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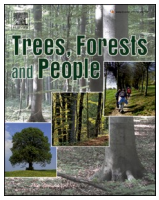

Review Article

Forest definitions applied for national United States forest reporting: Status, gaps, and opportunities

Lara T. Murray [a,*], Sonja N. Oswalt [b], Sara A. Goeking [a], Katherine M. Renwick [a]

[a] USDA Forest Service, Inventory, Monitoring, and Assessment Research, 1400 Independence Ave SW, Washington, D.C. 20250, USA
[b] USDA Forest Service, Southern Research Station, Forest Inventory and Analysis, 2730 Cherokee Farm Way, Suite 101, Knoxville, TN 37920, USA

Introduction

Forest measurement, monitoring, and reporting across jurisdictional, regional, national, and international scales requires transparent and consistently implemented definitions of forest and forest categories (Lund, 2002). A range of forest definitions exist worldwide, shaped by use and management objectives as well as the diverse forest ecosystems that countries seek to include in their forest land estimates (Chazdon et al., 2016). The expansion of global forest resource and environmental reporting instruments, as well as trade policies seeking to advance sustainable forest management, have driven the adoption of common definitions of forest land to support more rigorous, comparable, and objective reporting across time (Mather, 2005; McRoberts et al., 2009).

The United Nations Food and Agriculture Organization (UN FAO) Global Forest Resources Assessment (FRA) is among the most comprehensive and longest-running global forest resources reporting efforts, originating in 1948 (Garzuglia, 2018). The FRA also serves as the reporting mechanism for related indicators from the United Nations Sustainable Development Goals (SDGs) (FAO, 2020) and FRA data are complementary to other global reporting efforts such as the FAO Global Core-Set of Forest-Related Indicators that inform the State of the World's Forests report (Mather, 2005; Nesha et al., 2021).

In 2000, UN FAO introduced a common definition of forest for the FRA using a combination of a land-cover class and a land-use class (Mather, 2005). Land use characterizes the social and economic intent of the land (Coulston et al., 2014; Lund, 2002) whereas land cover describes the vegetation, exposed land, water body, and artificial structures dominating land surface at a point in time (Burley, 1961; Osborne, 1942) (Fig. 1).

Definitions and enhanced transparency and traceability requirements for reporting on other forest-related categories (e.g., other wooded land, primary forests) have also been established by the FAO to respond to evolving information needs, increase participation, lower reporting burden, and enhance compatibility with other international reporting processes (FAO, 2023b). These definitions and transparency requirements acknowledge the tensions presented by assembling data across many countries with existing definitions and associated national forest monitoring systems, as well as the growing but still limited capacity among reporting nations (Garzuglia, 2018; Romijn et al., 2015).

Nevertheless, countries confront challenges in harmonizing FAO definitions with existing national definitions and forest monitoring systems (McRoberts et al., 2009; Nesha et al., 2021; Ståhl et al., 2012). Where national definitions deviate from those established by international reporting bodies, total alignment may be impractical (Gabler et al., 2012), sometimes leading to ambiguous conclusions in global summaries such as the FAO Global FRA publications (McRoberts et al., 2009; Morales-Hidalgo et al., 2015).

This study offers a discussion on how interconnected forest monitoring and reporting frameworks rely on different definitions and address different goals, using the United States (US) reporting as a case study. Objectives were to: 1) review US forest definitions and how they compare with FAO definitions; 2) evaluate implications for data analysis and interpretation; and 3) explore ongoing efforts and opportunities to develop objective, transparent, and useful definitions of forest degradation, primary forests, and forest expansion. Because of the vast size, complex forest land management history, and biogeographic diversity of forests covered by the US forest inventory, lessons learned from this decades-long effort to align a lexicon of definitions can help inform other countries advance transparent, objective, and consistently applied definitions.

Definitions of forest categories applied in the US

US forest definitions are established by the USDA Forest Service, Forest Inventory and Analysis (FIA) program, which is legislatively mandated to "develop and publish national standards and definitions to be applied in inventorying and analyzing forests and their resources" (Forest and Rangeland Renewable Resources Research Act of 1978 as Amended, H.R.11778, Congress 95th Congress, 2019). Data collected by the FIA program are the foundation of both domestic and international forest reports, including national statistics on US forest resources and

* Corresponding author.
E-mail address: lara.murray@usda.gov (L.T. Murray).

