and potential applications of FIA data in forest-planning processes in the Interior West. The goal of this article is not to enumerate all the possibilities, but to provide examples that can help forest managers understand potential applications of FIA for forest planning and opportunities for pursuing additional and innovative applications of this dataset.

EI: Structure, Function, and Composition

To date, FIA data have been in used in a variety of ways to fulfill planning requirements associated with EI. For example, over the past decade, The Northern Region vegetation analysis program has developed a suite of tools that leverage FIA data for integrated vegetation classification, mapping, and inventory and monitoring to support forest-planning processes on forests across the region (Berglund et al. 2009). The Summary Database Suite of Analysis Tools (SDSAT) is used to analyze plot-level data from the base FIA grid that is stored in FSVeg, the NFS corporate database for spatial vegetation data. The data are classified according to NFS national vegetation standards, and the SDSAT is used to calculate attributes relevant for planning at multiple scales (Bush et al. 2013). As part of the assessment and analysis phase of plan revision on the Flathead, Custer-Gallatin, and Helena-Lewis and Clark National Forests, baseline FIA data stored in the SDSAT were used to assess the current condition of key ecosystem characteristics, such as potential vegetation types and existing cover types, individual tree-species distributions, forest size classes, density, snags, and downed woody material. The Northern Region has also developed "midlevel" inventory tools for generating relevant estimates of ecosystem characteristics at smaller geographic scales than are appropriate when using only base FIA plots (Bush and Reyes 2014). The Northern Region has adopted a modified Common Stand Exam protocol based on the FIA data-collection protocol that can be implemented on a context-appropriate intensification of the FIA grid. The resulting data are loaded into FSVeg and integrated with base FIA data in the SDSAT for further analysis (though they are not uploaded into the FIA database). The Helena-Lewis and Clark National Forests, for example, have a fourfold intensification across their entire forest that has allowed them to generate reliable estimates of key ecosystem characteristics for specific geographic areas as part of the plan-revision process (Helena-Lewis and Clark National Forests 2018).

In the Southwestern region, FIA data are used to support forest-plan assessment through a multipart modeling process. First, FIA data are translated to work in the Forest Vegetation Simulator (FVS), a forest stand dynamics model used widely in the NFS (Dixon et al. 2002). Data are then grouped by Ecological Response Units (ERU) and used to produce tree-regeneration estimates, which are then used to improve the FVS projections of future forest development in each ERU. The results are then used to parameterize and run state-and-transition models for each ERU (Vandendriesche 2010, 2012). The results from the state-and-transition model are then compared to those based on historic, or "reference" conditions—a type of NRV—which have been developed collaboratively with Northern Arizona University and the Nature Conservancy (Schussman and Smith 2006, Weisz et al. 2009). Comparing the FIA-based state-and-transition model results to the presumed historical conditions allowed the calculation of an "ecosystem condition class" showing the degree to which an ERU had departed from likely historic conditions. Similarly, national forests can simulate forest-management treatments (such as thinning or prescribed burning) on a portion of FIA-based stands in their landscape and compare the outcome of the model to the states expected under reference conditions. These tools have allowed planners on forests such as the Kaibab to assess the "departure" of forest conditions (both current and future) from what are believed to be historic conditions (Weisz et al. 2009) and analyze different forest-plan alternatives as required under NEPA (Kaibab National Forest 2014).

FIA data are also increasingly being used to support forest-plan and broader-scale monitoring in the Interior West. On the Flathead National Forest, FIA data are used to evaluate trends in key ecosystem characteristics of forest structure, function, and composition identified during the assessment phase, and linked to quantifiable desired conditions and plan components (Flathead National Forest 2018). The Rio Grande National Forest has identified questions and indicators in its draft forest plan that leverage FIA data to understand trends in forest cover type, mortality, regeneration, and recruitment (Rio Grande National Forest 2017). Monitoring strategies that leverage the SDSAT have also been incorporated into forest-plan monitoring programs on all the forests in the Northern Region as part of the regional broader-scale monitoring strategy.

Watershed Condition and Trends

There are also opportunities for using FIA to support watershed condition assessment, a priority within the agency and in the planning rule. Although decades of experimental watershed research has indicated that human-caused forest disturbance can result in increases in runoff (Bosch and Hewlett 1982, Brown et al. 2005, Hernandez et al. 2018), recent research has shown that natural forest disturbances, such as die-offs caused by insects or drought, may lead to no change or even decreases in water yield (Adams et al. 2012, Slinski et al. 2016). Further, forest density can be an important determinant of snow accumulation and retention, which in turn affects not only water supply but also soil moisture available to vegetation (Lundquist et al. 2013). FIA data can address the need for more detailed information about forest cover over time (e.g., change in crown biomass and canopy cover) required to assess the effects of disturbance on water resources (Andréassian 2004) and make projections about future water-resources trends, given future shifts in climate and disturbance regimes (Table 1, topic 3).

