Trees, Forests and People 7 (2022) 100178

Contents lists available at ScienceDirect

Trees, Forests and People

journal homepage: www.sciencedirect.com/journal/trees-forests-and-people

Forest inventory and analysis data in action: Examples from eastern national forests

C.M. Hoover[a,*], J.L. Bartig[b], B. Bogaczyk[c], C. Breeden[c], L.R. Iverson[d], L. Prout[e], R. M. Sheffield[f]

[a] USDA-FS Northern Research Station, 271 Mast Road, Durham, NH 03824, USA
[b] USDA-FS Wayne National Forest, Supervisor's Office, 13700U.S. Highway 33, Nelsonville, OH 45764, USA
[c] USDA-FS Regional Office, Eastern Region, 626 E. Wisconsin Ave, Milwaukee, WI 53202, USA
[d] USDA-FS Northern Research Station and Northern Institute of Applied Climate Science, 359 Main Road, Delaware, OH 43015, USA
[e] USDA-FS White Mountain National Forest, Supervisor's Office, 71 White Mountain Drive, Campton NH 03223, USA
[f] FIA Data Analyst/Consultant, Hendersonville, NC, USA

ARTICLE INFO

Keywords:
Inventory
Monitoring
National Forest System
Forest management

ABSTRACT

While many forestry practitioners and ecologists have a general understanding of the USDA Forest Service, Forest Inventory and Analysis (FIA) program and the type of data collected, most non-expert users of FIA reports and basic data are unlikely to be familiar with the breadth of information available and the many potential uses of the data. We present four case studies from National Forests in the eastern United States, to highlight a variety of applications of FIA data, though similar case studies could also be identified on private lands. These include informing a model to help managers decide where to invest in oak management, quantifying habitat characteristics as part of the Endangered Species Act listing process, developing focal species for forest monitoring, and assessing the health of the black cherry population. In three of the cases, collaboration between scientists and managers was the key to unlocking the power of the FIA database to address management questions without the expense of collecting additional field data. These case studies illustrate the utility of FIA data to meet managers' information needs and the importance of the linkages between research and management and serve as examples of potential applications of data collected by regional or nationwide forest inventory programs.

Introduction

Forest inventory has a long and rich history in the United States, beginning in 1928 with the passage of the McSweeney-McNary Forest Research Act. This legislation directed the recently created Forest Service to establish a Forest Survey unit tasked with surveying timber needs and supply and assessing forest productivity and related items (Shaw, 2008). The Forest Survey would change and grow over time, becoming the Forest Inventory and Analysis (FIA) program of today; for a detailed history, see LaBau et al. (2007). From a timber-focused periodic survey with methods that varied widely by region, FIA has transformed into a broader inventory program with nationwide coverage across all ownerships and annualized data collection. A core set of variables is collected nationally on every plot, for example, ownership, tree species, tree diameter, and crown class. Core-optional variables also have a nationally consistent set of methods and include attributes such as vegetation profile and down woody materials, although these variables may not be collected in every state or region (for information on data collected, see the Index of Tables and Index of Columns in Burrill et al. (2021) as well as the National Core Field Guides (USDA Forest Service, 2021). In addition, there are regionally-specific measurement protocols to address information needs specific to a geographic region (see https://www.fia.fs.fed.us/library/field-guides-methods-proc/index.php for regional information). Nationally-consistent data collection and analytical methods (Bechtold and Patterson, 2005; USDA Forest Service, 2011; USDA Forest Service, 2021) for a wide array of timber and non-timber variables (note that regional differences are more common with non-timber variables; for example, dwarf mistletoe class is core-optional) combined with an evolving set of data retrieval and analysis tools have broadened both the scope of questions that can be

* Corresponding author.
E-mail addresses: coeli.hoover@usda.gov (C.M. Hoover), jarel.bartig@usda.gov (J.L. Bartig), brian.bogaczyk@usda.gov (B. Bogaczyk), charlene.breeden@usda.gov (C. Breeden), louis.iverson@usda.gov (L.R. Iverson), leighlan.prout@usda.gov (L. Prout), rayshef@aol.com (R.M. Sheffield).

https://doi.org/10.1016/j.tfp.2021.100178
Received 29 September 2021; Received in revised form 11 December 2021; Accepted 17 December 2021
Available online 5 January 2022

addressed as well as the pool of potential users of this publicly available data.

While FIA data are employed by a variety of users for a wide range of applications (Tinkham et al., 2018, also see FIA Annual Business Reports for information on program accomplishments, data requests, and consultations, available from: https://www.fia.fs.fed.us/library/bus-org-documents/index.php) they have considerable potential to assist National Forest managers in meeting their information needs, since data collection often entails considerable time and expense. In addition, data are often collected on a Forest for a specific need at a specific point in time and may not have the spatial or temporal scale needed to address other management questions or may have been collected on temporary plots which cannot easily be relocated for remeasurement. Managers in the National Forest and Grassland system must address a variety of management objectives, including timber, recreation, wildlife, and cultural resources. The National Forest Management Act (1976) (16U.S.C. 1600) provides direction for the management of the National Forests and sets out requirements for the development of Forest Management Plans. The Act directed that a Planning Rule be developed to meet these requirements. A component of the 2012 Planning Rule (USDA Forest Service, 2012) directs managers to establish and implement monitoring programs for each Forest, and to also develop broader-scale monitoring approaches for questions that are more appropriately addressed at a regional level. FIA data play an increasing role in meeting these forest planning, plan monitoring, and broader-scale monitoring (Wurtzebach et al., 2019, 2020) requirements.

While FIA data are useful for forest planning and monitoring, there is a broad range of other potential applications for National Forest System (NFS) managers. Key advantages of using FIA data include: consistent collection protocols, frequently updated data, ability to address questions without the need for additional data collection, potential to intensify the sample grid in specific locations (the standard sample grid is one plot per 2428 ha), and the ability to remeasure plots more frequently than the standard schedule in the event of a major disturbance (plots are generally remeasured every 5–7 years in the East and every 10 years in the West). A challenge to effectively using FIA data to address management-related questions is the complex structure of the FIA database and large number of available variables. This is often managed by working in collaboration with FIA regional staff, Forest Service Research Station personnel, NFS Regional inventory personnel, university scientists, and/or scientists from conservation organizations. The Northern Region (Region 1) of the NFS bridges the gap between data and information with a specialized Vegetation Analysis Team which facilitates the use of FIA data by managers in the region by conducting analyses, developing data analysis tools, and providing other support to users. In other Regions, this challenge is often handled on a project-by-project basis, as in the examples presented here. The successful use of FIA data in the Ottawa National Forest example reported here was one factor that prompted the Eastern Region to hire a vegetation analyst to enable more routine use of FIA data for management needs.