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Acronyms

CONUS	Conterminous United States
COP	Conference of Parties
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FIA	Forest Inventory and Analysis
FRA	Forest Resources Assessment
GFG	Global Forest Goals
MOG	Mature and old growth
NFI	Nationwide Forest Inventory
OWL	Other Wooded Land
REDD+	Reduced Deforestation and Degradation plus
RPA	Resources Planning Act
SDGs	United Nations Sustainable Development Goals
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
US	United States of America
USDA	United States Department of Agriculture

FAO FRA reporting (Smith, 2002). In particular, the FIA's Nationwide Forest Inventory (NFI) provides much of the data for reporting through its network of approximately 325,000 permanent plots across 50 states and US affiliated islands.

Forest land

Different definitions of "forest land" are applied for US domestic and international reporting due to differing reporting objectives and the need to align the FAO forest definition with how FIA implements forest land measurement and monitoring in its NFI. Both the FAO and FIA definitions (Table 1) emphasize land use (Fig. 1), focusing on the intended use of the land over an extended period to classify land as "forest land" rather than basing the classification solely on the vegetative cover at a single observation time. This allows regenerating or unstocked lands to remain in the "forest" or "forest land" category if there is no evidence of conversion to a new land use.

The FIA and FAO definitions differ in their minimum forest land area thresholds as well as in-situ height requirements. Because the US uses the imperial system of measurement, forest land area is quantified in units of acres rather than hectares, and therefore the minimum area is 1 acre or 0.4 hectares, whereas the FAO area threshold is 0.5 hectare (1.2-acre). While an in-situ height requirement for trees was part of some historical regional FIA measurement schemas, when FIA adopted a nationally consistent annualized inventory design pursuant to the 1998 Farm Bill, the height requirement was dropped due to the subjective nature of identifying whether a particular plot of trees was capable of achieving the threshold height (Goeking, 2015).

The FIA program applies its forest land definition for domestic reporting and data delivery, but a so-called "international" forest land definition (Table 1) is applied in the US legislatively mandated Resources Planning Act (RPA) Assessment associated reports (e.g. USDA Forest Service, 2023) as well as international reporting frameworks such as for the FAO, United Nations Framework Convention on Climate Change, and the Montréal Process (*The Montréal Process*, 2015). To more closely align with the FAO forest definition, the modified "international" US forest definition uses inventory variables to filter out forest land assumed to not meet the in situ 5 m height threshold. This process is integrated into FIA estimation tools (e.g., the online EVALIDator tool (USDA Forest Service, 2024c)) whereby forest land is excluded based on a combination of forest types representing woodland species compositions and low productivity class (USDA Forest Service, 2024a). Plots that qualify as forest land by the FIA definition, but based on species composition and low productivity class are not assumed to meet the FAO's mean in-situ height requirement, are classified as woodland. For US reporting that applies the international US forest definition, the sum of woodland and forest land reported is equal to the area of forest land reported by FIA domestically.

The FIA's lack of in-situ height criteria for forests in its field sampling protocols, as well as its classification of woodlands based on forest types and productivity class, may broaden the gap between the FIA forest land and FAO forest definitions in the future. As trends toward increased drought severity, climate warming, and associated interactions with fire regimes persist, vegetation type conversion (Coop et al., 2020; Kodero et al., 2024) and shifts in tree morphology toward smaller-statured trees may occur in some regions of the US (Allen et al., 2015; Coulston et al., 2016). These climate- and disturbance-mediated type changes may increasingly affect the ability of some US forests to consistently meet the FAO definition's in situ height threshold.