FIA plot data can provide detailed forest input data for several existing hydrologic models that can simulate the linkage between forests and components of the hydrologic cycle, such as the Soil and Water Assessment Tool (Neitsch et al. 2011), the Distributed Hydrology-Soil-Vegetation Model (Wigmosta et al. 1994), and the Regional Hydro-Ecologic Simulation System (Tague and Band 2004). The FIA plot data or related disturbance maps can serve as inputs to modeling applications that provide quantitative assessments of how forest disturbances have influenced—or will influence—water resources at watershed scales (Table 1, topic 1). Most hydrologic models simulate not only runoff but also transport of sediment, nitrogen, and dissolved organic carbon (Table 1, topic 2). Hydrologic models with detailed forest input data also allow for projections that can be used to assess the ability of terrestrial and aquatic ecosystems to adapt to future conditions (Table 1, topic 3). A key aspect of these projections may be the ability to compare snow retention and soil moisture at the project level within a watershed, which can provide insights into how alternative management practices and climatic shifts may affect watershed resilience as forests become more moisture-limited (Grant et al. 2013). These tools therefore have the potential to support the analysis of forest plan alternatives, the development of forest-plan components, and the identification of priority watersheds. They may also represent an important opportunity for incorporating upland conditions into the watershed condition framework (USDA Forest Service 2011).

Ecological Function: Baseline Assessments of Carbon Stocks

The planning rule directs forest staff to assess the role of the plan area in sequestering and storing carbon, and the influence of climate change, disturbances, and management on carbon over time (FSH 1909.12.4). Assessment of carbon storage in timber and ecosystems has used FIA timber output data, and FIA-based Carbon Calculation Tool, which is used for international reporting (Domke et al. 2012; Stockmann et al. 2012). Large-scale assessments of the influence of climate change on carbon stocks likewise have used FIA data and the FVS to develop regionally representative productivity curves (Dugan et al. 2017).

The Forest Carbon Management Framework is an important analytical tool for evaluating the influence of disturbances, projects, and activities on carbon stocks, and is being used by many forests undergoing plan revision. This tool "grows" carbon stocks in each National Forest forward from 1990 using locally representative growth functions derived from running FIA plots through FVS (Raymond et al. 2015). These growth functions specifically account for alternative disturbance/management pathways, allowing carbon change associated with the forests' actual history (from satellite and agency records) to be compared with carbon storage in other scenarios (Healey et al. 2016, Zhao et al. 2018). Simulations supporting this comparison explicitly conform to FIA population estimates of forest-type proportions and other forest

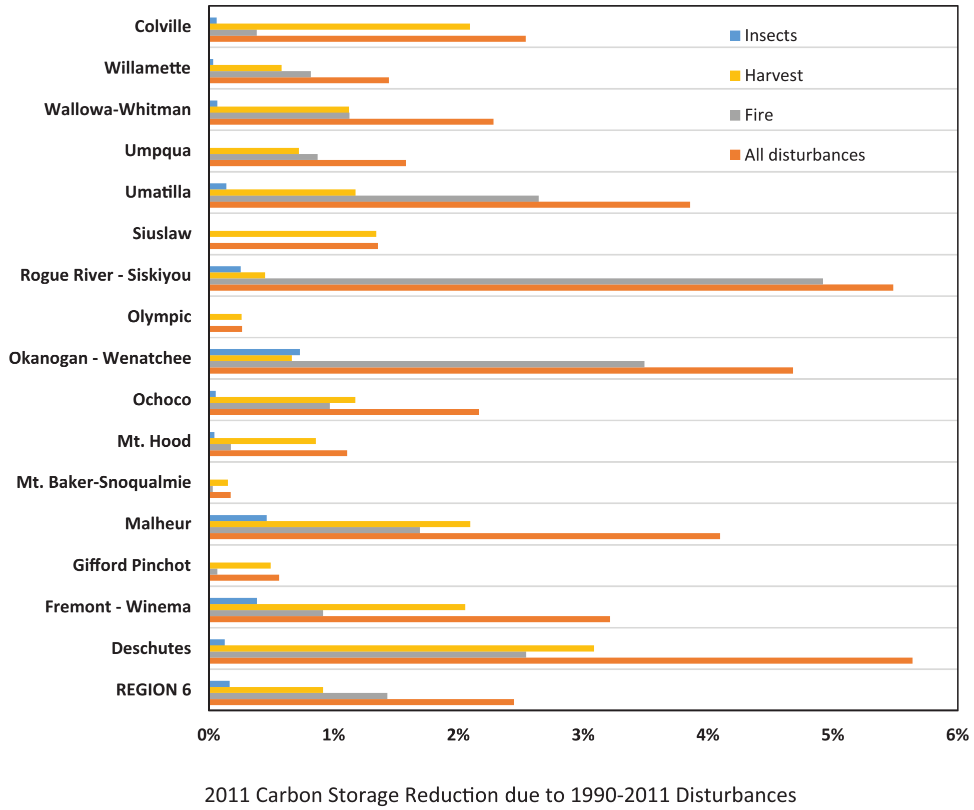

Figure 1. Impact of different types of disturbance (1990–2011) on carbon storage in Pacific Northwest (Region 6) national forests, drawn from the Forest Carbon Management Framework, which makes extensive use of Forest Inventory and Analysis data. This kind of analysis is specifically mandated in the planning rule and has been completed for all National Forest System planning units.

structural variables. This process allows the impact of specific disturbance agents, such as fire or harvest, to be quantified in relation to the carbon sequestration that would have happened in their absence (Figure 1) and provides the basis for understanding the assessment's uncertainty (Healey et al. 2016).