Our objective is to highlight examples where FIA data enabled NFS managers to meet their information needs without the time and expense of additional field data collection. We present examples of FIA data in action from the Eastern Region of the NFS (Fig. 1); applications include forest health, wildlife, updating a monitoring plan, and oak silviculture. Many users may be familiar with FIA state level reports and fact sheets which provide a range of summary statistics (for example Morin et al., 2020a; Oswalt and Smith, 2014) or data summaries produced from the retrieval tools available on the FIA website (https://www.fia.fs.fed.us/tools-data/), but the FIA database contains a wide variety of information that can be used for analyses well beyond typical forest resource statistics such as area, growth, mortality, and removals. Our goal is to show that FIA data may be used to address a broad range of management needs, and to illustrate how these data can be used to support forest managers, with the intent of building awareness of the many ways in which stakeholders can use this large and comprehensive dataset to meet their information needs. While these examples are drawn from National Forests in the Lake States and Northeastern US and rely on US Forest Service FIA data, they represent some of the types of applications for which standardized national forest inventory may be used, regardless of geographic location or stakeholder identity. Many countries have national forest inventory programs, and while these programs may not be as intensive as FIA, the data may potentially be used in a similar way to answer questions related to forest management and monitoring.

Case studies

Ottawa National Forest (ONF) – forest monitoring plan transition

The 2012 Planning Rule included some changes to Forest Plan monitoring; while the general approach remained the same, eight specific requirements needed to be addressed in the monitoring plan for each Forest (see Wurtzebach et al., 2020 for details). Forests not engaged in the forest planning process at the time were required to update their current monitoring programs to meet the new standard by 2016. Forests had flexibility in the approach taken to meet this mandate and could choose to develop an entirely new program, evaluate and adjust the current program, or use the eight requirements as a checklist (among

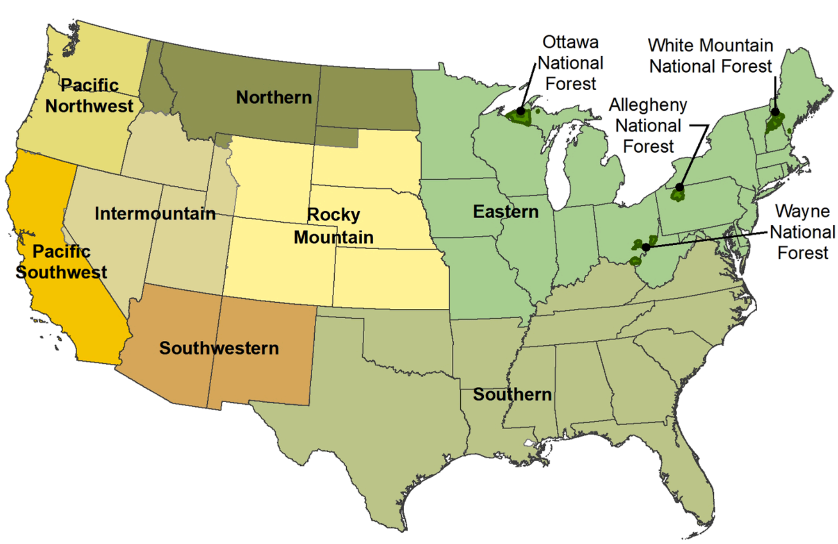

Fig. 1. Map of US Forest Service National Forest System regions, with project areas indicated. Developed by M. Peters.

other options). On the ONF, the only element not addressed in the existing plan was the requirement to monitor "the status of focal species to assess the ecological conditions required" under the 2012 Planning Rule. Focal species for each Forest were selected by Forest and Regional staff, and a variety of approaches were employed. On the ONF, the management team used the monitoring plan transition as an opportunity to improve elements of the current plan. Under the National Forest Management Act (1976), forests were required to select and monitor management indicator species (MIS) to assess the impacts of forest management actions. However, the criteria for choosing these species are not well-specified and no clear selection process was provided. Example criteria include species which are threatened, endangered, or rare, and species which serve as monitors for environmental factors, population trends of other species, or habitat condition. On the ONF, the staff viewed the requirement to choose and monitor focal species as an opportunity to address areas in the monitoring program that needed improvement; in particular, the transition away from MIS.

Forest Plan monitoring is designed to produce information to assess if the goals and objectives of the Forest Plan are being met; common objectives include moving parts of the landscape to a specified "desired future condition" which may be related to issues such as historic vegetation conditions, habitat requirements for sensitive species, and addressing an imbalance of age classes. The typical successional path on the ONF is toward an uneven-aged forest dominated by sugar maple (*Acer saccharum*), Eastern hemlock (*Tsuga canadensis*), and yellow birch (*Betula alleghaniensis*). Due to browsing pressure from white-tailed deer the proportion of hemlock has declined and species composition is often dominated by sugar and red maples (*Acer rubrum*), a process referred to locally as "mapleization" (Parikh and Webster, 2019). Because of this shift in species composition, many Forest Plan goals are related to maintaining and improving species diversity in the face of mapleization. Key objectives include promoting mid-tolerant (to shade) species on rich mesic sites, as well as white pine (*Pinus strobus*) where good seed sources are present. In order for mid-tolerant tree species to be useful as focal species in the new monitoring framework, adequate and accurate data on their distribution and abundance were necessary. Forest staff examined available stocking surveys, realized that these data would not meet their needs, and reached out to NFS Regional inventory staff for assistance.

One challenge when using FIA data to inform National Forest management is identifying a set of FIA plots that meet the analysis needs. While the FIA database does identify which plots are located on specific National Forests, the locations of FIA sample plots are confidential, to maintain plot integrity as well as landowner privacy (FIA plots are located on all lands, including those of private landowners). Users may acquire access to location specific data by working in collaboration with NFS Regional inventory or FIA staff to develop an approach that meets information needs without compromising location confidentiality. The first step in the analysis process for the ONF was to assign each FIA plot on the forest to one of two categories: (1) managed or (2) "typically unmanaged" lands (the FIA dataset was compiled in 2014 and included data from 2000 to 2014). This was achieved by creating a spatial layer delineating these classes. Typically unmanaged areas included wetlands, congressionally designated areas (such as wilderness), and any other areas not eligible for timber management activities. This layer was then intersected with the exact plot locations (working with NFS Regional inventory staff) and each plot was assigned to either the managed or typically unmanaged class. This enabled analysts to create a dataset which included vegetation, spatial, and other key variables as well as the managed/typically unmanaged attribute, but from which all information relating to plot location had been removed. In 2014 there were 287 managed and 152 typically unmanaged FIA plots on the ONF. Using only two classes ensured that confidentiality of plot locations was maintained, and a sufficient number of plots was available for analysis. With this dataset in hand, managers could assess the status and trend of variables of interest needed to develop the new monitoring plan.