Woodland

For FAO reporting, woodlands are a separate category from forests, termed "Other Wooded Land" (OWL). The FAO definition of OWL stipulates a canopy cover range of 5–10 percent of trees able to reach these thresholds in situ, or a combined cover of shrubs, bushes, and trees of at least 10 percent (Table 1). The US reports the woodland category separately in FIA's national compilation (e.g. Oswalt et al., 2019) and applies those estimates for the OWL category in FAO reporting. However, while the FIA NFI maintains permanent plots across all lands, it does not consistently collect vegetation data from plots that do not meet the FIA forest land definition (i.e., current or potential tree canopy threshold of at least 10 percent). Given US reporting is constrained by the domain of its NFI, its estimates for OWL are likely underestimates because areas with 5–10 percent tree canopy cover (currently or previously) are not sampled. However, land cover estimates from remote sensing integrated into national land cover products have been shown to

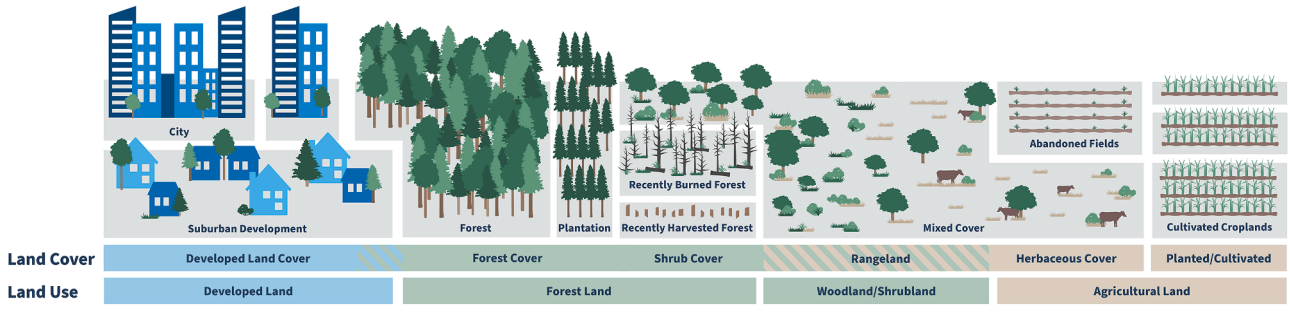

Fig. 1. Simplified illustration of the differences between land cover and land use classifications. Land use has more distinct categories, shown by the breaks in the bars, and land cover can be interpreted more on a continuum, as indicated by the crosshatched sections. Note that the land classes depicted above are often dynamic and may reflect transitionary states. Credit: USDA Forest Service.

Table 1
Forest land and woodland definitions.

UN FAO	FIA	FIA - International Reporting
Forest Land		
Land spanning >0.5 ha (1.2 acres) with trees higher than 5 m (16.4 ft) and a canopy cover of >10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use.	Forest land has at least 10 percent canopy cover of trees of any size or has had at least 10-percent canopy cover of trees in the past, based on the presence of stumps, snags, or other evidence, and that will be naturally or artificially regenerated. Additionally, the land is not subject to nonforest use(s) that prevent normal tree regeneration and succession, such as regular mowing, intensive grazing, or recreation activities. Forest land includes transition zones, such as areas between heavily forested and nonforested lands that are at least 10 percent canopy cover with trees and forest areas adjacent to urban and built-up lands. Also included are pinyon-juniper and chaparral areas in the West and afforested areas. The minimum area for classification of forest land is 1 acre (0.4 ha) in size and 120 feet (36.6 m) wide measured stem-to-stem from the outer-most edge. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if <120 feet wide.	Forest land is a land-use category that includes areas at least 120 feet (36.6 m) wide and at least one 1 acre (0.4 ha) in size with at least ten percent cover (or equivalent stocking) by live trees including land that formerly had such tree cover and that will be naturally or artificially regenerated. Trees are woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 cm) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 m) at maturity in situ. Forest land includes all areas recently having such conditions and currently regenerating or capable of attaining such condition in the near future. Forest land also includes transition zones, such as areas between forest and non-forest lands, that have at least ten percent cover (or equivalent stocking) with live trees and forest areas adjacent to urban and built-up lands. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if they are <120 feet (36.6 m) wide or an acre (0.4 ha) in size. However, land is not classified as forest land if completely surrounded by urban or developed lands, even if the criteria are consistent with the tree area and cover requirements for forest land. These areas are classified as settlements. In addition, forest land does not include land that is predominantly under an agricultural land use.
Woodland		
Termed "Other Wooded Land" for FAO reporting, this is land not classified as forest, spanning >0.5 hectares; with trees higher than 5 m and a canopy cover of 5–10 percent, or trees able to reach these thresholds in situ; or with a combined cover of shrubs, bushes and trees at least 10 percent. It does not include land that is predominantly under agricultural or urban land use.	Woodlands are a subset of forest land and therefore must comply with the FIA forest land definition (described above) to be sampled. Woodlands are distinguished based on species composition and associated forest types comprised of three softwood and six hardwood woodland types. To qualify as one of these woodland forest types, the majority tree stocking must comprise one or more of the 38 FIA-defined woodland tree species. Forest land estimates provided by FIA include woodland.	While the FIA program classifies woodlands as a subset of forest lands, for FAO and other international reporting, woodlands are reported as a separate category from forest land. As such for international reporting, FIA estimates woodland areas as the total area of forest land that is comprised of woodland forest types (see FIA woodland definition) that fall within the low productivity class.
Timberland		
	Unreserved forest land capable of producing 20 cubic feet per acre per year of wood from trees classified as timber species and designated as a timber forest type. Timberland excludes reserved forest land or forest land that is not managed for production of wood products through statute or administrative designation such as wilderness areas. Any tree species that has diameter measured at breast height (d.b.h.), 4.5 feet above the ground line, is considered a timber species.	Same as FIA.