Drivers and Stressors: Insect and Disease Mortality, and Wildland Fire Effects at Broad Scales

Data collected on FIA plots are also useful for addressing assessment and monitoring requirements associated with drivers and stressors, such as insect and disease outbreaks, noxious weeds, and fire. Nationally, FIA data are foundational input for the National Insect and Disease Risk Map (Krist et al. 2014). The Northern Region's Summary Database suite of tools has insect hazard ratings assigned to each plot, based on attributes such as total basal area, basal area in host species, and average diameter of the plot. These ratings are used to estimate acres with low, moderate, and high hazard of substantial losses to insect and disease for specific tree species should an outbreak occur. The Summary Database also supports analysis of non-native invasive plant infestation by variables such as forest cover type. On the Salmon–Challis, FIA data have been used to characterize the percentage of different host tree species infected with dwarf mistletoe (*Arceuthobium* spp.) (Salmon–Challis National Forest 2018). FIA data include cause of death for individual trees and assessments of disturbance at the stand level. For example, in the States of Wyoming and Colorado, which comprise most of the Rocky Mountain region, the area impacted by insect-caused mortality is much larger than that impacted by fire (Figure 2; DeRose et al. 2018).

FIA data are also an important resource for understanding fire activity and its influence on forest ecosystems. In the Northern Region, the regional vegetation analysis team helps forests design and implement midscale spatial and temporal intensification strategies to assess forest areas affected by fires and insect outbreaks. The Custer-Gallatin and Nez Perce-Clearwater have plots that have burned and been remeasured off of the cycle that FIA would normally visit the plots (i.e., a midcycle remeasurement). The Helena-Lewis and Clark has implemented a midcycle remeasurement

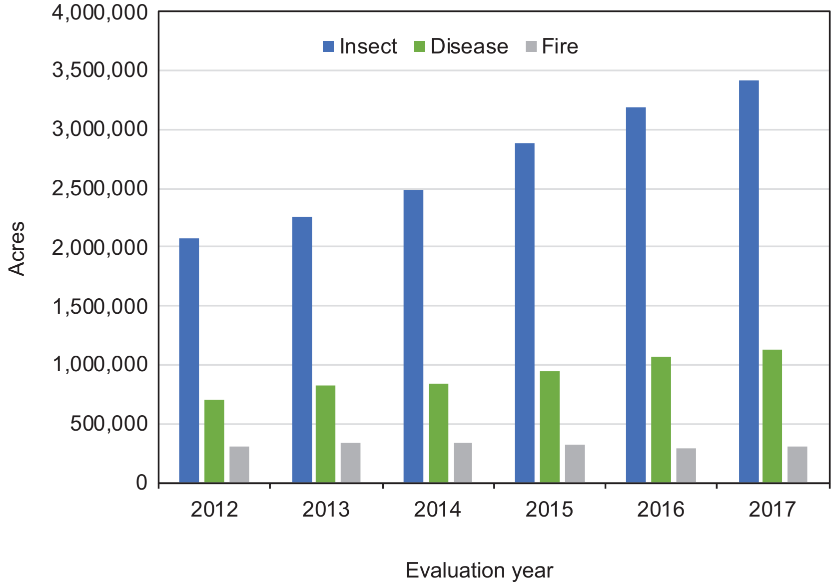

Figure 2. Area of forestland with >25 percent mortality as a result of insect infestation, disease, or fire in the Central Rockies Region (States of Wyoming and Colorado). Acreage estimates of mortality arise from plot measurements with >25 percent of indicated mortality. Evaluation year is the last year of the 10-year measurement cycle estimates that include the full 10-year panel of measurements. States with less than 10 years of measurements are adjusted accordingly.

on their intensified grid plots postmountain pine beetle outbreak. At a broader scale, Shaw et al. (2017) paired FIA plot data with data from the Monitoring Trends in Burn Severity program (MTBS) to assess the distribution and severity of fire across the Interior West states. They showed that 17.6 million of the 42.5 million unique burned acres mapped by the MTBS program (1984–2012) were forested land. Using pre- and postfire data from 735 FIA plots showed that, whereas most stands are classified as the same forest types before and after fire, a substantial proportion change type following the disturbance, and many of the changes are consistent with expectations that are based on prefire composition and known successional patterns (Table 3).

