RESEARCH ARTICLE

J. For. 113(5):475–483
http://dx.doi.org/10.5849/jof.14-088

history

Disentangling Forest Change from Forest Inventory Change: A Case Study from the US Interior West

Sara A. Goeking

Long-term trends in forest attributes are typically assessed using strategic inventories such as the US Department of Agriculture (USDA) Forest Service's Forest Inventory and Analysis (FIA) program. The implicit assumption of any trend analysis is that data are comparable over time. The 1998 Farm Bill tasked FIA with implementing nationally consistent protocols, including a spatially and temporally balanced sample design, whereas previous inventory methods varied spatially and temporally. To disentangle the artifacts of changing inventory designs from real forest change, this study assessed trends at plots that were measured both before and after implementation of the new inventory design in eight western states. Changes in live and dead tree volume, growth, and mortality were evaluated using only colocated plots and then compared with changes observed across entire inventories. The results sometimes differ in magnitude or are even contradictory, demonstrating that historical forest inventories may provide an incomplete picture of reference conditions in some western states.

Keywords: forest monitoring, tree volume, tree growth, tree mortality, Forest Inventory and Analysis (FIA)

Long-term trends in forest attributes are typically assessed using strategic resource inventories such as the US Department of Agriculture (USDA) Forest Service's Forest Inventory and Analysis (FIA) program. FIA data are used to assess overall forestland area; stand conditions such as forest type and stand age; wildlife habitat; tree growth, mortality, and removals; and standing wood volume, biomass, and carbon. FIA data serve not only as a snapshot of the current resource status but also as a source of data for long-term monitoring and trend analysis (Gillespie 1999). After passage of the 1998 Farm Bill, the FIA program implemented an annualized inventory, which was designed to be nationally consistent as well as spatially and temporally unbiased with respect to forest types and landownership groups (Bechtold and Patterson 2005). Within each state of the coterminous United States, permanent fixed-radius plots form a systematic sample grid that intersects all forest types and ownership groups in proportion to their abundance. This design is referred to as the "annual" inventory because a constant proportion of the plot grid is measured each year, and each year's sample is spatially dispersed across the landscape. Estimates of forest attributes are calculated at a variety of spatial scales based on standardized sampling and analysis procedures (Bechtold and Patterson 2005).

The annual inventory design replaced the spatially, temporally, and methodologically inconsistent forest inventories of the 1990s and earlier. Before the implementation of the current annual inventory design, FIA conducted inventories approximately every 10 years on a state-by-state basis (Frayer and Furnival 1999). Because these inventories occurred periodically rather than annually, they are referred to as periodic inventories. In the western United States, specific measurement years and protocols varied among states and were described in periodically published state reports. To assess temporal changes in forest attributes, users of FIA data often attempt to compare the estimates produced during the current annual inventories with those from earlier inventories, particularly from the last periodic inventory of the 1990s. However, the most recent periodic inventory reports in some western states were published in the late 1980s or early 1990s, so the methods and definitions used in the 1990s were not always well documented. The best available information about periodic inventory proto-

Received July 25, 2014; accepted April 14, 2015; published online June 4, 2015.

Affiliations: *Sara A. Goeking (sgoeking@fs.fed.us), USDA Forest Service, Rocky Mountain Research Station, Ogden, UT.*

Acknowledgments: *This work was supported by the Interior West Forest Inventory and Analysis Unit of the Inventory & Monitoring Program, Rocky Mountain Research Station, USDA Forest Service. I thank John D. Shaw, Paul L. Patterson, Michael T. Thompson, Greg C. Liknes, the journal editors, and two anonymous reviewers for their insightful comments.*

cols in the 1990s comes from three published reports based on data collected in that decade in Arizona (O'Brien 2002), New Mexico (O'Brien 2003), and Wyoming (Thompson et al. 2005), periodic inventory field manuals, maps showing periodic plot locations, and historical information that was included in the first annual inventory reports for Idaho (Witt et al. 2012) and New Mexico (Goeking et al. 2014).

The implicit assumption of any trend analysis is that the data are comparable over time, so the change in inventory designs raises the question: How comparable are estimates of forest attributes produced by historic forest inventories to those of the current inventory? In the Interior West region of the United States, specific differences regarding inventory methods call their comparability into question. The earliest estimates of forestland area relied on stand delineations from aerial photographs, whereas volume estimates were based on ground plots; over the next few decades, ground plots gradually became the standard basis for all estimates (Frayer and Furnival 1999). As ground plots were implemented, the distribution of plot locations often targeted specific forest types and/or ownership groups, or the intensity of the sample varied by forest type or ownership (Frayer and Furnival 1999). Plot configurations also changed over time: the current annual inventory's fixed-radius plot design replaced the variable-radius plots that were predominant in the periodic inventory era, and this change in plot design has the potential to affect estimates such as forest area (Azuma and Monleon 2011). However, the effects of most of these changes were accommodated within a framework of appropriate expansion factors and stratification schemes.

Other changes in inventory protocols have not been accommodated within FIA's estimation procedures and are therefore likely to produce discrepancies in broad-scale estimates of attributes such as total forestland area and tree volume. These include omission of specific forest types and/or ownership groups as well as definitional inconsistencies. Although proper implementation of stratification can minimize the effects of under- or oversampling of certain subpopulations, they cannot adjust for subpopulations that are completely omitted from the inventory. Therefore, in states where such omissions occurred, statewide estimates based on periodic inventory data assume that forest trends in sampled areas are representative of forest trends in nonsampled areas, and this may not be a realistic assumption. For example, in Idaho, post-1993 inventories consisted almost entirely of National Forest System lands, where each National Forest was responsible for its own inventory (Witt et al. 2012; Figure 1). Some national forests included reserved lands (e.g., the Selway-Bitterroot Wilderness), whereas others did not (e.g., the Frank Church-River of No Return Wilderness). Large areas of some national forests were not sampled at all (e.g., the Payette and Targhee National Forests). In contrast, Arizona's and New Mexico's inventories in the 1990s included all reserved lands, most national forestlands, some tribal lands, and all timber forest types regardless of owner; however, woodland forest types outside of national forests were excluded (O'Brien 2002, 2003). In the Interior West, woodland tree species and forest types are defined by FIA as those that are typically not capable of producing industrial wood products, which is presumably related to their omission from some inventories, and they are characterized by tree species that exhibit highly variable growth forms, e.g., *Pinus edulis* and *Juniperus* spp. (Goeking et al. 2014). Because the annual inventory samples all reserved statuses, ownership groups, and forest types in proportion to their actual occurrence, the population of interest is more comprehensive than that of the periodic inventories.