underestimate land cover thresholds (Nowak and Greenfield, 2010), so estimates based on land cover may generally contribute to uncertainty as well.

Primary forest

Many international forest reporting efforts include the area of primary forests as a reporting category (e.g., FAO FRA, Sustainable Development Goal [SDG] 15 (Goal 15: Life on land n.d.), the UN Forum on Forests Global Forest Goals [GFGs] (FAO and CPF, 2022)). Yet the concept of primary forests is highly value-based and emphasizes the so-called "natural" state of forests in the absence of post-settlement human alteration. The FAO defines primary forest as "Naturally regenerating forest of native tree species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed" and that it "[i]ncludes forests where Indigenous Peoples and local communities engage in traditional forest stewardship and management/use activities that meet the definition" (FAO, 2023c). While the FAO definition is generally adopted by reporting countries, its lack of measurable thresholds makes objective and repeatable primary forest reporting challenging, undermining the ability to obtain globally coherent estimates (Bernier et al., 2017; Morales-Hidalgo et al., 2015).

Historically, the US quantified primary forest area for FAO reporting as the aggregate of: (1) areas designated under the "Roadless Area Conservation Rule" (66 Federal Register 3244, January 12, 2001) (i.e., Roadless Areas on USDA Forest Service lands which are subject to limitations on road construction and timber harvesting (Riddle and Vann, 2020)); (2) reserved forest (i.e., forest land where timber extraction is prohibited); (3) 80 percent of the state of Alaska's unreserved natural forest; and (4) Land Trust forest (i.e., forest land managed and owned by major organizations entrusted to preserve and conserve it). This coarsely delineated forest land where primary forests may occur but was not

based on measurable physical attributes that indicate "primary-ness" (e.g., native species assemblages; lack of specific visual indications of human activity).

In 2023, the FAO released an approach to primary forest reporting for FRA 2025 (FAO, 2023a) that offered a "decision-tree" to aid in determining whether or not specific types of forest meet the FAO considerations for primary forest (FAO, 2023a). Subsequently, the US adopted a more strict method for approximating the area of primary forest, limiting it to the forest land of interior Alaska, estimated to be 44,516,000 ha (Oswalt et al., 2019). The rationale is that these forests are subject to minimal human influence, due to low local demand for timber, low population density, and long distances to major markets (Morimoto and Juday, 2019). The same characteristics are not assumed to apply to most of forest lands across the continental US (CONUS) due to the legacy of large-scale fire management and other alterations to US landscapes and their ecological processes following European settlement (Van Wagtendonk, 2007). As such, the latest US reporting to FRA shows a decline in the area of primary forests as compared to previous reporting, though it is assumed to be an underestimate because there are likely pockets of forest land within CONUS that exhibit primary forest characteristics.