The spatially unbiased nature of FIA data also permits the calculation of metrics such as fire rotation length. Fire rotation length is the time conceptually required for fire to burn an entire area, and it is useful for approximation of forest-regeneration rates. A generalized calculation of fire rotation length for the Interior West revealed high variability among states, with Idaho having the shortest estimated rotation and Colorado having the longest (Table 4). Although the data would have to be examined in more detail to draw conclusions about particular forest types, it is almost certain that the 750-year rotation length calculated for Colorado is too long to maintain a sufficient area of specific forest types in the younger, more vigorous and resilient age classes. This view likely contrasts with perceptions that fire has been prevalent in Colorado, because of the occurrence of a few large, destructive fires during the last several decades, primarily in the low-elevation ponderosa pine forest type. This type of analysis may therefore be useful for providing context for both forest planning and regional strategic planning processes.

At-Risk Species

FIA data have the potential to provide land managers and policymakers with reliable estimates of suitable forest habitat when the BASI has identified the specific features of forested environments that are important for specific species, and when the FIA protocol includes measurements of those attributes or suitable proxies. If estimates are possible with existing FIA variables, then monitoring habitat trend requires no additional effort beyond the normal FIA remeasurement cycle.

For example, Mexican spotted owls (MSO, S*trix occidentalis lucida*) commonly nest and roost in mixed-conifer and pine–oak forests of the southwest United States and Mexico. Forest stands that are attractive to MSO have many large-diameter trees, a majority of their basal area in medium (12–18 in. in diameter) and large-sized (>18 in. in diameter) trees, and sufficient canopy cover to provide both thermoregulation

Table 3. Prefire/postfire forest type group change matrix (*n* = 735 plots).

Prefire forest type group (*n*)	Postfire forest type group								
	Aspen/birch	Douglas-fir	Fir/spruce/mountain hemlock	Lodgepole pine	Other western softwoods	Pinyon/juniper	Ponderosa pine	Western larch	Woodland hardwoods
Aspen/birch (12)	7		1	1		1	2		
Douglas-fir (148)	8	101	7	7	1		12	4	8
Fir/spruce/ mountain hemlock (113)	13	10	54	30	2		1	1	1
Lodgepole pine (57)	2	1	3	49	1	1			
Other western softwoods (20)	1	1	5	3	5	1	1		3
Pinyon/juniper (145)	2	7	2	1		92	4		36
Ponderosa pine (172)	2	8				20	108		33
Western larch (5)				1				4	
Woodland hardwoods (63)			1			8	3		51
Total (gain/loss)	35 (+23)	128 (–20)	73 (–40)	92 (+35)	9 (–11)	123 (–22)	131 (–41)	9 (+4)	132 (+69)

Note: Some minor forest type groups have been omitted, so prefire and postfire totals do not match (from Shaw et al. 2017). Values shown are the numbers of plots.

Table 4. Fire rotation calculations for Interior West states, based on forest area estimates made from FIA plots and fire perimeters mapped by the MTBS program 1984–2012.

State	Forest acres	Forest acres burned	Acres burned annually	Average annual percentage	Rotation (years)
Arizona	18,631,553	2,617,307	90,252	0.48	206.4
Colorado	22,880,131	883,668	30,471	0.13	750.9
Idaho	21,481,328	4,563,130	157,349	0.73	136.5
Montana	25,597,280	3,926,986	135,413	0.53	189.0
Nevada	10,645,516	822,037	28,346	0.27	375.6
New Mexico	24,839,374	1,952,974	67,344	0.27	368.8
Utah	18,299,460	1,413,100	48,728	0.27	375.5
Wyoming	10,455,768	1,989,441	68,601	0.66	152.4
Total	152,830,410	17,597,001	606,793	0.40	251.9

and security from nest depredation. On NFS lands in Arizona, adequate canopy cover and basal area in large trees are comparatively rare in mixed-conifer forests (Figure 3). This information can be used to evaluate desired conditions associated with forest structure and MSO habitat, supplement "fine filter" data on species populations, and inform project planning and management implementation intended to increase canopy cover and large tree basal area. Additionally, because of annual data collection on the geographically unbiased grid, assessments using FIA data can be recalculated annually (or biennially) to track changes in MSO habitat associated with the species recovery plan.

