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Riparian forest buffers in the United States: Results from the National Agroforestry Producer Survey

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Abstract Riparian forest buffers are used in the United States for multiple conservation, cultural, and socio-economic benefits. To date, no comprehensive national survey has been conducted on producers with riparian forest buffers, limiting understanding of how they establish, manage, and value these systems. The National Agroforestry Producer Survey was conducted to address this knowledge gap. The survey was completed by 5,682 producers with agroforestry (52% response rate). This study provides results from the 2,433 producers who reported using riparian forest buffers, one of the five agroforestry practices covered in the survey. The average acreage in riparian forest buffers per farm operation was 20.9 acres (8.5 hectares), representing 7.7% of the land area per farm. Most producers (93%) reported that some or all their buffers were established by letting trees and vegetation grow naturally, while 48% reported that they planted some or all their buffer vegetation. Most producers (84%) used personal funds to establish their buffers, with 38% using Federal government program funding. Removing trees and debris from waterways (55%) was the most frequent management activity, followed by pruning tree branches (52%). The most cited benefits experienced were wildlife habitat (96%), erosion control (93%), and bank stabilization (91%), while key challenges were added labor and management complexity (46%), trees falling into waterways (42%), and expense of maintenance (36%). Seventy-two percent of producers reported using crops and products from their buffers for on-farm use, while 26% reported selling products. Most producers

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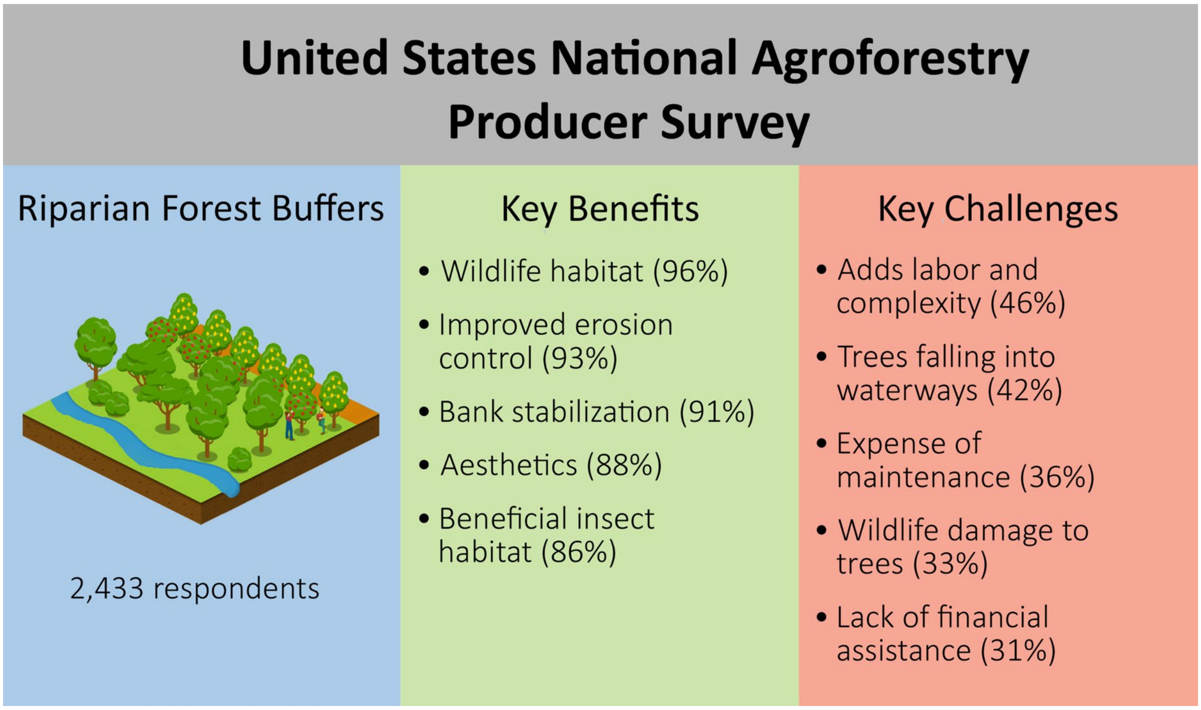
(91%) plan to maintain or expand their acreage in riparian forest buffers.

Graphical abstract



Keywords Riparian forest buffer · Agroforestry · Survey · Streamside management zone · Riparian forest corridor · Conservation buffer

Introduction

In the United States, riparian forest buffers are defined as managed areas adjacent to a stream, river, lake, or wetland that are predominantly covered by trees and or shrubs for the purpose of providing erosion control, bank stabilization, nutrient runoff mitigation, and wildlife habitat. When adjacent to agricultural lands, these managed buffers are considered as an agroforestry practice. While the term and use of riparian forest buffers is relatively new in the United States, riparian areas have been managed and stewarded by Indigenous communities for millennia to produce food, materials, and medicines (Hankins 2013; National Research Council 2002; Tainter and Tainter 1996).

In the 1960s, management of riparian environments was often encouraged in the western portion of the United States to mitigate the impacts timber harvesting can have on fish habitat and water quality (Richardson et al. 2012). Beginning in the 1980s, existing and planted riparian forest buffers were beginning to be used to reduce non-point source pollution in agricultural watersheds (e.g., Lowrance et al. 1984) and by the 1990s, riparian forest buffers were an approved Natural Resources Conservation Service (NRCS) conservation practice (Federal Register 1997). More recently, production-based objectives are being incorporated into riparian forest buffer designs as a form of productive conservation (e.g., Ferich 2019; McRae 2024; Robles-Diaz-de-Leon and Kangas 1999; Trozzo et al. 2014).

Regional surveys have been used to investigate potential adopters' interest, willingness, and perceptions of riparian forest buffers (e.g., Arbuckle et al. 2009; Armstrong and Stedman 2012; Kenwick et al. 2009). Several studies have also explored producer adoption of this practice, offering regional insight into how producers establish, manage, and value these systems (e.g., Chapman et al. 2019; Commender et al. 2020; Cooper and Jacobson 2009; Hagen 1996; Rhodes et al. 2018; Skelton et al. 2005). Producer-identified benefits from these studies include water quality protection, wildlife habitat, aesthetics, sense of stewardship, soil erosion control, recreation, and streambank stabilization. Producer-reported challenges include establishment and management difficulties, inadequate financial assistance, spread of invasive species, wildlife damage, and loss of income. Limited information exists on establishment and management methods, use, and extent of riparian forest buffers.

On the national scale, there are few surveys about riparian forest buffer adoption and use. Natural resource professionals across the United States were surveyed in 2000 to determine agroforestry practice extent, opportunities, and the types of assistance needed to advance adoption. Most natural resource professionals (81%) said riparian forest buffers were practiced in their area, more than any other agroforestry practice in the survey (USDA 2000). Respondents reported that buffers were often used to address more than one issue at a time with the most dominant uses being bank erosion control (89%), non-point source pollution control (83%), and wildlife habitat enhancement (73%). While results from the natural resource professional community are useful, national-level information from agricultural producers who have implemented this practice is lacking. To address this information gap, we conducted a national survey of producers who have riparian forest buffers. Questions addressing this knowledge gap include:

1. How many producers use riparian forest buffers across the country?
2. Where are riparian forest buffers located across the country?
3. How much land do producers allocate to riparian forest buffers on their farm operation?
4. What establishment and management activities are producers using for their riparian forest buffers?
5. When were riparian forest buffers established, and what plans do producers have for these systems in the future?
6. What funding sources are used to establish and maintain riparian forest buffers?
7. What information sources do producers use to learn about agroforestry?
8. What are the primary benefits and challenges of riparian forest buffers reported by producers?
9. What crops and products are producers harvesting from their riparian forest buffers and where are they selling them?

This new research information can support technical assistance delivery and help producers make well-informed decisions about their operations when designing and planning riparian forest buffers.

Methods

Sample frame

The sample frame for the National Agroforestry Producer Survey was agroforestry adopters identified in the 2017 United States Census of Agriculture (COA). A random sample, stratified by state, was taken from the COA agroforestry population (N = 30,853). Sample size for the survey was based on one of two methods. The first method was Cochran's modified formula for finite populations, using a 95% confidence level, a proportion of 95%, and margin of error of 2.5% (Eq. 1).

$$n = \frac{m}{1 + \frac{m-1}{N}} \tag{1}$$

where:

- n is the state sample size
- $m = [z^2 * p * (1-p)]/\varepsilon^2$
    - z is the alpha level z score
    - p is the proportion of farms that practice at least one of the five agroforestry practices
    - ε is the margin of error
- N is the state population

The second method was the minimum number of reports (Eq. 2). This method was required by the United States Department of Agriculture (USDA), National Agricultural Statistics Service (NASS) to ensure disclosure threshold rules were met.

$$nr = \frac{r}{pt} \tag{2}$$

where:

- nr is the number of reports
- r is the number of positive reports
- p is the proportion of farms that practice at least one agroforestry practice
- t is the percent of the proportion that is in at least one of the relevant agroforestry categories

Each state-level sample size was based on the larger sample of the two methods (Cochran's or minimum number of reports). Participants for the survey were selected by USDA NASS through a random/stratified approach, using farm size, farm value, and type of operation as the selection criteria. Previously collected data from the 2017 COA was used for this process. The final sample size across all 50 states was 11,029 farm operations (36% of the entire agroforestry population identified in the 2017 COA).

Questionnaire development

The first phase of questionnaire development was to conduct a systematic review of the riparian forest buffer adoption literature (unpublished results). Questionnaires from these studies were assessed for use in the national survey and helped identify potential regional nuances for response options. Following questionnaire development, agroforestry professionals reviewed the instrument in an iterative process. Five professionals initially reviewed the instrument, the research team made suggested edits, and the questionnaire was sent to another five professionals. Four total rounds (i.e., 20 total reviewers) were used. Finally, nine cognitive interviews with farmers were conducted by USDA NASS to further revise the questionnaire.

The final questionnaire was 24 pages, covering windbreaks, silvopasture, riparian forest buffers, alley cropping, and forest farming. The riparian forest buffer section of the questionnaire was four pages, and included questions on acres in the practice, site preparation activities, time since establishment, management activities, benefits and challenges, crops and products used and sold from riparian forest buffer vegetation, information sources, funding sources, and markets where crops and products were sold. Refer to the survey instrument (Online Resource 2) for items and measurement for each question set. Sociodemographic and farm operation characteristics were not collected in the questionnaire since those data were previously collected for each respondent in the most recent COA and will be the topic of a future study.