While a variety of variables was assessed for the two land categories (including number of standing dead trees per acre and number of stems by age class) because Forest Plan goals include promoting species diversity with a focus on mid-tolerant species, considerable attention focused on attributes related to species composition. Species groups are as follows: Mid-tolerant, defined as eastern white pine, white ash (*Fraxinus americana*), green ash (*Fraxinus pennyslvanica*), American basswood (*Tilia americana*), yellow birch, and northern red oak (*Quercus rubra*); Maples, defined as sugar maple and red maple; and Other, which includes all other species present but not assigned to another group. The number of stems per acre of mid-tolerant, maple, and other stems was computed by stem size class for the managed and typically unmanaged areas. An index of change was also computed (index sets 2004 as the base year and expresses subsequent years relative to the base value). This index provides a quick and consistent way to assess change in the number of stems over time to monitor progress toward Forest Plan goals. The number of stems per acre was computed for each species group and for the following stem size classes: seedlings, 5 cm (2 in) diameter at breast height (dbh), 10 cm (4 in) dbh, and 12.7+ cm (5 in) dbh, while the change index was calculated by stem size class only. The abundance of mid-tolerant stems in the 5 cm class is declining while abundance of stems in the Other category is increasing in typically unmanaged stands compared to managed areas; maples show a slight decline in abundance in both managed and typically unmanaged areas (Fig. 2a). Larger diameter stems show a similar pattern except for maple abundance, which remained steady in managed areas and declined somewhat in the typically unmanaged sites (Fig. 2b). The change index shows that in managed areas, the number of stems in each size class remained about the same from 2004 to 2014 except for the 10 cm class, which increased by about 10%. In typically unmanaged areas, the number of stems in all size classes declined, ranging from a decrease of 18% for 10 cm stems to 34% for seedlings. Most notable was the large decrease in stems in the 5 cm class, which decreased by 67% over the ten year period.

Another important attribute is the crown class position of mid-tolerant species; this variable provides information about species composition as stand development progresses. Stems that are

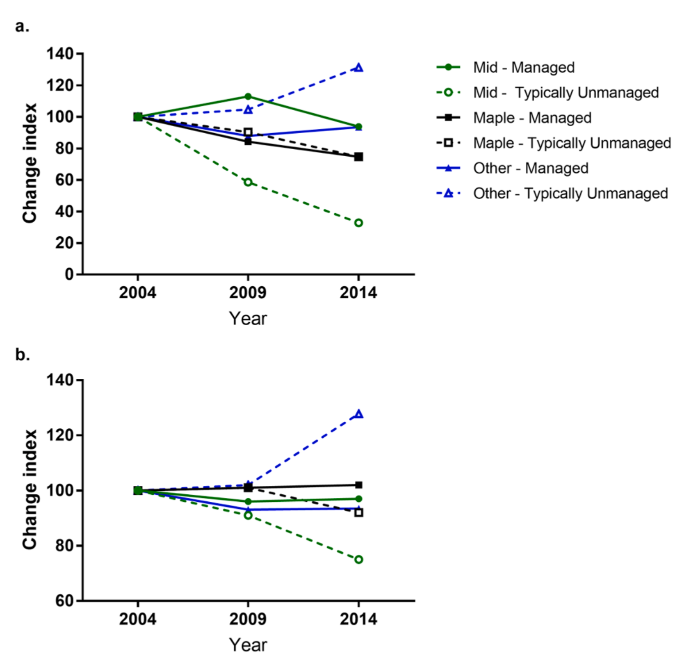

Fig. 2. Change index values over time in three vegetation categories for two stem size classes a) 5 cm (2 in.) dbh and b) 12.7 + cm (5 in) dbh in managed and typically unmanaged stands. Mid= mid-tolerant, Maple = all maple species, Other = all other species. Data from Ottawa National Forest. Base year (2004) set at 100.

overtopped or intermediate are most likely to suffer mortality or remain in the understory. FIA data include a crown class designation for each stem tallied on a plot, which was used to examine the distribution of mid-tolerant species in northern hardwood stands across the four crown classes (seedling, intermediate, overstory [defined here as co-dominant and dominant], and overtopped). Summaries such as this allow managers to assess progress toward stand composition targets; the high percentage of yellow birch in all crown classes in managed stands is readily apparent (Fig. 3a), as is the absence of green ash in typically unmanaged stands (Fig. 3b).

Working in partnership with NFS Regional inventory staff and a contracted vegetation analyst, ONF staff were able to use FIA data to select indicators and focal species and successfully transition to the new monitoring approach. The monitoring plan was improved in the process, no new data collection was required, and the resulting data product combining FIA data with the ONF'S existing spatial data can be used to address managers' information needs now and in the future. The success of this approach was a contributing factor to the decision of the Eastern Region leadership to hire a full time vegetation analyst to assist National Forests in the Region with their information needs.

White Mountain National Forest (WMNF)–northern long-eared bat summer habitat assessment

The northern long-eared bat (*Myotis septentrionalis*) is a small, agile bat of northern forests. On the WMNF, an area of 793,000 acres in New Hampshire and Maine, the northern long-eared bat was at once the second most abundant bat species found (Sasse and Pekins, 1996). During the winter, this species hibernates in caves, mines, and similar structures, while preferred summer habitat is the interior portions of mature forests. Within these forests, bats are dependent on multiple roost trees to rest in during the day and where adult females communally care for young. Roost trees are characterized by cracks, exfoliating bark, or other cavities, generally in trees at least 3 inches in diameter. Structural characteristics, rather than tree species, appears to drive roost tree selection (summarized in Sease and Prout, 2015).

In 2010, white-nose syndrome, a devastating new fungal (*Pseudogymnoascus destructans*) disease, was confirmed on the WMNF. In the following five years, annual bat surveys across the Forest showed bat population declines of more than 90% (WMNF unpublished data), similar to declines elsewhere. In 2015, the U.S. Fish and Wildlife Service listed the northern long-eared bat as Threatened under the Endangered Species Act. Understanding the extent of potential roost trees available on the WMNF became critical to informing management decisions in order to minimize additional impacts to bat populations.