Further research is needed for the FIA program to provide estimates that could more comprehensively report on area of primary forests following the FAO definition. This might be achieved by coupling spatial data delineating land based on management authorities with FIA data to objectively characterize and monitor the physical attributes embodied by primary forests in different ecosystems. For example, there may be opportunities to draw from efforts undertaken to define and map mature and old growth forests (MOG) which combined regionally appropriate old growth forest definitions with FIA data to map MOG forest areas (Gray et al., 2023; Pelz et al., 2023; Woodall et al., 2023). However, while MOG forests may have common characteristics with primary forests (e.g., presence of dead wood (Bernier et al., 2017; Pelz et al., 2023)), MOG forest designations do not preclude areas subject to recent human impacts (e.g., fire management).

Changes in forest land

Deforestation

Recent international trade policy developments such as the European Union's (EU) Regulation 2023/1115 (Regulation (EU), 2023) have brought heightened attention to capacity for tracking and reporting deforestation and degradation, often at very fine spatial scales. From a land use perspective, deforestation occurs where forest land is converted from forest to nonforest land use. However, because forest land is dynamic and often includes slow-growing plant communities subject to stochastic natural and managed disturbances, detecting conversion from forest land to undeveloped nonforest land uses such as grasslands or rangelands may be challenging, especially using remote sensing, even with repeated ground-based observations that serve as the basis for US forest land area and land-use change estimates. While the FIA and FAO forest land definitions include areas temporarily devoid of tree cover due to harvest or disturbance, conclusive determination of whether recently cleared land will remain forest can require assumptions about whether trees will grow or whether the land will be subject to cultivation or development (i.e., the future intentions of associated property holders).

Furthermore, boundaries between forest and non-forest land uses are often dynamic across space and time. FIA protocols and training procedures have undergone minor changes over time, mostly aimed at clarification, but this can result in small boundary adjustments that may appear to be deforestation but simply reflect a procedural change. This difficulty is not unique to FIA, and the effect is likely relatively minor in aggregate reporting. A more substantial source of error is likely the natural variation between forest and adjacent nonforest ecosystems that can be challenging to objectively classify (Mathys et al., 2006).

Changes between land use categories may also be challenging to identify over reporting periods, confounding efforts to determine not only the driver of change, but also permanence. Persistent drought, climate warming, and associated interactions with fire regimes are causing many forest ecosystems in the US to experience vegetation type conversion, including shifts from forest to grass or shrublands (Coop et al., 2020; Kodero et al., 2024) or woody encroachment (Yang et al., 2024). In arid regions, FIA continues to classify plots as "forest" for at least 30 years following stand-replacing disturbances such as severe wildfire, and 10 years in mesic or wet regions, meaning that any areas that previously supported at least 10 percent canopy cover will continue to be monitored and considered forest land even if vegetation changes reflect a type change from forest land to shrubland or grassland, provided that land use has not changed. Even where these kinds of ecosystem-specific forest monitoring protocols are in place, country-specific definitions and monitoring protocols may affect the ability to characterize shifts between forest land due to climate- and disturbance-mediated type changes that take place over protracted timeframes.

Forest land expansion

For FRA 2025 reporting, the US leveraged FIA data to estimate annualized changes on the area of forest land expansion based on the last two plot measurement cycles. This was done by nationally extrapolating the area of plots classified as nonforest in the first remeasurement cycle that were classified as forest in the second remeasurement. To differentiate between natural expansion and afforestation, the "Stand origin" variable collected in FIA's sampling protocol was leveraged, where field crews determine whether plots appear to have been planted or naturally regenerated.

While this approach is repeatable over reporting periods, it may be subject to error because determining stand origin can be challenging in heterogenous stands, such as naturally regenerated forests subject to enrichment planting. This approach may also underestimate the area of forest expansion in the US as reported to the FAO FRA. The FIA definition of forest land requires 10 percent cover of tree species, where individuals of any size contribute to tree cover. In cases of artificial regeneration of non-forest land, only the presence of least 150 established trees per acre is required to qualify the plot as forest land, even if those trees do not meet the 10 percent cover threshold. However, there is no agreed upon seedling threshold in cases of natural regeneration on land previously determined to be non-forest land (USDA Forest Service, 2024b). Prior to field sampling, the FIA program uses photo interpretation of remotely sensed imagery (which may be a few years old) to identify plots that possibly meet the definition of forest land and thus require visits by field crews. Given delays between when tree seedlings first appear on previously nonforest plots and when they can be detected as possible forest, FIA program protocol implementation may not consistently capture early stages of forest expansion. As mentioned, FIA's protocol of continuing to monitor sites that were previously forest facilitates change quantification from forest to nonforest and forestland that temporarily does not meet the 10 percent cover threshold, but changes from nonforest to forest under natural regeneration are more likely to be missed until they meet the 10 percent tree cover threshold. In particular, applying FIA's NFI data to estimate forest expansion may not fully capture forest expansion due to gradual woody encroachment onto nonforest land.