Survey implementation

The survey was implemented using a modified version of the Tailored Design Method (Dillman et al. 2014), involving the following four waves between December 2021–April 2022:

1. Advance notice postcard was sent to 11,029 producers December 2021, informing them that they were randomly selected to participate in the National Agroforestry Producer Survey and that a survey packet was forthcoming.
2. Survey packet was sent in January 2022, and included a cover letter, definitions sheet with pictures illustrating each agroforestry practice, paper questionnaire, and prepaid return envelope. The cover letter described the purpose of the research, the Office of Management and Budget approval number (OMB No. 0535–0271), and standard human subjects informed consent language.
3. Reminder postcards were sent two weeks after the survey packets were mailed.
4. Phone enumerators were used to contact respondents who had not responded 30 days after the survey packets were mailed. Phone enumerators were from the National Association of State Departments of Agriculture (NASDA).

Data entry and cleaning

Data from all survey collection methods (paper, online, phone) were collected and entered into a secure database by USDA NASS. Any information that could be connected to individual operations was removed in accordance with federal law (USDA NASS 2024a). USDA NASS uploaded the data to the Coleridge Administrative Data Research Facility (ADRF) enclave, which is a secure FedRAMP-authorized computational research platform for sensitive confidential data. All data exported from the enclave were reviewed by Coleridge and USDA NASS to ensure disclosure risk guidelines were followed.

Data analysis

Data analysis was undertaken using STATA 18 and Microsoft Excel within ADRF. Stringent rules govern how results can be published and prohibit publishing results without at least five responses within a given data cell due to disclosure risk (USDA NASS 2024b). Response frequencies with fewer than five observations were suppressed and coded with a "P" in the results. Most results are therefore reported at the national or regional level as state level results infrequently met the threshold. For the regional analysis, USDA Farm Production Regions (USDA NRCS 2022) were selected, since those regions used defined state borders which were necessary based on the available data for each respondent.

Descriptive statistics were calculated for numeric variables, with three authors ensuring accuracy of results by reviewing and revising the data cleaning program. Open-ended responses were analyzed using the constant comparison method to develop patterns and categories (Boeije 2002). With the aim of meeting the disclosure threshold wherever possible, results are presented by question set/individual item meeting the threshold.

Two results, acres of riparian forest buffers and acres in farmland, are weighted values as required by USDA NASS since census data were used in the analysis. All other data are presented as unweighted. Non-response bias was assessed by comparing the mean difference in average farm size between respondents (5682) and non-respondents (5347) using farm size data previously collected for each respondent in the most recent COA. A two-tailed t-test found that non-respondents have larger farm operations. To our knowledge, we are unaware of studies exploring non-response in agroforestry surveys, especially as it pertains to farm size. Pennings et al. (2002) explored non-response in farmer surveys and found that producers with larger farms were more likely to respond to surveys, potentially due to the topic being more related to their operation. This finding contrasts with ours.

Results and discussion

Response rate and regional distribution

The response rate for this survey was 52% with 5682 usable questionnaires (Online Resource 1, Table 1). The overall margin of error for the survey is 1.2% with a 95% confidence level. Of the producers who responded to this survey, 4068 specified which agroforestry practices they used and 2433 (60% of the agroforestry sample) reported using riparian forest buffers. The Farm Production Regions with the greatest number of respondents with riparian forest buffers were geographically dispersed (Fig. 1). The states with the highest number of respondents with riparian forest buffers were Pennsylvania, Virginia, Missouri, Oregon, and Illinois (Online Resource 1, Table 1). The states with the highest percentage of agroforestry respondents with riparian forest buffers were Maryland (87%), Pennsylvania (81%), and Virginia (81%) (Fig. 2). These three states are all part of the Chesapeake Bay Watershed and are in a region with well-established water quality initiative programs. In 36 of 50 states, at least 50% of the statewide agroforestry sample reported having riparian forest buffers.

Several regional studies in the United States have investigated producer use of riparian forest buffers, though data from these studies is not directly comparable to ours, as these surveys are of producers in general and not just those who have agroforestry. For example, Workman et al. (2003) found that 27% of producers surveyed in Florida and 52% in Alabama reported use of riparian forest buffers. A survey of Iowa farmers identified that 43.5% used riparian buffers (which included herbaceous buffers as well as riparian forest buffers) (Morris and Arbuckle 2021). In a survey of agroforestry adopters in 12 Missouri counties, 6.8% of respondents had riparian forest buffers, more than any other agroforestry practice (Stubblefield et al. 2025).

Table 1 Acreage comparison between farms with riparian forest buffers to all farms in the United States by farm size class

Farm size class (acres)*	Percent of farms with riparian forest buffers	Percent of all farms in the United States
1 – 9	3.5	12.3
10 – 49	24.0	29.8
50 – 179	37.1	27.9
180 – 499	23.1	15.2
500 – 999	7.3	6.3
1000 – 4999	4.9	7.0
5000 +	0.2	1.4

*Acre size classes correspond to 0.40—4.04 ha, 4.04—20.23 ha, 20.23—72.84 ha, 72.84—202.34 ha, 202.34—404.69 ha, 404.69—2023.43 ha, > 2023.43 ha

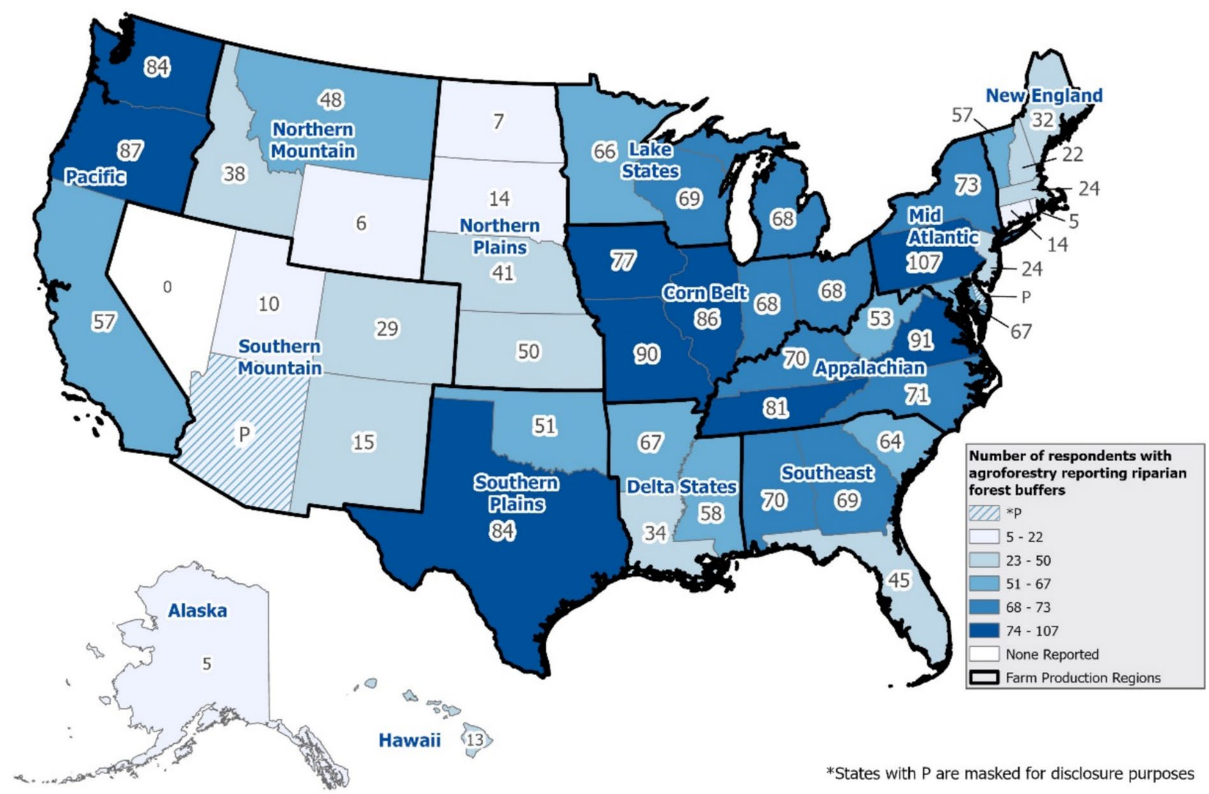


Fig. 1 Number of respondents in sample who reported riparian forest buffers by state and Farm Production Region (n = 2433). Figure notes: states with a "P" represent values where n < 5 and are masked for disclosure purposes

The large variation in adoption between these regional studies is also reflected in our national dataset. Differences by region may reflect availability of financial and technical assistance through state and federal programs and overall awareness of agroforestry (Gene et al. 2019; Kellerman et al. 2025). In addition, unlike other agroforestry practices, some states have laws that require riparian buffers, though these often differ in width, purpose, and structure, including whether they must include woody vegetation (Gene et al. 2019).

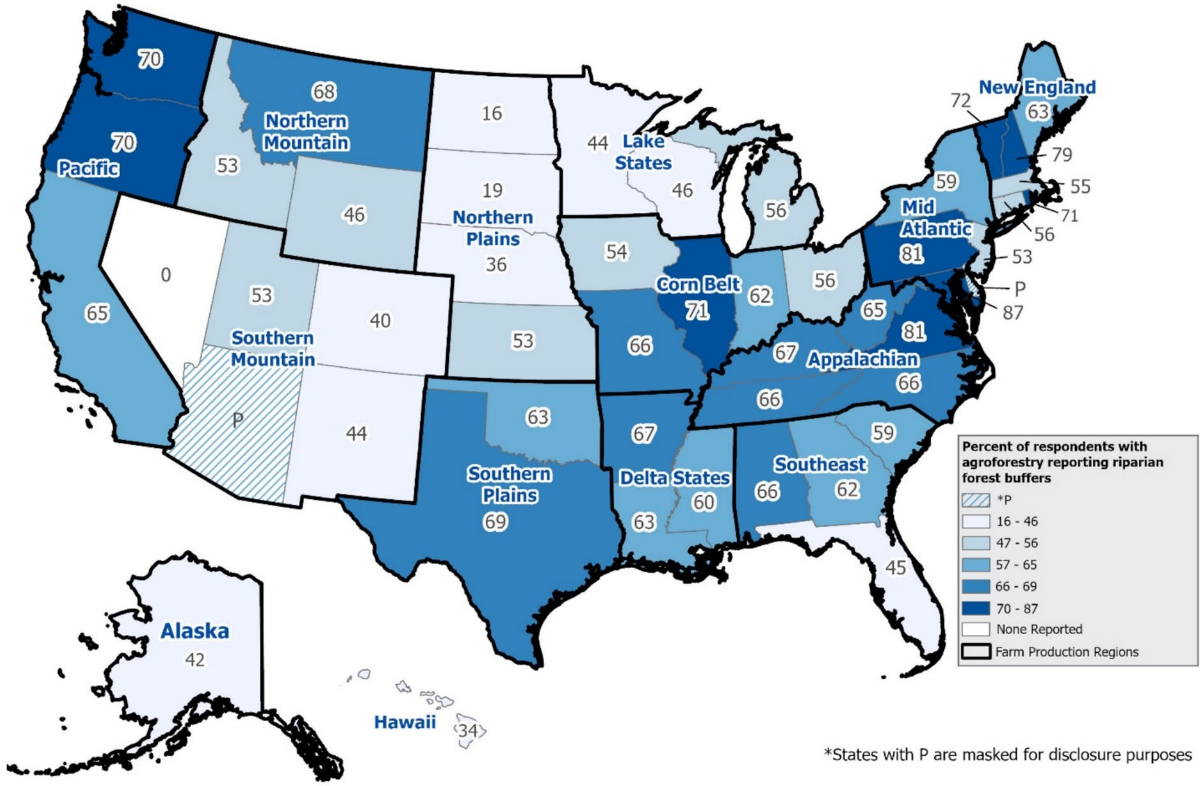


Fig. 2 Percent of respondents with agroforestry who reported use of riparian forest buffers by state and Farm Production Region. Figure notes: states with a "P" represent values where n < 5 and are masked for disclosure purposes

To understand whether predictive variables exist for riparian forest buffer extent across the country, further analyses are needed.

