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ORIGINAL RESEARCH

Family Forest Owner Attitudes Toward Oak Forests and Management in the Central and Eastern U.S.

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Abstract

Upland oak trees are ecologically, economically, and socially important across the central and eastern United States, but they are at risk of decline from myriad threats. Most of the forestland in this region is held by families and individuals (family forest owners, FFOs), so the future of these oak forests largely depends on the decisions they make about their land. We surveyed 20,000 FFOs and received 1,517 responses to better understand their attitudes towards upland oak forests and management practices that can be used to support oak, specifically harvesting, planting, using herbicides, and using prescribed fire. The Transtheoretical Model framework was used to assess the barriers and opportunities for landowners at different stages in relation to each activity. Overall, FFOs agree that upland oak forests provide numerous benefits, and almost half of FFO forest area is held by ownerships who want more oak trees on their land. Only a third of FFOs know that oak is at risk of decline, but those who do are more likely to want more oak on their land. The main barriers to management activities are not having enough information and not seeing a need for the management practice, but the needs and perceived barriers vary depending on stage of change, which should be considered when communicating with owners. Increasing awareness about the importance of and threats to oak trees and their management might encourage more landowners to actively manage for oak, although effective oak management is site-specific and can be intensive.

Keywords Family forest owners · Forest management · *Quercus* · Survey · Transtheoretical Model

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Introduction

Upland oak trees (*Quercus* spp.) are an important ecological, economic, and cultural component of forests across the central and eastern U.S., as they across many other parts of North America, Europe, and parts of Asia. Historically, oak is considered foundational to upland forests in the central and eastern U.S., shaping forest composition and structure and supporting diverse understory plant and animal communities (Hanberry and Nowacki 2016). Oaks are an important economic resource, both for lumber and for specific products such as bourbon barrels. As drought-tolerant and highly adaptable species, there is also the potential for oaks to have increased suitable habitat under climate change (Prasad et al. 2020). Oaks produce acorns in masts, which is important for some of the most valuable wildlife species across the region including white-tailed deer (*Odocoileus virginianus*) and eastern wild turkey (*Meleagris gallopavo silvestris*). However, in some areas, oaks have been considered undesirable due to their competition with more valuable species, such as with pine plantations in the South (Zhang and Polyakov 2010).

Oak trees face myriad pressures that threaten their future dominance on the landscape. In this paper, we use the term oak to refer specifically to upland oak forests, as the management and ecology can differ for bottomland oak-hardwood forests. Upland oak forests were historically maintained by frequent, low-to-moderate severity disturbances, especially fire, including burning by indigenous peoples (Abrams 1992; Hanberry et al. 2014). Fire exclusion and poor harvesting practices have led to mesophication, a shift to more shade-tolerant tree species (Nowacki and Abrams 2008). New and emerging oak pests and pathogens are also concerning to experts (Conrad et al. 2020), and can be especially damaging if trees are already stressed due to drought events (Asaro and Chamberlin 2019). Invasive plant competition and deer browse also contribute to poor oak regeneration, which are compounded by these other factors (Knoot et al. 2010b). Further, climate change is expected to increase or compound the threats that oaks face in the regions where they have historically occurred (Conrad et al. 2020).

Upland oak can be restored by management, but it may require intense or repeated mechanical, chemical, or fire treatments, often in combination (Miller et al. 2017; Dey and Schweitzer 2018; Vander Yacht et al. 2019) that are tailored to specific site conditions. Management is important at multiple stages in the oak life cycle to ensure successful recruitment and retention (Dey 2014). Timing management to align with acorn availability or sufficient oak advance regeneration is also critical (Miller et al. 2017; Dey and Schweitzer 2018). While oaks can also regenerate naturally, especially following disturbance, their dominance on the landscape is largely an artifact of human practices (Abrams and Nowacki 1992) as well as interactions with passenger pigeons (*Ectopistes migratorius;* Ellsworth and McComb 2003), and without intense management, oak is likely to decline across the region.

Families and individuals (family forest owners, FFOs), own a majority of the forestland in the central and eastern U.S. (Butler et al. 2021a), including much of the current and potential oak habitat. Consequently, FFO decisions have a huge influence on the success of oak regeneration and retention (Knoot et al. 2010a), but these landowners face a range of barriers to oak management, assuming this is something they

are striving to accomplish. There are ecological challenges, including climate change; high deer densities; invasive plants, pests, and diseases; and competition from other plants (Knoot et al. 2010a; Dey 2014). There are also economic challenges, since oak can be expensive to manage for, especially at smaller scales or compared to faster-growing species like pine (Knoot et al. 2010a). While oak currently has relatively strong markets across much of the region, the future value is an unknown. Connected with the ecological and economic challenges are social barriers, including concerns about aesthetics, tradeoffs to management, and the difficulty of managing on small parcels (Knoot et al. 2010a). While several studies have investigated expert opinion on oak management (Knoot et al. 2010b; Voss 2012; Conrad et al. 2020), questions remain about what the FFOs themselves think about oak and management and what motivates their management decisions and practices (Dey 2014).