Definitional inconsistencies between the two inventories include the definitions of "forest" and "tree." During the periodic inventories, forestland was defined by having at least 5% tree canopy cover of a tally tree species, where cover was treated as a surrogate for stocking. In contrast, the annual inventory uses a 10% canopy cover definition. As late as the 1990s, forest surveys in the eight Interior West states also differentiated between tree-form and shrub-form individuals rather than using a strict species-based definition, where shrub-form trees of tally tree species were not measured. For example, junipers (*Juniperus* spp.) that were less than 6 ft tall and were not expected to eventually produce a straight, 8-ft trunk section were not considered to be trees and were not measured (USDA Forest Service 1999). In contrast, the annual inventory defines trees strictly based on species. Therefore, many woodland plots in the current annual inventory would not have been measured under previous definitions.

Although periodic inventories were not designed to be completely representative of all forests, or they used definitions different from those of the current annual inventory, they nonetheless represent the best available information about historical conditions. State-level estimates are publicly available not only in FIA's state reports but also in national Resource Planning Act (RPA) documents and online data analysis tools (e.g., FIDO and EVALIDator). Periodic esti-

Management and Policy Implications

Forest managers and policymakers often rely on forest inventory data collected and compiled by the Forest Inventory and Analysis (FIA) program to provide information about changes in forest attributes such as forestland area and forest volume. FIA's historical data include detailed plot-level measurements rather than broad-scale paper maps, so it is tempting to analyze change in greater detail than is sometimes appropriate. Use of FIA data from different time periods assumes that inventory methods were consistent over time, yet in the US Interior West, this assumption is not always realistic. After FIA began implementation of its annual inventory protocol in 2000, the definitions, sample designs, field protocols, and estimation procedures differed from those of the previous periodic inventories. Therefore, FIA cautions users against making comparisons between periodic and annual inventory estimates without accounting for differences in protocol. An example of an appropriate comparison is to evaluate forest attributes per unit area, as measured only on plots that were surveyed during both the periodic and annual inventories. In contrast, comparisons based on entire inventories may show changes in volume, growth, and mortality that differ in magnitude and sometimes in direction (gain or loss) from comparisons based only on plots surveyed at both time periods. These discrepancies illustrate that FIA's periodic inventory data may not provide an accurate historical baseline for detecting future forest change across broad scales. Use of periodic data sets to analyze change is worthwhile only if appropriate care is taken as outlined in this study, along with the caveat that some forest types or other subpopulations may be underrepresented or missing. With the assumption that FIA protocols remain consistent, the current annual inventory design should allow analysis of change in considerably more detail once sufficient repeated measurements are available, which in most western states will be between 2015 and 2020.

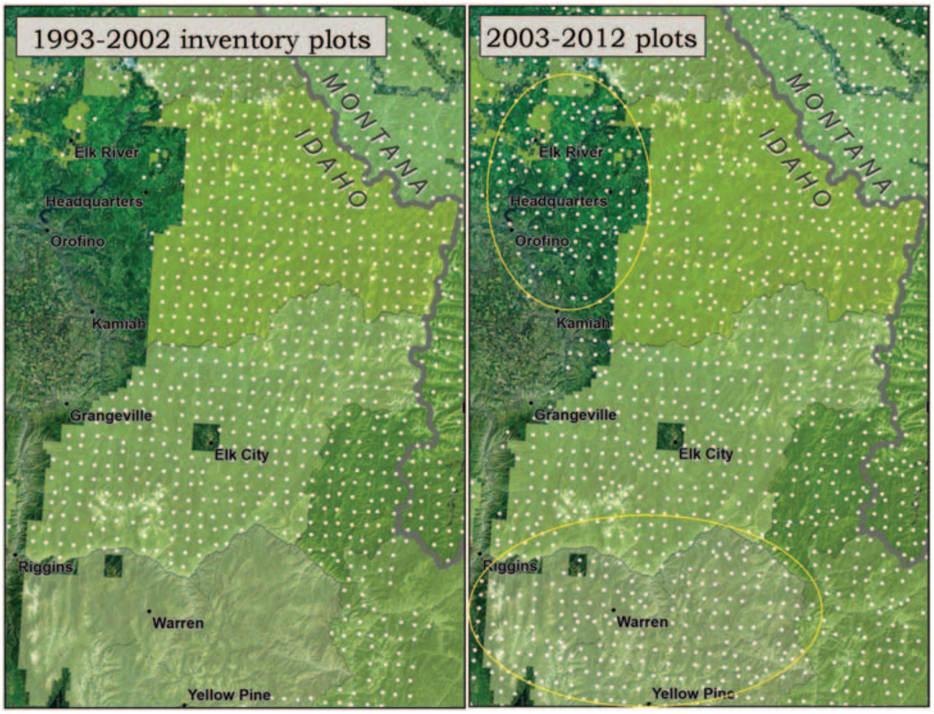

Figure 1. Forest plots sampled by FIA along the Idaho-Montana border during the periodic (left) and annual (right) inventories. Areas outlined in yellow highlight forest areas that were not sampled during the periodic inventory, including state and private timberlands near Headquarters, ID, and the Payette National Forest surrounding Warren, ID. Plot locations are approximate.

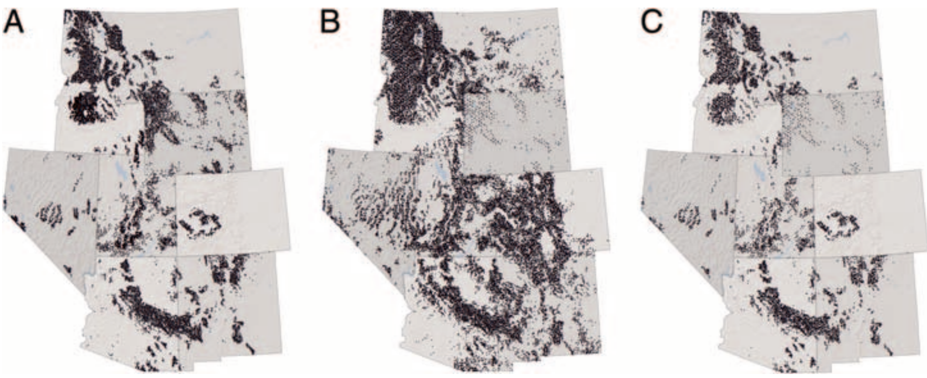

Figure 2. Geographic distribution of all plots from the periodic inventory (1993–2002) (A), the annual inventory (2003–2012) (B), and colocated plots measured during both inventories (C). Plot locations are approximate.

mates from these sources are sometimes used as a historical baseline and then compared with current estimates (e.g., US Environmental Protection Agency 2013). However, because of differences among inventory procedures and sample designs, such comparisons may produce misleading results. Indeed, Heath et al. (2011) suggested that apparent fluxes in forest carbon in specific western states may reflect changing inventory designs rather than actual forest trends.