Land area in riparian forest buffers

The national average acreage in riparian forest buffers per farm operation reporting the practice was 20.9 acres (80.2 acres SD) or 8.5 ha (32.5 ha SD) (Online Resource 1, Table 2). Over half of the farm operations in our sample (52.2%) had total riparian forest buffer acreages between 1 to 9 acres (Online Resource 1, Table 3). This was followed by 39.5% of farm operations who had riparian forest buffer acreages between 10 to 49 acres, 6.9% between 50 to 179 acres, and 1.4% with 180 or more acres.

Riparian forest buffer acreage varied by Farm Production Region, with 10.5 acres (4.2 ha) in New England to 110.2 acres (44.6 ha) in the Southern Mountain region (Fig. 3). Standard deviations for average acres in riparian forest buffers by farm were large for some regions, particularly the Southern Mountain region (525.61 SD), which may explain why the average acreage was so high for this region (Online Resource 1, Table 2).

When aggregating all respondent acreage data with corresponding census weights to expand the sample to the entire population with riparian forest buffers, there are 228,689 estimated acres (92,547 ha) of riparian forest buffers in the United States. The Appalachian (43,339 acres, 17,539 ha), Southern Plains (32,095 acres, 12,988 ha), and Southeast (30,363 acres, 12,287 ha) regions had the most estimated land in riparian forest buffers (Online Resource 1, Table 4). It is important to note that the acreage estimates from our study are for riparian forest buffers as an agroforestry practice. The total number of acres in riparian areas or floodplains adjacent to agricultural land are much higher. Future studies could combine producer survey data with geospatial data, including

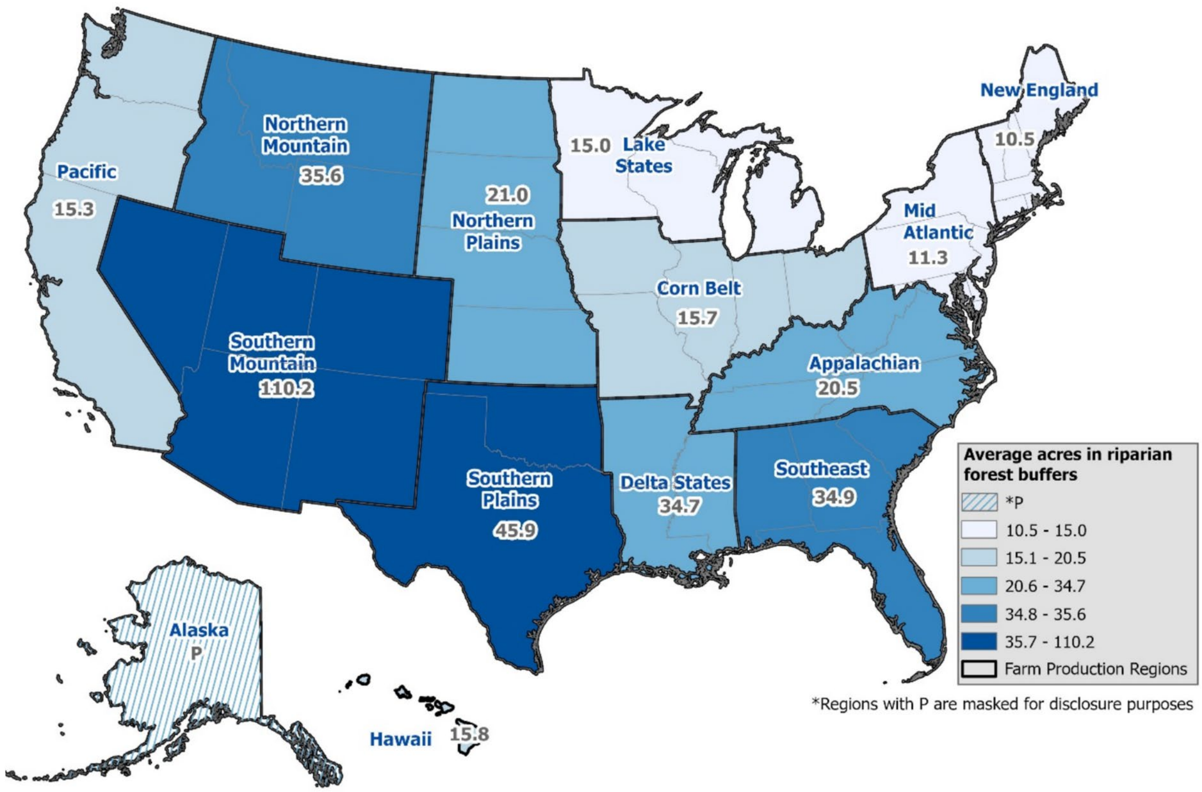


Fig. 3 Average acres of riparian forest buffers per farm operation with the practice by Farm Production Region. Figure notes: regions with a "P" represent values where n < 5 and are masked for disclosure purposes

property delineation, to help refine national estimates of riparian forest buffer extent.

Currently, there is no other national-level data for which total riparian forest buffer acreage can be compared to our study. One regional study of producers by Royer et al. (2016) found that the U.S. state of Pennsylvania has a total of 5808 acres (2350 ha) in riparian forest buffers. State-level estimates in our survey are not available due to disclosure rules, but the Mid-Atlantic region, which includes Pennsylvania, had an estimated 18,612 acres in riparian forest buffers (7532 ha).

The average acreage of farms with riparian forest buffers was 272.8 acres (648.5 acres SD) or 110.4 ha (262.4 ha SD). Acreage data was also compared to the average acreage of farms across the United States farming population using COA data (USDA NASS 2024a) to assess whether farms with riparian forest buffers trend toward smaller or larger farm sizes (Table 1) (Online Resource 1, Table 5). The highest percentage of respondents with riparian forest buffers by farm size were in the three mid-sized categories (10–49 acres, 50–179 acres, and 180–499 acres) which encompassed 84.2% of the farms in the sample. When compared to the percentage of all farms in the United States by farm size class, the riparian forest buffer percentages were generally comparable (Table 1). However, the percentage of small farms (1–9 acres) with riparian forest buffers was lower compared to the percentage of all farms in the country for that size class, which may be due to a lower probability of having a watercourse on a small farm.

As a percentage of farm size, riparian forest buffers occupy 7.7% of the land area per farm for operations with the practice. However, the percentage of land in riparian forest buffers per farm differs on a regional basis, ranging from an average of 3.5% of land area per farm for the Northern Mountain region to 25.0% of land area per farm for the Southern Mountain region (Online Resource 1, Table 6). It is unclear why there is a large difference between these two regions, which both have large average farm sizes (USDA NASS 2020).

There is limited riparian forest buffer acreage information from other surveys and data sources to compare to our study. In a survey of Pennsylvania landowners (n = 550) with riparian forest buffers enrolled in the Conservation Reserve Enhancement Program (CREP), responses yielded an estimated average of 9.9 acres (4.0 ha) in buffers per farm (Cooper and Jacobson 2009). In Missouri, Stubblefield et al. (2025) identified nine producers with an average acreage of 30.6 acres (12.4 ha) per farm in riparian forest buffers. Studies reporting average farm size with riparian forest buffers include Maryland with 138.5 acres (56.0 ha) (Hagan 1996) (n = 49) and Virginia with 263.0 acres (106.4 ha) (Commender et al. 2016) (n = 131).

Several factors influence riparian forest buffer use and acreage data, both quantitatively and spatially. Unlike other agroforestry practices, riparian forest buffers have the unique criterion of being limited to a specific landscape setting; being adjacent to a watercourse or waterbody (USDA NRCS 2020). For instance, perennial stream density is higher in the eastern half of the United States (Jaeger et al. 2021) which could affect reported use and acres of riparian forest buffers. Some states and local governmental entities also have mandatory buffer requirements on agricultural lands, which can include riparian forest buffers (Gene et al. 2019). Another factor potentially influencing acreage estimates is that respondents may vary in their interpretation of what constitutes as a riparian forest buffer on their farm. Some may focus on a managed riparian forest buffer with a fixed width while others may include a riparian area or vegetative

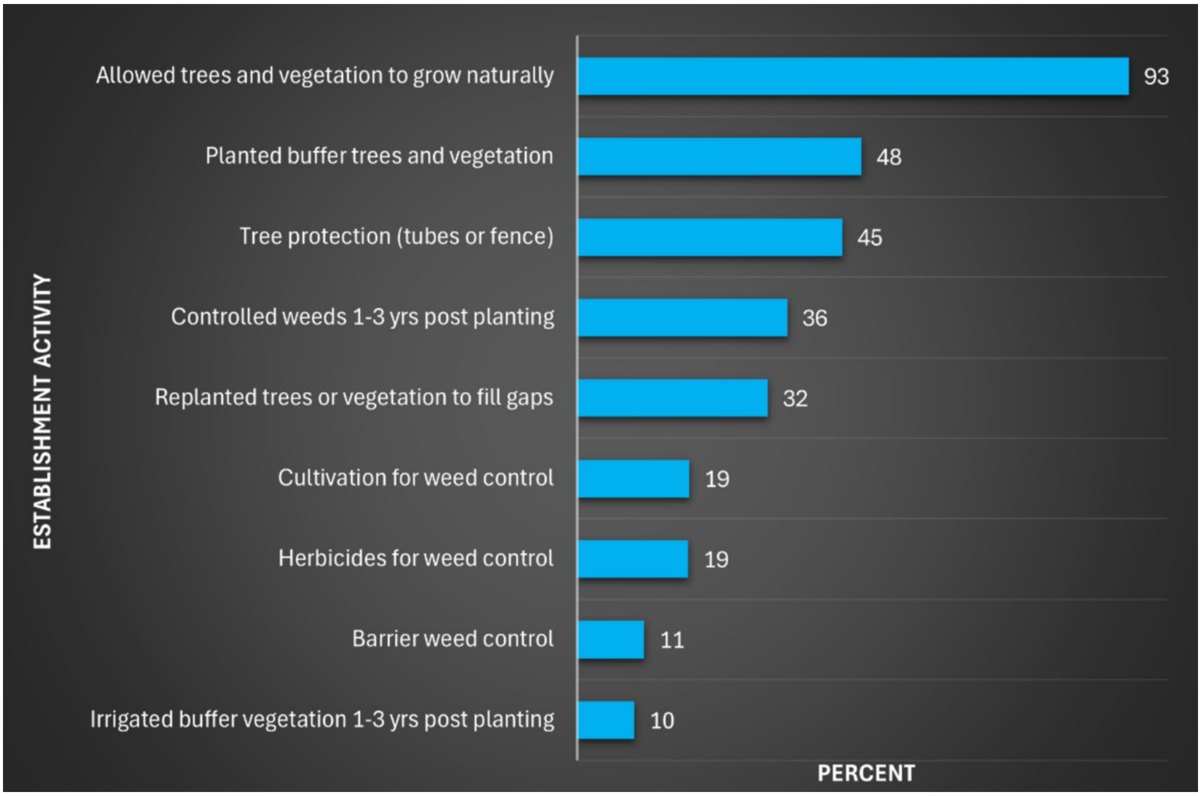


Fig. 4 Percent of respondents who used various establishment activities for their riparian forest buffers. Figure notes: number of respondents ranged from 2182 – 2361 depending on response option and are reported in the Online Resource 1, Table 7

floodplain in their response, which could affect the reported acreage. Yet others may have included the stream or river width in their estimation. In Pennsylvania, Cooper and Jacobson (2009) found that producers often overestimated their acreage of riparian forest buffers enrolled in CREP when compared to what the Department of Environmental Protection had on record.