To further understand landowner attitudes towards oak forests and oak management, we conducted a survey of FFOs with 4 or more forested hectares across the eastern and central U.S. Four hectares is a common threshold when describing forest owners, since many management practices are limited on smaller holdings, and owners of these smaller holdings can have different objectives and behaviors (Snyder et al. 2019). Specifically, we aimed to investigate: (1) if FFOs want more oak trees on their land, (2) what attitudes FFOs hold about upland oak forests, and (3) the benefits and barriers FFOs see for specific management practices that can support oak regeneration and recruitment. This work was completed as part of the broader White Oak Initiative (www.whiteoakinitiative.org), a collaborative effort aimed at ensuring the long-term sustainability of white oak forests across the eastern United States.

Stages of Change.

To better understand the barriers to specific management activities, we framed the relevant behaviors through the Transtheoretical Model of Behavior Change (TTM) and the model's Stages of Change construct (Prochaska and DiClemente 1983). The model was initially developed to describe the process of quitting smoking. It was subsequently used to understand other health related issues (Prochaska and Velicer 1997), and has had some limited applications in terms of natural resources and family forest owners (e.g., Quartuch et al. 2021). The framework was adapted here to describe where landowners are in relation to four specific management practices: cutting trees for sale (i.e., commercial harvesting), planting trees, using herbicides, and using prescribed fire. The Stages of Change hypothesizes that there are five stages an individual passes through for any change in behavior, namely: precontemplation, contemplation, preparation, action, and maintenance. In the precontemplation stage, there is no intention to change the behavior in the foreseeable future, or the individual is resistant to change. We separate out individuals who have never considered the activity from those who are resistant, since actively resistant landowners are likely the most difficult individuals to reach. In the contemplation stage, the individual has not made a commitment to change but is aware of the problem and may be weighing the pros and cons of the change. In the preparation stage, there is the intention to make a behavior change within a defined timeframe. The action stage describes individuals who are overtly changing their behavior, in this case those who have conducted the management practice or are in the process of doing so. Maintenance refers to the ongoing, often daily work of maintaining the behavior, such as preventing

relapse into smoking for at least six months (Prochaska et al. 1992). While repeated or subsequent activities may be necessary to increase or maintain oak, the actions may be periodic, dependent on site conditions, and include a mix of other activities (e.g., harvesting followed by burning). Therefore, we do not include this stage for each management activity, but we recognize that successful oak management can require future action (Table 1). While maintenance of oak activities can be critical to successful regeneration and growth, it does not necessarily require the repetition of the specific activities we asked about. For example, if someone conducts a harvest, it may be necessary to take other actions to promote oak, such as planting or using herbicides or fire but not necessarily repeated harvests.

Methods

To investigate landowner perceptions of oak forests and oak management, 20,000 FFOs were randomly selected from across the historic range of upland oak forests (Braun 1950); Fig. 1). This number of contacts was specified in American Forest Foundation's original Landscape Scale Restoration grant proposal, Upland Oak Sustainability & Management in the Central Hardwood Region and was determined prior to our team engaging with the project. To ensure a sample of ownerships with a diver-

Table 1 The Transtheoretical Model Stages of Change used in this study, how they were translated to the survey questions, and what percent of respondents identified with each category, (cut for sale n = 1,457; plant trees n = 1,450; use herbicides n = 1,445; use prescribed fire n = 1,437)

Stage	Question	Response selected	Cut for sale (%)	Plant trees (%)	Use herbicides (%)	Use prescribed fire (%)
Resist	Which of the following statements best describes your thoughts about <action> in the future?	I am not planning to do <action> on my wooded land	30.7	30.4	38.5	39.8
Precontemplation	Same as above	I have never considered whether to do <action> on my wooded land	6.3	14.0	20.7	38.4
Contemplation	Same as above	I have not decided whether or not to do <action> on my wooded land	30.6	26.7	17.8	12.9
Preparation	Same as above	I am planning to do <action> from my wooded land	9.7	6.9	4.6	3.5
Action	Which, if any, of the following activities have occurred on your wooded land since you have owned it?	<Action selected>	22.6	21.9	18.4	5.4
Total			100	100	100	100

