



Inventory Measurement Rates Lag in Wilderness Areas Across the Western USA

David L. R. Affleck¹ · George C. Gaines III² · Cici Conroy¹ · Gianna Santino¹ · Andrew J. Larson^{1,3}

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Abstract

The National Forest Inventory (NFI) for the USA draws sample data from all lands with equal intensity. Non-response in the NFI tends to be low on public lands relative to private lands, but this research documents higher rates of missing and delayed field plot measurements in wilderness areas relative to other federal lands in the contiguous western US. Given the extent and unique management directives of federal wilderness, discrepancies in field plot completion rates over this region could induce non-response bias in estimators of forest conditions at county or state levels. Further research is needed to identify the statistical impacts as well as the factors contributing to non-response and delayed response in wilderness.

Keywords Natural resource monitoring · Non-response bias · Survey non-response · Wilderness

Introduction

The National Forest Inventory (NFI) for the USA is administered by the Forest Inventory & Analysis (FIA) program of the USDA Forest Service (Forest Service). Bechtold and Patterson (2005) describe how the NFI was designed to span all lands with a balanced distribution of plots over space and time. Westfall et al. (2022a) detail post-stratification estimators for the NFI that are approximately unbiased under the design and that draw on both plot measurements and remotely-sensed data products. Virtually all sample surveys suffer non-response however, and NFI field measurements can not

✉ David L. R. Affleck
david.affleck@umontana.edu

¹ Department of Forest Management, W.A. Franke College of Forestry & Conservation, University of Montana, Missoula, MT, USA

² USDA Forest Service, Rocky Mountain Research Station, Missoula, MT, USA

³ Wilderness Institute, University of Montana, Missoula, MT, USA

always be obtained, or not obtained on schedule. This note is concerned with rates of non-response and delayed response among NFI field plots in federal wilderness, a land designation with unique management objectives and access considerations.

The FIA program has long recognized differential NFI non-response rates by land ownership class, with higher rates on private lands owing largely to denied access (Westfall et al. 2022b; Patterson et al. 2012; McRoberts 2003). Furthermore, apart from effects on precision, it's been recognized that this creates a potential for bias owing to the possibility of distinct management regimes on private vs. public lands. Thus, the post-stratification estimators originally developed for variance reduction are commonly extended by FIA to mitigate non-response bias by incorporating land ownership as a stratification factor (Goeking and Patterson 2013).

With an overriding emphasis on maintaining natural and untrammelled conditions, federal wilderness areas of the USA likewise present a distinct management regime (Wilderness Act 1964). The NFI provides the only nationally-consistent source of monitoring data for these areas but fieldwork is complicated by safety and logistical factors that are inherent to wilderness condition (e.g., motorized or mechanized transport is largely barred). Smith and Gray (2021) highlighted access difficulties as contributing to high levels of non-response within wilderness, with rates rising to the level of complete non-response in parts of coastal Alaska.

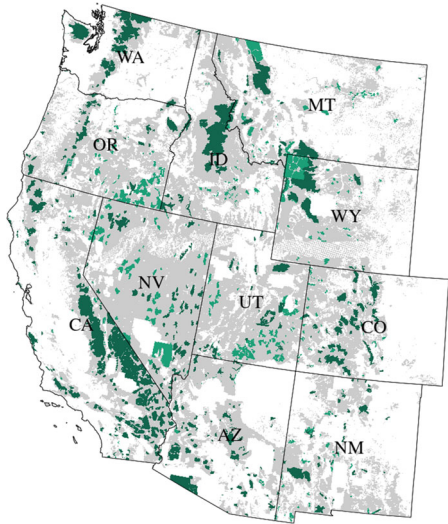
While NFI non-response tends to be infrequent on public lands relative to private lands, there is nonetheless the potential for bias if non-response is concentrated in areas with distinct character. This research therefore focuses on NFI plot measurement rates over two decades across federal lands in the contiguous western USA, where a significant expanse is designated as wilderness (Fig. 1). The primary objective was to compare rates of skipped and delayed field plot measurements on wilderness lands against rates for other federal land. Tied to this was an assessment of re-measurement rates and intervals across these management conditions. A second objective was to trace measurement rates and intervals over time and compare across the 11 states in the region. The methodology and results are described below, and are followed by a brief discussion of potential impacts and research needs.

Data & Methodology

Locations and measurement schedules were drawn for all base NFI plots from internal FIA databases. Plots attach to panels scheduled for inventory in different years, but have a common 10-year re-measurement cycle. Data spanned the 11 states in the contiguous western USA and the temporal record of the annualized NFI for each state. Intensified plots were excluded, as were measurements from periodic inventories undertaken before 2000.