Establishment activities

Respondents were asked to report which establishment activities they used to implement their riparian forest buffers (Fig. 4) (Online Resource 1, Table 7). Allowing trees and vegetation to grow naturally had the highest response (93%), well above the second highest response of planting buffer trees and vegetation (48%). Allowing vegetation to grow naturally may be a universal option since some natural regeneration will likely occur due to conditions being conducive for plant colonization in riparian areas (National Research Council 2002). In addition, respondents may have selected this option for when they are relying on existing vegetation as their riparian forest buffer. Further, producers may be trying to minimize their establishment efforts and expenses by limiting planting and instead relying on natural regeneration. For instance, some states require vegetated buffers along waterways and cost-share for planting may not be available (Gene et al. 2019). Nonetheless, the results suggest that producers are relying heavily on natural regeneration in comparison to planted vegetation.

Establishing riparian forest buffer vegetation naturally raises many questions. What species are allowed to grow? Are these species suitable for the landscape conditions and desired objectives? Are the species and types located in appropriate locations? Are invasive species allowed to establish? While our survey has some information on species used in riparian forest buffers (see Crops and Products section), this topic requires further investigation.

The percent of respondents using fencing and/or tree tubes (45%) was similar to planting trees and vegetation (48%), which may be due to these establishment techniques being more likely used together in a planted scenario (Palone and Todd 1998). A little over one-third of respondents controlled for weeds post planting (36%). Other weed control methods were lower, including cultivation (19%), herbicides (19%), and barrier weed control (11%). Minimal weed control is potentially concerning given that riparian areas are frequently disturbed in agricultural landscapes and often have invasive and competitive species (National Research Council 2002; Pannill et al. 2001). An assessment report of riparian forest buffers in Maryland determined that weed control was a key factor in the growth and survival of planted trees (Pannill et al. 2001).

When asked to provide other establishment activities used to establish their riparian forest buffers, 180 producers responded (Online Resource 1, Table 8). Unique responses included brush hogging (14%), thinning volunteer or invasive trees and shrubs (14%), bank stabilization (5%), prescribed burn (4%), and flash grazing (3%).

Limited research beyond this study is available on how producers establish their riparian forest buffers. Hagan (1996) noted that Maryland landowners with buffers said they established and maintained their buffers through mowing, herbicide application, and replanting trees that died. In another Maryland study consisting of 130 randomly selected planted riparian forest buffers (1 to 3 years in age), stocking consisted of planted seedlings with tree shelters/tubes (11%), seedlings without shelter (41%), balled and burlapped or containerized saplings (11%), natural regeneration (36%), and pre-existing trees (1%) (Pannill et al. 2001). In total, planted trees made up 63% of the stocking.

Time periods riparian forest buffers were established

Of the 2361 producers who responded to this question, 68% reported establishing their riparian forest buffers 15 or more years ago (Fig. 5). The percentage of respondents who established riparian forest buffers less than 5 years ago, between 5 and 10 years ago, and between 10 and 15 years ago varied by only 7%. As producers were allowed to select multiple time periods, the cumulative percentage values are greater than 100%. While no other national dataset exists for comparison, regional studies in Pennsylvania, Nebraska, and Maryland indicate that riparian forest buffers have been established in many regions several

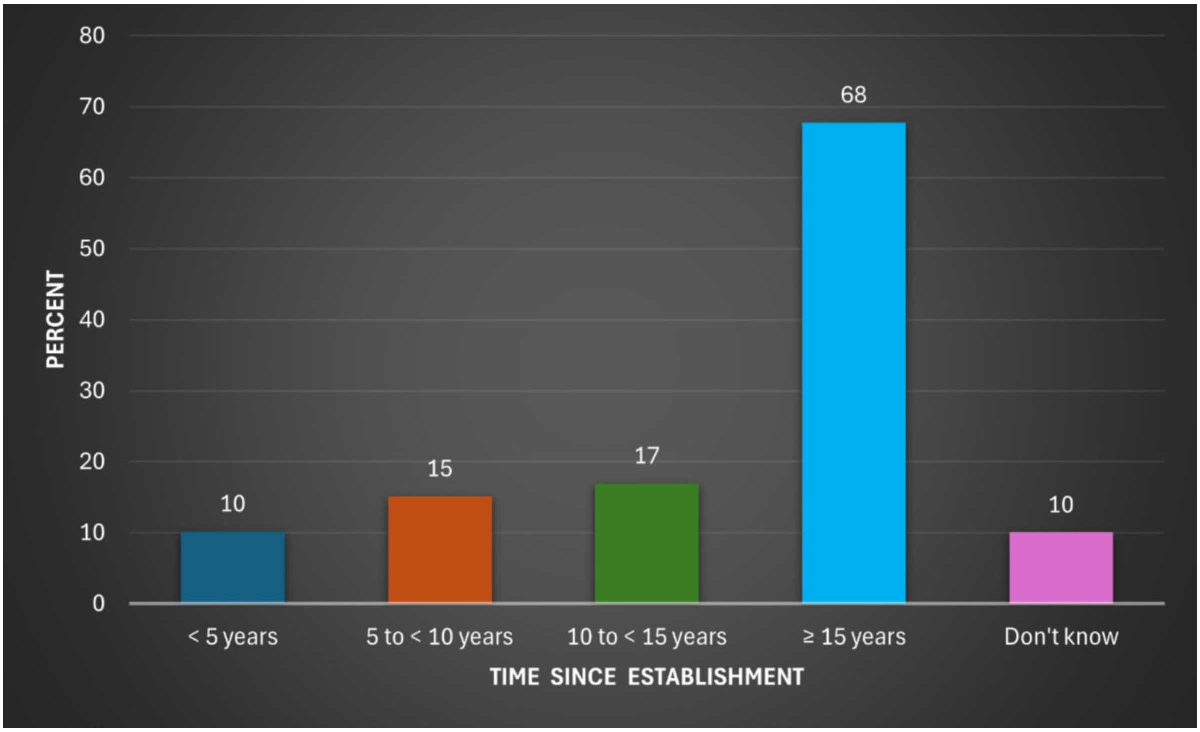


Fig. 5 Time periods riparian forest buffers were established by producers (n = 2361)

decades ago (Cooper and Jacobson 2009; Hagan 1996; Skelton et al. 2005).

Information sources

The most common information sources used to learn about agroforestry were books, print newsletters, and brochures (66%), internet (63%), and conservation district staff (61%) (Fig. 6) (Online Resource 1, Table 9). These results confirm the importance of printed publications for farmer audiences, previously identified by Witzling et al. (2021). In addition to these information sources, 130 respondents provided information sources other than the response options provided. Of these additional sources, 31% listed personal experience and trial and error, 16% said information came from university courses, 10% from family/generational experience, and 5% from local conservation staff (Online Resource 1, Table 10).

When producers were asked to report the information sources most important to them, they tended to select natural resource professionals more often than other response options, with conservation district staff (35%), university cooperative extension (35%), and state agricultural, environment or forestry staff (28%) being examples (Fig. 6). This illustrates the importance of natural resource professionals in providing information about riparian forest buffers and likely reflects their role in state and federal program delivery and content expertise about the practice.

Few regional studies in the United States have investigated how landowners access information about riparian forest buffers. Hagan (1996) surveyed landowners in Maryland and found that those with riparian forest buffers were most likely to have learned about the concept of installing a buffer through a personal meeting or conversation (43%), followed by other (21%), information from the media (17%), and written materials (15%).

Funding used to establish and manage riparian forest buffers

Because the survey asked about funding sources across all agroforestry practices, this analysis uses responses from producers who only had riparian