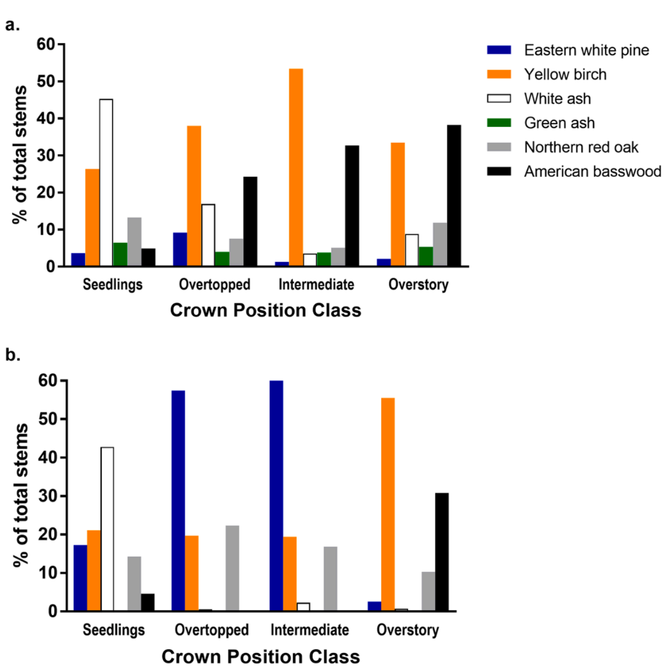

Fig. 3. Species composition of mid-tolerant vegetation category by crown position class for: (a) managed, and (b) typically unmanaged stands. Data from the Ottawa National Forest.

Earlier work on the WMNF indicated that northern long-eared bat roosts are more often found in lower elevation mature hardwood stands, although they can occasionally be found in softwood (conifer) trees (Sasse and Pekins, 1996). Forest management projects such as timber harvests are primarily focused on live, sound trees, but may result in the felling of dead, rough culls (live trees which are of poor form), and rotten culls (live trees of poor form with extensive rot) trees, some of which may serve as northern long-eared bat roost sites. Forest inventory data collected by WMNF staff only provides easily retrievable information on general stand characteristics, not individual trees. However, the FIA database includes many attributes related to live trees, including data on stems classified as rough or rotten culls. Data on standing dead trees (snags), which may also be used as roost trees, are also available. Individual tree data can be sorted by a number of additional variables, including diameter class and species. FIA plot data specifically from the WMNF (using 2009–2013 data) was retrieved to characterize the number of potential roost trees available across the Forest. A custom query on tree counts used species groups as the main classifier in order to be able to separate the more likely hardwood types from softwoods. Data were also sorted by tree class (i.e., rough culls, rotten culls, or growing stock) to extract potential roost trees from sound trees unlikely to support roost cavities. Rough culls and rotten culls at least 7.6 cm (3 in.) dbh (diameter at breast height)), and rotten culls greater than 7.6 cm dbh and snags at least 12.7 cm (5 in. dbh) were then summed (note data cannot be queried for snags smaller than 5 inches dbh). Results indicated that there were, on average, 125 potential roost trees per acre in addition to an average snag density of 59 snags/acre (Table 1).

In this example, FIA data enabled WMNF biologists to quantify key northern long-eared bat habitat elements over a large area quickly and reliably. This facilitated consultation with the U.S. Fish and Wildlife Service, demonstrating that abundant potential roost trees existed on the WMNF relative to the size of the bat population and that the risk of management activities impacting a northern long-eared bat was small. This is a straightforward application of traditional forest attributes that illustrates the utility of consistently collected and updated data that includes plot and tree level data. The ability to query the FIA database to retrieve tree level variables of interest enabled WMFN biologists to conduct the analyses needed without the time and expense of additional data collection.

Allegheny National Forest (ANF)– black cherry health

In the Allegheny hardwood forest type (cherry/ash/maple), black cherry (*Prunus serotina*) is an iconic species that plays important roles in forested ecosystems of the region and is highly prized for use in making fine furniture (Marquis, 1990). The ANF and surrounding forested areas have experienced a number of significant outbreaks of defoliating insects including gypsy moth (*Lymantria dispar*), cherry scallopshell moth (*Hydria prunivorata*), and elm spanworm (*Ennomos subsignarius*) since the mid 1980′s. In some cases, an outbreak involved multiple defoliation events in the same area, with some trees experiencing defoliation up to three times. Morin et al. (2004) estimated that between 1984 and 1999 over 85% of the 517,000 acre ANF experienced defoliation. Ongoing monitoring using remote sensing methods has established that significant defoliation of black cherry occurred on the forest in 2011 and 2012, largely due to the fall webworm (*Hyphantria cunea*), with an estimated 32,000 acres affected (Wolf and Turcotte, 2013); an additional cherry scallopshell moth outbreak occurred between 2014 and 2018, peaking in 2015 with over 56,000 acres of visible defoliation. Federal and state

Table 1
Estimates of key habitat attributes for Northern long-eared bat on the White Mountain National Forest.

	Snags ≥ 5″ dbh	Rough culls >3″ dbh	Rotten culls >3″ dbh	Potential roost trees	Potential roosts/ac	Snags/ac
Hardwood	26,412,600	43,278,363	4654,481	74,345,444	94	33
Softwood	20,411,172	4447,379	245,591	25,104,142	32	26
Total	46,823,772	47,725,742	4900,072	99,449,586	125	59

Note that totals may not sum due to rounding.
dbh = diameter at breast height.

land managers and private foresters have noted crown dieback, decreased seed production, and increased mortality of black cherry throughout the Allegheny region and have expressed concern regarding the health of this important species.

While the FIA program has a standardized plot design and intensity (Bechtold and Patterson, 2005), the program also has several provisions that add flexibility and enhance the ability to meet managers' information needs. One of these is "mid-cycle" measurements, where plots are remeasured before the typical measurement interval, usually in response to a localized disturbance. Another is intensification of the sampling grid; while the standard sampling grid is one plot per 2428 ha (6000 acres), more plots may be established at the request of managers (to address questions of local importance) if funding is available; the ANF has chosen to intensify the FIA sampling grid to twice the usual plot density. The Forest Health Protection program is a part of the USDA Forest Service State and Private Forestry mission area and oversees the Forest Health Monitoring Program. Responsibility for collecting forest health indicator data was transferred to FIA in 1999, and a core set of indicators are now measured on a subset of FIA plots (core-optional data may be collected depending on needs and resources); sampling intensity varies between 7 and 25% of plots and depends on local and regional needs as well as available budget (Morin et al., 2020b). On the ANF, sampling of forest health indicators is intensified; a total of 188 plots are utilized for health monitoring, most of which are FIA plots, although a small subset is part of the national Forest Health Monitoring network. This intensification was implemented to enable better monitoring and assessment of forest health after multiple defoliation and drought events.