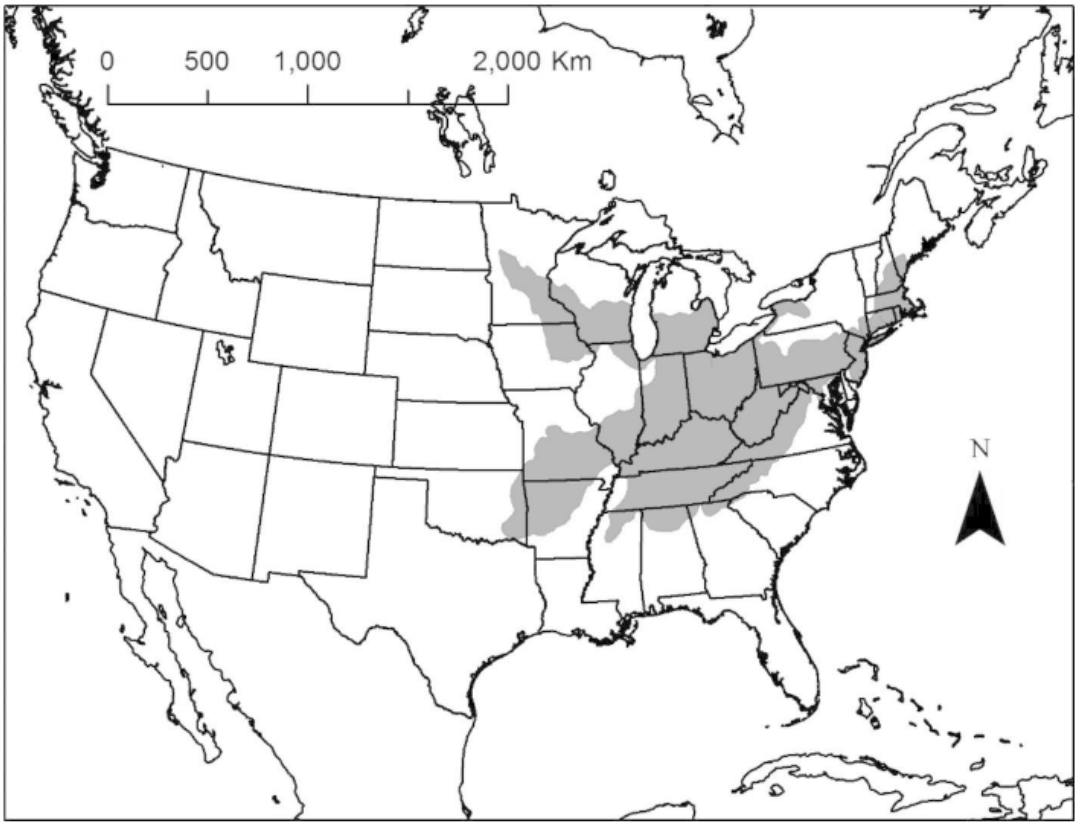

Fig. 1 The geographic range of upland oak forests (Braun 1950) and the survey across the eastern and central U.S.

sity of sizes of holdings, we used an area-based sample design following Butler et al. (2021a). A hundred and fifty thousand random points within the project boundary were generated and filtered based on if they were private and forested, as determined by forest cover from the National Land Cover Database with ecoregion- and state-specific forest cover thresholds based on Sass et al. (2020); (U.S. Geological Survey (USGS) 2014). Private points were selected based on their location outside of public ownership boundaries (Conservation Biology Institute 2012); only records with 4 or more ha were contacted. Names and addresses of the landowners from property tax records were manually formatted, and duplicates and non-FFO names were removed. From the final list, 20,000 names were randomly selected for future communication. Applying the Tailored Design Method (Dillman et al. 2014), landowners were contacted by three mail-based waves in June, 2020: an introductory postcard explaining the project, a letter sent a few days later with the survey URL and their unique access code, and a follow-up reminder/thank you postcard that also had the URL and their access code. FFOs were contacted via mail because that was the only information available for all participants.

The survey instrument was developed online using the Qualtrics platform, and it included questions about the landowner, characteristics of their forestland, and their thoughts on forest management and upland oak. The survey was tested in seven cognitive interviews with landowners from within the study boundary that lasted 30–60 min as well as in consultations with subject matter experts. The final instru-

ment took, on average, less than 15 min to complete (Supplementary Information 1). All questionnaires and survey methods were approved by the University of Massachusetts Amherst, Internal Review Board (IRB No. 1617).

Of the 20,000 FFOs who were contacted, 1,517 complete responses were collected, for a response rate of 7.6%. Complete surveys include only those with at least 75% of survey questions answered, including answering how many hectares of forestland they own. Knowing the number of hectares was required in order to calculate weights for population-level values, and 75% follows the cutoff procedure for the USDA Forest Service National Woodland Owner Survey (Butler et al. 2021a).

Non-Response

In and of itself, a low response rate is not an inherent problem. Issues arise when there are substantive differences between the respondents and nonrespondents, and we assessed the potential for unit non-response biases in two ways. The first 10% of respondents were compared with the last 10% of respondents for 25 selected questions (Ellis et al. 1970), which included questions about their land, their reasons for owning, their identity, whether they have and want more oak trees on their land, and demographic traits. Second, survey responses to 17 questions – including questions about their land, their reasons for owning, management plans, and demographic traits – were compared to responses to comparable questions from the NWOS (Butler et al. 2021a) for landowners within the project boundary who hold 4 or more ha ($n=2,763$). In both comparisons, Mann-Whitney U and chi-squared tests were used to quantify differences between groups for continuous and categorical variables, respectively. Cohen's d was used to determine effect size (Cohen 2009; Torchiano 2020), with $d<0.2$ considered negligible, $0.2\leq d<0.5$ considered small, $0.5\leq d<0.8$ considered medium, and $d\geq 0.8$ considered large. The p-values of each set of comparisons were adjusted to account for multiple comparisons using the Holm method (Holm 1979).