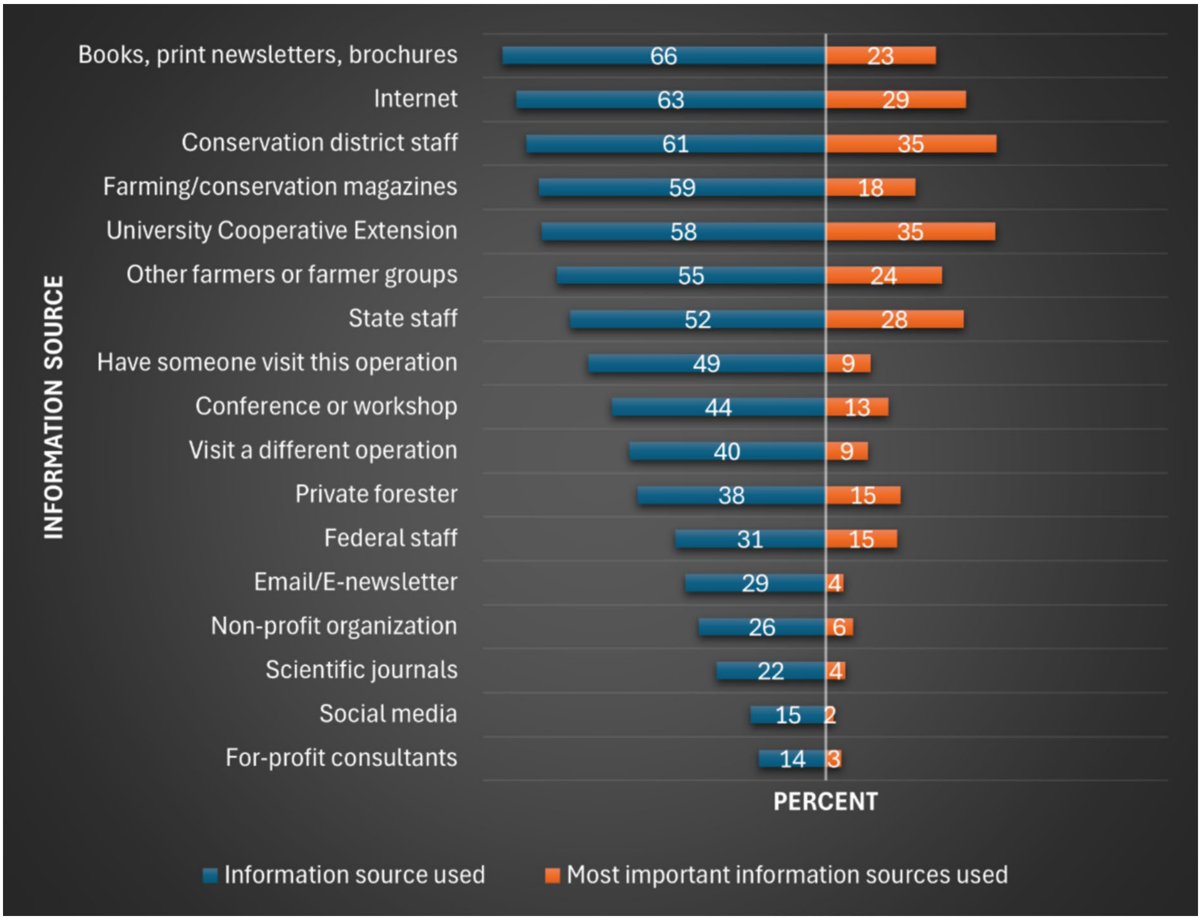


Fig. 6 Percent of riparian forest buffer respondents who used various information sources to learn about agroforestry, along with percent of respondents who reported an information source was among the three most important to them. Figure notes: number of respondents for information sources used ranged from 2046 – 2137 depending on response option and are reported in the Online Resource 1, Table 9. Number of respondents for most important information sources was 1852

forest buffers and no other agroforestry practices. Most respondents (84%) establish and manage some portion of their riparian forest buffers using their own funds (Fig. 7) (Online Resource 1, Table 11). This is likely because most programs that provide financial assistance or cost-share for riparian forest buffers also require some match or other funds to be provided by the participant. The high frequency of self-funding could also reflect the low costs associated with riparian forest buffer established through natural regeneration.

The second largest source of funding for riparian forest buffer establishment and management was federal programs, which 38% of respondents used. When asked to specify which programs were used, 157 producers provided information (Online Resource 1, Table 12). Of respondents who specified using federal programs to support riparian forest buffer establishment, 44% mentioned programs from the USDA Farm Service Agency (FSA), including the Conservation Reserve Program (CRP) and the Conservation Reserve Enhancement Program (CREP). Programs from the USDA Natural Resources Conservation Service (NRCS) were also listed by 40% of respondents and included the Environmental Quality Incentives Program (EQIP), the Conservation Stewardship Program (CSP), and the Wildlife Habitat Incentives Program (WHIP).

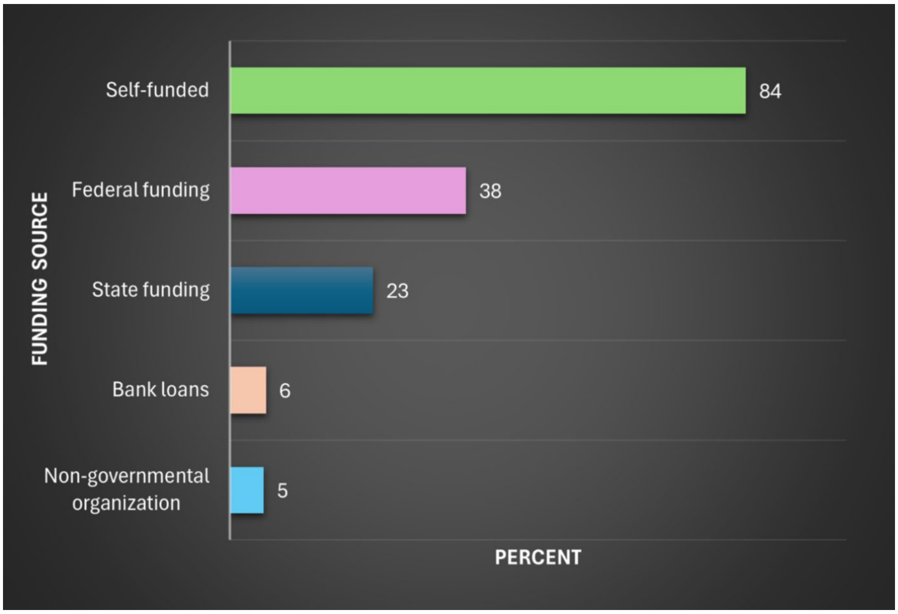


Fig. 7 Percent of respondents who used various funding sources to establish and or manage their riparian forest buffers. Figure notes: number of respondents ranged from 427 – 478 depending on response option and are reported in the Online Resource 1, Table 11

About 23% of respondents used state funding. This reflects the large number of state programs that support riparian forest buffers. When asked to provide information about which state programs were used, 90 producers responded. Thirty-eight percent listed a specific state program, 27% said they received cost share in general, and 22% listed a federal program implemented at a state level (Online Resource 1, Table 13). Loans from banks (6%) and funding from NGOs (5%) were uncommon, while private investment had too few respondents to report.

Some regional studies have investigated farmer attitudes toward specific state or federal funding sources for riparian forest buffers (Cooper and Jacobson 2009; Hagan 1996), which provide some insights into program funding. Chapman et al. (2019) investigated CREP and found that program rules and design guidelines that do not match farmer values and preferences may limit use of this program. This finding may explain why participation in state and federal financial assistance programs is not more widespread among producers, despite availability. Rhodes et al. (2018) found that while farmers were interested in financial assistance, more than 70% of non-adopters were not familiar with financial assistance programs. This suggests the importance of better understanding the relationship between information sources and financial assistance programs.

Management activities

The management activity most reported by respondents was removing trees/debris that have fallen into waterways (55%) (Fig. 8) (Online Resource 1, Table 14). Fallen trees and debris in a stream channel can contribute to streambank erosion and instability in addition to localized flooding (Lyons et al. 2000; Zhang et al. 2019). However, removal of coarse woody debris in stream channels can also have a detrimental impact by increasing stream velocity, which can increase bank and bed erosion (Smith et al. 1993). Coarse woody debris can also provide habitat for aquatic life and other ecosystem services (Hrodey et al. 2008). The net effect of removing fallen trees and other debris from stream channels is dependent upon landscape and site variables, as well as producer objectives. Given the propensity of this activity reported by producers with riparian forest buffers in our study, further analysis is warranted to understand the drivers of this management activity and its implications.

Tree maintenance, including pruning tree branches (52%) and removing/thinning trees (42%), were the second and third most selected activities by respondents. Pruning trees can improve growth rates and timber quality (Gold et al. 2024; Schultz et al. 2004). Removing/thinning trees can also be a beneficial economic activity if trees are harvested for timber

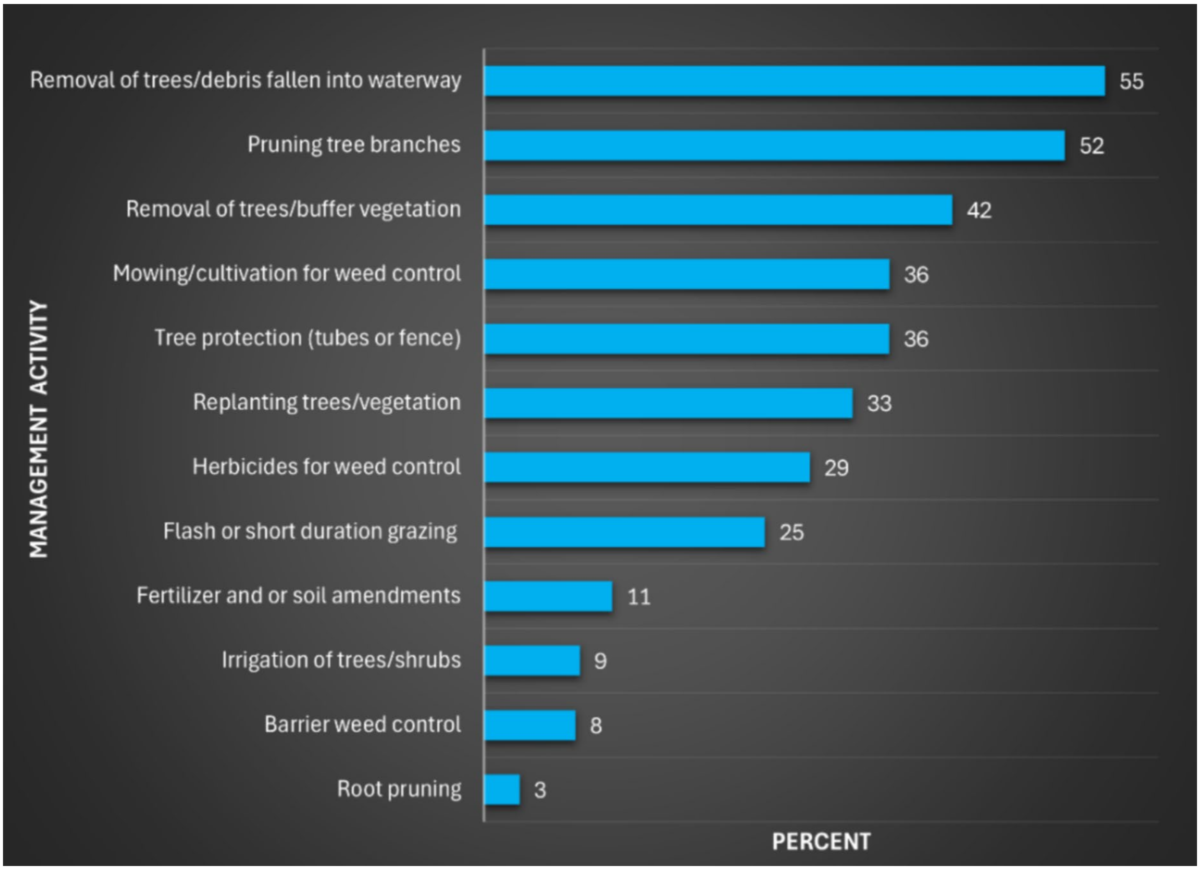


Fig. 8 Percent of respondents who use various management and maintenance activities in their riparian forest buffers. Figure notes: number of respondents ranged from 2242 – 2307 depending on response option and are reported in Online Resource 1, Table 14

or other products (Henri and Johnson 2005; Schultz et al. 2022). Appropriate thinning can also improve the effectiveness of nutrient uptake in a riparian forest buffer when combined with replanting or successful natural regeneration (Cole et al. 2020; Schultz et al. 2022).