Scientists and managers on the ANF used a subset of 97 plots with the highest number of black cherry trees to assess the health of the black cherry population and investigate possible factors linked to the condition of black cherry with the objective of identifying which stands may be most vulnerable to decline (Long et al., 2017). All the selected plots had been measured twice prior to the study. Using a geospatial database, plots containing black cherry were characterized as to the frequency and nature of defoliation and disturbance events experienced. Field crews (trained by FIA personnel) resurveyed the selected plots over two field seasons using FIA methodology; in addition, a small subset of plots was resurveyed an additional time after a defoliation event during the study period and a subset of plots with most healthy and least healthy black cherry trees (16 in each class) were intensively studied to identify possible risk factors for decline. These analyses were possible because of the availability of existing data collected by well-documented methods.

Data on crown health are not typically collected during routine forest inventory but are one of the indicators evaluated as part of forest health measurements; the availability of this information was an essential component in the black cherry health assessment. Without the presence of an intensified network of plots and crown health indicator data, managers would have an incomplete picture of the condition of this important species. Standing dead trees with a diameter at breast height (dbh) ≥ 12.7 cm (5 in) were inventoried on each of the plots; between the initial (1998–2001) and most recent (2014–2016) surveys, the number of standing dead black cherry stems increased from 16 to 22%, while standing dead stems of all other species combined declined marginally (from 12 to 11%). Similarly, the amount of standing dead black cherry basal area per acre increased to 17% in the most recent survey, from an initial measurement of 8% (Fig. 4). During the same period, the amount of basal area represented by standing dead stems of all other species decreased to 9% from an initial value of 12%. The amount of standing dead black cherry basal area does appear to be related to defoliation events; on plots not experiencing defoliation mean dead black cherry basal area is 12%, while plots experiencing defoliation average 16 (cherry scallopshell moth) –17.5% (fall webworm) basal area of standing dead cherry. Plots experiencing both types of defoliation did not exhibit higher mortality, indicating that an additive effect did not occur.

Uncompacted live crown ratio, expressed as a percentage, is a measure of the length of the tree with live foliage relative to tree height. The live crown ratio of black cherry trees decreased noticeably; in the first two surveys 60–70% of black cherry basal area was in the 25–45% live crown ratio class. By the 2014–2016 measurements this declined to 40%, while nearly 60% of the black cherry basal area was in the 0–20% crown ratio class, signifying that crowns of black cherry trees have become smaller (Fig. 5a). Another indicator of canopy status is crown density, a measure of the amount of sunlight blocked by a tree's branches and foliage, including dead portions. Crown density of black cherry also declined; in the initial survey, just over 40% of black cherry basal area was in the 50–70% class with a similar amount in the 25–45% class. In the 2014–2016 measurement period, the proportion of black cherry basal area in the 50–70% category was about 5%, with about 70% in the 25–45% class (Fig. 5b). The forest health indicators summarized here reveal that the black cherry population has undergone substantial changes in tree vigor, evidenced by increased mortality and smaller and thinner crowns.

Although this investigation did not identify any obvious factors related to the decline in health of the black cherry population on the ANF, the results suggest several lines of study for follow up. The key outcome from this effort is a detailed assessment of status and changes in the condition of the black cherry population between 1998 and 2016, which would not have been possible without an intensified grid of plots and the forest health indicator data. This effort was a collaboration between all three deputy areas of the Forest Service: National Forest System, Research and Development, and State and Private Forestry. Managers on the ANF rely on the long-term data from the expanded plot network and the work of researchers to guide management decisions on

Fig. 4. Amount of standing dead trees over 12.7 cm (5 in) dbh. Data from Allegheny National Forest.

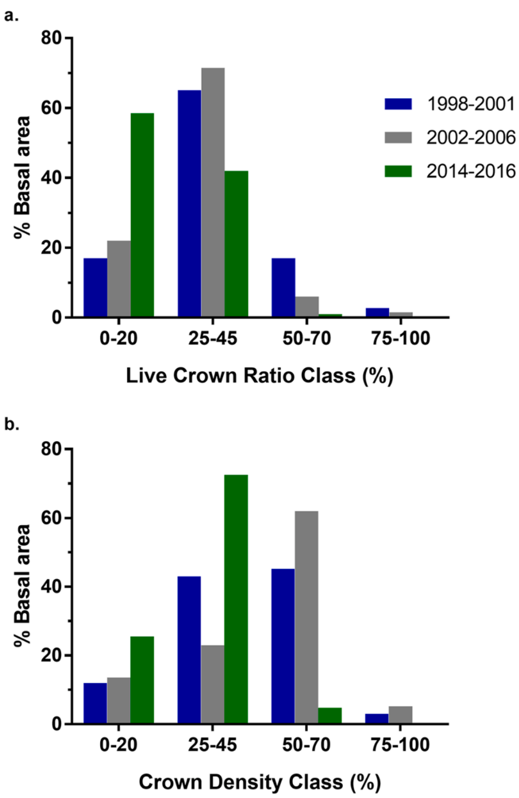

Fig. 5. Percentage of black cherry basal area by (a) crown ratio class and (b) crown density class. Data from Allegheny National Forest.

the Forest. This monitoring effort has resulted in a greater focus on black cherry health, collaborations with other landowners in the region (sharing mutual observations, management approaches, etc.), and a strong emphasis on regenerating stands in decline, as well as providing the background and rationale for intensified management approaches on public lands. These outcomes led to improved management of black cherry, which is not only economically and ecologically valuable but is an iconic species in the region.