The USA Protected Area Database (US Geological Survey 2024) was used to identify spatial extents of federally-designated wilderness and wilderness study areas. These areas are managed to preserve natural conditions, provide opportunities for solitude and primitive recreation, and protect cultural, ecological, and historical values (Wilderness Act 1964); wilderness study areas carry a distinct designation because they remain under congressional consideration for permanent inclusion in the wilderness

Fig. 1 Federal wilderness areas (dark green) and wilderness study areas (light green) across the western contiguous USA; other lands managed by the Forest Service, Bureau of Land Management, National Park Service, and US Fish & Wildlife Service are shaded grey (data from US Geological Survey 2024)



system. The same database was used to identify NFI plots centered within wilderness areas and on other lands administered by the four federal agencies that manage wilderness: the Forest Service, Bureau of Land Management (BLM), National Park Service (NPS), and US Fish & Wildlife Service (FWS). Records for these plots were then matched to the public FIA database (Forest Service 2025) to retrieve information on sampling status and timing. The FIA database was also used to identify measurements designated for field assessment. NFI plots without forested conditions are generally designated for assessment using remotely-sensed imagery (Westfall et al., 2022a, p. 16); different factors govern the completion and timing of such assessments. Where plot records did not appear in the public database, internal tables were used to identify those designated for field measurement. Densities of retrieved plots and correspondence between databases are described in the Supplementary Materials (Table S1).

Analyses focused on field measurement completion rates and, for those completed, when measurements occurred relative to the scheduled inventory year. Completion rates and timing of plot re-measurement intervals were also analyzed for cases where both measurements were slated for field visitation. Descriptive statistical methods were used; while the NFI plots are a sample of the landbase, the measurement record of the selected plot locations is itself the population of interest for this analysis.

Results

Federal wilderness spans 271,985 km² across the 11 western states, amounting to nearly 9% of the overall land area (Fig. 1; Table S1). Over this region, rates of NFI field plot measurements completed on schedule varied substantially before and after the onset of the COVID19 pandemic in 2020 (87.2% vs. 62.5%; Fig. S1). To focus on operational conditions before the unique challenges posed by the pandemic, we confine the results below to measurements scheduled for completion through 2019.

Similarly, special funding structures and NFI measurement programs existed for New Mexico before 2011 and for Nevada from 2006–2011 (Burril et al. 2021, appx. J; Fig. S1); data for these inventory years in these two states are therefore also excluded below.

Looking across scheduled inventory years and states, field measurement timing and completion rates differed appreciably between wilderness and non-wilderness areas. The accumulation of measurements on wilderness lands was delayed within and across calendar years relative to measurements on other federal lands (Fig. 2a). This differential also occurred at the state level (Fig. S2) but varied from Washington, where the lag on wilderness lands was most pronounced and persistent, to Colorado, where measurements accumulated at nearly the same rates across wilderness and non-wilderness. These figures also highlight that across this region, plot measurement activities are concentrated in the growing season. Figure 2b summarizes rates of measurement completion within, and within 3 years of, the scheduled inventory year. There was a consistent lag in both rates on wilderness lands, yielding an overall reduction of 11.2% in on-time completion rates and 5.1% in delayed (up to 3 years) completion rates in wilderness conditions. At state-by-year levels, on-time completion rates for wilderness lands were lower in 94% of cases (Fig. S1).

FIA attributed 77.7% of missing field plot measurements in wilderness to the presence of hazardous conditions (e.g., cliffs, high water). This compares to 67.3% for missed measurements outside of wilderness areas. However, 16.8% and 11.5% of the measurements within and outside of wilderness, respectively, were missed for reasons unspecified. Among completed field plots (on-time or delayed), the majority were fully measured (93.7% vs. 97.7% in wilderness and outside of wilderness); a further 4.9% of measurements in wilderness areas gathered data from three of the four subplots. FIA records also indicate that 83.8% of completed measurements on wilderness lands were more than 1.6 km from an improved road, as opposed to only