FIA data are also particularly relevant for at-risk tree species such as whitebark pine (*Pinus albicaulis* Engelm.). Whitebark pine occurs on many national forests in the Northern Rocky Mountains, provides a critical food source for grizzly bears, red squirrels, and Clark's nutcrackers, and is a species of concern (USFWS 2011; see Table 1, topic 5). Existing management guidelines highlight the concern that this species may be unable to adapt to changes in disturbance and climate regimes (Keane et al. 2012) (Table 1, topic 3). On the Helena-Lewis and Clark National Forest, FIA data have been used to estimate the proportion of planning unit, geographic areas, and habitat

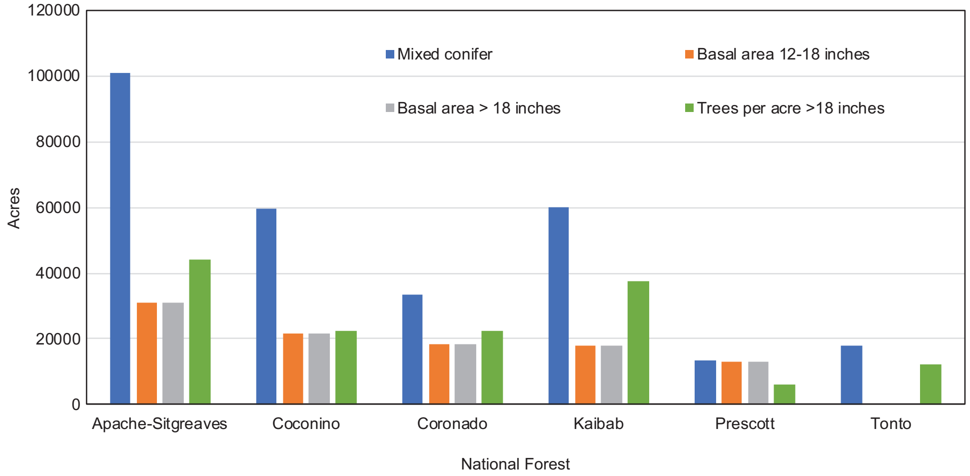

Figure 3. Acres of suitable habitat for the Mexican Spotted Owl in National Forests of the Southwest Region by various habitat metrics. The best available scientific information indicates that forests attractive to the owl are mixed-conifer, and need to have certain thresholds of their basal area in medium (12–18 in. diameter) and large-(>18 in. diameter) trees.

types where whitebark pine is present and dominant as a stand component. Additional key characteristics of relevance for planning might include the numbers of live versus dead whitebark pine by size class, the relative volumes of new growth versus the volume of recent mortality, and seedling density. Across the US portion of whitebark pine's range, more than half of all standing whitebark trees were dead, and mortality volume remained higher than growth in all size classes larger than 9 in. in diameter (Figure 4; Goeking and Izlar 2018). For National Forest planning, the status and trend information that can be derived for species like whitebark pine can be used to support both forest-plan assessment, and forest and broader-scale monitoring (DeRose et al. 2018, Witt et al. 2018a, b).

Socioeconomic: Timber Suitability

FIA data can also be used to address planning requirements associated with timber suitability and sustainable yield. In general, "suitable land base" describes productive forest land where timber can be extracted. As in the wildland fire example above, data from FIA plots can be intersected with other spatial data sets to create unique groups amenable to timber-suitability analysis. For example, in the State of Wyoming, administrative spatial layers of suitable land base were acquired from the Intermountain and Rocky Mountain Regions unique land-base categories (DeRose et al. 2018). Although 65 percent of NFS land in Wyoming is considered productive timberland, only about 21 percent is categorized as suitable for timber production. Once spatial data associated with areas suitable for timber production have been developed, FIA data can then be used to analyze the long-term sustained yield capacity of suitable timberlands as required by the NFMA. In the Southwest Region, FIA data and FVS have been used to calculate the long-term sustained yield capacity for different potential natural vegetation types across all the forests in the region, an effort facilitated by the development of regionally consistent desired conditions for potential natural vegetation types (Youtz and Vandendriesche 2011). Other examples of socioeconomic uses of FIA data can be found in Timber Product Output reports (https://www.fia.fs.fed.us/program-features/tpo/).

Discussion

Using FIA for 2012 Planning Rule Implementation

Given its robust "all lands" sampling design and estimation methodologies, FIA data represent the BASI and a defensible source of information that can be used to comply with regulatory requirements and fulfill the adaptive intent of the 2012 Planning Rule (Table 5). In terms of assessment requirements, FIA data can be used to evaluate the status of key characteristics associated with EI, such as carbon stocks, species composition and distribution, recruitment and regeneration, and forest size and age classes. FIA can also be used to assess the status of many key characteristics associated with wildlife and at-risk species, such as downed woody material, snags, and old growth. The FIA program is also a relevant source of data for modeling, mapping, and classification applications that can be used to assess the departure of existing conditions