The purpose of this study is to clarify forest trends that occurred in eight western states over the past two decades, spanning the implementation of FIA's annual forest inventory. This analysis focuses on three attributes of interest to forest managers: tree net volume (both live and dead), mortality, and net growth, all on a per acre basis. Actual trends are identified by comparing only data from stands that were surveyed in two inventories: the most recent periodic inventories of the 1990s and the recent annual inventory. The trends identified at colocated plots are then compared with the apparent trends exhibited by across-the-board comparisons of the two inventory periods to highlight potential discrepancies.

Methods

This study encompassed eight states in the US Interior West (Figure 2). Each state was analyzed individually because FIA implemented both periodic and annual inventories and continues to publish forest estimates on the basis of state boundaries. Periodic inventories were conducted throughout the 1990s and as late as 2002, although the specific years varied by state. Annual inventories began as early as 2000 and as late as 2011 in states that were not funded during the initial implementation. Whenever possible within the constraints of the FIA sample design, annual plots were colocated with previously measured periodic plots. The time periods for analysis of plot measurements were constrained to 1993–2002 for the periodic inventory (time 1) and 2003–2012 for the annual inventory (time 2), thus corresponding to a remeasurement interval of approximately 10 years. Because FIA plots are now remeasured every 10 years in the western United States, annual inventory plots measured between 2000 and 2002 were excluded to ensure that only one annual (time 2) measurement was included per plot.

Given these two measurement periods, comparisons of net volume, mortality, and growth could be made in two main ways: by comparing statewide estimates at time 1 versus time 2; or by comparing time 1 and time 2 estimates only at plots that were measured during both inventories. The former is often used by FIA data users not only because periodic (time 1) inventories are the best available historical data sets but also because such comparisons are easy to make using existing FIA publications or online tools. The second approach involves assessing change at a subset of plots that were measured during both inventories (time 1 and time 2), which can produce more precise estimates of change over time than use of independent sets of plots (Arner et al. 2005, Salk et al. 2013). This approach requires a sufficient sample size of colocated plots. It also precludes efficient estimation of forest attributes over broad areas such as entire states because FIA's stratification and estimation procedures are designed to work with full panels of data (Bechtold and Patterson 2005), wherein nonresponse occurs at random (Patterson et al. 2012), rather than subsets of plots designated by their remeasurement status. Note that nonresponse in this context refers to plot locations that were sampled only during the annual inventory and therefore cannot be included in the colocated plot analysis. Therefore, comparisons of plot-level attributes, such as mean or median volume per acre, are more appropriate than comparisons of statewide estimates when colocated plots drawn from two incongruent inventories are analyzed. Both periodic (time 1) and annual (time 2) plot designs allow estimation of tree attributes on a per acre basis. For variable-radius periodic inventories, basal area factors allow expansion of volume per tree to per-acre estimates. All annual inventories use four 24-ft fixed-radius subplots per plot for trees ≥5.0 in. dbh, where each tallied tree represents about 6 trees/acre (O'Connell et al. 2014).

All plots measured during either interval (1993–2002 or 2003–2012) were queried from the national FIA database (for documentation and access information, see O'Connell et al. 2014). The response variables of net volume, mortality volume, and net growth volume (respectively, VOLCFNET, FGROWCFAL, and FMORTCFAL from O'Connell et al. 2014) were queried for all standing trees 5.0 in. or larger in diameter. In both inventories, net volume excludes rotten, missing, and form cull and is expressed here as cubic feet per acre. The net volume for each tree was converted to a per-acre value using the appropriate expansion factor (TPA_UNADJ from O'Connell et al. 2014), resulting in net volume expressed as cubic feet per acre. Net volume was tallied separately for live and dead trees to allow comparisons of total, live, and dead net volumes. For plots that did not contain at least one standing tree of 5.0 in. or larger, values of these response variables were equal to 0.

Mortality and growth estimates throughout the study area are based on one-time observations rather than true tree-to-tree remeasurement; tree-level remeasurement data will not be available until FIA collects a second cycle of annual data in each state. Mortality is based on identification of standing dead trees that died within a specified mortality window, which is typically 5 years (USDA Forest Service 2013), and is expressed in cubic feet. The expansion factor for mortality (TPAMORT_UNADJ from O'Connell et al. 2014) annualizes the mortality volume, based on the length of the mortality window, to produce an estimate in cubic feet per acre per year. Annualized net growth is based on the previous 10 years' radial growth, as measured using increment cores. Net growth is expressed as cubic feet per year, and application of the appropriate expansion factor (TPAGROW_UNADJ from O'Connell et al. 2014) produces net growth in cubic feet per acre per year. Note that net growth may be negative due to mortality or due to live tree damage such as rot or broken tops.

Tree-level estimates of net volume, mortality, and net growth per acre were summed to the plot level based on expansion factors for individual trees (CONDPROP_UNADJ from O'Connell et al. 2014). To account for nonforest conditions on plots that were not entirely forested, plot-level estimates of net volume, mortality, and net growth were divided by the sum of the condition proportions of all forested conditions on the plot; note that this sum equals 1.0 for plots lacking a nonforest condition. Categorical condition-level variables such as forest type group were assigned to each plot based on the order in which conditions were encountered on the plot. For periodic (time 1) inventory data, tree-level values per acre were aggregated to the plot level by simple summation of per-acre values for all trees on the plot. Note that the intermediate step of calculating condition-level variables was unnecessary for periodic data because conditions were not differentiated during periodic inventories; each periodic plot was, by procedural definition, a single-condition plot so any condition proportion adjustments are equal to 1.

Annual plots that were established in the same locations as previous periodic plots were identified as colocated plots. Periodic (time 1) and annual (time 2) measurements from these plots were paired for assessing actual change. Because the annual plot grid is considered a spatially representative sample (Bechtold and Patterson 2005), the representativeness of the periodic inventory in each state was assessed by comparing the proportion of all periodic plots with the proportion of all annual plots in each forest type group. Forest types and forest type groups are based on the tree species that form a plurality of live stocking, and FIA uses a fixed set of forest type and forest type group definitions based on the dominant species (O'Connell et al. 2014). Note that in addition to the species with plurality of stocking, any particular forest type or forest type group may contain many other tree species, including species that correspond to a different FIA forest type or forest type group. For plots recorded as nonstocked, the forest type defaulted to the field-assigned forest type, which is based on either previous stand composition or current regeneration (USDA Forest Service 2013). Rather than assume that forest type group remained constant between the periodic and annual inventory measurements, the forest type group assigned to each plot at the time of measurement was used. Although some of FIA's forest type algorithms have changed over the past two decades, their effect is assumed to be minimal; most changes occurred within FIA's fir/spruce/mountain hemlock forest type group, which is presented here as an aggregate group rather than individual forest types.