The responses to 25 questions were compared between early and late responders, and the only significant difference ($p<0.05$) was in respondent age, with early responders being younger (median age 61) than late responders (median age 65), but the effect size was small ($d=0.401$). In comparing to the NWOS, 10 of the 17 questions were not significantly different, and four questions were different with negligible effect sizes ($d<0.2$; beauty as a reason for owning land, privacy as a reason for owning land, planning to cut trees for personal use in the future, and not planning to do any of the listed actions in the future). Two questions were different with small effect sizes ($0.2\leq d<0.5$): White Oak survey respondents were younger than NWOS respondents (median White Oak respondent age=62, median NWOS respondent age=66; adjusted $p<0.0001$; $d=0.323$) and were more likely to have received advice about their forestland in the past five years (39% of White Oak respondents, 29% of NWOS respondents; $p<0.0001$, $d=0.213$). One question had a medium difference: White Oak respondents were more likely to plan to reduce or remove invasive plants than NWOS respondents (White Oak survey respondents 56%, NWOS respondents 32%; adjusted $p<0.0001$; $d=0.513$). No differences had large effect sizes ($d\geq 0.8$). Overall, the respondents were largely similar between the surveys, with White Oak

respondents being slightly younger and somewhat more active on their land in certain ways.

Responses who did not answer at least 75% of the survey, or who did not answer how many hectares of forestland they own, were considered incomplete and excluded. For population-level summaries, items that were left blank were imputed following Butler et al. (2021a); van Buuren and Groothuis-Oudshoorn (2011).

Population Summaries

Population-level summaries were calculated for relevant variables, including FFO perceptions of oak trees, upland oak forests, and forest management. The area-based sample design resulted in inclusion probabilities that were proportional to size of forest holdings. As such, weights were calculated for each landowner following methods described in Butler and Caputo (2021) and adjusted for USDA Forest Service, Forest Inventory and Analysis forest area within the project boundary. Estimates and associated variances, using a bootstrapping approach, were calculated as described in Butler et al. (2021a).

Analyses

Models investigating relationships among variables used unimputed, unweighted, response-level data, and missing values were excluded.

Logistic regression was used to investigate factors related to landowners wanting more oak trees on their land. We used a generalized linear model with a binary distribution and a logit link function; there were 18 independent variables used in the model of which 7 evaluated various land use objectives and 8 evaluated various upland oak benefits. For the variable describing wanting more oak trees, respondents who were neutral were combined with those who said no. The Likert-scale questions about reasons for owning wooded land, perceptions of upland oak forest, and commonness of oak were collapsed to binary, with the top two categories (Very Important and Important or Strongly Agree and Agree, respectively) treated as '1' and all other responses treated as '0'. This is a common practice that simplifies the analysis and interpretation (e.g. (Butler et al. 2021b). For all models, the area of wooded land owned was included as the natural log of hectares.

The relationships of perceived barriers and benefits by TTM Stages of Change were assessed using separate multinomial logistic regression models for each of the assessed oak management activities. Landowners who consciously opted to not do an action were assigned to the "Resist" stage, landowners who had never considered the action were assigned to the "Precontemplation" stage, landowners who were aware of the activity, but had not decided whether to do it were assigned to the "Contemplation" stage, landowners who were planning to do the action in the future but had not yet done so were assigned to the "Preparation" stage, and those who had done the action in the past were assigned to the "Action" stage regardless of their future intentions (Table 1). While individuals theoretically move through the stages of change directionally, an ordered logistic regression was not appropriate for several reasons. First, we were interested in if and how variable coefficients differed between stages,

which would have been obscured by a logistic regression model that assumes one coefficient for each variable across all stages. Further, when a logistic regression model was conducted, the proportional odds assumption was violated (brant test, omnibus probability <0.05 for H0 that parallel regression assumption holds for all ordered logistic regression models), justifying conducting the more flexible multinomial logistic regression.

Multicollinearity was assessed using variance inflation factor (VIF) with scores under 2.5 considered acceptable (Allison 1999; Fox and Weisberg 2019); model fit was assessed using McFadden's pseudo R^2 (Signorell 2021) and the Hosmer-Lemeshow goodness of fit test (Lele et al. 2019). For the Hosmer-Lemeshow test, a non-significant result ($p>0.05$) indicates that there is not a significant difference between the data and the model. The action stage was set as the reference, and differences between the coefficients of adjacent stages were calculated using Wald chi-squared tests (Fox and Weisberg 2019); specifically, the precontemplation stage was compared to the contemplation stage, and the contemplation stage was compared to the preparation stage. Since landowners in the Resist category were actively uninterested in the activity, there was not an adjacent stage that was logical for them to move to, and they were excluded from the pairwise comparisons. The cutoff for significance for all analyses was $\alpha=0.05$. All analyses were run in the R statistical environment (R Core Team 2021), using the car (Fox and Weisberg 2019), pscl (Jackman 2020), generalhoslem (Jay 2019), and brant packages (Schlegel and Steenbergen 2020).

Results

Population-Level Summaries

Across the region, an estimated 1.4 million family ownerships (SE=29,000) with 4+ha hold 29.7 million ha of forestland (SE=370,000). The median size of forested holdings is 11.3 ha (SE=0.5). Over three quarters of FFOs agree or strongly agree that upland oak forests provide good scenery as well and game and nongame habitat (Table 2). However, less than a third of FFOs agree that upland oak forest is at risk of decline (Table 2). Almost half of the hectares are held by FFOs who want more oak on their land (Table 2). An estimated 10.0 million ha (SE=270,000) are held by

Table 2 Population estimates for key variables in the study region for family forest owners with 4+ha.