Informing the oak management investment model in southeast Ohio

FIA data have shown that throughout much of the Central Hardwoods zone, oaks are not regenerating at sufficient rates to ensure a sustained oak resource in the coming decades; this is particularly the case in Ohio (Widmann, 2014). Tracking the spatial and temporal changes in the oak resource, best done using FIA data, then becomes critical in designing and implementing appropriate management investments to ensure oak sustenance in the coming decades. Oaks play many roles in eastern forests, providing mast and habitat for many wildlife species, some of which are threatened or endangered, as well as supplying high-value timber (Bumgardner et al., 2011; Widmann, 2014). These long-lived trees also have important cultural value and serve a keystone role in some eastern forest types. In southeast Ohio, oaks have been a major part of the forested landscape since before recorded history. A variety of factors including the absence of recent fire, an increase in pests and disease, and poor past management practices have contributed to a decrease in the amount of oak present in the region (Pederson et al., 2014). Maple and other shade tolerant species are increasing in abundance (as in the Ottawa NF example) and are outcompeting oak seedlings, which require abundant light to thrive (Iverson et al., 2017). If an insufficient number of oak seedlings is present in the understory at the time of harvest, the next stand will be dominated by other species, leading to a decline in the amount of area in oak forest types. Silvicultural treatments such as prescribed fire, competition management, and creation of canopy openings can enhance the success of oak regeneration, but these management actions are costly to implement.

Another challenge to sustaining the oak forest type in southeast Ohio is the patchwork of ownerships across the forested landscape. Private landowners hold about three quarters of forested acres, with the remainder publicly owned. As is the case in much of the eastern United States, various ownerships are intermingled across the landscape. Since implementing management actions on public lands alone will be insufficient to ensure the maintenance of oak in the forests of southeast Ohio, an Interagency Forestry Team was established to evaluate the inventory data, and then develop and implement tools, strategies, and outreach across the region to foster the collaborative action necessary to sustain the oak resource.

One of the actions taken by the Interagency Forestry Team to address the challenges of oak regeneration was to develop a model for oak management investment. The objective was to construct a map of landtypes and landtype phases (Iverson et al., 2019, see Cleland et al., 1997 for background on landtypes) most likely to support oak species and test the maps against current oak distribution across the landscape. This model could then be used to identify areas where oak types would have the greatest likelihood of success, allowing managers to target those areas for silvicultural treatments to enhance and promote oak species. Variables used to develop the map include slope, aspect, and topographic position index (for details, see Iverson et al., 2018). Six landtype phases were defined; these were further informed with additional data including a soil moisture index and outcomes from prior oak regeneration research (Iverson et al., 2017; Iverson et al., 1997). The final output included three landtypes: dry oak, dry-mesic mixed oak hardwood, and rolling bottomland mixed hardwood. Once the landtype maps were applied to GIS data from partners, the next component of the project was to assess the condition of oak forests across the project landscape and validate the maps.

Inventory data for the public lands were available from a variety of sources: the Ohio Department of Natural Resources has a network of plots on State Forests and State Wildlife Management Units, and the Wayne National Forest also has a network of inventory plots. All plots were sampled with the SILVAH inventory approach (Brose et al., 2008), which includes information on both overstory and understory status; the presence or absence of advanced regeneration is an important variable when assessing the condition of oak stands. Overstory and understory metrics were calculated for plots meeting selection criteria (Iverson et al., 2018); an oak stocking index, a measure of regeneration potential, was also calculated for each plot. A GIS tool was developed to enable managers to retrieve information from an area of interest; the tool reports the percentage of basal area in oak and the oak stocking index for each inventory plot (and for all inventory plots collectively) in the defined area, the proportion of area in each landtype, and other variables.

Initial application and testing of the model show that the proportion of oak in the overstory is highest in the dry oak landtype (Table 2); fit tests indicate that the ability of the model to accurately predict the dry oak type is good (the selected statistic, AUC, had a value of 0.7). The oak stocking index (a value of 25 is needed for the understory to be considered stocked) was highest in the dry oak type; the ratio of stocked plots to the total number of plots indicates that 25% of the plots contain

Table 2
Percentage of inventory plots in each landtype with less than or greater than 50% of the overstory basal area in oak. Data from Wayne National Forest and state lands in Southeast Ohio.

	Dry Oak	Dry-Mesic Mixed Oak Hardwood	Rolling Bottomland Mixed Hardwood
<50%	29.2	62.3	56.5
>50%	70.8	37.7	43.5

adequate advance regeneration (Table 3).

While the Interagency Forestry Team had access to consistently collected data within the project area of southeast Ohio for use in building the model, the inventory plots are spatially clustered, densely spaced, and located only on State or Federal land. Since about 75% of forestland in the project area is held by private landowners, conditions on the inventory plots may not be representative of the state of the oak resource in southeast Ohio; team members understood that the oak management objectives of the region could not be met with State and National Forest data alone. In order for the model to be useful across the project area, and perhaps beyond, a larger dataset, using FIA data, was needed for training the model. In addition, once the model was validated, a more spatially extensive dataset would allow the oak stocking index to be computed and the condition of the oak forest type to be assessed on the larger forested landscape across all ownerships. For this, the Interagency Forestry Team worked in partnership with FIA to obtain the true plot locations since the landtype mapping had a fine spatial resolution, 10 m grids. Since FIA and SILVAH data collection protocols and plot designs differ, collaboration was a key element that enabled FIA data to be applied to the task of informing oak management in southeast Ohio. Utilizing information from FIA seedling regeneration data (Phase 2+ plots, see McWilliams et al., 2012) the FIA plots in the entire southeast Ohio region were evaluated and each plot's understory was characterized as stocked for oak if any of the following criteria were met: (a) stocked with competitive oak: at least 1 oak > 1 m height, or > 1.9 cm diameter root collar; (b) stocked with established oak: at least 12 oaks 15–100 cm in height, or 0.64–1.9 cm root collar diameter; or (c) stocked with new oak: at least 25 oaks < 15 cm in height). An understory oak stocking index was then calculated as [(25 * #competitve oak) + (2 * #established oak) + (#new oak)]. Oak stocking index values >25 indicate a reasonably high level of advanced regeneration, and therefore, potentially successful oak regeneration, while values <25 may need additional intervention to provide a good opportunity for oak in the next forest. Applying the model to the project area, about 40% of the forested area is classified in the dry oak type, with the remaining acreage split between the two types (dry-mesic mixed oak hardwood 29%, rolling bottomland mixed hardwood 31%).

Using FIA data with the oak investment model enables managers on all ownerships to use the GIS extraction tool to assess the condition of the oak resource (both overstory and understory). Managers can then identify areas that are the best candidates for silvicultural interventions to increase the success of oak. For example, management might be targeted to areas in the dry oak type where oak is present in the overstory, but the oak stocking index is less than 25. One of the strengths of the Oak Investment Model is the linkage to the SILVAH decision support system, which can provide recommendations for silvicultural prescriptions based on current conditions. The Interagency Forestry Team continues to work toward the objective of maintaining and promoting the oak forest in the region, with plans to use FIA data to expand the application of the tool throughout the project area and throughout the larger region as appropriate, as well as building a community of practice to assist landowners and managers working to ensure the continued presence of this important forest type, and the benefits it provides, on the forested landscape.