To distinguish between actual change and apparent change resulting from different inventory designs, the temporal differences in the response variables were compared between periodic versus annual estimates for two data sets: all plots measured in both inventories and only colocated plots. Because of the nonnormality of the response variables, nonparametric methods were used to identify statistically significant differences of medians. The significance of the observed changes between all periodic and all annual inventories was assessed with the Wilcoxon-Mann-Whitney test, also known as the Mann-Whitney or Wilcoxon rank sum test (Zar 1996), using PROC NPAR1WAY in SAS software (SAS Institute, Inc. 2009). This test assumes independence of observations, yet the presence of colocated plots clearly represents some degree of dependence. However, identifying colocated plots is not straightforward to casual users of FIA data, and such users are more likely to use tests that assume independence. Thus, the purpose of the comparison of all periodic and all annual plots is to illustrate a typical misapplication of historical inventory data, i.e., what not to do with FIA data. The significance of differences at colocated plots was assessed with Wilcoxon signed rank tests using PROC UNIVARIATE in SAS software (SAS Institute, Inc. 2009). Both tests were conducted separately for each state and each response variable. Note that parametric tests (unpaired and paired *t*-tests) were also used to test for differences in means. The conclusions drawn from the two sets of tests were nearly identical, but because of failure to meet the underlying assumptions of the parametric tests, those results are not presented here.

Table 1. Measurement years and numbers of plots in the periodic inventory, the annual inventory, and the subset of colocated plots in the periodic and annual inventories.

State	Measurement dates		Sample size			Mean (SD) remeasurement period of colocated plots
	Periodic	Annual	Periodic	Annual	Colocated	
	. . . . (yr)		. . . . (no. of plots)			. . . . (yr). . . . .
Arizona	1995–1999	2003–2012	1,966	3,229	1,642	11.51 (2.80)
Colorado	1993–1997	2003–2012	396	3,948	336	10.48 (2.89)
Idaho	1993–2002	2004–2012	2,736	3,386	1,584	9.68 (3.76)
Montana	1993–2001	2003–2012	2,374	4,451	2,123	11.98 (3.25)
Nevada	1994–1997	2004–2012	588	1,737	406	13.21 (3.40)
New Mexico	1993–2000	2008–2012	1,741	3,444	1,309	13.72 (2.24)
Utah	1993–1995	2003–2012	1,844	3,177	1,228	13.83 (3.02)
Wyoming	1998–2002	2011–2012	1,981	371	318	11.75 (1.39)
All states	1993–2002	2003–2012	13,626	23,743	8,946	11.98 (3.37)

Results

The colocated plot data set consisted of 8,946 plots in 8 states, and the mean interval between measurements was about 12 years (Table 1). The measurement years for annual inventories of New Mexico and Wyoming lagged behind those of the other states because of delayed funding; however, periodic inventories in these two states were conducted relatively recently, so their mean remeasurement periods for colocated plots were comparable to those of the other states. Figure 2 shows the geographic distribution of all periodic (time 1) and annual (time 2) inventory plots, as well as the colocated (time 1 and time 2) plot locations. Note that the periodic plot locations exclude large areas covered by annual inventory plots; for example, the Colorado periodic inventories were restricted to the Grand Mesa, Uncompahgre, and Gunnison National Forests in west-central Colorado.

Figure 3 shows the proportion of plots in each state within each forest type group for all periodic plots (T1), all annual plots (T2), and only colocated plots (T1 and T2) as measured during each inventory. For example, the upper left box in Figure 3 (Arizona) shows four sets of bars: first, the distribution of plots among forest type group for all periodic plots; second, the distribution of plots among forest type group for all annual plots; and third and fourth, the forest type groups for colocated plots during the periodic and annual inventories, respectively. Each state contains between 8 and 14 of FIA's forest type groups, so for the sake of brevity and clarity, only the 7 groups that constitute at least 5% of the entire annual inventory in any state are included in Figure 3. The proportion of all periodic plots in each forest type group, compared with the proportions for all annual plots, illustrates some of the biases in the periodic inventories. For example, the pinyon/juniper group (dominated by *Juniperus* spp., *Pinus edulis*, and/or *Pinus monophylla*) was underrepresented by the periodic inventory in every state except Wyoming. Compared with the annual inventory, underrepresentation of pinyon/juniper woodlands in the periodic inventory corresponds to a higher sample proportion of timber forest type groups such as aspen (*Populus tremuloides*) in Colorado and Utah; Douglas-fir (*Pseudotsuga menziesii*) in Idaho, New Mexico, and Utah; fir and spruce types (*Abies* spp. and *Picea* spp.) in Colorado, Montana, New Mexico, and Utah; lodgepole pine (*Pinus contorta*) in Colorado and Montana; and ponderosa pine (*Pinus ponderosa*) in Arizona, New Mexico, and Utah. Thus, statewide estimates from the periodic inventories in these states can be expected to disproportionately reflect conditions within the above-mentioned timber forest type groups.

Given the differential representation of forest type groups in the periodic versus annual inventories, it is expected that mean net volume, on a per acre basis, would exhibit different patterns, depending on consideration of all plots in both inventories versus only colocated plots. Figure 4 confirms this expectation. The mean volume at all annual plots (bars marked "All T2" in Figure 4) is appreciably less than the mean volume at colocated annual plots (bars marked "Colocated T2") in all states except Wyoming. Because the colocated annual plots comprise a subset of all annual plots measured between 2003 and 2012, this comparison excludes temporal effects and reinforces the bias of the periodic sample toward higher-volume forestland.

Figures 4 and 5 illustrate qualitative differences in net volume, mortality, and growth, and Table 2 presents statistical evidence for significant differences ($\alpha = 0.05$), between 1993 and 2002 and 2003 and 2014. In Montana, New Mexico, and Utah, comparing all plots in both inventories yielded significant decreases in total net volume, whereas colocated plots showed significant increases (Table 2). Therefore, these states demonstrate that comparisons of T1 versus T2 at all plots may yield results that conflict with those from comparisons of T1 versus T2 only at colocated plots. In Nevada, total net volume did not change significantly based on whole-inventory comparisons, whereas colocated plots showed significant increases. Comparisons of total net volume consistently showed significant increases in Idaho, no change in Wyoming, and significant decreases in Arizona and Colorado (Table 2), although the magnitude of these changes was different in the colocated comparison from that in the whole-inventory comparison (Figure 4).