	Ownerships		Acreage	
Variable	Percent	SE	Percent	SE
Want more oak on their land	41.2	1.2	48.3	0.9
Agree that upland oak… …provides good scenery	81.4	2.0	82.3	1.4
…provides game habitat	78.5	1.9	82.3	1.4
…provides nongame habitat	76.1	1.9	79.5	1.4
…provides good timber	65.9	1.9	73.6	1.4
…provides recreation	48.6	1.8	52.4	1.4
…is at risk of decline	30.5	1.4	35.1	1.1
…is at risk from diseases	25.5	1.3	29.8	1.0
…is at risk from fire	8.7	0.7	12.0	0.6

ownerships who want more oak and are planning to conduct at least one management activity (Fig. 2).

Oak and Management

Over 40% of ownerships want more oak on their forestland, and landowners who want more oak are more likely to have more forestland, have forestland at higher latitude, have wildlife habitat as a reason for owning forestland, and agree with several statements about upland oak forests: that they provide good scenery, good timber, recreational opportunities, and that they are at risk of declining. Wanting more oak is also associated with oak being less common on their forestland (Table 3). VIF values are below 2 and Hosmer-Lemeshow goodness of fit are nonsignificant ($p>0.05$) for all models.

Perceived benefits and barriers to cutting trees for sale, planting trees, using herbicides, and using prescribed fire vary by the stage of change of the respondent. For cutting trees for sale, landowners in the Action stage are more likely to have more forestland and to perceive money as a benefit than all other stages, and Action stage landowners are less likely to see not having enough information as a barrier (Table 4). The barrier of difficulty finding a logger they trust is higher for landowners in the Contemplation and Preparation stage than the Action stage, but not for those in the Resist or Precontemplation stage compared to the Action stage (Table 4). For planting trees, the barrier of not having enough information differs between each stage compared to the Action stage, as well as between the precontemplation and

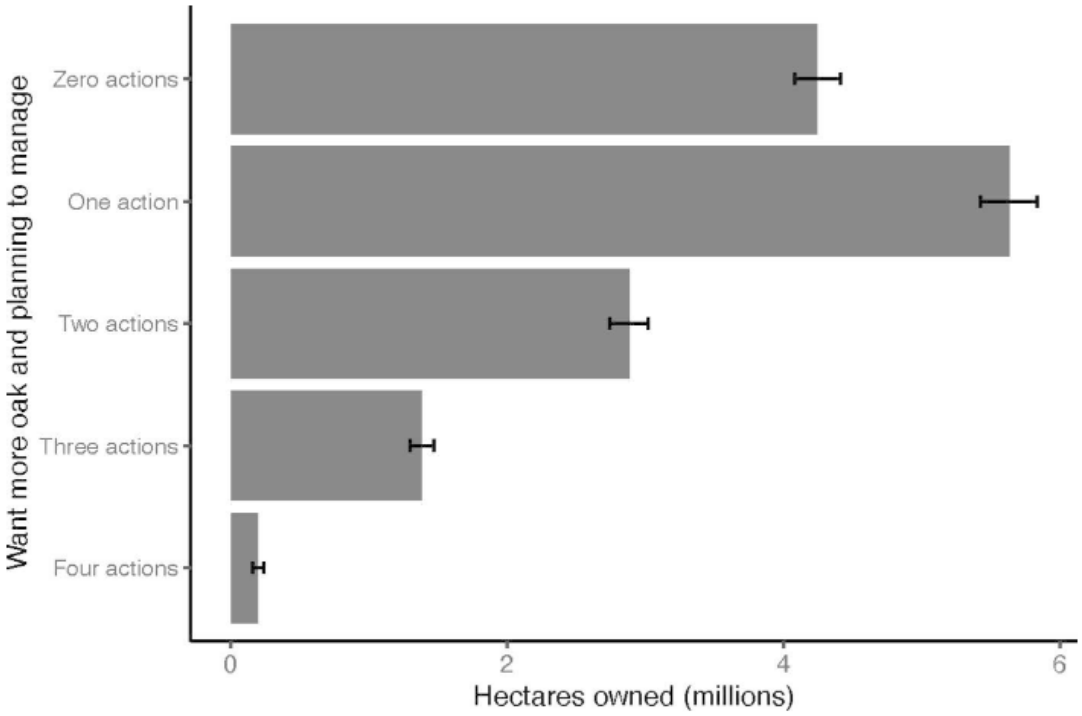

Fig. 2 Forest area held by family forest ownerships in the White Oak Initiative region that want more oak and how many management activities – of cutting trees for sale, planting trees, using herbicides, and using fire – they are planning to do on their forestland. Error bars represent SE.