Mowing and cultivation for weed control was reported by 36% of producers. This management activity has complex effects on the function of buffers depending on the timing, equipment, and location within the system. Annual or biannual mowing is recommended in woody and grass zones, particularly during the first few years after establishment to combat annual weed populations (Gold et al. 2024; Schultz et al. 2004). However, the use of machinery can increase soil compaction and reduce soil porosity impacting the ability of the riparian forest buffer to remove excess nutrients (Cole et al. 2020).

Flash and short duration grazing was used by a quarter of respondents. This was surprising given that most studies indicate that livestock grazing can reduce channel stability and degrade buffer vegetation (Magner et al. 2008; Sovell et al. 2000). However, grazing intensity and impact can be managed to reduce negative outcomes. For example, use of short duration or rotational grazing can be less impactful on vegetation (Magner et al. 2008) and can reduce fecal coliform and turbidity in streams (Sovell et al. 2000) when compared to continuous grazing. Additional investigation is warranted to better understand producer use of grazing in riparian forest buffers and its potential impact.

When asked to provide other management activities not listed in the question, 138 producers responded. Distinct management practices included control of invasive species (17%), prescribed burning

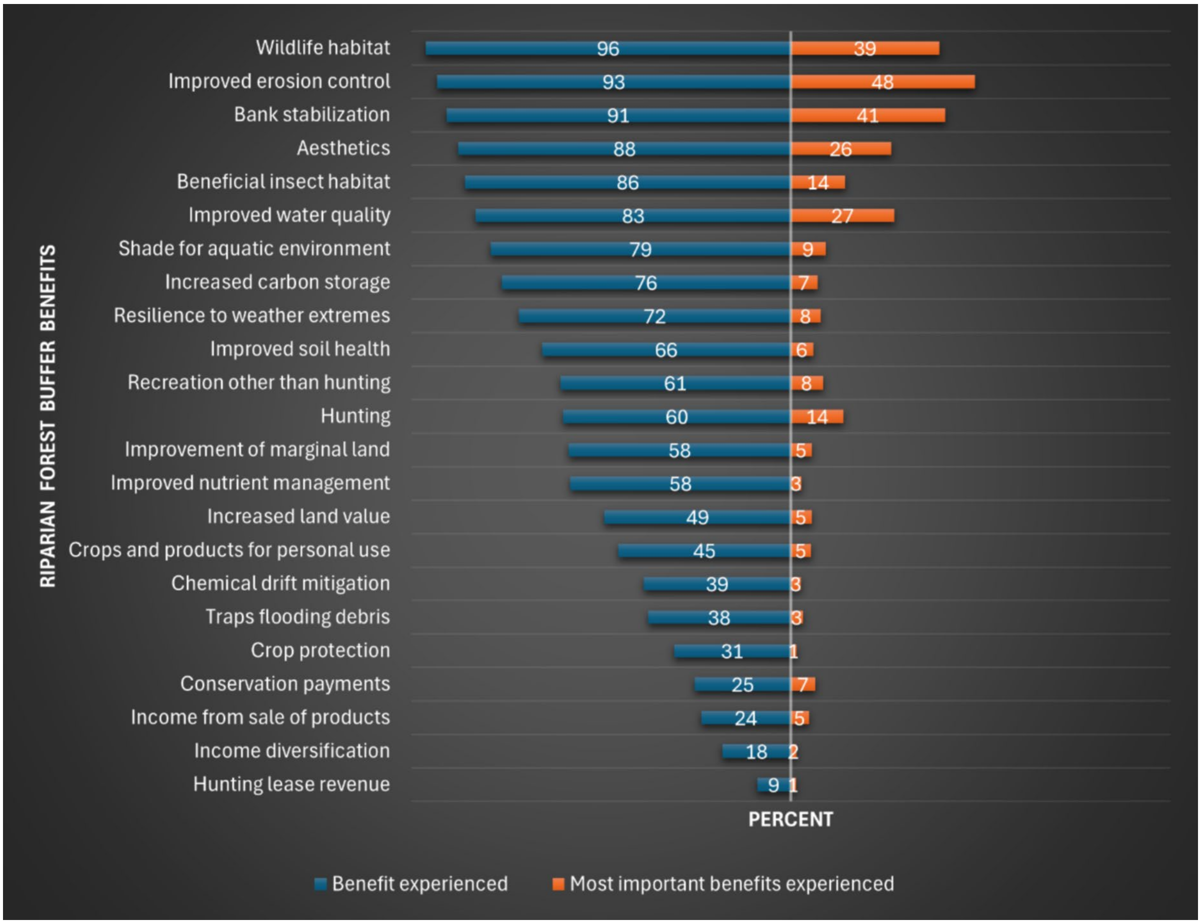


Fig. 9 Percent of respondents who received a specific benefit from their riparian forest buffers, along with percent of respondents who reported a riparian forest buffer benefit was among the three most important to them. Figure notes: number of respondents for benefits experienced ranged from 2198 – 2366 depending on response option and are reported in the Online Resource 1, Table 16. Number of respondents for most important benefits was 2139

(14%), adding new trees/shrubs to the buffer (7%), and creation of wildlife habitat (food plots) (6%) (Online Resource 1, Table 15).

Benefits of riparian forest buffers

In this study, producers were asked to report on benefits they have received from their riparian forest buffers, along with which three benefits they value most (Fig. 9) (Online Resource 1, Table 16). Wildlife habitat was selected by almost all respondents, with 96% reporting having received that benefit from their riparian forest buffers. This finding has also been reported in other studies investigating riparian forest buffer adoption (Chapman et al. 2019; Commender et al. 2020; Cooper and Jacobson 2009; McRae 2024). Wildlife studies have found that riparian forest buffers provide critical habitat in agriculturally dense landscapes, providing necessary habitat and corridors (Cole et al. 2020; Lind et al. 2019).

Improved erosion control (93%) and bank stabilization (91%) were also selected by most respondents as benefits received and were the most selected top benefits of having a riparian forest buffer. This finding makes sense, as these benefits are among the primary functions of implementing riparian forest buffers and have been reported in other studies (Hagan 1996; Skelton et al. 2005). These benefits are also easy to visualize and quantify.

Improved water quality (83%) was the sixth most selected benefit received, and fourth most reported top benefit. This is interesting, given that water quality is often considered as a primary function of implementing riparian forest buffers (USDA NRCS 2020). However, of the benefits listed, water quality is more likely to be an indirect benefit to the producer and more of a public benefit to those downstream, which may be why it was selected less often than some of the other benefits. The lower appraisal of improved water quality by respondents in our study contrasts with Hagan (1996) and Cooper and Jacobson (2009), who both reported that water quality was the most important benefit to riparian forest buffer adopters in their respective regions.

Benefits related to income, such as conservation payments (25%), income from sale of products (24%), income diversification (18%), and hunting lease revenue (9%) were the least selected benefits experienced by producers. While selected less frequently than other benefits, roughly a quarter of respondents in our survey still reported making some form of income from their riparian forest buffer systems. The number of producers selecting income-related benefits may be low due to the potential challenge of harvesting resources or vegetation from the buffer while not impacting its ecological function and integrity. Some conservation programs also have limitations on the degree of extraction that can occur during the contract period. Our findings on income-related benefits are like those reported by Commender et al. (2020), who found that producing agricultural goods and increasing income (28 – 38%) were some of the least reported management objectives of having a riparian forest buffer by producers. Rhodes et al. (2018) also reported that producers had difficulty producing income from existing riparian forest buffers.

Respondents were also asked to specify other benefits of their riparian forest buffers not listed as response options in the survey, with 117 producers responding. Unique responses included privacy (9%), livestock improvement (i.e., shade, protection, improved forages) (9%), personal enjoyment (6%), and noise control (4%) (Online Resource 1, Table 17).

Challenges of riparian forest buffers

The most reported challenge of establishing and managing a riparian forest buffer was added labor and management complexity (46%) (Fig. 10) (Online Resource 1, Table 18). This challenge was also the most selected (28%) when producers were asked to report the top three challenges of their riparian forest buffers. Added labor and management complexity has also been reported as a key challenge in other studies investigating riparian forest buffer adoption (Hagan 1996; McRae 2024).

The second most reported challenge experienced was trees falling into waterways (42%). This challenge was also selected often when producers were asked to select their top three challenges. Given that 55% of producers said removing trees and debris from waterways was a management activity, it is not surprising that this challenge was cited frequently. It may also be one of the reasons why added labor and management complexity was selected by many respondents. The issue of trees falling into waterways has not been covered extensively in other studies investigating riparian forest buffer adoption.

Expense of maintenance (36%) was the third most reported challenge experienced and was also reported the second most often for top challenges experienced (25%). This finding makes sense given that many of the management activities most used by respondents (removal of trees from waterways, pruning tree branches, thinning trees) can be quite costly to the producer. In a regional study of riparian forest buffer adoption, Commender et al. (2020) also reported that producers expressed concern with maintenance.

Wildlife damage (33%) was the fourth most selected challenge experienced and the fourth most selected top challenge of managing and maintaining a riparian forest buffer. This is interesting given that wildlife habitat was the most reported benefit of having riparian forest buffers. This finding is in line with a previous study from Hagan (1996), who investigated riparian forest buffer adoption in the U.S. state of Maryland and reported that some producers were concerned with increased deer populations that may result in increased buffer maintenance.