Live net volume significantly increased at colocated plots in Idaho, Montana, Nevada, New Mexico, and Utah (Table 2). This result conflicts with the results of the whole-inventory comparison, which showed either no change (Nevada) or significant decreases (Idaho, Montana, New Mexico, and Utah) in live volume. Both data sets showed significant decreases in live volume in Colorado and Wyoming. Although the whole-inventory data set showed a significant decrease in live net volume in Arizona, colocated plots were not significantly different. Increases in dead net volume were consistently detected in every state, although in Colorado and New Mexico these increases were only detected in the colocated plot comparisons.

The most consistent trends during this

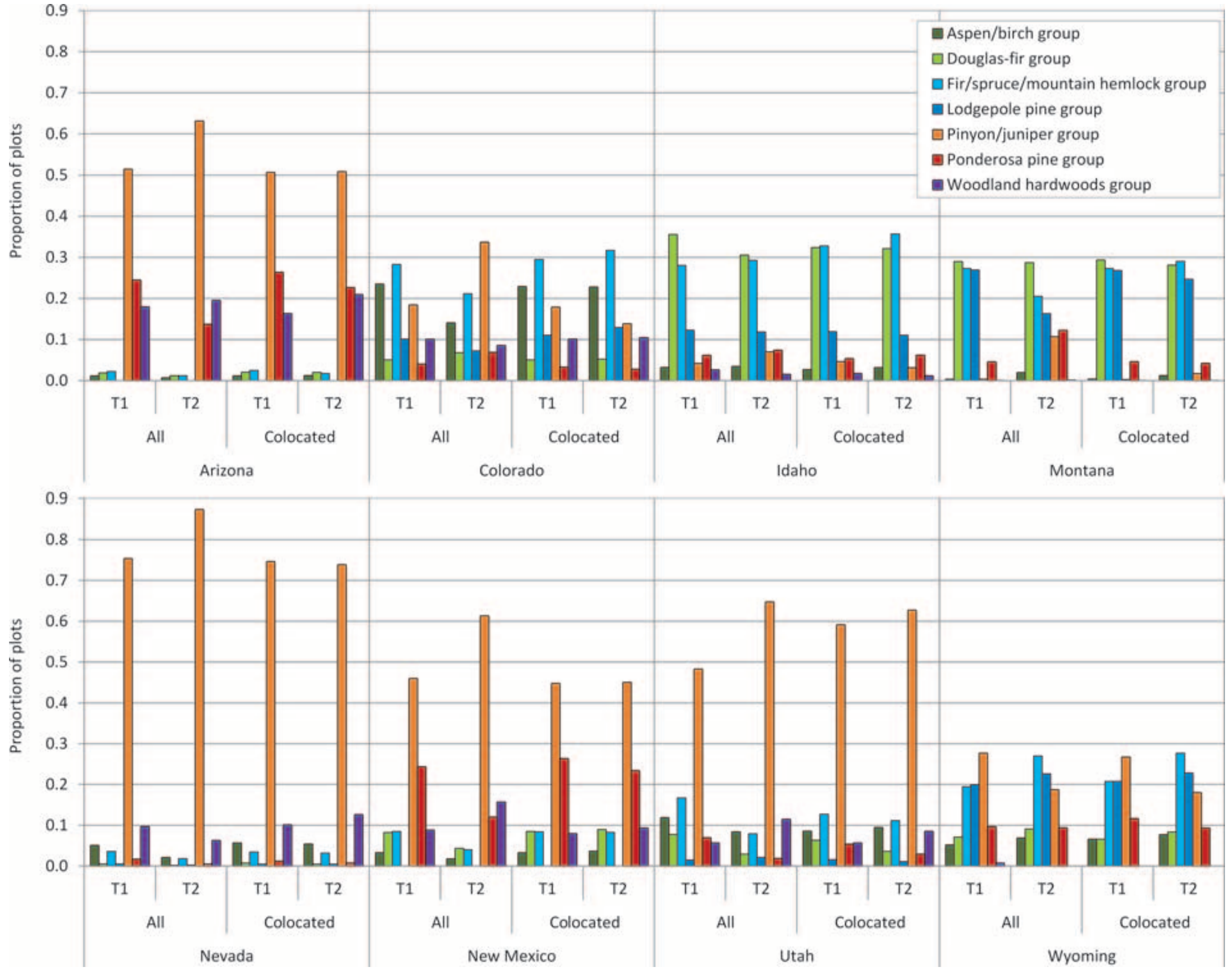

Figure 3. The proportion of all plots and colocated plots in each forest type group in the periodic (T1; 1993–2002) and annual (T2; 2003–2012) inventories, by state. Only forest type groups that constitute at least 5% of the total annual inventory sample in at least one state are shown.

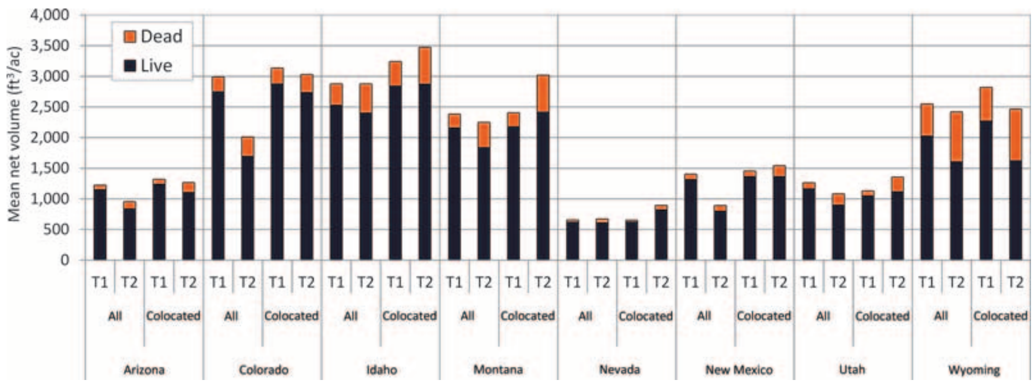

Figure 4. Mean net volume at all plots in the periodic (T1; 1993–2002) and annual (T2; 2003–2012) inventories and at only colocated plots from both inventories (T1 and T2), by state.

interval are significant increases in mortality and decreases in net growth in all states, regardless of the data set used for comparison (Figure 5). The only comparison that did not detect a significant increase in mortality was the whole-inventory comparison in Colorado (Table 2) despite exhibiting a qualitatively large change (Figure 5). The increase in mortality was greater at colocated plots than across entire periodic versus annual inventories in every state except for Colorado and Wyoming (Figure 5 and percentages in Table 2). In six of the eight states, net growth decreased significantly based on both whole-inventory and colocated plot analyses (Table 2). In Idaho, only the colocated plot comparison detected the decrease in growth, and in Nevada the colocated plot comparison detected no change in contrast to the decrease detected by the whole-inventory comparison (Table 2). In most states, the magnitude of the decrease in net growth was similar among the colocated versus all-plot comparisons (Figure 5).