Table 3 Output from the generalized linear model for whether FFOs in the study region want more oak trees on their wooded land, 2020† (n=1,481)

Item	Odds ratio	SE	p-value
Intercept	0.024	0.018	**<0.001**
Oak common	0.695	0.127	**0.046**
Objective – enjoy beauty	1.199	0.213	0.307
Objective – timber	1.197	0.157	0.168
Objective – wildlife habitat	1.434	0.207	**0.013**
Objective – hunting	1.223	0.149	0.097
Objective – recreation	1.024	0.128	0.852
Objective – privacy	0.818	0.112	0.143
Objective – land investment	1.216	0.143	0.097
Upland oak – provide scenery	1.485	0.244	**0.016**
Upland oak – provide timber	1.917	0.260	**<0.001**
Upland oak – risk of decline	1.713	0.222	**<0.001**
Upland oak – game habitat	1.029	0.197	0.883
Upland oak – nongame habitat	1.144	0.201	0.444
Upland oak – recreation	1.477	0.181	**0.001**
Upland oak – risk of disease	0.998	0.136	0.990
Upland oak – risk of fire	0.788	0.149	0.210
Latitude	1.039	0.018	**0.024**
Hectares owned (ln)	1.161	0.059	**0.003**

†Goodness of fit: $X^2=8.841$, df=8, p=0.356; pseudo $R^2=0.09$

contemplation stages, and the contemplation and preparation stages (Table 5). No other items differ between the Preparation stage and the Action stage, although they differ among other stages. Similarly, for using herbicides, the barrier of the action not being necessary differs between each stage and the Action stage, but no other items differ between the Preparation stage and the Action stage (Table 6). Finally, for the action of using prescribed fire, not having enough information is more of a barrier for each stage compared to the Action stage (Table 6). Those in the Action stage are more likely to own more land and to own land farther south than those in the Preparation stage (Table 7).

Discussion

Across the project region, there is widespread appreciation of upland oak forests and interest in having more oak trees, with almost half of FFO ha in the project region held by ownerships that want more oak trees on their land. Geographically, landowners at higher latitudes were more likely to want more oak on their land (Table 3), which may be due to the risk of oaks farther south encroaching in areas where forestland is used for other purposes, such as Southern pine plantations (Zhang and Polyakov 2010). Over 5 million hectares in the study area are held by owners who want more oak and are planning to cut trees for sale, plant trees, or use herbicides in the next 5 years; however, much less forestland is held by those planning to do multiple management practices, which is often required for regenerating oak. Fire, which can be critical to oak success in certain cases (Vander Yacht et al. 2019), is less common than the other practices, as it can be limited by additional barriers such as policy

Table 4 Odds ratios from a multinomial logistic regression model of family forest owners cutting trees for sale by Transtheoretical Model Stage of Change (n=1,457). The Action stage is the reference level[†]. * indicates difference between stage and reference stage (Action), [a] indicates difference between Precontemplation and Contemplation, [b] indicates difference between Contemplation and Preparation (α=0.05)

Item	Resist	Precont.	Contempl.	Preparation
Intercept	123.087*	3.574	57.271*[b]	2.530
Benefit – Improve wildlife habitat	0.586*	0.885	0.852	1.135
Benefit – Increase timber quality	0.319*	0.204*[a]	0.527*	0.598
Benefit – Earn money	0.155*	0.116*[a]	0.339*	0.477*
Benefit – Further goals for wooded land	0.245*	0.140*[a]	0.375*[b]	0.834
Barrier – Looks ugly	1.305	1.813*	1.524	1.046
Barrier – Will damage wooded land	2.319*	2.184*	2.187*	1.614
Barrier – Don't have enough information	2.161*	7.398*	6.338*[b]	3.008*
Barrier – Difficult to find a logger I trust	0.761	0.506[a]	1.572*	2.061*
Barrier – Neighbors would dislike	0.992	0.923	0.978	0.732
Barrier – Does not further goals	45.489*	24.186*[a]	6.190*	2.250
Latitude	1.006	1.108*[a]	0.993	1.008
Acres owned (ln)	0.548*	0.355*[a]	0.588*[b]	0.729*

[†]Goodness of fit: $X^2=39.961$, df=32, p=0.158; pseudo-$R^2=0.28$

and liability constraints and public perception, as well as operational constraints such as the availability of burn professionals and limited timing and climate requirements (Ryan et al. 2013).

While oak trees face threats that have been understood for decades (e.g., Abrams and Nowacki 1992) as well as emerging risks (Conrad et al. 2020), these challenges do not seem to be understood by most FFOs. Encouragingly, landowners who are aware of the risk to upland oak forests are more likely to want more oak on their forestland, suggesting that increased education may contribute to landowners wanting more oak or these may simply be the more engaged landowners. Similarly, Huntsinger et al. (1997) found that landowners in California who were aware that oaks were threatened or were aware of the benefit and value of oak forests were more likely to conduct management for oak. However, it is important to note that landowners who want oak may not be willing to do the intensive management sometimes required to restore it (Knoot et al. 2010b). The perceived benefits and barriers to management for oak-appropriate practices varied by stage of change and practice, but focusing on landowners who have not yet opted to take the action, but may be inclined to do so (i.e., landowners in the contemplation or preparation stage) and land that is most suitable to these activities may lead to the greatest outcomes (Butler et al. 2007). Not having enough information appears to be a major barrier for many owners, and it is important that this information be targeted to the specific needs of the stage where

Table 5 Odds ratios from a multinomial logistic regression model of family forest owners planting trees by Transtheoretical Model Stage of Change (n=1,450). The Action stage is the reference level[†]. * indicates difference between stage and reference stage (Action), [a] indicates difference between Precontemplation and Contemplation, [b] indicates difference between Contemplation and Preparation (α=0.05)