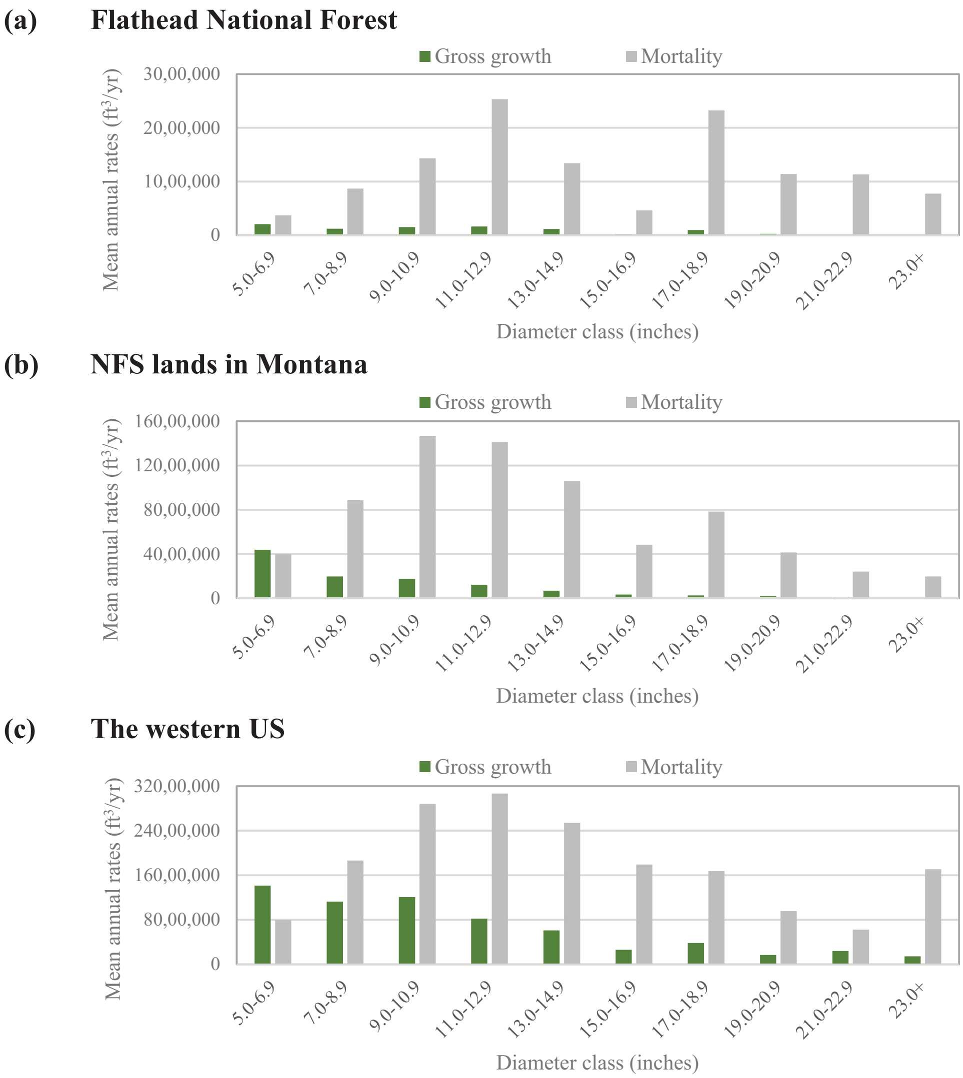

Figure 4. Estimates of mean annual growth relative to mortality of whitebark pine trees, at three spatial scales: (a) the Flathead National Forest, Montana, (b) National Forest System (NFS) lands in Montana, and (c) the western United States. A full 10-year panel of data was used to calculate estimates (2007–2016). Note that growth relative to mortality is lowest at the Flathead NF scale and highest at the west-wide scale, and that growth exceeds mortality only for small-diameter trees at the statewide and west-wide scales. Analysis methods are described in Goeking and Izlar (2018).

from NRV or historic conditions, inform the development of plan components, and create efficiencies for the development and analysis of plan alternatives required by NEPA.

The FIA data and program are particularly relevant for fulfilling monitoring requirements associated with new planning rule, especially since forests not going through revision may incorporate FIA-based monitoring strategies into their broader-scale and forest-plan monitoring strategies administratively at any time (USDA Forest Service 2015c). Leveraging FIA data and products for regional broader-scale monitoring strategies represents the most important near-term opportunity for generating efficiencies across the NFS. It also directly addresses the planning rule intent to incorporate data collected by the Research & Development branch (USDA Forest Service 2015c). By providing forests with data that can be used to fulfill forest-plan monitoring requirements, regions can create significant efficiencies for the development of their biennial monitoring evaluation reports. Broader-scale monitoring strategies that involve the evaluation of regional or subregional trends and conditions can also help forest staff evaluate the extent of observed trends, such as localized mortality events, in the context of the broader landscape, which can be used to assess the need for changes in plan direction. However, the greatest opportunity for using FIA data to realize

Table 5. Examples of assessment, monitoring, and planning requirements of the 2012 Planning Rule that can be supported with FIA data and products.