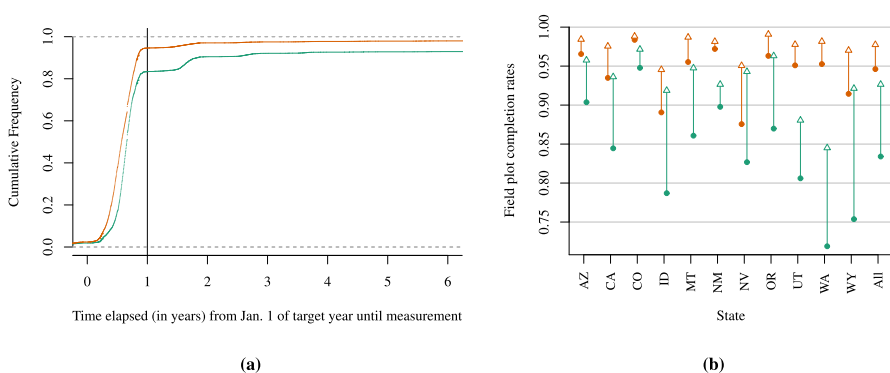


Fig. 2 Field plot measurement (a) accumulation curves and (b) completion rates for federal wilderness (green) and non-wilderness (orange) over scheduled inventory years 2000–2019. In (a), carryover measurements augment curves after the scheduled year (vertical line) but curves do not reach a cumulative frequency of 1 because some measurements are never obtained (or are carried over more than 5 years). In (b) points are completion rates within scheduled inventory years; triangles are completion rates including measurements taken within 3 years of scheduled inventory year

35.3% of completed measurements outside of wilderness areas. Unfortunately, 86.5% of missing field measurements had no information on proximity to roads.

Variance in measurement completion rates bears on both status and change estimation. Table 1 shows differences in the proportion of re-measurement intervals completed where both plot measurements were slated for field assessment. Proportions of intervals completed as scheduled (both measurements occurring within designated inventory years) were 15.4% lower for wilderness plots, though the difference lagged by only 5.5% when delayed measurements were considered. Higher proportions of intervals in wilderness areas were foreshortened by a delayed initial measurement, or extended by delayed re-measurement. Despite these variations, there was no difference in average re-measurement period length – for the subset of intervals completed. Similarly, there was essentially no overall difference between conditions in the extent to which the realized measurement intervals overlapped with the scheduled 10-year re-measurement periods. Completion rates and interval lengths did vary by state, however (Table S2).

Discussion

In the contiguous western USA, federal wilderness comprises 19.4% of the lands administered by the Forest Service, BLM, NPS, and FWS, and together these make up nearly half the landbase (Fig. 1; Table S1). Though not the subject of this communication, federal wilderness encompasses distinct distributions of ecosystems, productivity classes, and cover types (see e.g., Dietz et al. 2015). Also, different management emphases within wilderness can produce distinct disturbance regimes (Parks et al. 2023), that in turn can yield distinct distributions of forest structure, carbon stocks, and habitat characteristics relative to other federal lands. The analyses above show that NFI field measurement rates over federal lands differ between wilderness and non-wilderness (Fig. 2). This variation in plot completion rates is not itself an indicator of bias. Yet overlaid with distinct management or productivity regimes, it creates the potential for bias in estimates of forest status and change at county or state levels. The extent of this effect is anticipated to vary in proportion to the amount of federal wilderness within forested fractions of NFI estimation units (i.e., counties or states) and as a function of whether wilderness designations are integrated into post-stratification.

There were pronounced differences over time and across states in the rate at which field plot completion rates lagged in wilderness areas (Fig. S1). Yet there were no consistent differences between rates for first (initiation) and subsequent (re-measurement) cycles, suggesting that plot establishment activities were not a driving factor. Washing-

Table 1 Number and completion rates of field plot re-measurement intervals ending prior to 2020 as well as mean re-measurement interval length and mean years of overlap with scheduled 10-year periods

Condition	Num. intervals	Completion rate (%)				Length (yr)	Overlap (yr)
		On-time	Foreshortened	Extended	Overall		
Wilderness	3853	76.3	5.9	8.7	92.3	10.0	9.3
Other	15633	91.7	2.6	3.3	97.8	10.0	9.4

ton, Wyoming, Idaho, and Utah had the lowest rates of completion within scheduled measurement years, but subsequent year measurements in Wyoming and Idaho raised overall completion rates to levels more comparable to other federal lands (Figs. 2b, S2).

This research has focused on unit non-response in the form of missing plot measurements. Westfall et al. (2022b) noted that there is also partial non-response in the NFI in the form of missing subplot data, and this research found a higher proportion of incomplete plots in wilderness areas. However, there were much larger differences in the proportions of delayed field plot measurements. Absent disturbance, forest attributes often change relatively slowly over time (relative to variation across space). Therefore, despite the temporal error, completing missed plot measurements in later years can be effective in meeting NFI precision targets. The extent to which doing so is useful in reducing a non-response bias requires further research, however. Reduction of survey non-response rates without consideration of response mechanisms or within-population differences can in fact exacerbate non-response bias (Tourangeau et al. 2017).