Table 3
Percentage of inventory plots in each landtype with an understory oak stocking index less than or greater than 25 (a value of 25 is considered stocked). Data from Wayne National Forest and state lands in Southeast Ohio.

	Dry Oak	Dry-Mesic Mixed Oak Hardwood	Rolling Bottomland Mixed Hardwood
<25	38.8	25.6	16.8
≥25	13.1	2.9	2.8
Ratio stocked: total	0.25	0.1	0.14

Conclusion

While many practitioners are familiar with the state-level reports of common forest attributes summarized by FIA (for example, Morin et al., 2020a), the potential of the dataset goes far beyond estimates of volume, basal area, trees per acre, growth, and mortality. The FIA database is a complex set of linked tables containing a wide range of variables, including traditional forest attributes (such as those related to growth, mortality, and removals), forest health indicators (e.g., tree damage, down woody materials, and soils), tree regeneration, and forest carbon stocks, among many others. The FIA database includes a large number of linked tables containing tree and plot level attributes (consult Burrill et al., 2021 for details), and those users with database experience can extract a wide range of information. However, for many potential users, it can be challenging to determine if FIA data are appropriate for a particular need and extracting the applicable data presents another obstacle, especially for Forest managers who often face constraints on available staff time. The gap between data and information needs to be bridged in order to facilitate the use of FIA data by managers and other users; in many cases, the key is collaboration with NFS Regional inventory staff, FIA personnel, and/or research scientists.

The examples presented here highlight a few of the many types of applications for which FIA data can be used, and the importance of researchers and managers working in partnership to meet management needs. In each case, locally available data were unavailable or insufficient to meet managers' information needs. In the Ottawa NF example, Forest managers, Regional staff, and a vegetation analyst worked together to build an information resource that not only informed the development of the required monitoring indicators but provided information on the current status of key Forest Plan indicators and can serve as the basis to meet future information needs. On the White Mountain NF, the availability of tree-level data on snags and cull trees enabled biologists to assess the availability of potential roost trees for the Northern long-eared bat, part of necessary consultations with the U.S. Fish and Wildlife Service. The State and Private Forestry and Research and Development mission areas of the Forest Service worked in partnership with Allegheny NF managers to assess the health of black cherry, an important and iconic species on the Forest. In this instance, the availability of an intensified plot network, a record of repeat measurements, and data on forest health indicators made the health assessment possible; the results continue to inform management of black cherry on the Forest and in the Allegheny region. The Ohio Interagency Forestry Team had access to detailed inventory data for State and Federal lands, but much of the forested landscape of southeastern Ohio is in private ownership. FIA data enabled the Team to train and validate the Oak Investment Model across ownerships, extending its utility. Seedling data in the FIA database allowed the Oak Stocking Index, a key component of the Oak Investment Model, to be computed across the entire project area, expanding the reach of the tool to private landowners in southeast Ohio.

The FIA program has a designated point of contact in each Forest Service Research Station, as well as staff who can assist in determining if and how FIA data might be used to meet management needs; managers also often work with consultants, agency research staff, and researchers at academic institutions or non-government organizations to craft approaches to putting FIA data into action on the landscape. New areas of development in the FIA program include combining remote sensing data with field data from the FIA network to develop new data products, as well as small area estimation, a way of addressing the need for information for smaller areas (recalling that the program is designed to meet statewide accuracy targets). Progress in these areas will further increase the utility of FIA data to meet the growing information needs of land managers.

While these examples are focused on the Eastern Region of the National Forest System, they illustrate the potential of any regional or national-level forest inventory to support a wide range of forest management questions, monitoring needs, and policy development. Dozens of nations have ongoing forest inventory programs, and more are being developed with the support of the Food and Agriculture Organization of the United Nations. While some programs, such as Norway's, are a century old, others fairly recent (e.g., China, established in the late 1970′s) and some are newly established, all can provide data for a wide range of natural resources applications. Work is ongoing to support harmonization among these inventory systems (which may vary widely in design and sample plot intensity between countries), which may extend the utility of the data beyond national boundaries.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors gratefully acknowledge the contributions of Matthew Peters, Robert Long, Andrea Hille, and Susan Stout. Special thanks to Matthew Peters for developing Fig. 1. We also thank Linda Heath for feedback on the manuscript.

This research was supported by the U.S. Department of Agriculture, Forest Service.

References

Bechtold, W.A., Patterson, P.L., 2005. The Enhanced Forest Inventory and Analysis Program National Sampling Design and Estimation Procedures. US Department of Agriculture, Forest Service. Southern Research Station, Asheville, NC, USA. Gen. Tech. Rep. SRS-80.

Brose, P.H., et al., 2008. Prescribing Regeneration Treatments for Mixed-Oak Forests in the Mid-Atlantic Region. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA, U.S, p. 100.

Bumgardner, M.S., Graham, G.W., Goebel, P.C., Romig, R.L., 2011. How clustering dynamics influence lumber utilization patterns in the Amish-based furniture industry in Ohio. J. For. 109 (2), 74–81.

Burrill, E.A., DiTommaso, A.M. Turner, J.A., Pugh, S.A., Christiansen, G., Conkling B.L. 2021 The forest inventory and analysis database: database description and user Guide version 9.01 for phase 2. U.S. Department of Agriculture, Forest Service. 1026 p. [Online]. Available at web address: https://www.fia.fs.fed.us/library/database-documentation/index.php#FIADB [Accessed 10 December 2021].

Cleland, D.T., Avers, P.E., McNab, W.H., Jensen, M.E., Bailey, R.G., King, T., Russell, W. E, Boyce, M.S., Haney, A., 1997. National hierarchical framework of ecological units. Ecosystem Management: Applications for Sustainable Forest and Wildlife Resources. Yale University Press, New Haven, CT, pp. 181–200.

Iverson, L.R., Dale, M.E., Scott, C.T., Prasad, A., 1997. A GIS-derived integrated moistureindex to predict forest composition and productivity in Ohio forests. Landsc. Ecol. 12, 331–348.