Assessment requirements	Plan component requirements and NEPA	Monitoring requirements	FIA data and products
(1) Terrestrial ecosystems, aquatic ecosystems, and watersheds (Ecological Integrity requirement).	219.8 (a)(1) Ecosystem integrity 219.9 (a) Ecosystem integrity	(i) The status of watershed conditions (ii) The status of select ecological conditions including key characteristics of terrestrial and aquatic ecosystems	*Base FIA data, R1 SDSAT, Hydrologic models with FIA inputs, FIA informed modeling applications (e.g. VDDT)*
(3) System drivers, including dominant ecological processes, disturbance regimes, and stressors, such as natural succession, wildland fire, invasive species, and climate change (4) Baseline assessment of carbon stocks;	219.8 (a)(1) Ecosystem integrity 219.9 (a) Ecosystem integrity	vi) Measurable changes on the plan area related to climate change and other stressors that may be affecting the plan area.	*Monitoring Trends in Burn Severity, base and intensified FIA data, National Insect and Disease Risk Map, ForCAMF*
(5) Threatened, endangered, proposed and candidate species, and potential species of conservation concern present in the plan area;	219.9 (b) Species specific requirements	(iv) The status of a select set of the ecological conditions required under § 219.9 to contribute to the recovery of federally listed threatened and endangered species	*Base and intensified FIA data*
(8) Multiple uses and their contributions to local, regional, and national economies;	219.10 Multiple Use 219.11 Timber	(vii) Progress toward meeting the desired conditions and objectives in the plan, including for providing multiple use opportunities.	*Base FIA Data, FVS with FIA inputs, Timber Product Output Reports*

Note: FIA, USDA Forest Service's Forest Inventory and Analysis; ForCAMF, Forest Carbon Management Framework; FVS, Forest Vegetation Simulator; SDSAT, Summary Database Suite of Analysis Tools; VDDT, Vegetation Dynamics Development Tool.

the adaptive intent of the new planning rule lies on forests undertaking plan revision. Leveraging FIA data for all phases of the planning process allows planners to efficiently assess ecological conditions of relevance for plan direction, and develop quantifiable plan components that are amenable to evaluation with FIA-based monitoring strategies.

FIA data also reflect criteria for the BASI found in planning rule directives. FIA is a relevant source of information for many planning rule subjects at planning unit scales: it is accurate, as data collection is consistent and unbiased across ownerships and over time; and it is reliable, as derived estimates have a quantifiable degree of uncertainty. FIA's accuracy and reliability are particularly important given the historically adversarial context of NFS management, and the need for scientifically defensible information that can withstand judicial review (Nie 2008). In the early 2000s, for instance, the Northern Region analyzed FIA data to defend their decisions when litigated about old-growth standards—an event that led to subsequent investment in regional analyst positions and greater use of FIA data. FIA's systematic "all lands" sampling approach is also essential for assessing ecological trends and conditions at multiple scales and across ownerships within the broader landscape, which existing corporate databases (i.e., FSVeg) do not enable. Although inventory data collected by forest staff using common stand exams (CSE) are essential for project-level planning, stand exams are intended to provide point-in-time information on stand characteristics. To generate efficiencies for data collection, stand exam sample design and attribute data generally vary according to information needs within a project area, treatment unit, or stand.

Since the plots are not monumented, and trees are not mapped, the plots are not expected to be revisited over time. Although suitable for rapid, accurate assessment, CSEs are limited in their ability to characterize information at appropriate temporal or spatial scales for forest planning. Furthermore, whereas funding for forest inventory using CSEs has been declining in recent years, FIA's congressional budget has remained robust. A central advantage of FIA data is that it can be acquired at little cost to the NFS. However, there are some important considerations for effectively and efficiently leveraging FIA for forest-planning processes.

First, FIA is not appropriate for planning topics that require assessment and monitoring at small geographic scales, or short time intervals. Strategic uses of CSE protocols, including data collection in control and pre- and post-treatment plots (as has been done in the Northern Region and Collaborative Landscape Forest Restoration projects; see Larson et al. 2013), are more appropriate for evaluating the effectiveness of management treatments, and the efficacy of plan standards for management implementation. Using FIA data to assess and monitor key characteristics of wildlife species habitat is only possible when species habitat relations are well established. However, as our results demonstrate, there are nonetheless opportunities for addressing some of the limitations of FIA data for planning topics through temporal and spatial sampling intensification, modeling applications, and integration with other data sources.

A second consideration is data acquisition and interpretation. FIA data are available to the public for download in multiple formats (https://apps.fs.usda.gov/fia/datamart/). Customer service for access to FIA is supported regionally (https://www.fia.fs.fed.us/tools-data/customer-service/), and data requests can also be made via web portals (https://www.fia.fs.fed.us/tools-data/spatial/requests/index.php). However, the publicly available data can be difficult to analyze because of the relational structure of tables, and the fact that each plot can have multiple "conditions," such as forested and nonforested (Bechtold and Patterson 2005). The national and regional FIA programs have developed multiple tools that allow for in-depth analyses without having to download the data (https://www.fia.fs.fed.us/tools-data/). These tools have been designed to make estimates of common forest attributes (forest area, volume, number of trees, carbon, biomass) but require training to use proficiently (https://www.fia.fs.fed.us/tools-data/tutorials_training/index.php). Analysis tools provide estimates of many but not all attributes in the database, such as nontree vegetation or invasive plants, and analysis of the raw data can be complicated because of the database design. Further, these tools, like the entire FIA database, are designed to facilitate estimation of forested condition at the state level; analyses based only on plots within National Forest lands are more difficult to accomplish. Specific attribute estimates are generated only for forested conditions, making it difficult for forest staff interested in all acres in their jurisdiction, not just those with ≥10 percent tree cover. Another important resource for leveraging FIA will be the Design and Analysis Toolkit for Inventory and Monitoring (DATIM). DATIM is intended to allow users to analyze and derive estimates of FIA attributes for different spatial areas, and integrate outputs from FVS (https://www.fs.fed.us/emc/rig/DATIM/index.shtml). However, while tabular data and estimates are readily available, FIA plot location data are confidential to ensure the integrity of the dataset. To acquire plot locations, National Forest staff need to work with FIA points of contact in NFS regional offices who have comprehensive access to FIA through a national Memorandum of Understanding with FIA.