Westfall and Wilson (2022) highlighted that non-response can be doubly problematic for NFI change estimation because observations of change require measurement pairs. Here it was found that when delayed measurements were considered, differences between wilderness and non-wilderness were similar for both measurement completion rates and measurement-interval completion rates (Fig. 2b, Table 1). This suggests that the likelihood of obtaining a field measurement is strongly dependent on plot characteristics, such that if a plot is not measured in one cycle then it is more likely also to be missed in the next.

Research is needed into the logistical and programmatic factors yielding higher rates of missed and delayed NFI measurements in wilderness areas. Unlike the analyses of Westfall et al. (2022b) which considered private lands, hazardous conditions were here more commonly cited as contributing factors than denied access. Yet in many cases measurements were missed (or delayed) for reasons unspecified, such that it is difficult to draw conclusions from the FIA databases. Similarly, factors such as plot distances from roads were largely unavailable in the database for missing measurements, though spatial analyses could be undertaken to assess effects of accessibility on measurement propensity. More generally, it is worthwhile examining whether calibration or area control at the estimation stage to recognize wilderness condition would be useful to reduce non-response bias in estimation units where wilderness is a prominent component of the forested lands.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s44391-025-00047-3>.

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Data Availability Spatial distribution of wilderness and federal lands is available online from US Geological Survey (2024); measurement records for NFI plots are available online from the USDA Forest Service (2025).

Declarations

Competing interests The authors declare that there are no competing interests.

References

- Bechtold, W.A. and P.L. Patterson (Eds.) (2005) The Enhanced Forest Inventory and Analysis Program – National Sampling Design and Estimation Procedures. General Technical Report SRS-80, USDA Forest Service, Southern Research Station, Asheville, NC.
- Burrill, E.A., A.M. DiTommaso, J.A. Turner, S.A. Pugh, J. Menlove, G. Christiansen, C.J. Perry, and B.L. Conkling (2021) The Forest Inventory and Analysis database: Database description and user guide version 9.0.1 for phase 2. USDA Forest Service, <http://www.fia.fs.fed.us/library/database-documentation/>.
- Dietz, M. S., R. T. Belote, G. H. Aplet, and J. L. Aycrigg. 2015. The world's largest wilderness protection network after 50 years: An assessment of ecological system representation in the U.S. National Wilderness Preservation System. *Biological Conservation* 184:431–438.
- Goeking, S.A. and P.L. Patterson (Eds.) (2013) *Stratifying to reduce bias caused by high nonresponse rates: a case study from New Mexico's forest inventory*. Research Note RMRS-RN-59, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO.
- McRoberts, R. E. 2003. Compensating for missing plot observations in forest inventory estimation. *Canadian Journal of Forest Research* 33:1990–1997.
- Parks, S. A., L. M. Holsinger, K. Blankenship, G. K. Dillon, S. A. Goeking, and R. Swaty. 2023. Contemporary wildfires are more severe compared to the historical reference period in western US dry conifer forests. *Forest Ecology and Management* 544:121232.
- Patterson, P. L., J. W. Coulston, F. A. Roesch, J. A. Westfall, and A. D. Hill. 2012. A primer for nonresponse in the US forest inventory and analysis program. *Environmental Monitoring and Assessment* 184:1423–1433.
- Smith, R. J., and A. N. Gray. 2021. Strategic monitoring informs wilderness management and socioeconomic benefits. *Conservation Science and Practice* 3:303–313.
- Tourangeau, R., J. M. Brick, S. Lohr, and J. Li. 2017. Adaptive and response survey designs: a review and assessment. *Journal of the Royal Statistical Society A* 180:203–223.
- USDA Forest Service (2025) Forest Inventory & Analysis Database (FIADB), v. 1.9.3.01. <https://apps.fs.usda.gov/fia/datamart/datamart.html>.
- United States Geological Survey (2024) Protected Areas Database of the United States, v. 4.0. <https://www.usgs.gov/data/protected-areas-database-united-states-pad-us-4>.
- Westfall, J.A., J.W. Coulston, G.G. Moisen, and H.E. Andersen (Eds.) (2022a) Sampling and estimation documentation for the Enhanced Forest Inventory and Analysis Program: 2022. General Technical Report NRS-207, USDA Forest Service, Northern Research Station, Madison, WI.
- Westfall, J.A., T.A. Schroeder, J.M. McCollum, and P.L. Patterson (2022b) A spatial and temporal assessment of nonresponse in the national forest inventory of the U.S. *Environmental Monitoring and Assessment* 194:530.

Westfall, J. A., and B. T. Wilson. 2022. Nonresponse bias in change estimation: a national forest inventory example. *Forestry* 95:301–311.

Wilderness Act (1964) Public Law 88-577. 16 U.S.C. 1131-1136, 88th Congress, 2nd Session, 3 Sept. 1964.

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