Producers were also asked to specify whether they have experienced additional challenges of managing and maintaining their riparian forest buffers other than the response options provided, with 183 producers responding. The most reported response was maintenance, particularly cleaning up fallen trees and branches on farm fields (10%). This was followed by weather damage (10%) and controlling the spread of

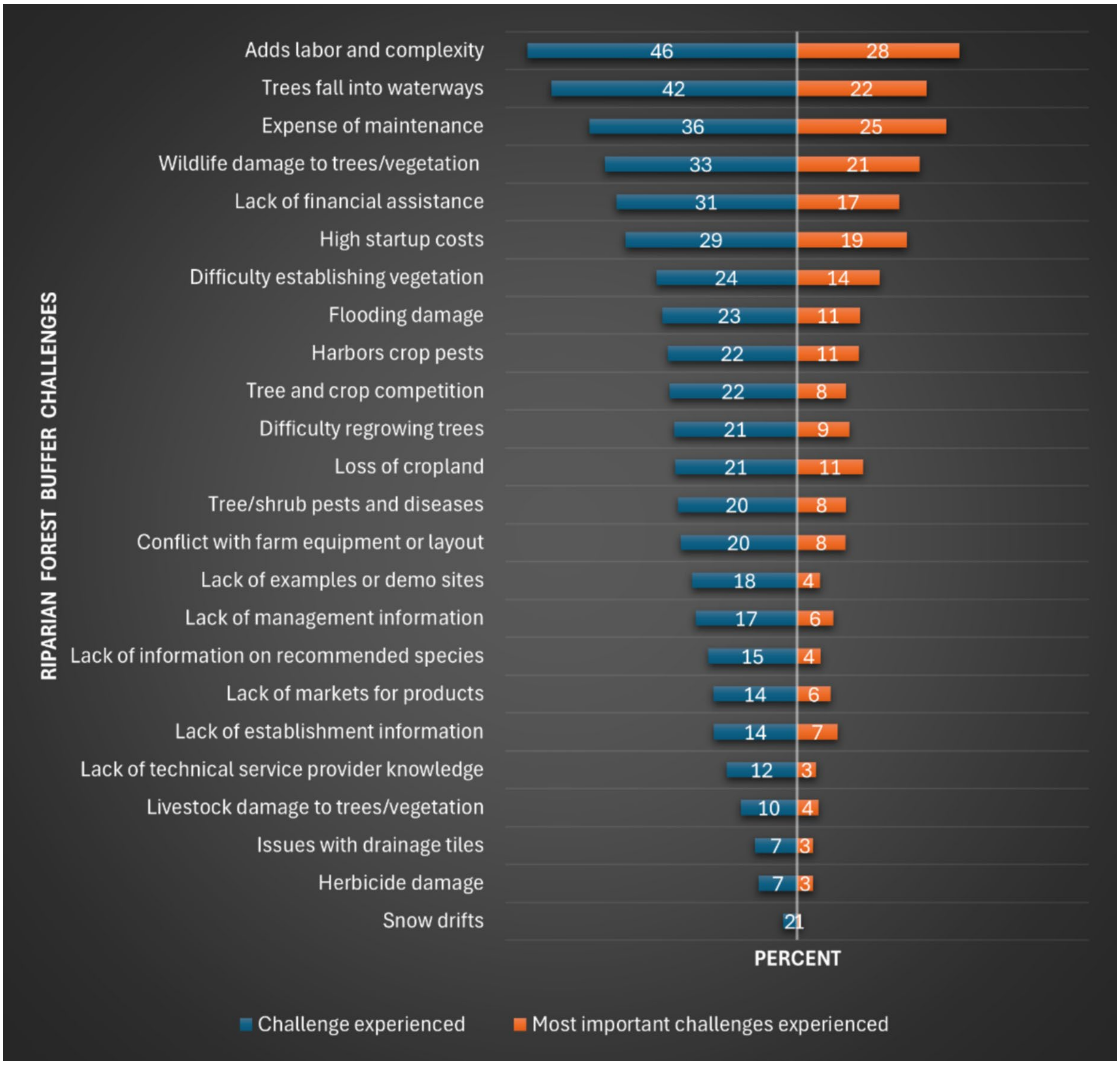


Fig. 10 Percent of respondents who experienced a specific challenge when establishing or managing their riparian forest buffers, along with percent of respondents who reported a riparian forest buffer challenge was among the three most important to their operation. Figure notes: number of respondents ranged from 2175 – 2226 depending on response option and are reported in Online Resource 1, Table 18. Number of respondents for most important challenges was 1731

invasive or nuisance species (9%) (Online Resource 1, Table 19).

Crops and products

Producers were asked whether they have sold, plan to sell, or use crops and products for personal or on-farm use from their riparian forest buffers. Eight different product categories were provided as response options (Fig. 11). Of the 2433 respondents, 80% reported that they sold, plan to sell, or use crops or products for personal or on-farm use from their riparian forest buffers. More specifically, 72% use crops and products for personal or on-farm use, 29% plan to sell crops and products, and 26% have sold crops and products from their riparian forest buffers.

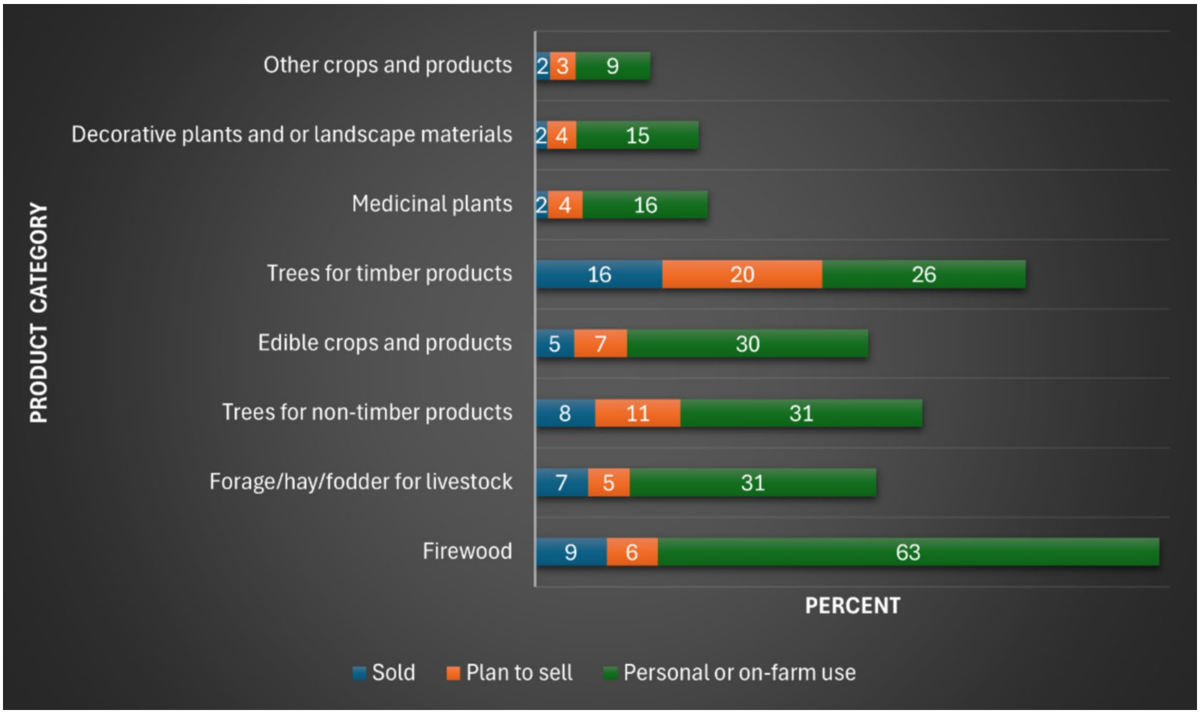


Fig. 11 Percent of respondents who sold, plan to sell, or use crops and products from riparian forest buffers (n = 2433). Figure notes: across all product categories, 26% have sold products, 29% plan to sell, and 72% use products from their riparian forest buffers

The most reported crops and products sold from riparian forest buffers were trees for timber products (16%), firewood (9%), trees for non-timber products (pulp, fence post, woodchips, etc.) (8%), and forage for livestock (7%). The most reported crops and products producers plan to sell in the future were trees for timber products (20%), trees for non-timber products (11%), edible plants (7%), and firewood (6%). The most reported crops and products for personal or on-farm use were firewood (63%), forages for livestock (31%), trees for non-timber forest products (31%), and edible plants (30%) (Fig. 11).

When asked to report which edible crops were harvested from their riparian forest buffers, 494 respondents specified 59 different edible crops. The three most common crops, which spanned geographic region, were walnuts (*Juglans* spp.) (27%), blackberry (*Rubus* spp.) (20%), and raspberry (*Rubus* spp.) (15%). The fourth most common response was maple syrup (primarily *Acer saccharum*) (13%) and was most common in the Lake States, Mid-Atlantic, and New England regions. Pecans (*Carya illinoinensis*) were a common species in the Southern Plains and Southeast regions, while persimmon (*Diospyros* spp.), shagbark hickory nuts (*Carya ovata*), and mulberry (*Morus* spp.) were most common in the Corn Belt. Other species identified by respondents are described in the Online Resource 1, Table 20.

Producers (n = 110) also specified 58 different medicinal plants that were harvested from their riparian forest buffer systems. Of these producers, the most common medicinal plants were American ginseng (*Panax quinquefolius*) (25%), elderberry (*Sambucus* spp.) (10%), and goldenseal (*Hydrastis* spp.) (8%). Ginseng was most prevalent in the Appalachia and the Corn Belt regions, while goldenseal was most prevalent in the Appalachia region. Additional responses are detailed in the Online Resource 1, Table 21.

Across the country, 108 respondents specified 46 different decorative plants that were harvested from their riparian forest buffers. The most common response was cut flowers (31%), with several types of lilies (*Lilium* spp.), daffodils (*Narcissus* spp.), and hydrangea (*Hydrangea* spp.) being mentioned most often (Online Resource 1, Table 22). The second most common response was evergreen trees and shrubs for wreaths and Christmas arrangements (30%). Some of the most frequently listed species were eastern white pine (*Pinus strobus*), English holly (*Ilex aquifolium*), balsam fir (*Abies balsamea*), Norway spruce (*Picea abies*), and blue spruce (*Picea pungens*). Respondents also listed woody material for floral arrangements (18%). Species included stems from curly willow (*Salix matsudana*), berries from Chinese bittersweet (*Celastrus orbiculatus*), stems from red twig dogwood (*Cornus sericea*), and foliage from boxwood (*Buxus* spp.). Respondents also listed non-woody plant material for floral arrangements (8%), which included ferns, moss, and lichen. Respondents (n = 116) also specified other crops/products from their riparian forest buffer systems with 64 unique responses (Online Resource 1, Table 23). However, most of these crops and products were covered in existing response options.

Few studies have reported on whether producers are harvesting crops and products from their riparian forest buffers. This may be in part due to the conservation-focus of most riparian forest buffer studies. The few studies that have examined crop production in riparian forest buffers indicate that these systems have the potential to provide a wide variety of crops and products (Ferich 2019; McRae 2024; Workman et al. 2003).