A final consideration is classification. Despite the presence of a nationally consistent classification system (Nelson et al. 2015), NFS regions, and sometimes forests, have their own vegetation classification systems. FIA estimates can often easily be made using FIA forest types, but effectively using the data for forest planning often requires translating tree list data to local classification schemes. Using FIA to assess and monitor old-growth conditions, for instance, requires an agreed upon and established definition of specific old-growth characteristics that can be evaluated with FIA-collected attributes. These hurdles are time-consuming for forest staff to surmount and can prevent effective use of FIA by NFS staff.

Given these considerations, leadership and investment in capacity-building tools from the Washington Office of the USFS are essential for effectively leveraging FIA for forest planning and management in NFS. One critical tool is systematic investment from the Washington Office in dedicated positions and analytical capacity for FIA integration in NFS and FIA regional offices. In NFS regional offices, investment in skilled analysts dedicated to FIA integration is essential for coordinating data acquisition, exploring and developing FIA applications internally or with partners, translating FIA data into regional classification standards, and providing training and technical assistance to forest-level staff. Although many NFS regions have designated FIA liaisons, this responsibility is often just another "duty as assigned" in addition to others (Wurtzebach et al. 2019). Likewise, the creation of designated liaison positions within FIA regional offices, as has been done in the Rocky Mountain Research Station FIA, can facilitate effective communication and coordination with NFS staff and regional points of contact. Funding from the Washington Office for FIA intensification and investment in an "all-condition" inventory (i.e., sampling where there is <10 percent forest cover), perhaps allocated through a competitive proposal process, is another important tool that would help to increase the relevance and accuracy of FIA data for NFS staff.

Further development of national decision-support tools and guidance is also needed. Although DATIM represents a promising platform in this respect, more work needs to be done to make it more functional and user-friendly, and training and investment in staff (i.e., designated points of contact in NFS regional offices) that can provide user support will likely be essential. The development of concrete examples of FIA applications for forest plan assessment and monitoring that could be used systematically across NFS would also be valuable.

Investment in capacity-building tools has the potential to generate significant efficiencies and increase the relevance and application of FIA data in forest-planning processes. For example, it is far easier for forest staff to coordinate with regional staff rather than work with FIA staff on a forest-by-forest basis. Investment in regional analytical capacity is also essential for the development of modeling and analytical tools or intensification strategies that leverage FIA. In addition to addressing the spatial and temporal limitations of FIA data, these strategies also create significant efficiencies for fulfilling regulatory requirements associated with forest plan revision, such as the analysis of management alternatives required by NEPA. Modeling and decision-support tools can also be used to support programmatic and project-level planning, providing a mechanism for tiering forest planning to management implementation. FIA-validated state-and-transition models can support landscape planning, as in the Southwest's ERUs, and FIA data can be integrated with inventory and treatment location data generated by forest staff to inform programmatic planning and project-level analysis, as is done in the Northern Region.

Conclusions

The FIA program represents an important resource for forest planning under the 2012 Planning Rule. FIA data represent a defensible source of the BASI and can be used to comply with multiple planning rule requirements, including those associated with EI. Beyond base FIA data, modeling, spatial and temporal intensification, and integration with other datasets represent "value added" strategies that can support forest-planning processes, create efficiencies for NEPA review, and support programmatic and project-level planning. However, strong leadership from the Washington Office of the USDA Forest Service is needed for systematic investment in capacity-building tools that can enable FIA use for forest planning across NFS. Although the USDA Forest Service has long been characterized by a culture of decentralized and "bottom-up" decisionmaking (Kaufman 1960), national leadership and coordination are essential for mitigating regional and local capacity gaps and discrepancies in FIA data utilization. Although NFS regions such as the Northern Region have made investments in FIA use and applications, others have not, and applications developed in one region may not be applicable in others given issues such as diverse classification methodologies. National leadership and investment in capacity building tools for FIA integration are therefore essential for systematically realizing efficiencies for compliance with regulatory requirements, and ensuring a strong and defensible science base for forest planning and adaptive ecosystem management in an era of rapid change.

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