Iverson, L.R., Hutchinson, T.F., Peters, M.P., Yaussy, D.A., 2017. Long-term response of oak-hickory regeneration to partial harvest and repeated fires: influence of light and moisture. Ecosphere 8, e01642.

Iverson, L.R., Peters, M.P., Bartig, J.L., Rebbeck, R., Hutchinson, T.F., Matthews, S.N., Stout, S., 2018. Spatial modeling and inventories for prioritizing investment into oak-hickory restoration. For. Ecol. Manag. 424, 355–366.

Iverson, L.R., Bartig, J.L., Nowacki, G.J., Peters, M.P., Dyer, J.M., Hutchinson, T.F., Matthews, S.N., Adams, B.T. 2019. USDA forest service section, subsection, and landtype descriptions for southeastern Ohio. Research Map NRS-10. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 68 p. doi: 10.2737/NRS-RMAP-10.

LaBau, V.J., Bones, J.T., Kingsley, N.P., Lund, H.G. Smith, W.B. 2007. A history of the forest survey in the United States: 1830–2004. FS-877. Washington, DC: U.S. Department of Agriculture, Forest Service. 82 p. Available from: https://www.fia.fs.fed.us/library/historical-documentation/docs/1830-2004%20History%20of%20Forest%20Survey.pdf [Accessed 10 December 2021].

Long, R., Hille, A., and Turcotte, R. 2017. Black cherry health and mortality on the Allegheny National Forest. Final Report for FHM evaluation monitoring grant: evaluating and monitoring black cherry health trends in response to multi-year stressors in Northwestern Pennsylvania. On file with Northern Research Station.

Hardwoods Marquis, D.A., Burns, R.M., Honkala, B.H., 1990. Black cherry (*Prunus serotina* Ehrh.). In: Silvics of North America, 2. Tech. Coord. U.S. Department of Agriculture, Forest Service, p. 292. Hardwoods.

McWilliams, W.H., Canham, C.D., Morin, R.S., Johnson, K., Roth, P., Westfall, J.A., Morin, R.S., Liknes, G.C., 2012. Sampling forest regeneration across northern US forests: filling a void in regeneration model input. comps Moving from Status to trends: Forest Inventory and Analysis (FIA) Symposium 2012. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA, pp. 290–294, 2012 December 4-6; Baltimore, MD. Gen. Tech. Rep. NRS-P-105[CD-ROM].

Morin, R.S., Liebhold, A.M., Gottschalk, K.W., 2004. Area-wide analysis of hardwood defoliator effects on tree conditions in the Allegheny Plateau. North. J. Appl. For. 21 (1), 31–39.

Morin, R.S., Dooley, K., Jovan, S., Kurtz, C., McWilliams, W., Nelson, M., Oswalt, S., Perry, C.H., Randolph, K., Schulz, B., Woodall, C.W., 2020a. Forest Ecosystem Health Indicators. U.S. Department of Agriculture, Forest Service, Washington, DC, p. 26. FS-WO-1151.

Morin, R.S., Butler, B.J., Crocker, S.J., Horton, J., Kurtz, C.M., Lister, T.W., McWilliams, W.H., Nelson, M.D., Riemann, R., Walters, B.F., Woodall, C.W. 2020. New Hampshire forests 2017. Resour. Bull. NRS-119.

National Forest Management Act, 16U.S.C. §§1600-1687 (1976). Available at https://www.fs.fed.us/emc/nfma/includes/NFMA1976.pdf [accessed 10 December 2021].

Oswalt, S.N., Smith, W.B., 2014. U.S. Forest Resource Facts and Historical Trends. U.S. Department of Agriculture, Forest Service, Washington, DC, p. 64. FS-WO-1035.

Parikh, Grace, Webster, Christopher, 2019. Press-Pulse Odocoileus Virginianus Herbivory in Relict Tsuga Canadensis Stands in the Western Upper Peninsula of Michigan, USA. Forests 10 (6). https://doi.org/10.3390/f10060496.

Pederson, N., et al., 2014. The legacy of episodic climatic events in shaping temperate, broadleaf forests. Ecol. Monogr. 84 (4), 599–620.

Sease, J., Prout, L., 2015. Biological Assessment for Ongoing Project Activities with Determinations of no Effect or May Affect, not Likely to Adversely Affect, for the Northern Long-Eared Bat on the Green Mountain National Forest and White Mountain National Forest. USDA Forest Service, White Mountain National Forest, Campton, NH, p. 120.

Sasse, D.B., Pekins, P.J., Barclay, R.M.R., Brigham, R.M., 1996. Summer roosting ecology of northern long-eared bats (Myotis septentrionalis) in the White Mountain National Forest. In: Proceedings of the Bats and Forests symposium. British Columbia Ministry of Forests, Victoria, Canada, pp. 91–101. Working Paper 23/1996.

Shaw, J.D., 2008. Benefits of a strategic national forest inventory to science and society: the USDA forest service forest inventory and analysis program. iForest 1, 81–85.

Tinkham, W.T., Mahoney, P.R., Hudak, A.T., Domke, G.M., Falkowski, M.J., Woodall, C. W., Smith, A.M.S., 2018. Applications of the United States forest inventory and analysis dataset: a review and future directions. Can. J. For. Res. 48, 1251–1268.

USDA Forest Service. 2011. Phase 3 Field Guide Version 5.1. https://www.fia.fs.fed.us/library/field-guides-methods-proc/ [*Accessed* 15 *July* 2021].

USDA Forest Service. 2012. US forest service planning rule website. https://www.fs.usda.gov/planningrule [Accessed 10 December 2021].

USDA Forest Service. 2021. FIA national core field guide volume I: field data collection procedures for phase 2 plots version 9.1. https://www.fia.fs.fed.us/library/field-guides-methods-proc/docs/2021/core_ver9-1_9_2021_final.pdf [Accessed 9 December 2021].

Widmann, R.H., 2014. Forests of Ohio. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA, p. 4, 2013Resource Update FS-26.

Wolf, L.M., Turcotte, R.M., 2013. Supplemental biological evaluation of fall webworm on the Allegheny National Forest. Northeastern Area State and Private Forestry, Forest Health Protection, U.S. Forest Service, Morgantown, WV, p. 12. Internal report.

Wurtzebach, Z., Schultz, C., Waltz, A., Esch, B., Wasserman, T., 2019. Broader-scale monitoring for federal forest planning: challenges and opportunities. J. For. 117 (3), 244–255.

Wurtzebach, Z., et al., 2020. Supporting National Forest System planning with forest inventory and analysis data. J. For. 118 (3), 289–306.