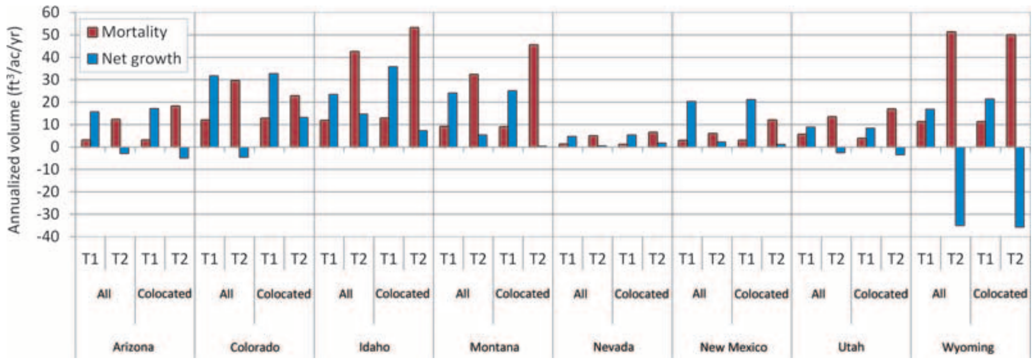

Figure 5. Mean annual mortality and net growth (cubic feet per acre per year) at all plots in the periodic (T1; 1993–2002) and annual (T2; 2003–2012) inventories and at only colocated plots from both inventories (T1 and T2), by state.

Table 2. Summary of changes in five response variables between time 1 (1993–2002) and time 2 (2003–2012), based on comparisons of all periodic and all annual plots versus comparisons of colocated plots from the two inventories.

		All plots				Colocated plots			
State	Variable	Absolute difference*	% difference	*P* value	Conclusion	Absolute difference*	% difference	*P* value	Conclusion
Arizona	Total net volume	−271.2	−22.2	<0.0001	Decrease	−53.4	−4.0	<0.0001	Decrease
	Live net volume†	−314.7	−27.3	<0.0001	Decrease	−136.2	−11.0	0.9354	No change
	Dead net volume	43.5	59.6	<0.0001	Increase	82.9	105.8	<0.0001	Increase
	Mortality	9.2	290.8	<0.0001	Increase	15.2	480.9	<0.0001	Increase
	Net growth	−18.5	−118.2	<0.0001	Decrease	−22.1	−128.5	<0.0001	Decrease
Colorado	Total net volume	−981.2	−32.8	<0.0001	Decrease	−104.4	−3.3	0.0003	Decrease
	Live net volume	−1,053.9	−38.3	<0.0001	Decrease	−139.8	−4.9	0.0166	Decrease
	Dead net volume†	72.8	30.2	0.6812	No change	35.4	13.6	0.0200	Increase
	Mortality†	17.6	144.8	0.3130	No change	10.0	77.6	<0.0001	Increase
	Net growth	−36.2	−114.2	<0.0001	Decrease	−19.5	−59.7	<0.0001	Decrease
Idaho	Total net volume	0.3	0.0	0.0367	Increase	231.4	7.1	<0.0001	Increase
	Live net volume†	−127.5	−5.0	<0.0001	Decrease	28.6	1.0	0.0041	Increase
	Dead net volume	127.8	36.8	0.0469	Increase	202.8	51.1	<0.0001	Increase
	Mortality	30.6	255.3	<0.0001	Increase	40.4	312.1	<0.0001	Increase
	Net growth†	−8.9	−37.7	0.9781	No change	−28.5	−79.6	<0.0001	Decrease
Montana	Total net volume†	−133.9	−5.6	<0.0001	Decrease	613.6	25.5	<0.0001	Increase
	Live net volume†	−318.1	−14.7	<0.0001	Decrease	238.9	11.0	<0.0001	Increase
	Dead net volume	184.1	82.1	<0.0001	Increase	374.7	165.6	<0.0001	Increase
	Mortality	23.2	252.7	<0.0001	Increase	36.5	405.3	<0.0001	Increase
	Net growth	−18.8	−77.7	<0.0001	Decrease	−24.7	−98.4	0.0241	Decrease
Nevada	Total net volume†	14.1	2.2	0.0894	No change	241.0	37.0	<0.0001	Increase
	Live net volume†	−13.1	−2.1	0.7099	No change	196.3	31.5	<0.0001	Increase
	Dead net volume	27.2	87.5	<0.0001	Increase	44.7	158.7	<0.0001	Increase
	Mortality	3.8	281.3	<0.0001	Increase	5.4	451.8	<0.0001	Increase
	Net growth†	−4.2	−89.1	<0.0001	Decrease	−3.7	−68.0	0.8999	No change
New Mexico	Total net volume†	−514.0	−36.6	<0.0001	Decrease	86.8	6.0	<0.0001	Increase
	Live net volume†	−516.6	−39.3	<0.0001	Decrease	1.5	0.1	<0.0001	Increase
	Dead net volume	2.5	2.8	0.0001	Increase	85.4	93.6	<0.0001	Increase
	Mortality	3.1	104.4	<0.0001	Increase	9.0	292.8	<0.0001	Increase
	Net growth	−18.1	−89.2	<0.0001	Decrease	−20.0	−94.7	<0.0001	Decrease
Utah	Total net volume†	−183.7	−14.5	<0.0001	Decrease	225.5	20.0	<0.0001	Increase
	Live net volume†	−266.3	−22.8	<0.0001	Decrease	68.2	6.5	0.0011	Increase
	Dead net volume	82.7	84.4	<0.0001	Increase	157.3	193.4	<0.0001	Increase
	Mortality	7.7	135.1	<0.0001	Increase	13.0	330.0	<0.0001	Increase
	Net growth	−11.3	−127.9	<0.0001	Decrease	−11.8	−140.8	<0.0001	Decrease
Wyoming	Total net volume	−128.3	−5.0	0.5162	No change	−356.0	−12.6	0.4473	No change
	Live net volume†	−421.4	−20.8	0.0633	No change	−647.4	−28.5	<0.0001	Decrease
	Dead net volume	293.1	56.4	<0.0001	Increase	291.5	53.0	<0.0001	Increase
	Mortality	40.0	352.2	<0.0001	Increase	38.7	342.4	<0.0001	Increase
	Net growth	−51.8	−308.1	<0.0001	Decrease	−57.1	−266.8	<0.0001	Decrease

"Difference" refers to the quantity "time 2 − time 1" and is calculated as the difference of the sample means in the all-plots comparison and as the mean of the differences at colocated plots in the second comparison; percent differences are relative to time 1 values. *P* values are based on Wilcoxon-Mann-Whitney tests (all plots) and Wilcoxon signed rank tests (colocated plots). Note that although mean values are reported for qualitative interpretation of changes between time 1 and time 2, the nonparametric tests used here test for differences in medians.