Degradation

The increasing international emphasis on measuring and monitoring forest degradation is reflected in the growing set of countries engaging in REDD+ programs (*UN REDD Program Partner Countries*, 2021), other international forest reporting platforms previously mentioned, as well as the 2023 COP28 UNFCCC decision calling for enhanced efforts towards halting and reversing deforestation and forest degradation by 2030 (United Nations, 2023). While forests are inherently dynamic systems

subject to endemic disturbance regimes, forest degradation is broadly understood to manifest where disturbances fundamentally alter forest structure and function, undermining ecosystem services and resilience (Allison et al., 2023; Vásquez-Grandón et al., 2018). The process or state of forest degradation can be driven by a multitude of factors in sometimes subtle, spatially heterogenous ways, and along protracted timelines. This makes establishing a common definition and associated monitoring structures for forest degradation uniquely challenging (Sasaki and Putz, 2009).

The FAO has not yet established a definition for degradation (Allison et al., 2023; FAO, 2023c). While the US has existing data streams and research which offer bases for identifying forest land conditions (e.g., FIA's NFI, the USDA Forest Service Forest Health Protection program, and the National Land Cover Database), key challenges remain in how existing data systems have been designed, implemented and interpreted to support the development of a nationally consistent approach for measuring and monitoring forest degradation in the US. Additional research is needed to explore the spatial and temporal dynamics of different drivers of forest degradation across complex gradients of forest ecosystems as well as to align existing measurement and monitoring infrastructure to develop and implement measurable, repeatable, and statistically defensible ecosystem-relevant definitions of forest degradation for the US.

Conclusion

The complex landscape of definitions of forest land and associated categories present challenges and opportunities for global forest monitoring and reporting. Comparisons of US definitions and subcategories against global definitions validates the importance of transparency in reporting processes to support accurate interpretation. Understanding the underlying goals of each reporting process is equally important as they influence the selection of different populations and definitions.

The USDA Forest Service's FIA program is legislated to "inventory and analyze, in a timely manner, public and private forests and their resources in the United States" (Forest and Rangeland Renewable Resources Research Act of 1978 as Amended, 2019) enabling the program to consistently meet a large variety of user needs, including domestic and international reporting. The use of multiple similar, but slightly different, forest land definitions used in reports across a variety of scales, time periods, and authorities can be a source of confusion to users who assume estimates are directly comparable because they are based on the same underlying data source. Ultimately, the FIA program works to continually improve forest sector surveys as well as efforts to scale that data globally in ways that enhance the goals of sustainable management and natural resource conservation.

Recommendations

- Continued emphasis on transparency around the degree to which measurement and monitoring systems capture forest definitions is critical for accurate interpretation of results.
- While there is existing capacity in the US to identify changes in forest land use at broad national and sub-regional scales, further research and processes for identifying deforestation at more refined spatio-temporal scales is needed.
- Creative and efficient discussions among experts and policy makers are needed to evaluate drivers of forest degradation including how existing measurement and monitoring infrastructure could be leveraged to establish a robust, actionable US definition.

CRediT authorship contribution statement

Lara T. Murray: Writing – review & editing, Writing – original draft, Project administration, Conceptualization. **Sonja N. Oswalt:** Writing – original draft. **Sara A. Goeking:** Writing – original draft. **Katherine M. Renwick:** Writing – original draft.

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.

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Disclaimer

The findings and conclusions in this publication are those of the authors and should not be construed to represent any official USDA or U. S. Government determination or policy.

Data availability

No data was used for the research described in the article.

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