Item	Resist	Precont.	Contempl.	Preparation
Intercept	13.960*	9.562	21.059*	4.342
Benefit – Improve wildlife habitat	0.188*	0.261*[a]	0.522*	0.725
Benefit – Increase timber quality	1.110	1.577	1.758*	1.077
Benefit – Further goals for wooded land	0.102*	0.090*[a]	0.265*[b]	0.768
Barrier – Planted trees at risk from deer	1.000	0.664	0.790[b]	1.537
Barrier – Planted trees at risk from insects	0.575*	0.320*	0.465*[b]	0.852
Barrier – Requires a lot of time	1.427	1.835*	1.271	1.291
Barrier – Expensive	1.338	1.210	1.391	1.481
Barrier – Difficult to get seedlings	0.561	1.004	0.529*	0.479
Barrier – Don't have enough information	4.550*	13.923*[a]	7.216*[b]	3.172*
Barrier – Don't need to plant trees	15.916*	12.733*[a]	4.247*[b]	0.461
Latitude	0.970	0.974	0.953	0.947
Acres owned (ln)	0.923	0.769*	0.898	0.867

[†]Goodness of fit: $X^2=40.672$, df=32, p=0.140; pseudo-$R^2=0.23$

they are at and, as much as possible, be provided by trusted sources in the formats and the levels of detail that are most important.

Many studies have investigated FFO attitudes towards harvesting on their forestland, with size of forestland and the price for timber being among the most common predictors of harvesting (Silver et al. 2015). Similarly, in this study, the size of holdings and the benefit of earning money from the sale of timber was significantly more common for landowners in the Action stage compared to the Preparation stage. The barrier of finding a logger they trust also separated landowners in these two stages; in Kentucky, forestland owners association members consider "strong educational/technical and management assistance" to be a strength of long-term white oak supply (Thomas et al. 2021), which may help landowners overcome some of these barriers to move into the Action stage. The barrier that cutting trees for sale can look ugly does not differ between stages, but this is commonly cited as a concern for landowners managing for oak (Knoot et al. 2010b), especially given the importance of aesthetics and privacy for many FFOs (Butler et al. 2021a). While lighter harvests, such as single tree or group selection, may be less visually disruptive, they often do not create enough light to successfully support oak and may further shift the stand toward more shade-tolerant species (Dey 2014).

Table 6 Odds ratios from a multinomial logistic regression model of family forest owners using herbicides by Transtheoretical Model Stage of Change (n=1,445). The Action stage is the reference level[†]. * indicates difference between stage and reference stage (Action), [a] indicates difference between Precontemplation and Contemplation, [b] indicates difference between Contemplation and Preparation (α=0.05)

Item	Resist	Precont.	Contempl.	Preparation
Intercept	1.206	1.195	0.412	0.011*
Benefit – Improve wildlife habitat	0.202*	0.330*	0.337*[b]	1.370
Benefit – Improve timber quality	0.935	1.575	1.498	1.134
Benefit – Reduce invasive plants	0.161*	0.160*[a]	0.481*[b]	2.004
Benefit – Encourage plants I want to grow	0.368*	0.333*[a]	0.750	0.849
Benefit – Further goals for wooded land	0.229*	0.242*[a]	0.508*	0.846
Barrier – Will damage wooded land	5.405*	4.574*[a]	2.376	1.249
Barrier – Will damage wetland areas	4.761*	3.493*	2.686*[b]	0.389
Barrier – Neighbors would dislike	1.145	1.850	1.239	1.443
Barrier – Expensive	0.902	0.789	1.021	1.562
Barrier – Will damage plants I want	1.941*	2.048*	2.337*	1.488
Barrier – Don't have enough information	9.087*	17.678*	15.081*[b]	1.380
Barrier – Don't need to use herbicides	75.387*	55.414*[a]	17.542*	7.078*
Latitude	1.021	1.009	1.013	1.065
Acres owned (ln)	1.065	1.022	1.068	0.950

[†]Goodness of fit: X=37.162, df=32, p=0.243; pseudo-R^2=0.27

For planting trees, using herbicides, and using fire, the barrier of not having enough information and not seeing a need for the activity was higher for some or all of the non-Action stages, as well as between adjacent stages, with the barriers decreasingly reported in more advanced stages. Fewer than one in five FFOs have received advice about their forestland in the last five years (Butler et al. 2021a), and oak management can be complex (Knoot et al. 2010a), so it is reasonable that information is a common barrier to these management practices.

While these specific management practices can be helpful for oak regeneration and growth, they often need multiple or repeated actions to succeed (Izbicki et al. 2020). The requirements for oak management can be more expensive, long-term, and visually disruptive than management for other species, and oak success can be challenging, uncertain, and take decades to reap rewards (Knoot et al. 2010a). While landowners may want oak because of the benefits it provides, this desire can be outweighed by these additional challenges of managing for oak (Knoot et al. 2010b). Of landowners who want more oak on their land, a plurality is planning to do one of the four management actions we investigated (cut trees for sale, plant trees, use herbicides, or use prescribed fire), but fewer are planning to do successively more

Table 7 Odds ratios from a multinomial logistic regression model of family forest owners using prescribed fire by Transtheoretical Model Stage of Change (n=1,437). The Action stage is the reference level[†]. * indicates difference between stage and reference stage (Action), [a] indicates difference between Precontemplation and Contemplation, [b] indicates difference between Contemplation and Preparation (α=0.05)