* Absolute difference units are ft^3/acre (total, live, and dead net volume) and ft^3/acre/yr (mortality and net growth).

† These rows represent response variables with conflicting conclusions ($\alpha = 0.05$) at colocated plots compared with all plots.

Discussion

This study used the common currency of colocated plots for assessing changes that occurred between the most recent periodic inventory of several western states and the implementation of FIA's annual inventory design. The results demonstrate the potential pitfalls of relying on broad-scale estimates from historical inventories to assess subsequent forest change when the population of interest changes over time. In several states, direct comparisons of statewide periodic inventory estimates from 1993 to 2002 with statewide annual estimates from 2003 to 2012 produce changes that are contradictory to those observed for the large samples of colocated plots that were measured during both inventories. Both comparisons confirmed, however, that nearly every state in the Interior West has experienced increased mortality and decreased net growth. Nonetheless, in many cases for which the two comparisons yield similar conclusions, the magnitude of change differs considerably. The observed change at colocated plots represents actual change, whereas wholesale comparisons of all periodic plots with all annual plots may represent changing inventory protocols. Use of colocated plot analysis to disentangle changing the inventory design from real forest change could be implemented in other states and regions, provided that their annual inventory designs incorporated at least some of their legacy plots from periodic inventories. However, some of the definitional issues pertaining to woodland forest types and sparse tree cover may be unique to parts of the arid West.

Comparison of the proportion of each inventory by forest type group confirmed suspected or known biases in some states' periodic inventories, which overrepresented timber types and underrepresented less productive forests, particularly pinyon/juniper woodlands. The historical bias toward timber forest types is due not only to sample design differences but also to different definitions of "tree" and "forestland." As mentioned above, some periodic inventories included woodland forest types but did not sample woodland plots where trees were deemed to be incapable of attaining a certain height or growth form. Other inventories omitted specific woodland types, excluded some geographic regions from the field inventory (Figure 2), and/or targeted certain ownership groups. Thus, the definition of the target population of forestland was not consistent among inventories. These collective differences confound interpretation of forest change based on statewide estimates derived from historical inventories.

One caveat of this analysis is that the sample of colocated plots cannot be as representative as the annual inventory sample. Analysis of colocated plot data cannot compensate for underrepresentation or omission of subpopulations in the periodic inventory; it can, however, constrain overrepresentation of subpopulations due to the balanced design of the annual inventory. Thus, it removes some of the noise inherent in comparing data from two incongruous sample designs that differentially sampled subpopulations within each state. It also provides more precise estimates of changes in tree volume than comparisons of all periodic to all annual plots (Arner et al. 2005).

Despite these caveats, the demonstrated effects of different inventory designs on change assessments have implications for forest managers who are responsible for monitoring attributes such as timber supply, wildlife habitat, forest biomass, and forest carbon, among other resources. Forest managers and other FIA data users need reliable data on forest trends, and they are already making wholesale comparisons of periodic and annual inventory estimates. This article should serve as a cautionary tale to uninitiated FIA data users who want to assess long-term forest change in the Interior West. For example, biomass and carbon are assessed using FIA estimates relative to baseline assessments from the 1990s (Heath et al. 2011, US Environmental Protection Agency 2013, Domke et al. 2014). The volume changes observed here represent parallel trends in tree biomass and carbon, so use of periodic baselines of these metrics may lead to similarly confounded conclusions about carbon fluxes and changes in forest productivity over time.

The implications of this study are that, at least in the Interior West, managers and scientists may need to reevaluate the adoption of periodic inventory data as reference conditions or historical baselines. To facilitate appropriate use of these data, future research should identify applicable methods for reconciling multitemporal statewide and regional estimates of forest attributes. Because annual inventories are more consistent and usually more complete than periodic inventories, the most promising approaches allow revision of historical baselines using a combination of colocated plot data and statistical modeling to compensate for missing historical observations at annual plot locations. Eskelson et al. (2009) reviewed several methods of nearest neighbor imputation as applied to forest inventories, in which missing values are typically assigned based on observations from the same inventory period (e.g., the same FIA cycle), and compared these methods to traditional regression. Domke et al. (2014) tested several methods of compensating for missing FIA observations in statewide carbon assessments but found that the most appropriate method varied by state. In their study, the percentage of missing values ranged from 0 to 25% of the sample, encompassing the observed range of nonresponse in a single inventory cycle in all states (Patterson et al. 2012). However, if periodic observations were compared to the annual inventory sample in Interior West states, the percentage of missing periodic observations would be much higher and thus pose a different set of analytical challenges. Gray et al. (2014), in their estimation of carbon fluxes in Oregon, used a combination of remeasured plot data and empirical regression models of growth and mortality to populate missing values where the vast majority of the observations in a specific subpopulation were missing.

Although periodic and annual inventory data are not directly comparable, periodic inventories nonetheless represent the best available information at the time the data were collected. Because discrepancies between periodic and annual inventory data sets can produce misleading conclusions even at fairly small temporal and spatial scales, i.e., a single decade within individual states, evaluating change over longer time periods may be even more problematic. Historical forest assessments that accompanied decadal census data (e.g., Walker 1874, Sargent 1884) provide snapshots of forest status but typically include little documentation or validation. Liknes et al. (2013) compared Walker's (1874) historical, broad-scale forest density map to a present-day forest probability map that was developed from FIA and satellite data but mimicked the structure of the historical data; however, the authors suggested that such comparisons are applicable only at regional or even national scales. Even the massive USDA Forest Service (1958) report on America's forests focuses on national and regional assessments, acknowledging that data quality varies sufficiently among individual states such that state-level estimates should not be compared with earlier data sets. Regardless of spatial or temporal scale, users of FIA data should acknowledge the limitations of comparisons with historical data and make efforts to reconcile inconsistencies as much as possible, as presented in this analysis.