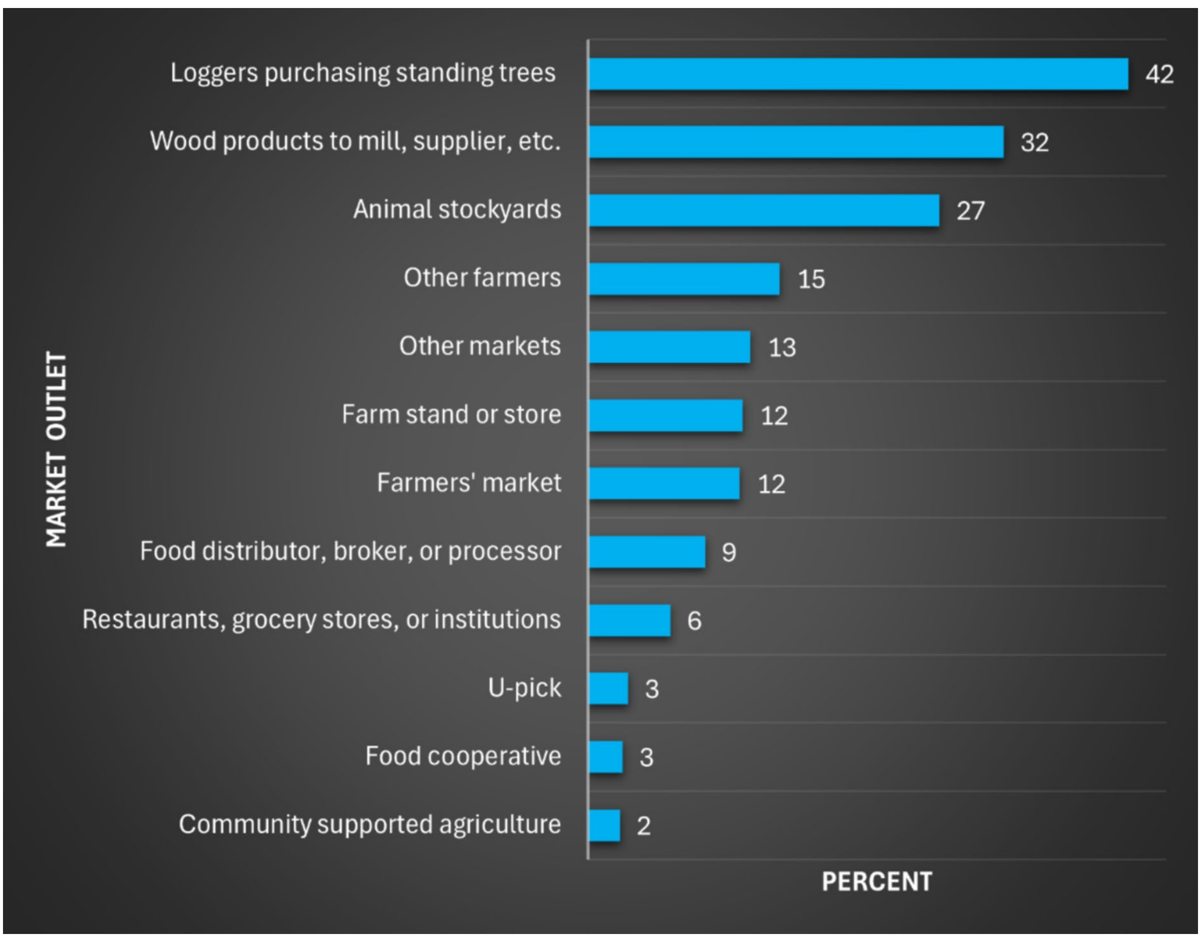


Fig. 12 Distribution of markets where respondents sold crops and products from their riparian forest buffers (n = 483)

Markets where crops and products are sold

Respondents were asked to report where they sold crops and products originating from their riparian forest buffers, with 483 producers responding. The most selected markets by producers were loggers buying standing trees (stumpage) (42%), wood products sold directly to mills or other suppliers (32%), and animal stockyards (27%) (Fig. 12). These markets correlate to what respondents reported as their primary crops and products sold (timber, non-timber, and forage for livestock) and with two of the three top management activities reported (tree pruning and thinning). When asked to specify additional markets, only 16 respondents provided responses. Most responses were covered in existing response categories. The only exception was selling products to non-farm neighbors.

Though no national dataset exists for where producers sell crops and products from riparian forest buffers, a few regional studies, such as McRae (2024) and Ferich (2019), have identified markets such as wholesale, retail, community supported agriculture, and tree cooperatives as outlets for products from riparian forest buffers. Additionally, several researchers have suggested a need to investigate the use of crops and products from riparian forest buffers and associated markets to incentivize the adoption and retention of the practice (Commender et al. 2020; Rhodes 2018). This is especially important, given that conservation practices are more likely to remain in place when income-generation is possible (Piñeiro et al. 2020).

Future of riparian forest buffers

Across the sample, 2359 producers with riparian forest buffers specified their future intentions for their systems. Most respondents (81%) plan to keep their riparian forest buffer acreage the same over the next five years (Fig. 13). Many fewer respondents (10%) plan to increase the acreage they have in riparian forest buffers, while only 2% plan to decrease acreage.

Producers who reported plans to increase riparian forest buffer acreage were asked to specify why, for which 212 provided open-ended responses. The most common reasons were widening or adding trees to an existing buffer (18%), increasing acreage for conservation and ecological reasons (14%), natural growth and expansion (12%) which was usually associated with fencing off areas adjacent to wetlands, and 11% reported they were planning to plant entirely new riparian forest buffers where none existed prior. Additional reasons are detailed in the Online Resource 1, Table 24.

The number of respondents planning to decrease their acreage in riparian forest buffers was small, with 47 producers responding to the open-ended question. The primary reasons for decreasing buffer acreage

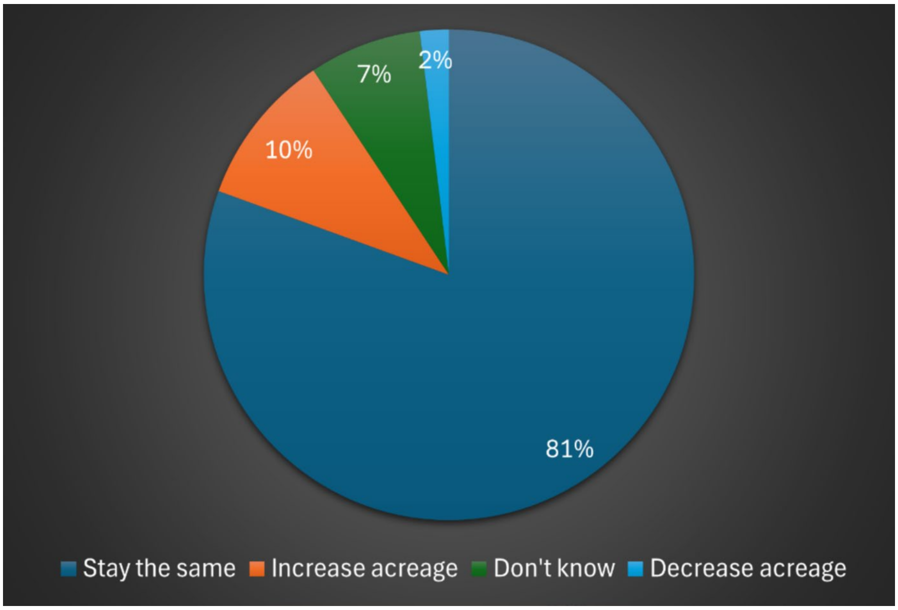


Fig. 13 Future plans respondents have with their riparian forest buffers over the next five years (n = 2359)

over the next five years were clearing buffers for more pasture, cropland or orchard (13%) and loss of land due to bank erosion (13%). Other responses are detailed in the Online Resource 1, Table 25.

Data from this study are similar to Cooper and Jacobson (2009) who reported that 70% of those with riparian forest buffers in the state of Pennsylvania were going to leave their buffers intact when their conservation contract expired. Only 2% said they were very likely to remove the buffer. Commender et al. (2020) found that producers who were more likely to retain their riparian forest buffers were less likely to have reported financial strain or maintenance challenges, while more likely to report that their buffers provided environmental services. Stubblefield et al. (2025) also reported on agroforestry discontinuation, though only one producer in that study reported discontinuation of riparian forest buffers, primarily due to economic considerations.

Study limitations and future research

One limitation of this study was that we did not ask producers whether their riparian forest buffers were implemented due to their choice or because the state or region in which they reside requires buffers as part of regulation. This type of information may be of use, especially if separating these producers into distinct groups for further analysis. It is hypothesized that differences are likely to occur for certain establishment, management, and beneficial functions.

A second question that would be valuable to ask in future surveys would be on tree and shrub species selection for producers who planted their riparian forest buffers. Understanding which tree species were planted, and their relative success would be of value to producers to understand what has and has not worked. This type of information would also be useful for state and federal agencies who support riparian forest buffer installation and would serve as a form of program evaluation. These species lists could also be compared to other components of the survey, such as crops and products and retention of the practice.

Conclusions

This study provides the most comprehensive assessment of riparian forest buffer use in the United States to date with the largest sample size of adopters. Key findings include:

1. Riparian forest buffers are used by 60% of producers with agroforestry in the United States.
2. The average acreage in riparian forest buffers per farm operation reporting the practice is 20.9 acres (8.5 ha).
3. Ninety-three percent of respondents established all or part of their riparian forest buffers by allowing trees to grow naturally, while roughly half planted buffer vegetation.
4. Most riparian forest buffers were established 15 or more years ago.
5. Producers with riparian forest buffers use a wide range of information sources to learn about agroforestry, with printed materials being the most reported.
6. The most reported funding sources used to establish or manage riparian forest buffers are personal funds followed by federal funding.
7. The most reported management activities used in riparian forest buffers are removing trees and debris from waterways, pruning tree branches, and thinning trees.
8. The top producer-reported benefits of riparian forest buffers are improved erosion control, bank stabilization, and wildlife habitat.
9. The top producer-reported challenges of managing riparian forest buffers are added labor and management complexity, expense of maintenance, and trees falling into waterways.
10. Seventy-two percent of producers use crops and products originating from their riparian forest buffers for personal or on-farm use, while 26% reported selling crops and products.
11. The most utilized market for crops and products sold from riparian forest buffers are loggers purchasing standing trees.
12. Most producers plan to maintain or expand the acreage they have in their riparian forest buffers, with only 2% planning to reduce the acreage.

Data from this national survey show that riparian forest buffers are one of the most used agroforestry practices in the United States. These data also show that this practice tends to be more hands-off than other agroforestry practices, as evidenced by the establishment and management activities reported by producers. However, while more hands-off, producers reported challenges with management complexity, cost, and maintenance. This, combined with the fact that most respondents established vegetation naturally, suggests that riparian forest buffer management and outcomes need to be investigated carefully. More specifically, would more active management and intentionality, especially during buffer establishment, result in less management in the future and lower overall cost to maintain the system? For instance, removal of trees from waterways was the top management challenge, which could be exacerbated by inappropriate tree locations due to the haphazard aspect of natural regeneration. Could more intentional designs result in increased potential for crops and products to offset maintenance costs? Addressing these questions, and those associated with the challenges of buffer management identified by respondents, may help increase retention of the practice for current adopters, and support producer decision making for producers considering the practice in the future.

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Author contributions All authors contributed to study conception and design. KF, MMS, and MB cleaned, summarized, and coded the data. All authors collectively wrote and reviewed the manuscript.

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Data availability All shareable data are available in the Online Resource 1. Some data summaries were derived using data collected in the 2017 Census of Agriculture by the National Agricultural Statistics Service (NASS), United States Department of Agriculture. Any interpretations and conclusions derived from these data represent author viewpoints and are not necessarily those of NASS.

Declarations

Competing interests The authors declare no competing interests.

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