Item	Resist	Precont.	Contempl.	Preparation
Intercept	1.550	1.764	5.210[b]	708.267*
Benefit – Improve wildlife habitat	0.136*	0.127*[a]	0.388*	0.567
Benefit – Promote trees I want	0.891	1.042	1.335b	0.482
Benefit – Reduce unwanted plants	0.169*	0.175*[a]	0.376b	1.140
Benefit – Further goals for wooded land	0.109*	0.116*[a]	0.246*[b]	2.425
Barrier – Risky or dangerous	3.147*	2.795*	2.326*[b]	0.833
Barrier – Damage plants I want	1.764	1.224	1.725	0.835
Barrier – Neighbors would dislike	6.005*	4.531*	3.223*	2.653
Barrier – Expensive	4.490*	3.771*	3.603*	1.782
Barrier – Don't have enough information	9.997*	31.528*	23.427*[b]	7.987*
Barrier – Don't need to use fire	29.928*	25.364*[a]	6.530	4.241
Latitude	1.096	1.098[a]	1.013[b]	0.870*
Acres owned (ln)	0.841	0.799	0.858	0.673*

[†]Goodness of fit: X=30.636, df=32, p=0.536; pseudo-R^2=0.22

actions, highlighting the challenge of persuading landowners to undertake the multiple actions that may be required for oak regeneration. Knoot et al. (2010b) highlight the importance of ongoing, personal relationships with natural resource professionals in order to conduct and maintain oak management. Other studies have found working with consulting foresters tend to increase best management practice compliance (Jones and Work 2022). A more direct strategy may be to reach landowners with a simpler message about the benefits of oak and encouragement to work with a natural resource professional, and to reach natural resource professionals with information and technical support for oak management.

For cutting trees for sale, planting trees, and using prescribed fire, size of holdings differs across each stage, aligning with previous work showing the increasing relationship between size of holdings and probability of harvesting and other landowner attributes (Butler et al. 2021b). Increased parcelization of forested parcels across the U.S. (Caputo et al. 2020) is of particular concern to oak management, as it can constrain what is operationally and economically feasible (Knoot et al. 2010a). Other structural characteristics, such as latitude (e.g., TTM stage for prescribed fire varying by latitude, Table 7) and land tenure, such that shorter-term owners want to see faster results of management (Knoot et al. 2010b), also influence the likelihood of effective oak management.

Effective oak management is site-specific, and while landowners' feelings toward each activity in the survey are helpful to indicate their openness to and likelihood of conducing oak-appropriate management, we do not know which combination of management behaviors would best align with each landowner's property. We also did not specify an oak focus for the management activities, such as planting oak species or cutting to a certain intensity to allow enough light to support oak regeneration, so these analyses remain general to the landowners' attitude towards each management practice. And although we asked about different activities, we did not explicitly ascertain information regarding doing management activities in tandem.

Pseudo-R-squared values in this study were relatively low. For example, the model predicting whether landowners wanted more oak captured less than 10% of the total variation, suggesting that the primary drivers are objectives, motivations, and perceptions outside of those surveyed, as well as inherently idiosyncratic preferences. Future research will need to test a wider suite of predictor variables and bring more and different theoretical backings to bear on the question, to better resolve what drives landowners' ecological objectives and preferences.

This work highlights the potential to focus on opportunities and barriers for landowners in different relationships to management activities, as well as the items that cross many stages and activities, especially size of holdings and needing more information. While providing information seems to be a possible way to encourage more landowners to engage in these management activities, future work should assess the success of different kinds of educational programs, and if removing this barrier is enough to increase landowners' participation in management. While the area of forestland held by each owner is a structural characteristic, and a concern that is potentially increasing due to parcelization, cross-boundary work is a potential way to bridge the management gap for smaller parcels, and has been successful for some oak habitat case studies (e.g., (Fischer et al. 2019). Previous studies have also highlighted the potential benefits of government incentive programs to encourage landowners to adopt good oak management practices (Knoot et al. 2010a) and the potential for policies that target a variety of motivations that may be successful in encouraging landowners to conserve oak (Fischer and Bliss 2008).

It is important to note here that FFOs are not the only landowners in the region and that public, corporate, and other ownerships hold substantial forested acreage as well. Future research should focus on understanding the objectives, motivations, and constraints of these landowners to develop a fuller picture of the potential to increase oak in the region.

Conclusions

Overall, we find that FFOs in the project region have a high rate of interest in having oak trees, and most agree with multiple benefits of upland oak forest. There is a lack of knowledge among FFOs of the threats and risk of decline that oak trees and forests face, and increasing awareness might encourage more landowners to actively manage for oak. There is also the potential for education and programs to support landowners to help overcome barriers to specific management practices that

can benefit oak. All of these efforts should be tailored to the greatest extent possible to match the decisional stage where the owner is at for an activity in order to maximize efficacy. However, effective management for oak is site-specific and can require ongoing, concerted effort; rather than reaching landowners directly with oak management resources, a more direct route may be to provide landowners with resources on the benefits of and threats to oak forests and encouragement to work with a natural resource professional.

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Declarations

Conflicts of interest/Competing interests The authors declare no conflicts of interest.

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