Before the implementation of the annual inventory, FIA wrestled with problems of incongruous historical data sets. This study presents a method of robustly assessing forest change in the Interior West, where changing inventory methods and definitions have led to a series of inconsistent inventory data sets, and demonstrates that further progress regarding reassessment of historical baselines is needed in the Interior West states. Although integration of historical data with ancillary data sets such as high-resolution imagery could enhance the ability to detect historical changes by accounting for differences in inventory procedures and definitions, the use of colocated plot data provides a shovel-ready analysis. Fortunately FIA's annual inventory design should allow robust assessments of current and future forest change, provided that the design does not change appreciably in the future.

Literature Cited

Arner, S.L., J.A. Westfall, and C.T. Scott. 2005. Comparison of annual inventory designs using forest inventory and analysis data. *For. Sci.* 50(2):188–203.

Azuma, D., and V.J. Monleon. 2011. Differences in forest area classification based on tree tally from variable- and fixed-radius plots. *Can. J. For. Res.* 41:211–214.

Bechtold, W.A., and P.L. Patterson (eds.). 2005. *The enhanced forest inventory and analysis program—National sampling design and estimation procedures.* USDA For. Serv., Gen. Tech. Rep. SRS-80, Southern Research Station, Asheville, NC. 85 p.

Domke, G.M., C.W. Woodall, B.F. Walters, R.E. McRoberts, and M.A. Hatfield. 2014. Strategies to compensate for the effects of nonresponse on forest carbon baseline estimates from the national forest inventory of the United States. *For. Ecol. Manage.* 315:112–120.

Eskelson, B.N.I., H. Temesgen, V. Lemay, T.M. Barrett, N.L. Crookston, and A.T. Hudak. 2009. The roles of nearest neighbor imputations methods in imputing missing data in forest inventory and monitoring databases. *Scand. J. For. Res.* 24:235–246.

Frayer, W.E., and G.M. Furnival. 1999. Forest survey sampling designs: A history. *J. For.* 97(12):4–10.

Gillespie, A.J.R. 1999. Rationale for a national annual forest inventory program. *J. For.* 97(12):16–20.

Goeking, S.A., J.D. Shaw, C. Witt, M.T. Thompson, C.E. Werstak, M.C. Amacher, M. Stuever, T.A. Morgan, C.B. Sorenson, and C.P. McIver. 2014. *New Mexico's Forest Resources, 2008–2012.* USDA For. Serv., Res. Bull. RMRS-RB-18, Rocky Mountain Research Station, Fort Collins, CO. 144 p.

Gray, A., T.R. Whittier, and D.L Azuma. 2014. Estimation of aboveground forest carbon flux in Oregon: Adding components of change to stock-difference assessments. *For. Sci.* 60(2):317–326.

Heath, L.S., J.E. Smith, K.E. Skog, D.J. Nowak, and C.W. Woodall. 2011. Managed forest carbon estimates for the US greenhouse gas inventory, 1990–2008. *J. For.* 109(3):167–173.

Liknes, G.C., M.D. Nelson, and D.J. Kaisershot. 2013. *Net change in forest density, 1873–2001. Using historical maps to monitor long-term forest trends.* USDA For. Serv., Res. Map RMAP-NRS-4, Northern Research Station, Newtown Square, PA. 12 p.

O'Brien, R. 2002. *Arizona's forest resources, 1999.* USDA For. Serv., Res. Bull. RMRS-RB-2, Rocky Mountain Research Station, Ogden, UT. 116 p.

O'Brien, R. 2003. *New Mexico's forest resources, 2000.* USDA For. Serv., Res. Bull. RMRS-RB-3, Rocky Mountain Research Station, Fort Collins, CO. 117 p.

O'Connell, B.M., E.B. LaPoint, J.A. Turner, T. Ridley, D. Boyer, A.M. Wilson, K.L. Waddell, S.A. Pugh, and B.L. Conkling. 2014. *The Forest Inventory and Analysis database: Database description and user guide version 6.0 for phase 2.* Available online at www.fia.fs.fed.us/library/database-documentation/current/ver6.0/FIADB%20User%20Guide%20P2_6-0-1_final.pdf; last accessed Feb. 17, 2015.

Patterson, P.L., J.W. Coulston, F.A. Roesch, J.A. Westfall, and A.D. Hill. 2012. A primer of nonresponse in the US Forest Inventory and Analysis program. *Environ. Monit. Assess.* 184(3):1423–1433.

Salk, C.F., R.L. Chazdon, and K.P. Andersson. 2013. Detecting landscape-level changes in tree biomass and biodiversity: Methodological constraints and challenges of plot-based approaches. *Can. J. For. Res.* 43:799–808.

Sargent, C.S. 1884. *Report on the forests of North America (exclusive of Mexico).* US Government Printing Office, Washington, DC. 612 p.

SAS Institute, Inc. 2009. *Base SAS 9.2 Procedures Guide.* SAS Institute, Inc., Cary, NC. 1705 p.

Thompson, M.T., L.T. DeBlander, and J.A. Blackard. 2005. *Wyoming's forests, 2002.* USDA For. Serv., Res. Bull. RMRS-RB-6, Rocky Mountain Research Station, Fort Collins, CO. 148 p.

USDA Forest Service. 1958. *Timber resources for America's future.* USDA For. Serv., For. Res. Rep. No. 14, Washington, DC. 713 p.

USDA Forest Service. 1999. *Forest survey field procedures.* Available online at www.fs.fed.us/rm/ogden/data-collection/pdf/manual_1999.pdf; last accessed Feb. 17, 2015.

USDA Forest Service. 2013. *Interior west forest inventory & analysis: P2 field procedures.* Available online at www.fs.fed.us/rm/ogden/data-collection/pdf/iwfia_p2_60.pdf; last accessed Feb. 17, 2015.

US Environmental Protection Agency. 2013. *Inventory of US greenhouse gas emissions and sinks: 1990–2011.* Available online at www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2013-Main-Text.pdf; last accessed Feb. 17, 2015.

Walker, F.A. 1874. *Statistical atlas of the United States based on the results of the ninth census (1870) with contributions from many eminent men of science and several departments of the government.* J. Bien, New York.

Witt, C., J.D. Shaw, M.T. Thompson, S.A. Goeking, J. Menlove, M.C. Amacher, T.A. Morgan, and C. Werstak. 2012. *Idaho's forest resources, 2004–2009.* USDA For. Serv., Res. Bull. RMRS-RB-14, Rocky Mountain Research Station, Fort Collins, CO. 142 p.

Zar, J.H. 1996. *Biostatistical analysis,* 3rd ed. Prentice Hall, Upper Saddle River, NJ. 662 p., plus appendices.